Project Code/Version Number:
NGGDGN03/2

1. Project Summary

1.1. Project Title	HyDeploy
1.2. Project Explanation	The project will demonstrate that natural gas containing levels of hydrogen beyond those in the GS(M)R specification can be distributed and utilised safely & efficiently for the first time in a section of the UK distribution network. Successful demonstration has the potential to facilitate 29TWh pa of decarbonised heat in the GB, and more by unlocking extensive hydrogen use.
1.3. Funding licensee:	National Grid Gas Distribution
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)** The first UK practical deployment of hydrogen onto a live gas network since the transition from town gas. Taking advantage of Keele University's gas network risk manages project delivery and enables a more ambitious trial than would otherwise be achievable. This 3 year project, starting April 2017, is based on the principle of survey, test & trial necessary to secure HSE Exemption to GS(M)R and roll out the testing programme. **1.4.3. The Solution(s) it is looking to reach by applying the Method(s)** The project provides a body of practical, referenceable data which is an essential pre-requisite to enable wider deployment of hydrogen and therefore delivery of cost-effective, 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 120 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)	*6,777*	1.5.2 Network Licensee Compulsory Contribution (£k)	*764*
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)			7,635

1.6. List of Project Partners, External Funders and Project Supporters	National Grid Gas Distribution Northern Gas Networks Keele University Health and Safety Laboratory ITM Power Progressive Energy		
1.7 Timescale			
1.7.1. Project Start Date	April 2017	1.7.2. Project End Date	March 2020
1.8. Project Manager Contact Details			
1.8.1. Contact Name & Job Title	Andrew Lewis Project Delivery Specialist, Network Innovation	1.8.2. Email & Telephone Number	Tel: 01455892524 Mob: 07970831058
1.8.3. Contact Address	National Grid (Gas Distribution) Brick Kiln St, Hinckley LE10 0NA		
1.9: Cross Sector Projects (only include this section if your project is a Cross Sector Project).			
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

Section 2: Project Description

2.0. Executive Summary

The UK has recently signed up to its fifth Carbon Budget as part of its ambitious carbon reduction plan. Heat contributes a third of the UK's carbon emissions. The Carbon Plan specifically identifies the need for low carbon heat in order to meet these targets. Whilst progress is being made to decarbonize electricity, decarbonising heat has proved challenging.

Great Britain has a world class gas grid and gas dominates the heat supply curve, heating 83% of its buildings and providing most of its industrial heat. Carbon emissions can be reduced by lowering the carbon content of gas through blending with hydrogen. Compared with solutions such as heat pumps, this cost effectively capitalises on existing gas distribution assets which are designed to deliver peak heat, and importantly means that customers do not require disruptive and expensive changes in their homes. This route has the potential to deliver 29TWh per annum of decarbonised heat in Great Britain, saving £8.1 billion and 119 million tonnes of carbon by 2050.

The UK Gas Safety (Management) Regulations (GS(M)R) currently only permit 0.1% hydrogen in the network, despite formerly distributing town gas with 40-60% hydrogen. There has been substantial study work into hydrogen injection, but limited practical experience. To pursue this decarbonisation route, the UK needs to undertake practical hydrogen injection to establish feasibility and determine the appropriate level of blending on current networks and in appliances. This requires carefully executed, safely managed, real deployment, to demonstrate that the practical, regulatory and operational barriers can be successfully addressed. Specifically this project sets out to:

Demonstrate hydrogen injection into a network under safe & controlled conditions, at the highest concentration that safe operation allows whilst maintaining appliance performance.

Develop practical experience in hydrogen mixing and injection, understand the impact on network behaviour, end user appliances as well as metering, monitoring, and operations.

Build on international hydrogen injection knowledge & best practice, as well as UK best practice in terms of unconventional gas injection, particularly that undertaken at Oban.

Develop best practice in a controlled environment for subsequent testing and roll out of hydrogen injection onto the wider network including engagement with customers.

HyDeploy will provide a foundational reference work for the industry, address regulatory barriers through securing a GS(M)R Exemption, providing a pathway to wider deployment.

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. On the 30th June 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 Carbon Plan[1] specifically identifies the need for low carbon heat in order to meet these targets. In its July 2016 Progress Report to Parliament[2] the Committee for Climate Change has highlighted that whilst there has been progress in decarbonising the power sector, there has been *'almost no progress in the rest of the economy',* citing specifically the slow up take of low carbon heat.

The Carbon Plan identifies that by 2030 there is a requirement for between 83-165TWh of low carbon heat per annum. In 2015 the combined domestic and non-domestic RHI delivered less than 4.5TWh, with an expectation by DECC[3] in 2016 that by 2020/21 the Renewable Heat Incentive (RHI) could deliver 23.7TWh 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. Alternative means of delivering low carbon heat other than low carbon gas include:

Electrification: Efficient electric heat pumps will make a contribution, but, as recognised in DECC's Heat Strategy[4], and more recently in its RHI consultation, they require substantial consumer capital outlay and disruption, as well as national infrastructure investment.

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[1] The Carbon Plan: Delivering Our Low Carbon Future December 2011, updated 2013.

[2] https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament/

[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505972/The_Renewable_Heat_Incentive_-_A_reformed_and_refocussed_scheme.pdf

[4] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf

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.

Biomass Boilers: Biomass installations require substantial capital outlay, are large and cause disruption. There are also concerns about potential air quality issues arising from biomass combustion, particularly when running at part load, and in urban areas.

Heat networks: Heat networks have a role in delivering low carbon heat, but themselves require a low carbon source of heat, new infrastructure and sufficient heat density of the load which constrains their use, and have challenges associated with counterparties to provide the basis for investment.

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 study undertaken by WWU in 2015[5], 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 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 entire existing gas network asset has over 284,000km of pipelines, delivering over 720TWh per annum to over 23 million customers with 99.99% security of supply[6]. 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[7]. A key element of this is delivering low carbon gas, as outlined in NGGDs Future of Gas review.

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 entirely by using hydrogen. The latter is identified as important by DECC[8] but recognises further development activity is required. Two hydrogen scenarios are envisaged; 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 future. It offers not only valuable decarbonisation and financial savings across the distribution system with no disruption to consumers, but it also provides a pathway to establishing hydrogen more widely through areas of 100% conversion as proposed by the H21 Leeds CityGate project. Key to taking this forward is establishing the safe and practical feasibility of delivering a natural gas blend across the network and utilising it in real appliances.

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

[6] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas/

[7] 'The Role of Gas in UK Energy Policy', Le Fevre C, Oxford Inst. for Energy Studies (2015)

[8] 'The Future of Heating: Meeting the challenge' DECC (March 2013)

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

The UK currently only permits 0.1%vol hydrogen in the network, despite formerly distributing town gas with 40-60%vol hydrogen. There has been substantial study work undertaken supporting the theory of hydrogen injection into the grid, but limited practical experience, and none in the UK. Examples of such work in Europe include the NaturalHy Project and the GERG HIPS-net project. In Germany up to a 10%vol natural gas blend is permitted, and a few projects have undertaken hydrogen injection. In Amerland[9], work was undertaken between 2007 and 2011 to establish the feasibility of injection of hydrogen up to 20%vol into their natural gas grid. Recently the HSE issued a document[10] assessing the feasibility of injecting hydrogen into the gas distribution network, which concluded that *'concentrations of hydrogen in methane of up to 20% by volume are unlikely to increase risk from within the gas network or from gas appliances to consumers or members of the public.'* However, due to the current regulated limits, there has been no UK practical experience of hydrogen injection into the gas grid.

The evidence base indicates that blending should be feasible at a level between 10-20%vol. Accounting for the differences in volumetric calorific value between natural gas and hydrogen, and based on a level of 414TWh pa in the distribution network, this equates to 15-29TWh pa of decarbonised heat. This is potentially more than the projected delivery of renewable heat from the entire RHI by 2021 and is a material contribution to our low carbon heating requirements.

The purpose of the project is to provide seminal unique & referenceable data for all GDNs and other stakeholders looking to produce or utilise hydrogen delivered via the gas grid. The knowledge generated will be from a set of existing appliances operating on a hydrogen blend delivered through a live network, with the practical realities this entails. The specific learning comprises appliance operation including gas mixing into and throughout the network, pipeline and jointing materials issues, leak detection & network maintenance, metering & associated commercial issues, and the principles of securing a hydrogen GS(M)R Exemption from HSE. As part of potential wider regulatory changes, IGEM are seeking to develop an evidence base for widening the GS(M)R regulatory limits, and this work will provide an important contribution to this.

2.1.3 The Development or Demonstration being undertaken

The Project is a foundational study based on practical deployment. It builds on international work and existing NIA activities including HyStart being undertaken by NGN and NGGD, as well as best practice from other NIC projects.

Keele University has a closed, private gas network, which it is utilising as a 'living laboratory' under its Smart Energy Network Demonstrator (SEND). It comprises a network and appliances typical of the GB gas distribution systems, domestic & commercial users including a CHP, but under the control of the University as a local, licenced supplier. It is an ideal host for the first national step towards hydrogen deployment, risk managing the delivery of the project & enabling a more ambitious trial than would otherwise be achievable. The Method comprises 3 phases described in more detail in Section 2.3.

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[9] PILOT PROJECT ON HYDROGEN INJECTION IN NATURAL GAS ON ISLAND OF AMELAND IN THE NETHERLANDS, M.J. Kippers et al, International Gas Union Research Conference 2011

[10] Injecting Hydrogen into the gas network – a literature search' Hodges et al HSE (2015)

PHASE 1: Using best practice from SGN's Oban NIC, HyDeploy will engage with all local customers, as on a public network. Every appliance and installation will be baseline surveyed and tested locally on NG-H2 blends, including supporting offline tests. The network will be surveyed, modelled & operational procedures for leak detection and management processes established, including training of operational staff. The evidence base will collated and a Quantitative Risk Assessment undertaken to seek an Exemption to GS(M)R. In parallel the regulatory position with regard to billing of consumers on the private network will be addressed with OFGEM as discussed in Section 7.

PHASE 2: Installation of onsite hydrogen production, injection plant & network monitoring. Equipment will be capable of delivering up to 20% hydrogen, with network sample points and compositional, pressure & flow analysis facilities installed.

PHASE 3: An extensive trial programme will be undertaken to confirm, understand and document the operational behaviour of the network and appliances, validating network modelling and developing best practice for network management. NGGD and NGN are liaising with stakeholders within both GDNs to identify suitable public networks for a subsequent project, based on the best practice developed in this programme. HyDeploy results will be fully disseminated to ensure all stakeholders can benefit from this work.

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. 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 £8,060 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 in appliances, mixing and the flow of energy in the network, chemical effects on materials on the network and in appliances, explosibility characteristics, impacts on leak detection and network maintenance, as well as impacts on the billing, metering and therefore 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. Based on the theoretical body of evidence, this innovative project will execute the practical work to undertake a quantitative risk assessment of hydrogen injection in a real GB network, to present the case for an Exemption to the GS(M)R regulations, and to physically blend hydrogen into that network with extensive network and appliance monitoring.

The details of the trials are described Section 2.3, the underlying technical issues being addressed are summarised below. This summarises extensive foundational work which has already been undertaken, both by this project team and a NGN/NGGD Network Innovation Allowance project delivered by DNV-GL 'HyStart' focused on hydrogen blends. More detail can be found in Appendix F.

The principle requirement for a change to gases being distributed to consumers is that they provide similar heat inputs, good flame stability, reliable ignition and complete combustion. Specifically this must also ensure that sooting is controlled, that the flame does not lift, and light back does not occur. Ensuring that gases can be safely and efficiently combusted in appliances without adjustment, 'gas interchangeability', was initially undertaken by BC Dutton of the British Gas Corporation Research and Development Division. The key characteristic is the Wobbe Index, this indicates the effect of composition change on appliance heat input with a constant pressure supply. Based on this core parameter Dutton produced the interchangeability diagram (See Appendix C), which provides an envelope of acceptable Gas compositions and Wobbe. Dutton's original work was expanded[11] to consider a third axis which accounted for the effect of hydrogen on these factors, although it is simplified in the GS(M)R as shown below, with the limits on Wobbe being ≥46.50 MJ/m3 and ≤52.85 MJ/m3, with the hydrogen at 0.1%vol.

All appliance sold post 1993 must comply with the 1990 Gas Appliance Directive 90/396/CCE (GAD), which demonstrates that they can operate on a wider range in gas quality than specified in the GS(M)R. This includes a gas composition of 23% hydrogen. However, not all appliances are post 1993 (although numbers are reducing, projected to be at 2% by 2020[12]), & the tests undertaken under GAD do not consider long term operation.

In practical terms, the issue is ensuring that installed appliances (boilers, cooking appliances, fires and other heating units) of different burner types are able to maintain performance and combust the hydrogen blend safely and that the flame characteristics remain acceptable. In particular this must ensure that there is no significant change to the thermal profile of the burner and associated equipment that affects the materials of construction. This is an issue which could affect the longer term operation of the appliance. Flame sensors which govern appliance control must also continue to operate.

In addition to the core combustion characteristics, the hydrogen blend has a number of other potential impacts. Extensive assessment of these have been undertaken by both HSL and DNV-GL as found in Appendices E & F, which summarise the outcome of previous studies, as well as identify knowledge gaps that need to be addressed.

Hydrogen can have an adverse effect on network and appliance materials of construction. Metals can be susceptible to hydrogen embrittlement resulting in loss of ductility and

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[11] A New dimension to gas interchangeability, Dutton BC (1984)

[12] "Assessment of the size & composition of the UK gas appliance population", Crowther M, UKDTi (2005)

reduced load carrying capacity. Polymers are generally not degraded by the presence of hydrogen through physical or chemical means, although hydrogen can diffuse through polymers more easily than metals. Whilst this does not have a significant leakage it may have an adverse influence on the integrity of subsequent fusion joints. This, along with other knowledge gaps relating to seals and elastomers as well as applicability of standards to iron pipeworks are knowledge gaps that need to be addressed.

Initial reviews, particularly the HyHouse work[13], indicates that the addition of up to 20% hydrogen by volume is unlikely to present significant changes to the fire and explosion risk following an uncontrolled leak, accounting for both explosibility limits and dispersion. This will form part of the detailed risk assessment.

HyDeploy will be the first project in Great Britain to inject hydrogen into a natural gas grid. The hydrogen injection and mixing unit is a key element in this project. It is critical that the hydrogen properly mixed and that the blend is maintained as the gas flows vary, placing stringent demands on the hydrogen production unit, the mixing unit control and analytical equipment. HyStart has provided an initial functional specification for the mixing unit (Appendix C), which will be developed through to equipment delivery and testing in HyDeploy. Once in the gas grid it is important to confirm that the gas mix is maintained throughout the network, through appropriate instrumentation.

Safe operation and management requires confidence that odourisation remains effective; experimental already undertaken work has shown no evidence masking by Hydrogen in the laboratory, although impacts on the network must be confirmed. Leak detection equipment must also be selected and demonstrated to continue to be effective with hydrogen blends, and operators need to be appropriately trained.

There are regulatory issues which need to be addressed; not only the GS(M)R Exemption process, but also implementation of an appropriate billing regime with OFGEM, as described in Section 7. Throughout, engagement with customers must ensure their needs are met and that they understand their role in opening up new decarbonisation opportunities.

This innovative project will fill knowledge gaps which exist with regard to the technical implications of operation on hydrogen including experimentally rigorous testing on British appliances and their installation, it will develop the design of equipment suitable for physically injecting hydrogen onto the network as well ensuring that equipment & processes are developed to ensure safe network operation. Uniquely it will trail blaze the Exemption process for a hydrogen blend. Through the operational work it will complete a body of data that provides a platform for a trial on a public network and therefore wider roll out.

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 H.

2.3.1 Site Selection

Careful consideration has been given to the optimum location to undertake the first GB trial of hydrogen injection. In discussion with experts, and as endorsed by the HSE, the strategy

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[13] http://www.igem.org.uk/media/361886/final%20report_v13%20for%20publication.pdf

of using a closed private network for the first trial of hydrogen injection prior to a subsequent trial on a public network is considered to be the best strategic approach. It risk manages the delivery of the project & is expected to enable a more ambitious trial than would otherwise be achievable. Keele University has a network and appliances typical of the GB gas distribution systems, domestic & commercial users but under the control of the University as a local, licenced supplier on a private closed network. This is described more fully in Appendix C and D; the key benefits are:

- Detailed data sets of historic gas consumption of consumers on the network.
- A comprehensive dataset on appliances in most buildings.
- University support facilitating property access reducing risk, & enabling engagement.
- A cohesive site team who can be trained in the changes associated with hydrogen.
- Closed network and supply arrangements enabling an appropriate billing regime.
- SEND programme provides strategic links into research & training opportunities.

This environment allows the project to focus on addressing the core hydrogen related issues, risk managing project delivery (see Section 6). It also makes it less likely that an individual constraint limits the level of blend achievable, and therefore significantly increasing the experimental and enduring value of the work. It has always been planned that, subject to success at Keele, a follow on trial would be undertaken on a public network prior to roll out. Candidate sites are already being considered by NGGD and NGN and provision is made in this NIC programme to define and plan that trial. Equipment and facilities would be transferred from this project to such a site.

2.3.2 Phase 1: Pre-Exemption work

Customer Engagement

Delivering a customer-focused low carbon solution is the primary purpose of the project. The programme involves surveys of customer installations and appliances to ensure continued safe and reliable operation. Based on the best practice from SGN's 'Opening up the Gas network' NIC, both the impact on individual customers will be minimised and a customer focused communications plan will be implemented. No specific customer engagement will be undertaken until the communications plan has been approved by both OFGEM and Keele's ethics committee, as discussed in more detail in Section 8.

Pre-Exemption Scientific Scope of Works

Delivery of the HyDeploy project requires a robust experimental programme and scope of works, providing the scientific evidence to form the basis of the Safety Case to support an application for an Exemption against the GS(M)R Regulations. It will also gather the scientific evidence to confirm the safety and performance of a hydrogen / natural gas mix when injected into the gas network at Keele, to underpin a subsequent trial on a public network. The experimental scope of works falls into two main stages; the work undertaken Pre-Exemption (outlined below), and the gathering of robust data during the deployment trials (outlined in 2.3.5, Phase 3). Further detail can be found in Appendix C.

The purpose of the Pre-Exemption scientific investigative and experimental work is to inform the safety case for hydrogen injection. In addition to the work necessary for the safety case for injection at Keele, some experimental work is included in the project to understand the effects of up to 100% hydrogen on system tightness in isolated parts of the network.

Literature review: Through the extensive literature review work already undertaken by HSL and DNV-GL to date, confidence has been gained that seeking a hydrogen blend between 10-20% is a reasonable approach. This will need to be collated and reviewed to provide a comprehensive reference set suitable for the Exemption for the trial at Keele as well as a full gap analysis for wider deployment. This will cover appliance performance, material embrittlement, explosion characteristics and hydrogen detection / odourisation. In some areas the published data is either not available, or not suitable for GB applications. Laboratory tests and offline experiments are required to complete the evidence base.

Laboratory Testing: Laboratory testing of 18 appliances with a variety of burner types will be undertaken to assess safety performance of appliances with variable natural gas compositions and additions of different quantities of hydrogen. Testing will cover the mix of appliances at Keele, and based on the SGN Oban work will ensure good representation of the GB. Measurements of CO, CO_2 and NOx will be made along with observations of flame picture, flashback potential, temperature of burner head and flame and verification of operation of safety devices. Testing will also be undertaken with dynamic changing of Wobbe index and / or hydrogen concentration to mimic representative changes to gas quality. Laboratory testing will also establish longer term performance of appliances when exposed to hydrogen given that the hydrogen is expected to increase the burning temperature with potential impacts on the longevity of appliance components. These impacts will be studied, during laboratory based accelerated appliance tests, using temperature measurement and component inspection techniques. Work to date suggests knowledge gaps exist regarding the performance of solders and new plastic joints exposed to hydrogen. This will be addressed with appropriate laboratory testing.

Testing at Keele prior to Exemption: The results of laboratory tests will be combined with literature evidence and computational modelling by Keele (investigating flashback with different hydrogen blends in selected burner geometries), and a view taken on a 'safe' injection limit. Once determined, this limit will be verified in all appliances at Keele University using bottled gas with an onsite testing programme similar to Oban. During this baseline appliance survey any poor installations will be identified and remedial works undertaken. A full baseline condition survey of the Keele network will also be completed prior to Exemption application. Identified areas of concern will be subject to remedial works to ensure it is robust for the trials, whilst being representative of typical networks.

Scientific evidence for the Safety Case: The results from the laboratory testing, on site testing and modelling work will be reviewed by the HSL and recommendations made about safe limits for injection based on appliance and materials performance. In addition any monitoring or mitigation measures required to support the safety case will be identified.

Specification for Mixing: The hydrogen must be well mixed with the natural gas at the injection point. Detailed specification of this system and its fail safe controls will build on HyStart, covering causes of excessive hydrogen injection, mitigation measures and responses. If well mixed, the prevailing view is that the blend will likely remain homogenous. Desk based study of previous work and first principles assessment of gas properties will look to support this hypothesis, and confirmed experimentally during trials.

Detection: Building on work by HSL and HyStart, information on odourisation and hydrogen / natural gas detection techniques will be collated and assessed in the context of the trial, as well as wider roll out. This will include training for Keele and GDN teams on appropriate hydrogen detection equipment as part of revisions to the emergency response.

Explosion Characteristics: Building on the wider evidence base already available, comprehensive assessment and documentation of the explosion characteristics of a blended mixture compared with a pure natural gas mix will be completed to inform any changes to area classification, venting, or emergency response procedures on site.

Composition Measurement and CV: For the purposes of the trial, analytical equipment is currently available for determining composition / flow / pressure measurements and resulting CV for hydrogen-natural gas blends. This will be specified for the trial, and supported by third party accredited laboratory gas testing used to confirm the declared CV for billing (Section 7). Wider deployment requires confidence that existing network pressure and flow measurements remain suitable. New analysis equipment supplied with hydrogen-blend entry units must be robust and reliable, and able to be accredited by OFGEM. Early enabling work on this process will be undertaken in this project to support next stage roll out. HyDeploy could act as a test bed for instrumentation developed by others.

GS(M)R Exemption

Based on the scientific evidence base, the case for an Exemption to GS(M)R by the HSE will be developed (Section 7). Integral to this will be the Quantitative Risk Assessment, informed by the testing work. The Exemption will include modifications to procedures in the network Safety Case, including emergency response, to accommodate the hydrogen blend. HyDeploy has already engaged extensively with the HSE, who has had an opportunity to consider the scope of the evidence base to be presented, which it considers to cover the relevant elements. The project is also working with IGEM who have been asked by the HSE to provide an evidence base justifying widening of the GS(M)R gas quality requirements.

Metering and billing

Although HyDeploy is on a closed private network, gas is supplied to customers and so an appropriate billing regime for the trial needs to be agreed with OFGEM (Section 7).

Equipment & Installation enabling works

To support the Exemption process, to de-risk the project and to expedite the installation phase, key enabling work is required relating to hydrogen production, injection and monitoring equipment including design, HAZOP assessment and permissions. This builds on work already undertaken to define functional specifications & site assessments (Section 6).

Project Gateway

The Project steering committee will only permit the project to proceed to the next phase if the Exemption has been secured, an agreed billing regime has been agreed, and the Keele University's Ethics committee & other partners have reviewed the revised risk assessment.

2.3.3 Phase 2: Installation of hydrogen production, injection plant & network monitoring

Phase 2 encompasses the placement of orders for fabrication of equipment, installation and commissioning. This covers the hydrogen production equipment, the mixing and injection unit, and associated connections and pipelines which interface with the existing network at Keele. In addition, the analysis equipment will be procured and installed, including the establishment of sampling points on the network for the flow, pressure and compositional measurements as well as material test samples. Further details can be found in the project description in Appendix C, along with the Project plan, Appendix H. During this phase training of operatives from both Keele and the GDNs will be undertaken by HSL based on the agreed procedures under the Exemption.

2.3.4 Phase 3: Hydrogen Injection Trials

Data Capture during Injection

Post-Exemption data gathering during the trials will include checking actual appliance performance and comparing this with expected appliance performance; monitoring composition, pressure and flow around the grid; on site materials testing and gathering anecdotal evidence of appliance performance from consumers. During the trials themselves the following activities will be undertaken to collate evidence supporting the safe performance of the network:

1. Some appliances will be revisited to check actual against anticipated performance.
2. Some appliances will also be instrumented during the course of the trial to provide real-time data for the purpose of assessing safety and operational performance. In the case of some of the larger boilers this instrumentation will be linked into the BMS.
3. Materials testing will be ongoing during the trial to inspect for degradation.
4. Mobile equipment will be deployed around the site to measure composition, pressure and flow at a minimum of two simultaneous points on the network. This will act to build up a picture of mixing and flow behaviour for model validation purposes.
5. As part of the study participants will be encouraged to report on appliance performance using a dedicated phone line and website. Selected households will also be asked to engage in a more in depth review of appliance performance during the course of the hydrogen injection though monitoring activities and a number of in depth interviews.
6. During the project, a watching brief will be maintained on relevant developments in this area (e.g. developments in gas analysis, changes to area classification standards etc).

The material from the study will be written up and disseminated as both a published scientific report and in journals and at conferences. As a final output of the scientific study there will also be a scientific gap analysis reported in order to inform the next trial on a public network and wider roll out.

Next steps and Wider Dissemination

HyDeploy is the first key step to establishing roll out of hydrogen delivery via the gas network. A trial on a public network is the final gateway to wider deployment, and will be developed in the programme. NGGD and NGN are already liaising with stakeholders in both GDNs to identify suitable areas of the public network, and have undertaken network modelling on a potential site. HyDeploy has been developed such that much of the equipment, learning and training will transfer over to the next trial.

The purpose of this project is to develop seminal reference data, as well as best practice for all GDNs and other stakeholders looking to produce, or utilise hydrogen delivered via the gas grid. Therefore knowledge dissemination is integral to the project, see 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 and reduced based on more detailed information arising from the extensive work undertaken by the project team in developing this bid.

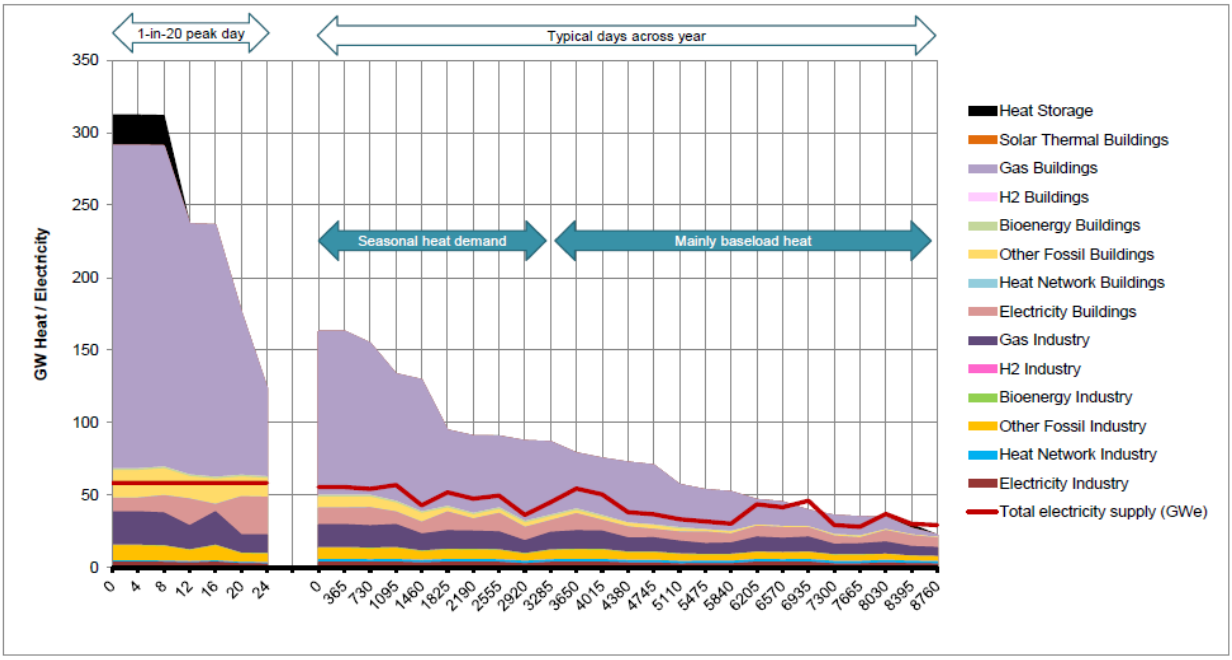
Section 3: Project business case

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. 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, as can be seen by the heat demand curves shown below.



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, even using heat pumps as the need to peak heat results in a substantial load on the electricity network. This requires not only substantial additional generation[14], but importantly extensive reinforcement to both the electricity transmission and distribution networks to deliver this power. Without this 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

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[14] KPMG 2050 Energy Scenarios , July 2016

of low carbon heat. This approach requires no changes to appliances and network providing a non-disruptive to customers. Longer term, this approach has the potential to unlock even deeper decarbonisation through 100% conversion of zones of the network, such as that exemplified by NGN's H21 project. This 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 have an enduring role.

The majority of the benefits 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 NGGD and NGN are seeking to make best use of the gas network in a low carbon economy. For example NGGD's stakeholders have said they want NGGD to remove barriers for the development of renewable gas and educate stakeholders on the role for gas in a low carbon economy[15]. This has been an ongoing activity for both parties, including specifically the use of hydrogen. For example National Grid has recently launched a series of documents engaging with stakeholders on the role of the Future of Gas[16], of which one dedicated to renewable gas specifically recognises the role of Hydrogen[17]. NGN have undertaken the Leeds H21 project, which has recently reported. Together both NGGD and NGN have undertaken the HyStart NIA project which has provided key background work on Hydrogen blends[18]. NGGD and NGN are not alone in their pursuit of Hydrogen; WWU, SGN have both independently been involved in hydrogen related projects, are supportive of the HyDeploy project and will sit on its Advisory Panel.

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. For example introduction of hydrogen may offer longer term opportunities such as delivery of hydrogen as a transport fuel.

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 NGGD suggests that this is of the order of £8 billion.

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[15] http://www.talkingnetworksngd.com/assets/downloads/2013_Committing.pdf
[16] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas/
[17] http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=45609
[18] http://www.smarternetworks.org/Project.aspx?ProjectID=1907

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 air source 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 detail in Appendix B. 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 the redeployment of the Keele hydrogen production and injection equipment onto a public network.

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 accounting for projections of cost and performance developments expected over the period, based on referenced sources, along with the expected cost of power. The cost of "business as usual" is then subtracted from this 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 (in 2016/17 prices) of these has been calculated based on referenced data sources for capital cost and performance of the production methods, as well as underlying 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 £80-84/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 £67/MWhr compared with hydrogen at £45/MWhr. At 2050, this is £55/MWhr and £38/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. Two cases were considered; a 10%vol level which is already permitted in parts of Europe and supported by the conclusions of the NaturalHy project, and 20%vol which is considered to be the maximum feasible level. The expectation is that this work will establish a level of hydrogen blending between these two conditions. 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, National Grid has calculated the savings associated with avoidance of network reinforcement otherwise required to deliver the equivalent level of low carbon heat delivered by heat pumps. 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	To 2020	To 2030	To 2040	To 2050
	(Method)	£million	£million	£million	£million
GB Values	20% Blend (M1)	0	1,897	6,025	8,060
	10% Blend (M2)	0	855	2,548	3,269
Licensees Values (63% of GB)	20% Blend (M1)	0	1,195	3,796	5,078
	10% Blend (M2)	0	539	1,605	2,059
Post Trial	Either blend	0	0.4	0.7	0.7

The savings are shown for the GB case, just the NGGD and NGN networks and a post trial case, which is the relocation of the mixing & injection unit & electrolyser onto a public network, avoiding 164 Air Source Heat pumps.

At its peak this equates to a GB saving of around £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. 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.

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 recent 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.

Analysis by the National Grid Future Energy scenarios team has evaluated the carbon savings expected by blending hydrogen into the distribution system, thus reducing the carbon intensity of the gas grid. This analysis is based on its extensive baseline scenario modelling of the energy system and 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 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	To 2020	To 2030	To 2040	To 2050
	(Method)	Te CO_2 eq	Te CO_2 eq	Te CO_2 eq	Te CO_2 eq
GB Values	20% Blend (M1)	0 mill	8.7 mill	60.2 mill	119.3 mill
	10% Blend (M2)	0 mill	4.4 mill	30.1 mill	59.6 mill
Licensees Values (63% of GB)	20% Blend (M1)	0 mill	5.5 mill	37.9 mill	75.1 mill
	10% Blend (M2)	0 mill	2.7 mill	19 mill	37.6 mill
Post Trial	Either blend	0	3,002	6,504	6,504

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

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 2015 the combined domestic and non-domestic RHI delivered less than 4.5TWh, with DECC's 2016 RHI consultation document[19] anticipating *'that by 2020/21, the RHI could deliver 23.7TWh of renewable heat'*. In order to meet UK carbon commitments, a substantial step change is required. The requirement to address the challenge of delivering low carbon heat was candidly recognised by the Secretary of State in her response to the Energy and Climate Change Select Committee (November 2015). The Committee for Climate Change in its July 2016 Report on Progress to Parliament[20] states that whilst progress has been made in the power sector, *'There has been almost no progress in the rest of the economy, where emissions have fallen less than 1% a year since 2012 on a temperature-adjusted basis'.* It goes on to cite the first reason for this as being *'because there has been slow uptake of low-carbon technologies and behaviours in the buildings sector*'.

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 DECC's overall framework, which was embodied in two further documents focused specifically on the low carbon heat sector.

In its low carbon heat strategy document[21], DECC identifies that *'Two low carbon fuels could be deployed through a national grid network, similar to how natural gas is delivered today: biomethane and hydrogen'*. It recognises 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*

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[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505972/The_Renewable_Heat_Incentive_-_A_reformed_and_refocussed_scheme.pdf

[20] https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament/

[21] "The Future of Heating: A strategic framework for low carbon heat in the UK", DECC (2012)

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[22] focused on implementation steps, where it stated that the *'need to focus particular effort will be on heat storage and on hydrogen'*.

This is exactly the purpose of this project; to establish the principles of injection of hydrogen into the gas grid, address and overcome the barriers associated with the current regulatory regime, to determine the safe level of hydrogen blending which can be achieved and to demonstrate physical injection in a GB network.

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

The Great Britain gas distribution network alone delivers over 400TWh. Establishing practical injection of hydrogen at between 10-20%vol fraction into this would deliver between 15-29TWh of decarbonised fuel. This is equivalent to the projected delivery of renewable heat from the RHI by 2021, according to DECC's recent 2016 consultation on the scheme, and therefore a material contribution. That RHI projection itself relies on substantial penetration of heat pump and biomass technologies, which DECC recognises still have the challenges outlined in its earlier Carbon plan, and so solutions which avoid these issues 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.

Furthermore, establishing the principles of injection, as well as key elements of the technical evidence base which will be developed in this project would unlock progress on a more substantial hydrogen roadmap, as exemplified by NGN's H21 Programme. With current hydrogen levels at 0.1%, there is a significant body of work required to consider complete conversion to Hydrogen. The HyDeploy project will lift the bar from the current level and engage key stakeholders in the process of reviewing the existing regulations. It will provide a consolidated, GB focused body of work, much of which will be important to higher levels of hydrogen blends. The H21 project explicitly identifies such barriers which need to be addressed and the role which the HyDeploy project has in helping overcome them. Conversion to 100% hydrogen will require changes to appliances and the wider network. The H21 proposes that this will focus 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 have an enduring role; this project offers carbon savings in its own right, but also provides a pathway to, and a role in an H21 world.

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[22] "The Future of Heating: Meeting the Challenge", DECC (March 2013)

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.

Delivery of low carbon heat via heat pumps face substantial barriers to entry as outlined in the Carbon plan, and evidenced more recently 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. This is evidenced by the low rates of uptake experienced by DECC in the RHI, which shows that by the end of May 2016[23] there are only 525 accredited Ground Source Heat Pumps (GSHP) and 143 accredited Air Source Heat Pumps (ASHPs) in Great Britain, despite the fact that the RHI was launched in 2011. DECC is now (March 2016) proposing to raise the tariff levels upwards by a third for ASHPs to £100/MWhr and to the maximum 'Value for Money' cap for GSHPs at £195/MWhr, although 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 Steam Methane Reformation (SMR) 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 production process which is in use in Sweden already, and being demonstrated in the UK. Production of hydrogen by SMR is established technology, but this route does depend on establishment of CCS infrastructure and is therefore expected to contribute from around 2030 onwards. 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.

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[23] https://www.gov.uk/government/statistics/rhi-deployment-data-may-2016

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	8.7 mill	60.2 mill	119.3 mill
	10% Blend (M2)	0 mill	4.4 mill	30.1 mill	59.6 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. Alternatively this is double the saving from Hinkley Point C at 3 million tonnes per annum, assuming it comes on stream in 2025, with the relative carbon benefit delivered falling further as the electricity grid further decarbonises more widely.

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, the lowest cost heat pump solution. 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	1,897	6,025	8,060
	10% Blend (M2)	0	855	2,548	3,269

By comparison, the cost per tonne of carbon abatement is less than half of that for Hinkley Point C, on the basis of its £92/MWhr strike price.

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 National Grid. In addition, both SGN and WWU are supportive of the programme and have agreed to sit on the Project's Advisory Panel.

The programme is focused on enabling the GDNs themselves to understand and develop the capabilities of their network as a practical and safe means to deliver low carbon, flexible heat. 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 £6.8 million of NIC funding enables a low carbon solution which delivers discounted savings of £8,060 million. Assuming the project successfully completes in 2020, the modelling suggests that the breakeven on the project support would be achieved around 5 years later in 2025.

The project scale, and site selection has been carefully undertaken to maximise the learning whilst managing the project delivery risks and minimise costs.

The strategic selection of Keele University as a site leverages its wider SEND project designed to use the site as a 'Living Laboratory', as described in 2.3.1 and in Appendix D. Their private gas network delivers gas to a wide diversity of consumers from individual residential dwellings, to flats, larger administrative and recreational facilities. The selected network onsite is the largest and most diverse with over 100 residences and 31 larger buildings. Appliances range from 15kWth to 1.1MWth and include a wide range of representative boilers, heating and catering appliances. The 10km gas network has been installed over the last 55 years and comprises a range of materials of construction, both underground, but also in above ground risers and laterals.

In terms of undertaking this first GB injection of hydrogen, there is agreement amongst experts and stakeholders that utilising a closed private network is the best, and most risk-managed way to address the issues. This position has been endorsed by the HSE, and in the work undertaken by DNV-GL in the HyStart NIA (Appendix E). As shown in Section 2.3.1 as well Appendix C & D, Keele offers many specific advantages. This controlled environment provides the right context for the first GB injection of hydrogen, and will provide a body of evidence which will underpin a subsequent wider trial on a public network and then roll out across the GB.

The Programme has built on the learning from the "Opening the Gas Market" by SGN in order to ensure that it is well structured and able to deliver the outcomes required. This covers not only the technical issues, but also the communications and stakeholder engagement requirements.

The purpose of the project is to provide seminal unique & referenceable data for all GDNs and other stakeholders looking to produce or utilise hydrogen delivered via the gas grid. The knowledge generated will be from a set of existing appliances operating on a hydrogen blend delivered through a live network, with the practical realities this entails. The specific learning comprises appliance operation gas mixing into and throughout the network, pipeline and jointing materials issues, leak detection & network maintenance, metering & associated commercial issues.

Through the process of securing an Exemption to the GS(M)R from HSE, and the subsequent trial, the evidence generated will provide a basis to support a revision to the GS(M)R more widely. This is to the benefit of all GDNs and ultimately to the consumer by providing a route to low cost, non-disruptive low carbon heat.

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

The project leverages Keele's SEND project, supported financially by BIS & potentially the European Regional Development Fund. It benefits from the wider indirect support for energy projects on the campus as well as opportunities for engagement with the supply chain. The valuable contribution from Keele in hosting the project is acknowledged. Whilst the project bears the cost of network changes necessary to accommodate the trial, additional training required, and the direct costs of the trial, it is not contributing to the day-to-day operation and maintenance of the network.

Key items of equipment such as the gas mixing and injection unit and analysis equipment will be procured through an appropriate tendering process to ensure that best value is achieved. Through the partnering agreement, the electrolyser is being delivered under non-standard commercial arrangements. Should it be necessary, ITM has agreed to a buy-back option for the electrolyser; 50% before on-site commissioning, 25% post on-site commissioning, the proceeds of which will be returned compliant with the OFGEM process for return of funds.

However, in order to maximise the value for money to the gas consumer, NG and NGN undertake that the equipment developed for the project (Hydrogen production, gas injection and mixing unit, and analytical facilities) will be available for a follow on project on a public network as part of wider roll out.

The programme has been designed such that orders for capital cost items will not be placed until the Exemption is granted from the HSE. This ensures that such costs are only incurred once it is confirmed that this phase of the project is able to go ahead.

As outlined in Section 6.1.3 National Grid and Northern Gas Network engaged with a number of partners for key roles, making selections based on experience and competiveness of commercial offering. A number of these partners are providing in kind contributions to the project such as analytical equipment and facilities which would normally be charged separately.

NGGD 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 J, and is summarised in the Table below:

	Total Labour across Project					Equipment	Total
	No of staff	Man-days	Rates Range	Rates Ave	Labour Cost		
	FTEs	Days	£/day	£/day	£0	£0	£0
Phase 1	10.8	2976	225-1475	596	1,772,426	1,366,711	3,139,137
Phase 2	7.1	1179	225-1475	565	666,872	2,136,008	2,802,879
Phase 3	4.1	894	225-1475	803	717,394	975,128	1,692,521
Total	7.6	5049	225-1475	625	3,156,692	4,477,846	7,634,538
NIC Funding request	Not accounting for bank interest				2,841,022	4,030,062	6,871,084
	After OFGEM Bank interest provision						6,777,241

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

Both NGGD and NGN have internal processes to identify new project ideas and participants in their innovation projects. This is explained in more detail in Section 4.4 below.

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 for why the Project is innovative and evidence it has not been tried before;

Physical injection of hydrogen blended with natural gas into the network never been undertaken in UK, although there have been numerous theoretical studies. 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.

This project represents the first time in over 40 years that hydrogen will be injected into the gas network in the GB. Furthermore, the purpose of this project is specifically to establish the upper level of hydrogen-natural gas blend which can be safely accommodated and which provide continued appliance performance. The use of hydrogen prior to the changeover provides some confidence regarding feasibility, however there have been a number of key changes since then; different types of burners, sensors, controls and materials of construction, changes to network operation and maintenance including leak detection equipment, network materials of construction, especially with a dry gas, procedures & equipment to measure the gas quality, particularly for the purposes of billing.

This project builds on the theoretical evidence base developed in projects such as NaturalHy and the GERG HIPS project, as well as the valuable experienced gained through deployment in other European countries. It also draws on the practical experimental work undertaken in the HyHouse project, and in process terms, the programme undertaken at SGN Oban.

However, in order to establish the safe level of blending, the evidence must be assimilated for the HSE to make the specific case for Exemption. Theoretical assessments can only go so far, and this is the only way to establish the practical basis for deployment. This is why HyDeploy has received such a high level of support from the GDNs and wider stakeholders. Having then secured the Exemption, the trial then provides a body of practical evidence under controlled conditions to support a transition to a trial on a public network.

Not only does this novel project enable blending hydrogen onto the gas network, it unlocks wider development of hydrogen as a vector. This includes some experimental testing of 100% Hydrogen. 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 I, with an overview in Section 6.1.4 below. In summary, the key risks this programme seeks to address are (a) **Technical & Operational:** Operation of appliances safely on a blend, safe operation of the network including network flows, pipeline integrity, network maintenance and leak detection; (b) **Commercial:** Metering of hydrogen and appropriate billing regimes; and (c) **Regulatory:** Securing a derogation for the initial network, & establishing best practice for subsequent derogation on a public network.

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

Both NGGD and NGN have internal processes to identify new project ideas and participants in their innovation projects. Both GDNs are actively focused on innovation which enables gas networks to play a role in the low carbon economy. This is exemplified by the Future of Gas[24] work undertaken by NGGD over the last 6 months. The importance of gas, and the challenges associated with changing consumer behaviour to non-gas solutions is exemplified by the recent work undertaken by WWU in Bridgend. Specifically both GDNs have been developing activities relating to the role of hydrogen; NGN has recently completed the H21 NIA Project. Both partners have also collaborated in the HyStart NIA which has provided key enabling information for this project.

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 support for the HyDeploy Project has been established. In evaluating innovation projects NGGD and NGN assess: (a) is it aligned to the vision of the GDN, specifically in this case the role of gas in the future, (b) whether it meets OFGEM's criteria; accelerating the low carbon economy, benefiting the gas customer and innovative, (c) project deliverability - the level of risk attached to achieving the outcome and clarity of scope outputs, and (d) is it collaborative with credible partners.

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. NGGD and NGN engaged with a number of partners for key roles, making selections based on experience and competitiveness of commercial offering. Through this they have assembled a team of experts in their field to undertake this project.

The core partners will all be signatories to the Project Collaboration Agreement, along with specific arrangements with Keele, given their pivotal role in the project. Other suppliers will be contracted using established sub-contract structures. Most of the participants have contracted with GDNs for this type of work in the past and all partners have reviewed the draft collaboration agreement, and understand its provisions.

This project is a true collaboration between two GDNs. **National Grid Gas Distribution** is the Funding Licensee & project sponsor and **Northern Gas Networks** is the collaborating GDN. They both bring their expertise and experience to the project. As explained in more detail in Section 6 and Appendix K, the partners are: **Keele University** is the site sponsor, host network and academic collaborator. **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. **ITM Power** is uniquely experienced in hydrogen grid injection projects and will supply the hydrogen production plant. **Progressive Energy** has a track record in undertaking NIC projects and are responsible for Project management, planning and overall programme co-ordination. In addition to the core partners, the project is supported by key industry experts: **KIWA Gastec** will undertake practical survey, test and trial work, building

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[24] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas/

on their extensive experience, particularly from the SGN Oban project. **Dave Lander** is a well-respected specialist in the field, and will 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 of the new facilities.

External Funding

As outlined in Section 4.3.2, this is a network enabling project. It is seeking to address key technical and regulatory issues associated with hydrogen in the gas network, with the primary beneficiary being the GB gas customer, rather than commercial entities. However, it has been possible to secure elements of in kind contributions from key Partners, particularly access to equipment. ITM have offered non-standard commercial terms for the provision of the electrolyser. The project also benefits from the SEND programme at Keele which provides indirect support to the project.

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. As of 30th June 2016 it signed up to the commitments of the 5th carbon budget, commencing in 2027, with the substantial delivery gap highlighted subsequently by the Committee for Climate Change which it needs to solve.

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. Achieving the practical deployment of hydrogen as a blend onto the GB network and establishing the level of contribution this can make to the national targets is vital in developing the wider decarbonisation strategy to meet the 5th carbon budget.

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, which will provide valuable information from 2018 to 2020 is apposite, and can provide the kind of evidence base that DECC requires in order to evaluate new technologies for introduction into such schemes.

In relation to the wider energy debate, there are discussions with Government and the wider industry around the long term role of gas networks and it is likely decisions will need to be made about the future approach to gas networks within this RIIO period. This project will 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. Its purpose is to provide seminal unique & referenceable data for all GDNs and other stakeholders looking to produce, deliver or utilise hydrogen using the gas grid. More widely it will inform policymakers and consumers about the opportunity Hydrogen as a blend offers as a non-disruptive low carbon heat solution. The knowledge generated will be from a set of existing appliances operating on a hydrogen blend delivered through a live network, with the practical realities this entails.

The overarching learning generated is to establish the safe level of hydrogen blend which can be accommodated on the 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 blend hydrogen in the network. This project comprises both NGGD and NGN and SGN & WWU have both agreed to participate in the project's Advisory Panel due to their interest in contributing to and learning from the outcomes of this project.

Assessing Safe Appliance performance	This will provide a consistent and coherent set of new data on GB appliances operating on hydrogen. It will build on the learning from Oban to laboratory test 18 selected appliances with arrange of hydrogen blends providing a referenceable data set on O_2, CO/CO_2, flashback, leakage, pressure systems and safety systems. This work will also include impact of live concentration variation. The second data set will be the survey and testing of every appliance and installation on the network, baselined on natural gas and using bottled hydrogen blends. The results from both tests will be analysed for consistency and understand key differences. This will provide a unique and experimentally rigorous GB-focused data-set on domestic & commercial appliances using a hydrogen blend, akin to the SGN Oban work.
Assessment of long term appliance behaviour	This has been identified as a specific international learning gap by the HSE. It relates particularly to materials be in direct contact with hydrogen or experience higher surface temperatures due to changes in flame position and shape. This comprises newly commissioned laboratory work on appliances as well as computational modelling by Keele.
Assessment of installations & tightness tests	Every installation will be surveyed using a baseline natural gas and hydrogen blends up to 20%. This will deliver consistent, practical data on the tightness of operational installations with blends of hydrogen.
Extension of tightness testing to 100% hydrogen	The above work will be extended to include 100% hydrogen testing. This has never been undertaken internationally on 'real world' installations, but is a logical extension to include cost-effectively in this project. This has been discussed with H21 City Gate who recognise this as extremely important and valuable learning. This will explicitly cover example domestic installations and multi-occupancy buildings including laterals and risers as well as a section of underground network pipeline which

	includes a 56 year old 8" steel pipe section as well as jointing to a modern MDPE line. All testing will be against a natural gas baseline.
Materials and Embrittlement and network jointing	Based on a full literature review for all materials relevant to the network and installation, this work includes laboratory testing of materials and joints (identified as a particular knowledge gap). Uniquely this project includes testing of materials sampled on the live H2 blended network.
Risks of poor mixing	Safe operation of a network on a hydrogen blend requires confidence (a) that the injected blend is fully mixed and (b) that no segregation or stratification occurs. The former will be used to develop the mixing unit design. The latter will be uniquely tested on the live network at Keele under operational conditions. Whilst there is widespread agreement that stratification is unlikely, the learning gap is well monitored operational evidence, which this project will provide.
Analysis equipment for monitoring hydrogen blend	For the purpose of the trial and to inform requirements for future deployment, robust analysis is required of compositions. Measurement of hydrogen represents challenges to conventional equipment; this project will select and test such equipment under operational network conditions, accounting for factors such as flow and pressure fluctuation, as well as practical issues such as operational resilience in the field.
Explosibility	This work is not experimental, but will uniquely assimilate the literature evidence suitable for use in Exemption application on a gas network.
Appropriate detection	Deployment of hydrogen on a network requires confidence in the performance of odorants for the public as well as specialist monitoring equipment (installations and mobile) with a blend. This will build on the work from the previous NIA to provide detailed specifications for such equipment. This will be used to refine network management and emergency plans. Uniquely these will deployed on an operating network in the field with hydrogen and their performance monitored.
Metering	Existing meters will be assessed in terms of safe operation on a hydrogen blend, and reliable volumetric measurement. This will be undertaken to support the trial at Keele, but will inform considerations for wider roll out in the future. (Note that this links into other Network Innovation projects such as Future of Billing)
Network management & emergency procedures	Based on the evidence built up through the programme, network management and emergency protocols will be revised to include operation on a hydrogen blend. This has never been undertaken in the GB before.
Development of a mixing & injection unit suitable for the GB distribution system	This is the first time that hydrogen will injected into a live GB network, although has been undertaken in Germany. A new mixing/injection unit will be developed, building on the German experience, on the functional specification developed by DNV-GL under the previous NIA, as well as GB experience in biomethane injection units. Key issues will be mixing and blending reliability over a range of flows, as well as ensuring continuity of gas delivery. The output of this project will provide a unit suitable for operation at Keele, provide operational data on an operating network and inform design for units for roll out.
Operation and performance of electrolyser dynamic conditions	Hydrogen for this project will be provided by electrolysis. This project provides a unique opportunity for long term operational testing of the operation of an electrolyser of the wide range of flow conditions required on a real gas distribution system. Electrolysers are expected to have an important role in deployment of a hydrogen blend, particularly in the early take up, as well as a potential role in balancing across gas and electricity network. Operational data under real gas network operation provides important learning for the industry to enable deployment.
QRA	The QRA process draws together the evidence base in a form which assesses the risk quantitatively. This has never been undertaken for

	hydrogen blends in a form suitable for a UK Exemption.
The Process and Precedent of securing an Exemption	Exemptions have been secured for widening of the Wobbe bands, and also for oxygen content. However, an application has never been made for blending of hydrogen. This process will establish the necessary evidence base required. Furthermore, securing an Exemption would set a valuable precedent for hydrogen blending as part of a wider decarbonisation strategy. It is fully recognised that a subsequent Exemption on a public network would require additional specific issues to be considered, but these would be incremental to the primary experimental and scientific evidence base produced by this project
Operational evidence from actual operation	Physical deployment on an operational network provides unique evidence relating to the technical and operational issues associated with blending, and validation of the individual trial and test programme. Very few such system based projects are feasible, and this will be a valuable contribute to the international body of work.
Design of a public network trial	A key part of this project is the definition of a subsequent trial on a public network which is recognised by experts as the next step in roll out of hydrogen blending. This will be informed by the detailed learning outcomes developed by HyDeploy, and wouldn't be possible without it.

5.1.1 Knowledge capture

Much of the learning arises from rigorously designed experimental activities. HSL provides unmatched, and internationally recognised experience in structuring and delivering such work. This is combined with the depth of experience of KIWA Gastec 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.

Keele University & its consumers	As host for the project, Keele's own community and gas consumers, the project has a priority to inform and share knowledge with them. This is integral to the important work of customer care throughout the programme, discussed in Section 8
Gas network owners & operators	The purpose of this project is to provide the body of evidence that allows gas network companies to evaluate the opportunities and issues associated with blending of hydrogen into their networks. This understanding is necessary for them strategically as well as in delivering their regulatory duties and practicalities of network entry agreements. All four GDNs are fully supportive of this project, with letter of support from WWU in Appendix M.
Gas Shippers & Suppliers	Changes to the gases being transported in the network has important impacts on commercial arrangements for gas shippers and suppliers. This trial is being executed on a private network with Keele as a supplier, behind the fiscal meter of the LDZ. However the next stage trial on a public network and further role out will need their

	collaboration, supported by work such as the "Future of Billing" project. British Gas is supporting this project and will sit 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. DECC is therefore a significant stakeholder in this project. The project team has already engaged with DECC at a number of levels; there is significant interest in the role hydrogen could play in future energy policy.
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 M.
Appliance Manufacturers & Trade bodies	Changes to the gas composition needs co-operation with appliance manufacturers. Whilst the purpose of this project is to establish the level of blend feasible without changes to appliances, they remain a key stakeholder in this process. The team has already engaged with the Heating and Hot Water Industry Council (HHIC) have provided a letter of support under the umbrella of the EUA for this project in Appendix M.
Academic institutions	This work opens up a new direction for our gas networks, builds on academic research and provide new opportunities for further innovation. Keele's own research capacity is already contributing to this project through the Professor of Engineering Mathematics.
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 M.
Customers and consumers	Ultimately this project opens up a 'democratic' way for consumers to 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. They are the ultimate stakeholder in this project.

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 for other innovation projects, 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 Keele University NGGD and NGN at the start of the project. This will use a variety of channels dissemination as shown below.

Knowledge sharing Events at the Host Site	The University, in its role as a 'living laboratory' provides a compelling location for events. This is important for its own community, but also provides a forum to hold events for third parties, who will be able to see the hydrogen production and injection equipment as well as witness operation of a network on a hydrogen blend. The university facilities provide an ideal forum for such events.

Project Website	The domain www.HyDeploy.com has already been secured, and a dedicated project website will be set up for the project with links from Keele University, NGN and NGGD websites. The website will also be accessible and informative to the general public and will contain high-level information relating to, for example, the environmental benefits. It will also provide a portal for project information, including progress and technical reports for key stakeholders.
Social media	The website will be supported by a wider social media presence. Including a You Tube video, such as that produced by the H21 CityGate project.
Literature Development	Development of literature including factsheets, flyers & brochures to help communicate the Project to the various audiences. This includes specific information for consumers on the Keele network, see 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 ENA R&D working group and the EUA. Hydrogen focused bodies, such as the GERG HIPS forum provide an opportunity for sharing in amongst experts, which will facilitate two way flow of knowledge and learning
Progress & Close out reports	The 6 monthly 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 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

Required level of protection

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

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

NGGD and NGN are confident in the ability of this project to deliver due to the level of preparation which has gone into developing this proposal.

A host site has been carefully selected which, endorsed by experts, provides the appropriate location for the first GB trial, which both manages risks and provides maximum opportunity for learning act as a foundation for the industry going forward.

The team which has been assembled is drawn from some of the most knowledgeable and experienced organisations and personnel in the UK. The proposal builds on a substantial evidence base in the field, combined with more recent foundational work undertaken in the HyStart NIA by DNV-GL. A summary of these findings can be found in Appendix F. This material has been used to develop the project by key project partners and contractors, particularly HSL and KIWA Gastec to define the scope and programme of activities required. HSL has wide experience in undertaking safety related experimental work, and understands the issues that the HSE need to see addressed. Synopses of the work already undertaken by HSL can also be found in Appendix F. In particular experience has been drawn from the SGN 'Opening up the gas network' project at Oban, which has developed best practice for much of the work, which was led by KIWA Gastec. In addition, the project partners have already engaged with the appliance manufacturers, to ensure they are aware of the project. This includes their trade body the HHIC, who have provided a letter of support under the umbrella body the Energy Utilities Alliance (EUA) and will sit on the Advisory Panel, (see Appendix L,M)

Integral to delivering the experimental programme is the installation of the necessary equipment for the production and mixing & injection of hydrogen into the network, as well as the analytical equipment required across the network. The Electrolyser partner delivered the first fast acting, self-pressurising PEM electrolysis equipment for grid injection in Germany, which is currently operating on the gas network. Their experience has also provided confidence in underpinning the budget and programme for delivery of the mixing unit, through liaison with the German provider, supported by functional specifications developed in the supporting HyStart NIA.

A key objective of this project is to undertake the process of securing an exemption under GS(M)R for hydrogen injection. This will be the first time this has been done and so the team has engaged with the HSE throughout the development of the project. By sharing with them programme of activities and evidence based which will be drawn up, confidence has been secured that the scope is appropriate for this type of application.

As exemplified by the SGN Oban project, effective communications is key to ensuring that customers understand the purpose of the project and their needs underpin delivery of the programme. A particular benefit of undertaking the project at Keele University is that they are well experienced in engaging with their community. There is no doubt that this ensures the customer experience is positive, and also reduces project delivery risk.

These factors have enabled the development of 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 H. This is divided into three key project phases: Pre-Exemption, installation delivery and network trial. Within these sections are the 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 2017 and is a three 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. There are some areas of the project programme which are strictly outside of the control of the project partners, such as the process of review and granting of the exemption. Through engagement with the HSE, solid estimates of the expected timeframes have been developed to provide collaboratively, with risks mitigated by an agreement to 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, in particular Keele University as the host for the project. The Project organisation is summarised in the management diagram in Appendix G.

National Grid has a well-developed and proven collaboration agreement, which has formed the basis for two NIC projects to date. This has already been reviewed by the project partners and will form the basis for this project.

The governance framework is in place to ensure appropriate oversight and control over key decisions and to delegate authority for scope delivery to a Steering Committee.

The Steering Committee made up of representatives nominated by each of the project partners. The Chair of the Steering Committee shall be the Project Director for NGGD, should the Chair not be available the Chair shall be 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 rules of the Steering Committee will be set out in the Project Collaboration agreement, and are summarised in Appendix G.

The Project Director for NGGD is accountable for the successful allocation of Milestones and allocation of stage funding under the NIC allowance. The Project Directors for both NGN and NGGD shall report progress to their Executive Committee. The Project Director for Keele University is responsible for reporting progress to its Board.

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 the technical management of the experimental programme throughout the project. This will be undertaken in close co-operation with Keele University where activities are undertaken on site.

Otto Simon Limited is the construction manager responsible for project delivery of the hydrogen production and mixing installation, as well as gas monitoring and analysis installations around the network, in close cooperation with the Keele University Estates team. It will take the role of CDM Principal Contractor and be responsible for SHE management until the plant has completed commissioning and handed over.

There will be clear agreements setting out the rights and responsibilities of each of the Project participants. 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.

6.1.3 Project Partners, contractors and team

NGGD and NGN have carefully constructed 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 K.

This project is a true collaboration between two GDNs. **National Grid Gas Distribution** 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, and between them have undertaken NIA and NIC projects in the past.

Keele University: Site sponsor, host network and academic collaborator. Keele provides a unique site which both de-risks and provides unprecedented opportunity for network learning under their SEND programme. This establishes Keele as a ‘Living Laboratory’ in the energy sector, for which this project will be an important early user. More details of this can be found in Appendix D.

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 will plan and oversee the experimental programme at Keele, at KIWA and in their own labs. Their work includes analysis and synthesis of the results from the testing and trial programme.

ITM Power: provider of electrolysis unit and sourcing of grid injection facilities. They are uniquely experienced in hydrogen grid injection based on their work in Germany on two projects (RWE's Power-to-Gas installation in North Rhine-Westphalia, and the Thüga project in Frankfurt), where their equipment is current injecting hydrogen into the network.

Progressive Energy: Project management, planning and overall programme co-ordination. They have been selected based on a proven track record in undertaking NIC projects.

In addition to the core partners, the project is supported by key industry experts:

KIWA Gastec will undertake practical survey, test and trial work onsite, building on their experience of such work. They are international experts in this field, undertaking extensive trial and demonstration work specifically relating to hydrogen. Furthermore they bring direct and relevant experience from the SGN Oban trial work.

Dave Lander Consulting is a well-respected specialist in the field, and will develop the safety case and manage the QRA for submission to the HSE to secure the Exemption, based on the survey and test programme. He also was a key member of the SGN Oban project, developing the case for the Exemption for that project.

Otto Simon (OSL) provides engineering services for projects, particularly more innovative systems in the process engineering sector and has a track record of delivery in NIC projects. Their role is construction management of the new facilities and engineering design/management resource.

6.1.4 Project Delivery Risk Assessment and Mitigation

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

A standardised approach is used for the project, where risks are categorised and assessed in terms of Likelihood and Impact. Likelihood is assessed on a scale from 0 to 5, from Impossible to Certain, and Impact assessed between 0 and 7, from Low to Disastrous. In both cases standardised guidance is used against each category. Mitigation measures against each risk are identified and actions proposed. The risk, on the basis of the mitigation measures being put in place, is reassessed. This tool will be used proactively to manage the project throughout the delivery phase, with clear responsibility for each action and risk status. It will be updated regularly throughout the project and will provide the basis for reporting.

The HyDeploy project risk assessment is grouped into three main categories of risk; namely health and safety risks, technical delivery risks and project risks.

The first of these areas covers risks where there is a possibility of injury and death associated with the demonstration project. The use of hydrogen does have some inherent safety issues and until these are fully understood and evidenced the likelihood of impact in these areas remains moderate; making the overall health and safety risk high. These risks are the focus of much of the scientific work being undertaken by HSL as a precursor to the live demonstration. Through a combination of literature review and new experimental work, the evidence base for safety will be produced. This evidence base will then be interpreted by Dave Lander in the QRA and made specific to Keele as the safety case for exemption to allow the trial to take place. Given the critical nature of the safety risks on the project, this exercise will be done in conjunction with HSE. It is acknowledged in the risk register, that whilst the likelihood of harm can be reduced significantly by understanding it and managing it to ALARP (as low as reasonably practical), these health and safety risks cannot be eliminated altogether and will be the focus of the safety case and ongoing management of the site during the trials.

Technical delivery risks cover those risks that undermine the study objectives, for example relating to obtaining good quality data from the study. Deploying appropriate instrumentation for measurement of gas quality is one of these risks as poor choice of instrumentation could mean poor quality results. Some of these technical risks have already been investigated at submission stage and an outline technical scope for the project produced. This means that these risks are considered to have medium impact but fairly low probability. Each of the areas of technical risk will undergo detailed design and planning as part of the first stage of the main project, as such it is anticipated that the likelihood of technical delivery risks impacting on the project outcome will reduce to being low.

Project risks include risks to the cost and duration of the overall study. Several of these risks are high at the moment and will require further work in the early stages of the main project to bring the risk levels down. In terms of asset degradation this will mean some laboratory testing work to look at the long term performance of appliances and infrastructure on the grid and will require management of any residual risk through insurances. Other peripheral risks in this area require the project to 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 are likely to come into force in 2-3 years after the start of the project. This is highly unlikely to effect the Keele application for exemption to complete the demonstration works at Keele, however the project team should continue engagement with IGEM to ensure that the evidence base for hydrogen blending is on the agenda in these discussions.

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. Upstream it builds on the existing NGN/NGGD NIA (2016) "Hydrogen feasibility study", the SGN NIC (2013-) "Opening up the Gas network, the two NGGD projects into BioSNG (2014-,2016-) , as well as many other projects such as the WWU Future of Energy and Investments in gas Network NIA (2015-). Both NGN and NGGD are considering NIA projects including hydrogen blends in engines and CHPs, development of novel hydrogen analysis equipment to reduce costs, as well as demonstrating bio-hydrogen production using the existing pilot BioSNG plant.

It also draws on the vision created by the NGN NIA (2015) H21 Leeds City Gate Project. The focus of HyDeploy is the ability to blend hydrogen into the gas distribution network; the nearest term opportunity for decarbonisation via hydrogen. H21 Leeds Citygate is assessing the feasibility of conversion of elements of the network to 100% hydrogen, achieving even deeper carbon savings through the gas grid. This is a longer term opportunity, although HyDeploy contributes to its progress. HyDeploy will establish key principles with the HSE associated regarding the use of hydrogen on networks as well as cost effectively incorporating specific tasks into the programme (WP 3 in the programme) which provide an evidence base for dedicated hydrogen operation. The H21 work is led by NGN, one of the partners in this project. The two projects are therefore well integrated, and the contribution the HyDeploy project makes towards H21is acknowledged in H21's outputs[25].

Downstream it interfaces with project such as the NGGD NIC (2016) "Future of Billing", considering the changes to billing methodology necessary to facilitate adoption of new gases and blends more widely. Understanding the detailed impacts on the downstream distribution system is a pre-requisite to allowing injection of hydrogen in the Transmission system.

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 best practice from the SGN Oban project in particular, as well as other NIC projects NGGD is undertaking. This ensures that not only are the technical activities accounted for, but important facets such as communications and consumer engagement are properly considered and costed. Based on a significant amount of technical work, both from the HyStart NIA as well as the work undertaken by HSL itself for this project, and KIWA's experience at Oban, the scope of activities necessary to present a case for Exemption have been drawn up. There has been extensive engagement with the HSE to ensure this scope is aligned with their expectation, including their estimates of the costs associated with assessing the Exemption application itself.

In addition to the overall experimental scope, the project delivery has been thoroughly considered. This includes the installation required, building on the experience from ITM in terms of electrolyser and grid mixing unit, and Otto Simon have costed the delivery element of the installation. Third parties have been approached for costs for individual elements such as analysers, based on specifications developed by HSL. National Grid has costed wider network changes based on their experience. Costs during the network trial phase have been carefully assessed, including the requirements for training of operatives responsible for the gas network, costs of operation and the experimental activities. Throughout, the interfaces and costs associated with delivery of the project at the University host site have been included.

The consolidated costs have been reviewed by the project partners. In particular, the detailed risk register for the Project has been reviewed to identify areas which require allowances to be made against specific activities.

This is an experimental programme which is taking place on an operating network, involving existing operating equipment which is being surveyed. As with the SGN Oban project, this may identify equipment and appliances which need replacement. Provision must therefore be made to ensure that this if funded and that reinstatement is undertaken swiftly. The outturn appliance failures at Oban was 56 replacements following a survey of 2650 with only half requiring replacement. Given the detailed information already available on appliances at Keele, as well as greater confidence in the provision for maintenance, it is

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[25] Leeds City Gate h21 Report (July 2016) pp301

anticipated that there will be lower risk of such a requirement. However, the Keele network does include larger appliances than at Oban, and so the impact of an issue with a single boiler is more significant. The Project team has made a judgement on the overall provision required. Key emergency provision is also required during the trial phase, such as hire of back up boilers for critical facilities, recognising that larger boilers cannot necessarily be replaced as rapidly. Provision has been made for this, based on the matrix below.

Category	Safety concerns requiring immediate replacement	Provision to make unplanned changes in order to execute trial	Failures caused by the trial	Continuity of supply provisions
Domestic Appliances	At Oban only (28 in 2650) appliances needed replacement £5,000	Assumes no more than 10% of appliances needing modification at £1,000 ea. Beyond this trial unlikely to proceed. £10,000	Given the rigour of the Exemption, highly unlikely, but £10,000 provision made for rapid replacement	Covered by immediate replacement
Commercial Appliances	Highly unlikely given university maintained facilities. Any BAU issues covered by the University	Assumes no more than 10% of appliances needing modification at £5,000 ea. Beyond this trial unlikely to proceed. £30,000	Given the rigour of the Exemption, highly unlikely. An overall Provision of £200,000 to cover any remedial work	£40,000. Keele estimate for temporary large boiler hire and install.
Internal Installations	£5,000 for domestic properties	£5,000 overall		N/A
External network	Highly unlikely given university maintained facilities. Any BAU issues covered by the University	Key issues already addressed in the budget with £30,000 set aside		N/A

Given that these are contingent provisions, 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 NGGD and NGN for sign off.

National Grid 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 Scope	This was developed early in the project, drawing on the experience at the SGN Oban project. It underwent a substantial review and sign off process by the project partners
Experimental Programme & Budget	The overall experimental programme was developed by HSL and reviewed by KIWA. The content was also reviewed against the outcomes HyStart NIA. Through dialogue with the HSE, provided confidence that the relevant programme elements were included. KIWA's proposal for the appliance testing phase was reviewed by HSL, with reference to the work at Oban. The combined programme was reviewed by Progressive Energy and NGGD/NGN
Exemption Process	Costs to develop the safety case and QRA were proposed by Dave Lander and verified by discussions with potential sub- contractors. HSE provided estimated costs for review of the Exemption.
Installation programme & budget	This was developed by ITM in conjunction with NRM, a supplier of hydrogen gas mixing units. The Installation programme was reviewed by Otto Simon
Trial phase programme & budget	This was developed by HSL, and reviewed by KIWA. The combined programme was reviewed by Progressive Energy and NGGD/NGN
Dissemination	Figures were developed by the partners and reviewed by NGGD against the costs under other NIC projects.
Carbon Benefits	National Grid's FES team undertook the assessment of carbon benefits, building on its FES work, supplemented by 3rd party referenced material. This was reviewed by Progressive Energy, then project team
Financial Benefits	National Grid's FES team undertook the assessment of carbon benefits, building on its FES work, supplemented by 3rd party referenced material. This was reviewed by Progressive Energy, then project team

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

The execution of this project will provide valuable learning; the value it achieves is not wholly dependent on the uptake in the trial area. The development of the evidence base and synthesis into a coherent case for Exemption to GS(M)R for the injection of hydrogen at a level of blending which is accepted by the HSE provides a valuable precedent of itself. It will provide a robust and referenceable evidence base for the industry here in the UK, as well as beyond. The existing UK regime only allows hydrogen at 0.1%, and the only way to be confident that this can be raised is by taking a specific case through the regulatory process with the rigour that this requires. In the same way that the SGN Oban project has wider ramifications for the operation and role of the gas grid, this project will establish the basis for decarbonisation via the gas grid.

In the full submission two cases of hydrogen blending are considered. A level of 10% is widely considered to be well founded through extensive work undertaken internationally, and there are a number of key pieces of work which suggest that 20% is feasible. The expectation is that this programme will achieve a level between these two figures. In the unlikely event that this isn’t the case, even raising the level above the existing UK level of 0.1% to a level below 10% is of value to the opportunities for the gas network. For example it would still unlock the opportunities for the gas grid to play a role in 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.

The project is structured with a key project gateway at the end of Phase 1, show in the project plan as Activity 7. This requires that (a) an Exemption is secured from the HSE for hydrogen injection (b) that Keele University sanctions commencement of the installation and trial phase, and (c) that the Steering committee has agreed that the project delivery risk relating to the next two phases of the project has been assessed by the project partners and is agreed to be acceptable.

These three gateway criteria must be met for the Steering Committee to sanction placement of equipment orders for execution of 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

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. As discussed in Section 2, the reasons for the existing hydrogen limit was a pragmatic simplification of the multidimensional interchangeability as existing sources of natural gas do not contain hydrogen.

Phase 1 of this project will provide the body of evidence needed to support an Exemption from the limit in the GS(M)R to allow the trial to proceed, in particular this application will include the Quantitative Risk Assessment.

During the course of Phase 1 of the project, consideration will be given to whether it is appropriate for the Exemption to include a reduction to the lower Wobbe limit in Schedule 3 of the GS(M)R. This will depend on the underlying gas composition, and the outturn level of hydrogen blending which is considered to be acceptable, as well as wider impacts of a Wobbe reduction, noting the three dimensional nature of the interchangeability diagram along the hydrogen axis. Historic data suggests that across the ranges of underlying gas compositions at Keele, a blend of up to 20% hydrogen would be feasible within the constraints of the Wobbe limit in GS(M)R. However this will be reviewed against the possibility of gas from other sources in the network, such as from biomethane, or different UK national gas sources, as well as the wider evidence base on acceptable hydrogen levels arising from the programme.

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. This will be informed by the baseline survey work, extensive test data and existing literature, and corresponding QRA. Based on available data, DNV-GL have considered a theoretical QRA for blends of hydrogen up to 20%, which has concluded that any changes to the overall risk factor are small. To execute a fully populated QRA requires the evidence base that phase 1 of this project will deliver, but this provides confidence to undertake the programme proposed. Along with literature review undertaken by the HSE in 2015[26], this supports the basis of the project being designed to assess levels up to 20%.

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[26] Injecting Hydrogen into the gas network – a literature search' Hodges et al HSE (2015)

Subject to securing an Exemption for the trial at Keele, the project as whole including the evidence from the live network trial will provide the primary body of evidence necessary for a subsequent Exemption for hydrogen injection on a public network. The design of such a trial and the specific additional implications associated with it is included in this project.

Subject to a successful outcome, 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.

Throughout the development of this project, the team has engaged extensively with the HSE including a series of four face to face meetings with members of the project team, and intermediary communication by phone and email. By these means, the HSE is fully aware of what is being proposed, and has had an opportunity to consider the scope of the evidence base which will be presented, which it considers to cover the relevant elements.

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 OFGEM

Billing arrangements for domestic customers at Keele will need to be addressed for the purposes of the trial to ensure that at no point are they disadvantaged.

Keele University is licensed as a ‘Gas Supplier’, classified as a ‘Non-Transporter/Private Network (without Standard Conditions)’, one of only 11 in Great Britain according to OFGEM’s 2016 list of Gas Licensees. The network is shown in Appendix C in full, and as a schematic.

Gas is shipped to the NGGD-owned fiscal meters at the boundaries of the network. For this trial this will include a new fiscal meter upstream of the point of injection of hydrogen, at the Clock House, with a new pipeline to accommodate 1 barg to Horwood. The university then uses that majority of the gas for its own facilities, but acts as a Supplier to the 101 domestic properties on the relevant sub-network.

Currently these 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 within Keele's own network (i.e. downstream, of the site fiscal meter). Therefore the CV 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. Two approaches have been considered to address this:

Determined CV. The CV could be measured using agreed measurement techniques with OFGEM which are considered to be fiscally robust. However, this hasn't yet been undertaken for hydrogen blends and so achieving this prior to execution of the trial phase would represent a significant project cost and risk. (Although an output of the work will be to assist OFGEM in establishing how this could be achieved for wider roll out, noting the necessary, complementary work on Future Billing Methodology)

Declared CV. This is already used for parts of the GB gas network, where the billing CV 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 CV 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 CV of gas conveyed is greater than the declared billing CV. The effective 'CV shrinkage' experienced by Keele associated with under-billing of the domestic consumers over the period of the trial would be compensated by the energy of the added hydrogen to Keele.

For the purpose of the trial Declared CV is considered to be the most appropriate methodology, providing confidence that the customer is not disadvantaged (and indeed is offered a benefit), as well as being the most cost effective and risk free solution for the project. This billing strategy and CV determination regime will be developed in detail with OFGEM to ensure that the evidence base and detailed approach provides absolute confidence that the interests of the customer are protected.

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.

Section 8: Customer Impact

8.1 A Customer focused Solution

Keele University, NGGD and NGN all 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 recent work by WWU[27] 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"*.

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 upfront capital investments of between £9,900-£23,200, which can pull against the important focus on fuel poverty. The cumulative carbon benefits of incremental reductions in carbon intensity of the gas network are significant and cost effective, as described in Sections 3 and 4. Furthermore it offers a route to even deeper carbon reduction possibilities through complete conversion of sectors of the gas grid such as being considered by the H21 project.

8.1 Customer interactions

In order to undertake this trial it is essential that customers gas supply and appliances operate safely, reliably and deliver the performance they expect. This necessarily involves undertaking surveys of every installation and appliance on the effected network. Based on the best practice at the SGN Oban project, the project has been designed to minimise the impact on individual customers.

There are 101 residential properties on the network, and they are the key focus on the customer engagement strategy discussed below. In addition to the needs of the domestic customers, the safety, reliability and performance of the University facilities is also critically

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

important, as these are providing critical services to its community and represent around 90% of the gas consumption on the network. The difference is that the University already has the management structures necessary to make decisions about the operation of its own facilities. As an active partner, the University is able to understand the project rationale, as well being empowered to participate in the decision making processes to ensure continuity of service, and to schedule survey and test work to minimise impact. However, domestic customers need to be taken on this journey in order to understand the project and its practical implications for them, but importantly the valuable role they will be playing in revolutionising how the UK could decarbonise its heating sector.

An important and unique aspect of hosting project on Keele's network is the level of information available regarding existing appliances as shown in Appendix D, and much higher confidence that installations and appliances are well maintained. It is recognised that this won't necessarily be the case for a follow-on trial on a public network, but there is universal agreement amongst the experts (the partners, as well as the HSE and DNV-GL) that for the first UK hydrogen blending trial this risk management is important. However, this means is that the likelihood of requirement for appliance replacement and consequential disruption to customers is substantially mitigated.

47 of the domestic properties on the site are owned and maintained by the University itself. With this responsibility comes the opportunity to ensure that the surveys required for this project can be seamlessly integrated into its existing processes. 54 of the domestic properties are owned by the residents. They, rather than the university are responsible for maintenance of appliances, as on a public network. However even here, the university surveys and undertakes remedial work each time a property is sold, again giving higher than confidence in the state of repair of appliances.

The specific impact on the domestic customers will be the installation and appliance survey during the latter part of phase 1 of the programme following the offline laboratory work. Access will be required for approximately 2 hours with appointments arranged by mutual agreement, with customers able to choose slots and have the opportunity to ask any questions they may have.

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. This baseline assessment will include a safety check of all appliances. 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.

Should any appliance be identified which is unsafe, the householder would be offered a new appliance. As part of the detailed project planning phase, the necessary contingency plans will be put in place to ensure such replacement can be undertaken without delay. Should an individual appliance or installation be incompatible with execution of the wider trial by significantly "gating" the level of blend that would otherwise be considered feasible, a process will be put in place to evaluate the best strategy to deliver the overall project outcome, respecting the needs of the customer, including appliance replacement.

During Phase 2, the construction and installation phase, there will be some minor impacts on the University community. The system design is based on prefabricated units, minimising onsite works and the siting of the installation adjacent to the Horwood Energy centre minimises the wider impact. The scale of the works will be minor compared with the substantial developments being undertaken more widely at Keele as a growing and developing University. However, this aspect of the project impact will not be overlooked, and the University will take a pro-active approach to ensuring this is integrated seamlessly with the wider campus developments, engaging with its community. Changes to the physical connections on the gas network will be managed under the existing University procedures, using best practice to minimise any customer impact.

During phase 3, the operating trial period, there will be a requirement for some spot checks on installations and appliances, covering both university facilities and domestic properties. 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.

Given the University context, and with a carefully developed customer engagement plan, there is every expectation that access will be gained to all properties, with the project team learning from the experience at Oban.

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. Therefore this project will comply with the conditions relating to customer engagement and data protection as set out in the NIC Governance Document. Furthermore every aspect of the customer engagement plan will require consent from the University's Ethics committee. This combination means that the interests of the customers are fully protected.

The project will not initiate any form of customer engagement until the plan has been agreed by the University Ethics committee and agreed by OFGEM. In line with the NIC Governance process, this plan will be submitted to OFGEM at least two months prior to the required date of engagement.

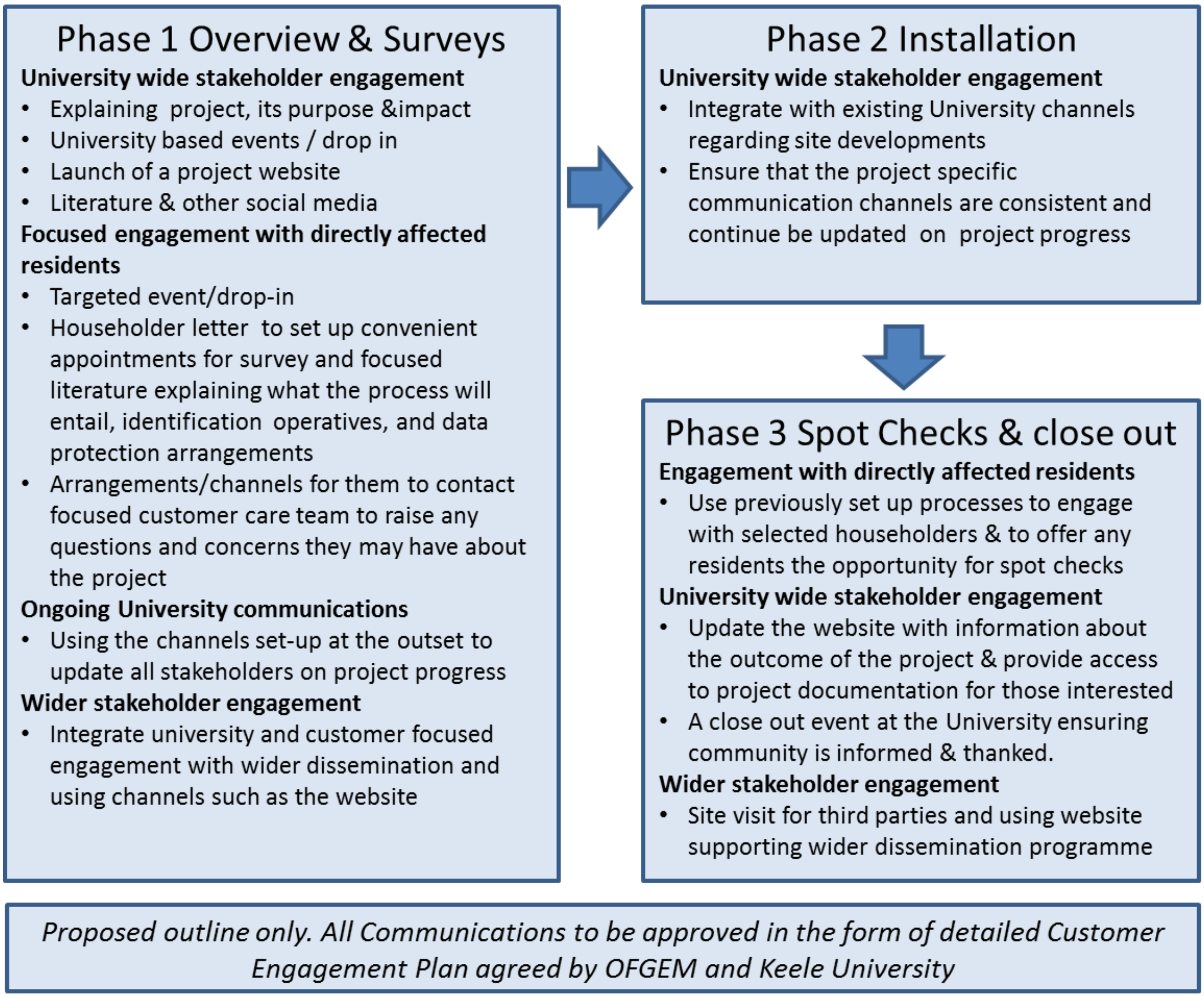
The very strong similarities between this project and the SGN Oban "Opening up the gas network" project means that HyDeploy can learn from their experience and further refine the strategy to deliver 'best practice' from a customer perspective.

In line with NIC Governance requirements, the final Customer Engagement Plan will include:

- *a communications strategy which sets out inter alia:*
    - *any proposed interaction with a Relevant Customer or premises of a Relevant Customer or proposed interruption to the supply of any Relevant Customer for the purposes of the Project, and how the Customer will be notified in advance;*
    - *ongoing communications with the Relevant Customers involved in the Project; and*
    - *arrangements for responding to queries or complaints relating to the Project from Relevant Customers;*

- *Information on the Priority Services Customers who will be involved in the Project and how they will be appropriately treated (including providing information to any person acting on behalf of a Priority Services Customer in accordance with condition 37 of the Gas Supply Licence, where applicable);*
- *Details of any safety information that may be relevant to the Project; and*
- *Details of how any consents that may be required as part of the Project will be obtained.*

The figure below provides an overview of the expected key elements of the engagement plan. NGGD, NGN and Keele University will publish the final Customer Engagement Plan by making it readily available via the project website with appropriate links from other sites as required. Furthermore, one of the key learning outcomes of this project is to develop and refinement the customer engagement plan for a subsequent trial on a public network.



Phase 1 Overview & Surveys

University wide stakeholder engagement
- Explaining project, its purpose &impact
- University based events / drop in
- Launch of a project website
- Literature & other social media

Focused engagement with directly affected residents
- Targeted event/drop-in
- Householder letter to set up convenient appointments for survey and focused literature explaining what the process will entail, identification operatives, and data protection arrangements
- Arrangements/channels for them to contact focused customer care team to raise any questions and concerns they may have about the project

Ongoing University communications
- Using the channels set-up at the outset to update all stakeholders on project progress

Wider stakeholder engagement
- Integrate university and customer focused engagement with wider dissemination and using channels such as the website

Phase 2 Installation

University wide stakeholder engagement
- Integrate with existing University channels regarding site developments
- Ensure that the project specific communication channels are consistent and continue be updated on project progress

Phase 3 Spot Checks & close out

Engagement with directly affected residents
- Use previously set up processes to engage with selected householders & to offer any residents the opportunity for spot checks

University wide stakeholder engagement
- Update the website with information about the outcome of the project & provide access to project documentation for those interested
- A close out event at the University ensuring community is informed & thanked.

Wider stakeholder engagement
- Site visit for third parties and using website supporting wider dissemination programme

Proposed outline only. All Communications to be approved in the form of detailed Customer Engagement Plan agreed by OFGEM and Keele University

Section 9: SDRCs

The following Specific Delivery Reward Criteria are on the basis of project commencement on 1st April 2017.

REF	Title	Description & Evidence	Date
9.1	Communications Plan	Development of Communications plan Sign off by OFGEM and by Keele University Ethics Committee. Allows proceeding to survey phase. Evidenced by sign off from OFGEM/Keele	24 Nov 2017
9.2	Laboratory Appliance Tests	Laboratory work completed. This covers both the initial 18 appliances and the longevity testing Evidenced by Laboratory Report	30 Mar 2018
9.3	Onsite Survey programme	Completion of onsite installation and appliance survey Evidenced by Summary Report	25 May 2018
9.4	Exemption & QRA	Completion of Exemption and QRA documentation. Evidenced by Submission to HSE	29 Jun 2018
9.5	Exemption Approval	Grant of exemption by HSE Evidenced by Granting of Exemption	31 Aug 2018
9.6	Gateway to Phase 2	Steering Committee sign agreement to proceed to Phase 2 Evidenced by Steering committee minutes showing approval	31 Aug 2018
9.7	Hydrogen system installation	Completion of the installation of the hydrogen production & Injection system Evidenced by Otto Simon as Construction Manager	26 Apr 2019
9.8	Completion of Field Trial	Trial completed Evidenced by Trial Report	28 Feb 2020
9.9	Public network trial definition	Completion of definition of follow on network trial, including application of learning from the Keele customer engagement plan. Evidenced by Definition Report	31 Mar 2020
9.10	Dissemination & Close out report	Evidenced by Close out report, including summary of dissemination activities	31 Mar 2020

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				Notes	Cross-references
				2020	2030	2040	2050		
Post-trial solution *(individual deployment)*	Method 1	App B	App B	0	0.4	0.7	0.7	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	0.4	0.7	0.7		
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	App B	App B	0	1,195	3,796	5,078	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	539	1,605	2,059	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	1,897	6,025	8,060	Displacing 2.9 mill ASHP	All assumptions in Appendix B, summarised in Bid Section 3.5
	Method 2	App B	App B	0	855	2,548	3,269	Displacing 1.5 mill ASHP	

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

Scale	Method	Method Cost	Base Case Cost	Benefit				Notes	Cross-references
				2020	2030	2040	2050		
Post-trial solution *(individual deployment)*	Method 1	App B	App B	0	3,002	6,504	6,504	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	3,002	6,504	6,504		
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	App B	App B	0 mill	5.5 mill	37.9 mill	75.1 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	2.7 mill	19.0 mill	37.6 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	8.7 mill	60.2 mill	119.3 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	4.4 mill	30.1 mill	59.6 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 ability to blend hydrogen into the gas network enables consumers to decarbonise without having to make expensive or disruptive changes to their appliances.

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 UK 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. 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 of 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.

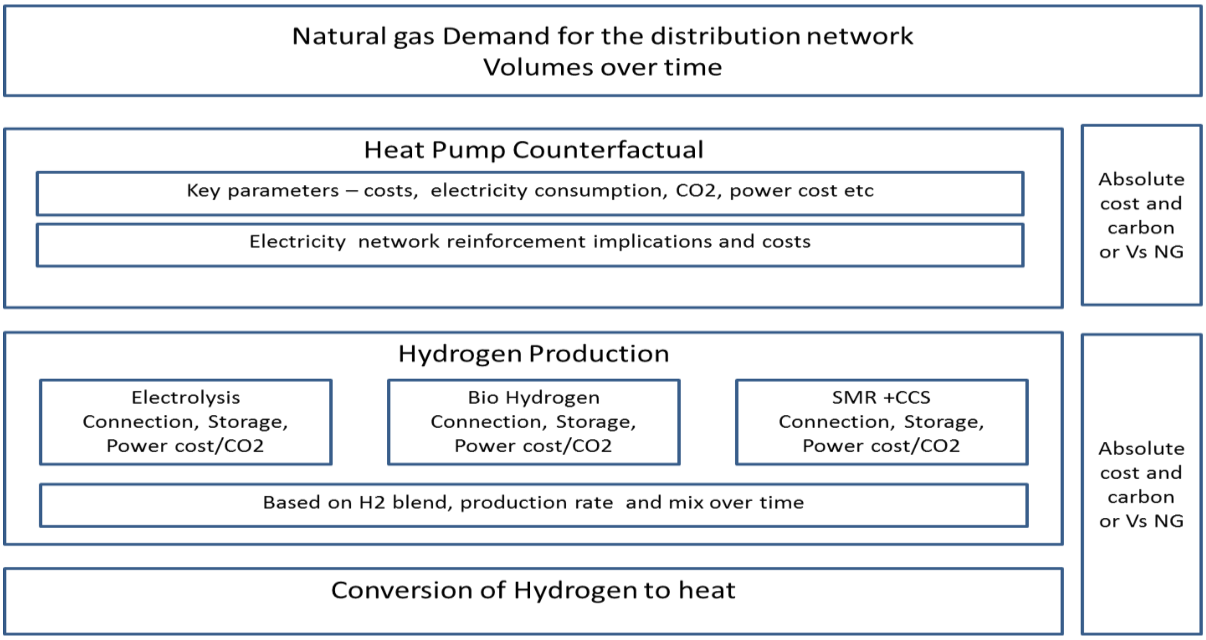


Figure B1. Overview of modelling approach

B.2 Assumptions

B.2.1 Baseline Scenario

The Slow Progression scenario was used as the reference scenario in this case, with gas consumption on the distribution network going from 483TWh down to 414TWh 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; 10%molar level which is already permitted in parts of Europe and supported by the conclusions of the Natural Hy project, and 20%molar which is considered to be the maximum feasible level in HSE's recent literature review. The expectation is that this work will establish a level of hydrogen blending between these two conditions. 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 Steam Methane Reformation with Carbon Capture and storage. For the purposes of this analysis a blend of these production routes was considered, albeit with the SMR+CCS route, not considered to be deployed until 2030. 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.

Bio-Hydrogen production

The production of bio-hydrogen is a simplification of the thermal process for the production of biomethane (Bio-SNG). The feedstock is gasified and the syngas processed and polished to provide a catalytic quality gas. For BioSNG production this undergoes the water gas shift to achieve the correct molar balance of carbon and hydrogen for the subsequent catalytic production of methane. The gas, which is a mixture of CO_2 and methane then has to be separated, typically with a further downstream refining stage to produce a substitute natural gas.

The production of hydrogen is a considerably simplified process. Methanation catalysis is a multistage process, and demands extremely high quality gas to avoid poisoning, with contaminants at parts per billion levels. This entire stage can be removed, along with both upstream and downstream processing. Instead the water gas shift, which is a much less sensitive catalyst fully shifts the syngas to hydrogen and CO_2 for straightforward separation.

BioSNG is currently produced in Sweden at the Gobi-gas plant from wood-based feedstocks. In the UK there are two successful NIC supported projects already underway[28] to establish the production of BioSNG from waste based feedstocks, with a demonstration plant being built which will inject biomethane into the grid at the start of 2018 at a scale of 22GWhr production per annum.

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[28] http://gogreengas.com/

Costs: As part of these projects the costs of BioSNG production has been established, based on waste fuelled plants at scales between 300-600GWhr and demonstrating production at cost parity with fossil fuel by mid 2020s. For the purpose of this assessment, it has been assumed (a) that only the smaller plant is feasible, (b) that hydrogen is produced at this cost, although with the process simplifications this is a conservative figure, and (c) a requirement for storage and distribution of the hydrogen to points on the distribution network.

Carbon Intensity: The BioSNG project undertaken extensive Greenhouse Gas analysis showing intensity to be 61 -19 kgCO2e/MWhr as grid electricity carbon intensity falls. In line with the assumptions above, the value for bio-hydrogen is assumed to be the same. This is conservative; using the same approach that DECC has used in its recent RHI consultation, 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. Industry quality CO_2 is produced so the demo plant will sell its CO_2 which will displace fossil derived CO_2. This could be credited to the plant under the assessment regimes; reducing the emissions further to -351 & -415kgCO2e/MWhr. None of these benefits have been credited in the assessment, but show that the values are conservative.

Volumes: Under the BioSNG NIC programme, a trajectory of potential capacity was developed, based on the volumes of waste available, assuming diversion from current waste exports and landfill. This showed a potential increase to 25TWh of BioSNG by 2030, and a full potential of 100TWh by 2050. This is substantially higher than the levels of hydrogen considered in the scenarios for this project. Assuming blending of hydrogen into the grid is enabled, then the process simplification would lead to production of hydrogen in favour of SNG. Therefore this route would have sufficient capacity to deliver hydrogen at the levels of blend required.

Electrolysis

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[29], and recent work by Element Energy projecting developments into the future[30]. 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. National Grid assessed the expected blend of marginal low carbon

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[29] Fuel Cell & H2 joint undertaking (FCH JU), Multi - Annual Work Plan (2014 – 2020)

[30] http://www.fch.europa.eu/sites/default/files/study%20electrolyser_0-Logos_0.pdf

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.

Steam Methane 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 had carbon capture fitted. The key dependency is the existence of CO_2 transportation and offshore geological storage infrastructure.

Costs: The recently completed H21 Project has provided a suite of reference data[31], based on engineering assessments by Amec Foster wheeler, building on the previous work by the Teesside Collective[32]. This includes assessment of the efficiency & costs of hydrogen production, storage & distribution, as well as costs for CO_2 transport & storage.

Carbon intensity: The capture rate from the Teesside Collective work was 90%. 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 be available later 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.

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, as bio-Hydrogen comes on-stream this is expected to dominate the supply curve until mid 2030s, when SMR plus CCS makes a contribution. The figure shows the blend for 20% hydrogen injection for the whole GB distribution network. For the 10% case the blend was maintained, but the volumes

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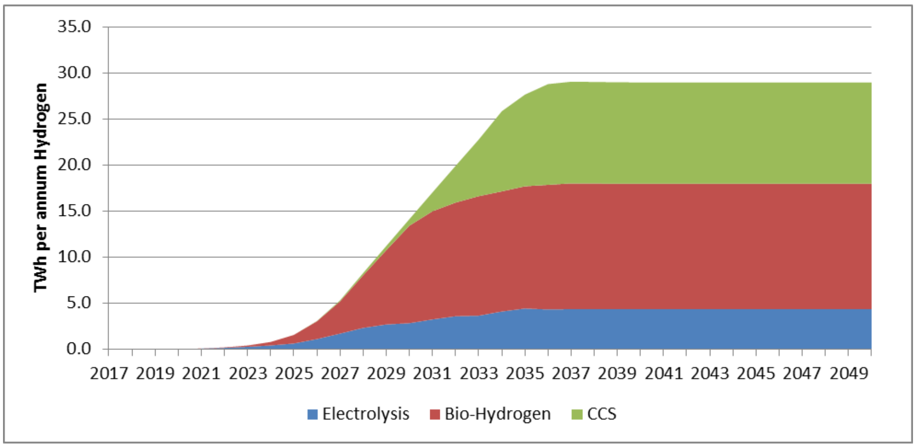
[31] http://www.kiwa.co.uk/uploadedFiles/Our_Services/Energy_and_Carbon_Advice/H21%20Report%20Interactive%20PDF%20July%202016.pdf

[32] http://www.teessidecollective.co.uk/wp-content/uploads/2015/06/Teesside-Collective-Business-Case1.pdf



reduced. Costs for this case are slightly higher as there are twice as many connection points per unit of hydrogen delivered.

<u>Overall Hydrogen cost</u>

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 DECC's March 2016 RHI consultation[33] and its January 2016 work on cost savings attributed to mass market deployment[34] which accounted for expected performance improvements and cost reductions over the period. 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 2015 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 Gone Green Scenario, and this confirmed that 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.

Furthermore, whist National Grid FES models show a requirement for a significant level of heat pumps by 2050, their stakeholder engagement has reinforced that for practical reasons, particularly high upfront cost and disruption, achieving such levels of penetration will be challenging.

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[33] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505972/The_Renewable_Heat_Incentive_-_A_reformed_and_refocussed_scheme.pdf

[34] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf

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 a recent NIA[35] 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 NGGDs networks compared with the overall usage, which equates to 63%. A ‘post trial’ solution was also considered. Here it is assumed that the mixing & injection unit and electrolyser are relocated to a public network site. This equipment is transferred to that project at no cost, although 4 hours of additional storage has been costed. 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.

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

Cumulative NPV	Blend rate	To 2020	To 2030	To 2040	To 2050
	(Method)	£million	£million	£million	£million
GB Values	20% Blend (M1)	0	1,897	6,025	8,060
	10% Blend (M2)	0	855	2,548	3,269
Licensees (63% of GB)	20% Blend (M1)	0	1,195	3,796	5,078
	10% Blend (M2)	0	539	1,605	2,059
Post Trial	Either blend	0	0.4	0.7	0.7

At its peak this equates to GB savings of around £800 million per annum. By comparison, the cost per tonne of carbon abatement is less than half of that for Hinkley point C, on the basis of its £92/MWhr strike price.

B.3.2 Environmental Benefits

Cumulative Carbon Saving	Blend rate	To 2020	To 2030	To 2040	To 2050
	(Method)	Te CO_2 eq	Te CO_2 eq	Te CO_2 eq	Te CO_2 eq
GB Values	20% Blend (M1)	0 mill	8.7 mill	60.2 mill	119.3 mill
	10% Blend (M2)	0 mill	4.4 mill	30.1 mill	59.6 mill
Licensees (63% of GB)	20% Blend (M1)	0 mill	5.5 mill	37.9 mill	75.1 mill
	10% Blend (M2)	0 mill	2.7 mill	19 mill	37.6 mill
Post Trial	Either blend	0	3,002	6,504	6,504

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. Alternatively this is double the saving from Hinkley Point C at 3 million tonnes per annum, assuming it comes on stream in 2025, with the relative carbon benefit delivered falling further as the electricity grid further decarbonises more widely.

B.4.Assumptions

Prices		Unit	**2020**	**2030**	**2040**	**2050**
Electricity	Wholesale	£/MWhr	£45.20	£53.54	£59.02	£59.02
	Retail	£/MWhr	£179.23	£195.07	£195.07	£195.07
Gas	Wholesale	£/MWhr	£15.49	£19.36	£20.41	£20.41
	Additional price for retail	£/MWhr	£21.40	£21.40	£21.40	£21.40
	Retail	£/MWhr	£36.89	£40.76	£41.81	£41.81
ASHP	Capex	£/KWth inst	940.5	792	742.5	693
	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	£179.23	£195.07	£195.07	£195.07
	Levelised Cost	£/MWhr (heat)	£139.23	£130.08	£124.07	£118.49
Gas Boiler	Capex	£/KWth inst	80	80	80	80
	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	£5.00	£5.00	£5.00	£5.00
	Gas price	Retail £/MWhr	£36.89	£40.76	£41.81	£41.81
	Levelised Cost, excl gas	£/MWhr	£18.48	£18.48	£18.48	£18.48
	Levelised cost delivered heat	kg/MWhr (heat)	£59.25	£62.78	£63.93	£63.93
	Carbon intensity delivered heat	kg/MWhr (heat)	232	228	228	228

Prices		Unit	2020	2030	2040	2050
Electrolysis	Capex	£/KWth inst	987	735	662	662
	Inst Capacity	kW	2500	2500	2500	2500
	H2 Storage Capital Cost	£000	150	150	150	150
	Grid Injection Capital Cost	£000	600	600	600	600
	Load Factor	%	50%	50%	50%	50%
	Efficiency	%	81%	83%	85%	85%
	Electricity Price	(£/MWh)	45.2	53.5	59.0	59.0
	Disc Rate	%	7.5%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£91.39	£92.91	£95.90	£95.90
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£124.62	£124.26	£127.50	£127.50
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£143.11	£142.74	£145.99	£145.99
	Carbon intensity delivered heat	kg/MWhr (heat)	77	22	8	1
Bio hydrogen	Capex Bio-SNG	£/KWth inst	2330	2205	2095	1990
	H2 Storage Capital Cost	£M	14.2	14.2	14.2	14.2
	Grid Injection Capital Cost	£M	1.6	1.6	1.6	1.6
	Hydrogen Transmission System Cost	£M	16.0	16.0	16.0	16.0
	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	-£37.50	-£37.50	-£37.50	-£37.50
	Disc Rate	%	12.0%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£71.91	£51.96	£49.03	£46.25
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£103.10	£79.74	£76.55	£73.53
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£121.58	£98.22	£95.04	£92.01
	Carbon intensity delivered heat	kg/MWhr (heat)	53	33	27	21
SMR + CCS	Capex SMR	£/KWth inst	492	466	440	415
	H2 Storage Capital Cost	£M	72.5	72.5	72.5	72.5
	Grid Injection Capital Cost	£M	7.6	7.6	7.6	7.6
	Hydrogen Transmission System Cost	£M	57.5	57.5	57.5	57.5
	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	£40.00	£30.00	£20.00	£10.00
	Disc Rate	%	12.0%	7.5%	7.5%	7.5%
	Life	Years	20	20	20	20
	Levelised Cost Hydrogen	£/MWhr	£57.38	£54.65	£53.31	£50.44
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£87.05	£82.66	£81.21	£78.08
	Levelised Cost heat (+ boiler capex & opex)	£/MWhr (heat)	£105.53	£101.14	£99.69	£96.57
	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	£	89744
	Grid Injection Capital Cost	£	0
	Load Factor	%	50%
	Efficiency	%	75%
	Electricity Price	(£/MWh)	45.2
	Disc Rate	%	7.5%
	Life	Years	20
	Levelised Cost Hydrogen	£/MWhr	£84.08
	Levelised Cost heat (+ retail cost & efficiency)	£/MWhr (heat)	£116.55
	Carbon intensity delivered heat	kg/MWhr (heat)	77

Method 1: 20%mol Blend	**YEAR**	**2020**	**2030**	**2040**	**2050**
GB Distribution Gas Consumption	**TWh pa**	**476**	**425**	**414**	**414**
Hydrogen blend rate by volume	Vol%	0.0%	9.5%	20.0%	20.0%
Hydrogen blend rate by energy	Energy%	0.0%	3.3%	7.0%	7.0%
Hydrogen consumption pa	**TWh pa**	**0.0**	**14.1**	**29.0**	**29.0**
Heat Pump carbon reduction					
Heat Pump Units off	1000s	0.1	1273.4	2753.5	2910.1
Heat pump levelised cost	£/MWhth	139.2	130.1	124.1	118.5
BAU levelised cost (gas boiler)	£/MWhth	(59.2)	(62.8)	(63.9)	(63.9)
Heat pump additional levelised cost	£/MWhth	80.0	67.3	60.1	54.6
Heat pump additional cost pa	£M pa	0	950	1,742	1,580
Network reinforcement cost pa	£M pa	0	403	12	17
Heat pump cost over BAU pa	**£M pa**	**0**	**1,353**	**1,754**	**1,598**
Hydrogen blend carbon reduction					
Volume of Hydrogen from Electrolysis	TWh pa	0.0	2.8	4.3	4.3
Volume of Bio-Hydrogen	TWh pa	0.0	10.6	13.6	13.6
Volume of Hydrogen from SMR+CCS	TWh pa	0.0	0.7	11.0	11.0
Hydrogen levelised cost of mix	£/MWhth	91.4	60.3	57.7	55.3
Hydrogen delivered heat cost (total)	£/MWhth	143.1	107.3	104.4	101.8
BAU levelised cost (gas boiler)	£/MWhth	(59.2)	(62.8)	(63.9)	(63.9)
Hydrogen total additional levelised cost	£/MWhth	83.9	44.5	40.5	37.9
Hydrogen cost over BAU pa	**£M pa**	**0**	**628**	**1,174**	**1,098**
Annual saving using Hydrogen	**£M pa**	**0**	**725**	**580**	**500**
Net present value of savings	**£M pa**	**0**	**464**	**263**	**161**
Total Net present value of savings by decade	**£M pa**	**0**	**1,897**	**6,025**	**8,060**
Carbon intensity of BAU					
Carbon intensity of Natural Gas	kg/MWhth	210.0	210.0	210.0	210.0
Carbon intensity of heat from Natural Gas	**kg/MWhth**	**232.0**	**228.3**	**228.3**	**228.3**
Carbon savings from Hydrogen					
Carbon intensity of Hydrogen mix	kg/MWhth	69.7	28.0	24.6	20.7
Carbon intensity of heat from Hydrogen	**kg/MWhth**	**77.0**	**30.5**	**26.7**	**22.5**
Carbon saving from heat using Hydrogen	**kg/MWhth**	**155.0**	**197.8**	**201.5**	**205.8**
Annual carbon saving from heat using Hydrogen	**000te pa**	**0**	**2,792**	**5,837**	**5,960**
Cumulative Carbon saving by decade	**000te pa**	**0**	**8,714**	**60,214**	**119,262**
Scaled for Licencees regions (63%)					
NG&NGN Financial Saving	**£M pa**	**0**	**1,195**	**3,796**	**5,078**
NG&NGN Carbon Benefit	**000te pa**	**0**	**5,490**	**37,935**	**75,135**

Method 2: 10%mol Blend	**YEAR**	**2020**	**2030**	**2040**	**2050**
GB Distribution Gas Consumption	**TWh pa**	**476**	**425**	**414**	**414**
Hydrogen blend rate by volume	Vol%	0.0%	4.8%	10.0%	10.0%
Hydrogen blend rate by energy	Energy%	0.0%	1.7%	3.5%	3.5%
Hydrogen consumption pa	**TWh pa**	**0.0**	**7.1**	**14.5**	**14.5**
Heat Pump carbon reduction					
Heat Pump Units off	1000s	0.1	636.7	1376.7	1455.0
Heat pump levelised cost	£/MWhth	139.2	130.1	124.1	118.5
BAU levelised cost (gas boiler)	£/MWhth	(59.2)	(62.8)	(63.9)	(63.9)
Heat pump additional levelised cost	**£/MWhth**	**80.0**	**67.3**	**60.1**	**54.6**
Heat pump additional cost pa	£M pa	0	475	871	790
Network reinforcement cost pa	£M pa	0	202	6	9
Heat pump cost over BAU pa	**£M pa**	**0**	**677**	**877**	**799**
Hydrogen blend carbon reduction					
Volume of Hydrogen from Electrolysis	TWh pa	0.0	1.4	2.2	2.2
Volume of Bio-Hydrogen	TWh pa	0.0	5.3	6.8	6.8
Volume of Hydrogen from SMR+CCS	TWh pa	0.0	0.4	5.5	5.5
Hydrogen levelised cost of mix	£/MWhth	96.8	65.7	62.7	60.3
Hydrogen delivered heat cost (total)	£/MWhth	149.0	113.1	109.9	107.3
BAU levelised cost (gas boiler)	£/MWhth	(59.2)	(62.8)	(63.9)	(63.9)
Hydrogen total additional levelised cost	**£/MWhth**	**89.8**	**50.4**	**45.9**	**43.3**
Hydrogen cost over BAU pa	**£M pa**	**0**	**355**	**665**	**628**
Annual saving using Hydrogen	**£M pa**	**0**	**321**	**212**	**171**
Net present value of savings	**£M pa**	**0**	**205**	**96**	**55**
Total Net present value of savings by decade	**£M pa**	**0**	**855**	**2,548**	**3,269**
Carbon intensity of BAU					
Carbon intensity of Natural Gas	kg/MWhth	210.0	210.0	210.0	210.0
Carbon intensity of heat from Natural Gas	**kg/MWhth**	**232.0**	**228.3**	**228.3**	**228.3**
Carbon savings from Hydrogen					
Carbon intensity of Hydrogen mix	kg/MWhth	69.7	28.0	24.6	20.7
Carbon intensity of heat from Hydrogen	**kg/MWhth**	**77.0**	**30.5**	**26.7**	**22.5**
Carbon saving from heat using Hydrogen	**kg/MWhth**	**155.0**	**197.8**	**201.5**	**205.8**
Annual carbon saving from heat using Hydrogen	**000te pa**	**0**	**1,396**	**2,919**	**2,980**
Cumulative Carbon saving by decade	**000te pa**	**0**	**4,357**	**30,107**	**59,631**
Scaled for Licencees regions (63%)					
NG&NGN Financial Saving	**£M pa**	**0**	**539**	**1,605**	**2,059**
NG&NGN Carbon Benefit	**000te pa**	**0**	**2,745**	**18,967**	**37,567**

Appendix C: Project Technical Definition

C.1 Introduction

The UK currently only permits 0.1% hydrogen in the network, despite formerly distributing town gas with 40-60% hydrogen. There has been substantial study work undertaken supporting the theory of hydrogen injection, but limited practical experience.

To pursue this decarbonisation route, the UK needs to undertake practical hydrogen injection to establish that it is feasible and determine the appropriate level of blending on current networks and in appliances.

This requires carefully executed, safely managed, real deployment, to demonstrate that the practical, regulatory and operational barriers can be successfully addressed.

This document summarises the project rationale and key attributes, providing a consistent single point of reference for project partners and collaborators.

C.1.2 Project Technical Purpose

- To demonstrate the injection of hydrogen into a gas network under safe and controlled conditions, seeking to inject at the highest concentration that safe operation allows.
- To develop practical experience in gas mixing and injection, understand the impact on network behaviour, end user appliances as well as metering, monitoring, and operational issues.
- To build on existing knowledge and best practice with regard to hydrogen injection internationally, as well as UK best practice in terms of injection of unconventional gas compositions, particularly that undertaken at Oban.
- To develop best practice in a controlled environment for subsequent testing and roll out of hydrogen injection onto a public network including technical and engagement with customers.

C.1.3 Project Outcomes

- Physical operation of a gas network with typical appliances and network attributes on a hydrogen blend to act as a reference for the industry.
- A clear understanding of the practical limitations in a controlled environment, and identification of any specific barriers to deployment of hydrogen more widely.
- Definition of the next stage of deployment of hydrogen onto the low pressure distribution network, specifically a follow-on project phase to inject into a nationally representative public network.

C.2 Site & Network Description

C.2.1 Rationale

Keele University has been selected as the host site for the project. It has a closed, private gas network, which it is exploiting as a 'living laboratory' under its Smart Energy Network Demonstrator (SEND). It comprises a network and appliances typical of UK gas distribution systems, domestic & commercial users but under the control of the University as a local, licenced supplier. The key attributes are:

- The energy management system has an extensive time stamped data set of historic gas consumption of consumers the network at a level of detail which is not available for a public network
- There is already a comprehensive dataset on appliances in many buildings which covers domestic, commercial, recreational and catering equipment. This has been used extensively to inform the programme proposed.
- The ability to secure support from the University and facilitate access to properties and reduce risk of project not being successful
- The campus provides excellent opportunities for engagement with consumers and stakeholders.
- The Estates Department provides a cohesive local team on the site who can be well trained to address the changes associated with hydrogen, backed up during the trial by the operations teams at NG and NGN.
- Because of the supply arrangements and 'closed' nature of the network it is possible to establishing an appropriate billing regime during the trial for the domestic consumers downstream of injection point. Data can then be gained during this project, combined with wider industry work on Future Billing Methodology to enable an appropriate regime for operation on a public network
- The SEND programme provides strategic overview and interest in the outcome of the project, as well as links into supporting research and training opportunities.

Further information about the SEND programme can be found in Appendix D

C.2.2 Selected network

The G3 network has been selected as the largest and most diverse network on the site for deployment. All consumers on this network are either university facilities or customers supplied by Keele as their registered Supplier. This network comprises individual residential dwellings, multiple occupation buildings, office and laboratory buildings and service and recreational facilities.

The network has 101 domestic properties of which 47 are privately owned and 54 University owned facilities/commercial/recreational buildings. It includes a range of appliances, boilers from 15-1080KWth, gas cookers from domestic to commercial catering units, recreational unit direct air heaters and water heaters.

A.2.3 Network Modifications ahead of the trials

Currently 22 dwellings at Springpool are on a 'Sub-Deduct' network. As part of its routine business National Grid Gas Distribution will be connecting directly to these properties from their existing gas line to the East of the site and taking them off the private network. This alteration is not part of the project.

Currently Keele Hall and Horwood Staff housing are supplied by a 6" steel pipe. As part of the project planning and assessment, it has been identified that uncertainties associated with this pipeline could present a risk to project delivery. To mitigate this, this pipeline will be taken out of service (with buildings connected onto the G1 network), and dedicated hydrogen tightness testing undertaken on this section of pipeline separately from the main network trial. The requirement for this is a direct consequence of the project but in recognition of the life extension this provides, only 50% of the new pipeline costs will be attributed to the project.

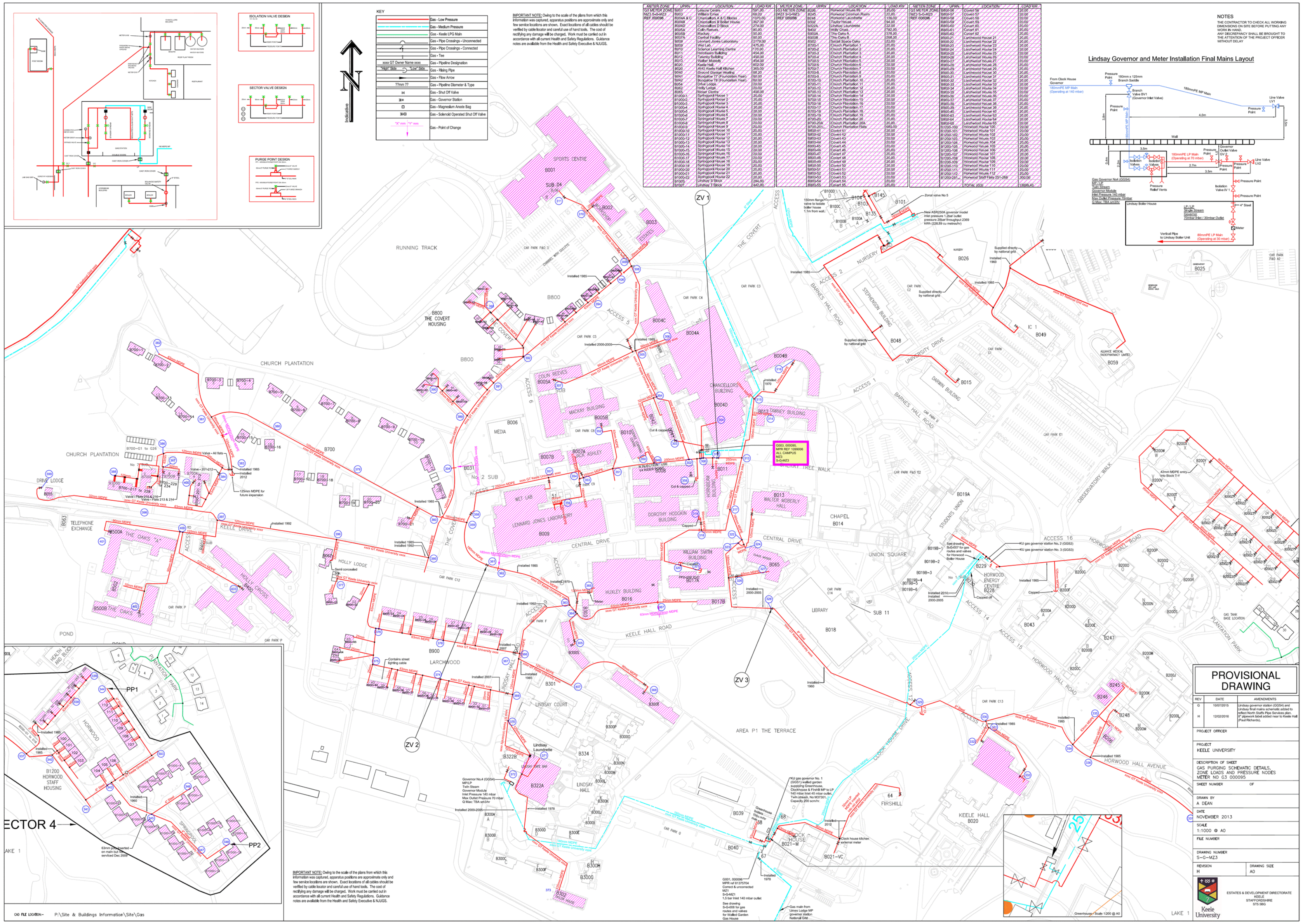


Figure C.2.1 Keele University G3 Network

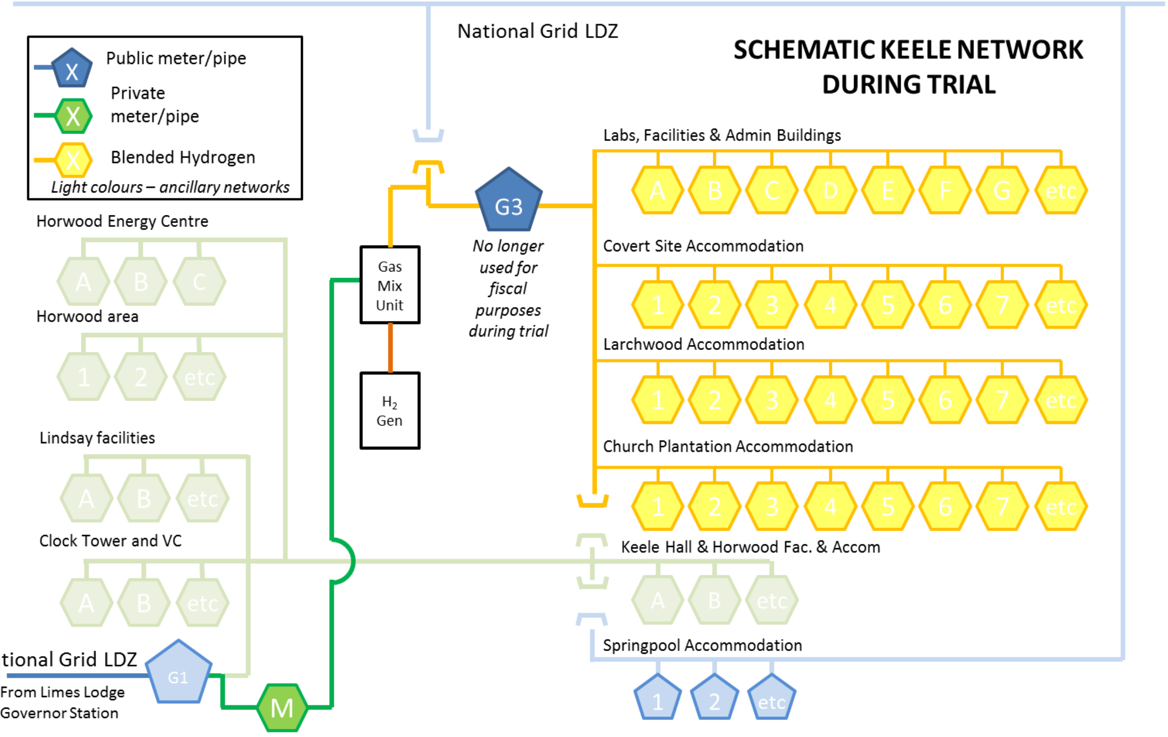
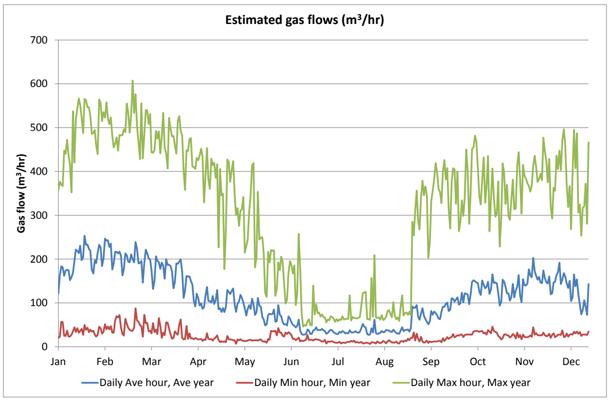


Figure C.2.2 Keele University G3 Network schematic during trial

A.2.4 Gas demand on Network

Keele University has a sophisticated energy management system which means that a considerable amount of data is available on the demand over the last 3 years. Based on this data, typical demand has been assessed for the relevant portion of the network.

Figure C.2.3 shows the estimated natural gas flows in m^3/hr (no hydrogen blend) for the relevant network showing daily average m^3/hr (ave year), daily maximum m^3/hr (max year) and daily minimum m^3/hr (min year). Note that under hydrogen blending conditions, the inlet natural gas flow will reduce. Figure C.2.4 shows Diurnal Natural Gas flow in m^3/hr (no hydrogen blend) for revised network for February and July showing monthly average m^3/hr, monthly maximum m^3/hr and monthly minimum m^3/hr at the times shown. Note that in this figure, the minimum and maximum are based on the same annualised average data to demonstrate the variation in a given year.



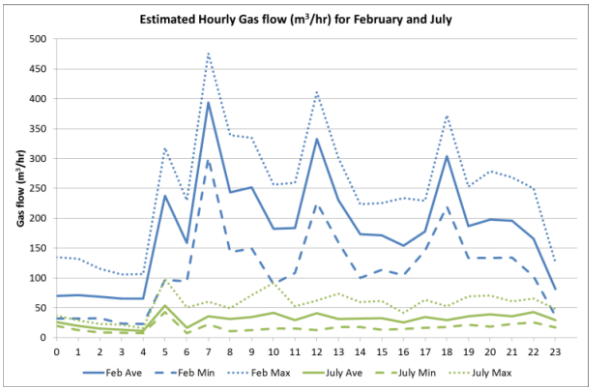


Figure C.2.3 Gas flows on the network Figure C.2.4 Diurnal Gas flows on the network

A.2.5 Gas Quality at Keele

As part of the HyStart NIA, the historic gas quality at Keele has been assessed, and plotted on the interchangeability diagram below.

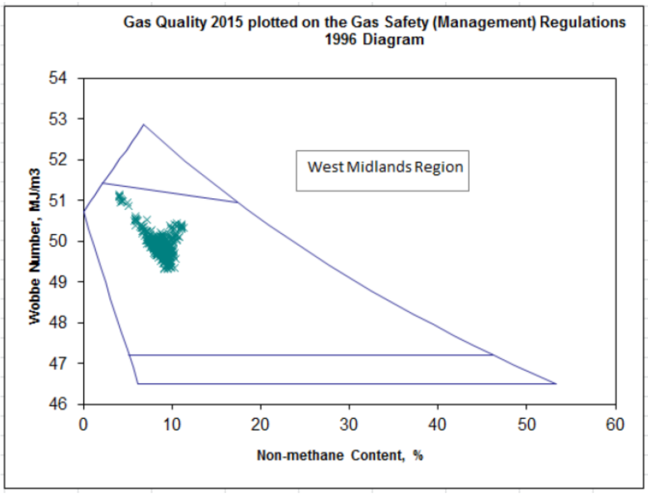


Figure C.2.5 Gas Quality in the Keele area of the LDZ measured over 2015

A.2.5 Expected Hydrogen demand on Network

The current UK regulatory limit is 0.1% molar fraction of hydrogen. European practice indicates that 2% is widely undertaken, with some countries allowing 10% molar fraction. The project is designed to be capable of delivering up to 20% molar fraction of hydrogen, which equates to 7.3% by energy. This is an upper limit. Work during the programme will establish the permitted level, expected to be in excess of 10% molar fraction. The peak daily requirement for hydrogen (at 20% molar) is 7kg/hr which has been used to specify hydrogen supply for the trial.

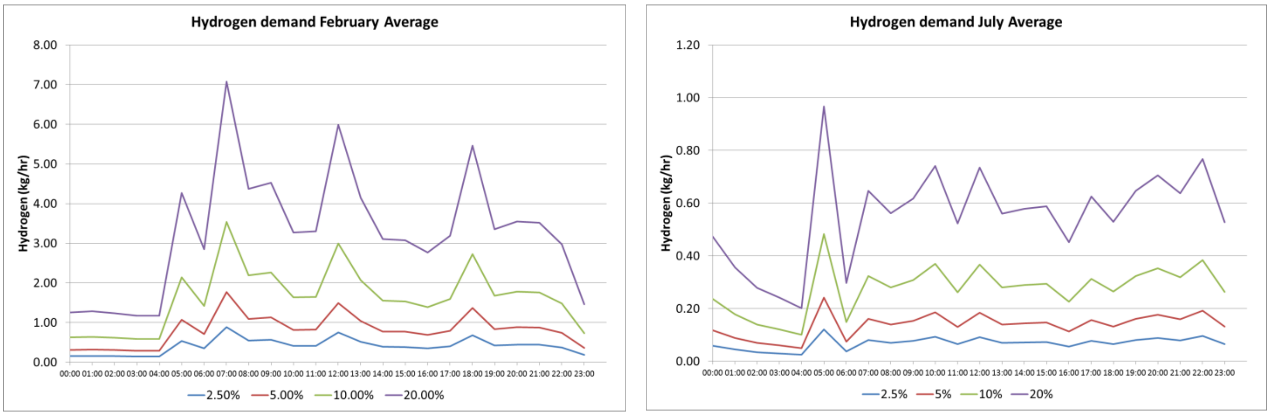


Figure C.2.5 Winter & Summer hydrogen demand

C.3 Installation

C.3.1 Overview

Hydrogen will be produced on site and mixed with metered natural gas in a dedicated mixing and injection unit and injected into the network. All equipment will be fully instrumented for experimental purposes and for validation purposes with regard to billing as described below.

C.3.2 Siting and connection to the network

The hydrogen production and mixing units will be located adjacent to the existing Horwood Energy Building. The Installation site has been reviewed by Otto Simon, and a layout is shown below

Natural gas will be taken from the existing G1 meter unit where it will be regulated to 1barg and piped to the Horwood energy centre using a 250mm MDPE 2 barg rated pipeline to the gas mixing unit. Appropriate isolation valve and fiscal quality metering will be installed at the entry to the pipeline.

A described below, the mixing unit will take natural gas and hydrogen and will be capable of blending the two gases at molar ratios from 0-20%. The hydrogen flow rate will be controlled by the natural gas flow rate, driven by network demand and the hydrogen/gas blend will be adjusted by the mixing unit control system accordingly.

A new 250mm MDPE 2 barg rated pipeline will be routed from the mixing unit to the existing pressure regulation unit at the Hornbeam G3 metering point via an appropriately controlled isolation valve.

An isolation valve will be installed in the existing 150mm MDPE/ 6” steel gas supply line at the Covert from Newcastle Lodge to ensure (a) that the blended gas cannot be back fed to alternative networks and (b) that the gas composition from the mixing unit is maintained at the pressure let down station at the existing G3 meter unit.

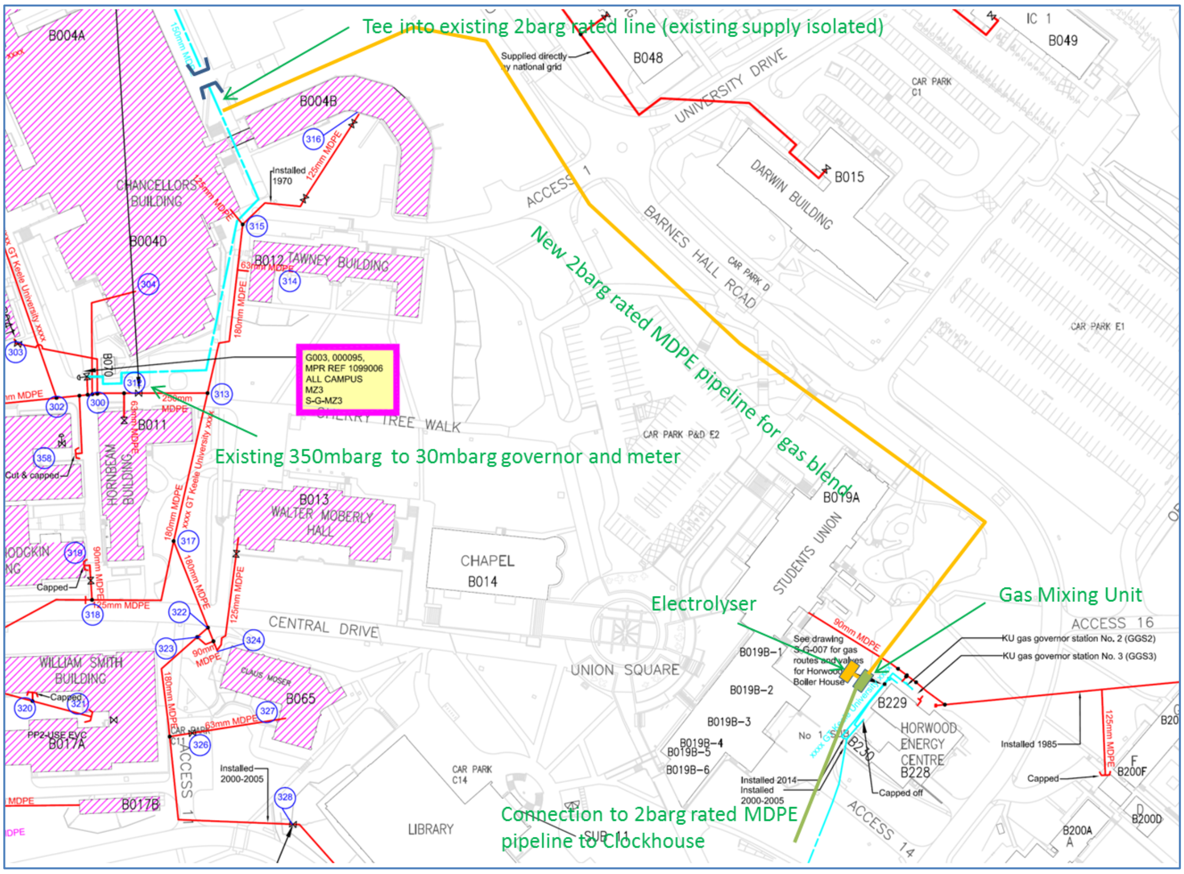


Figure C.3.1 Installation area

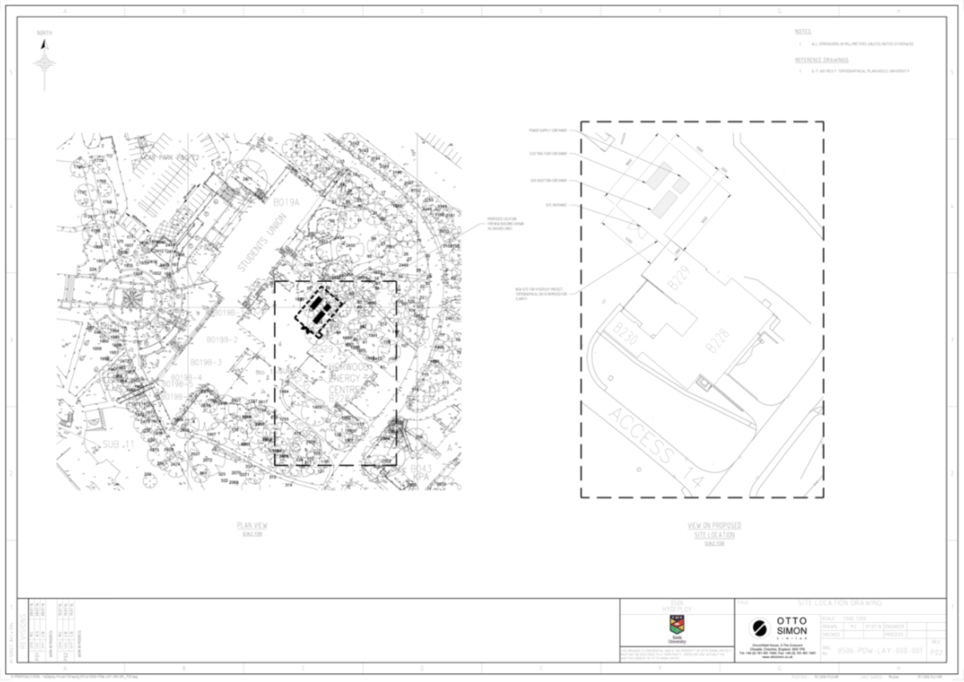


Figure C.3.1 Installation layout

C.3.3 Hydrogen Production

Hydrogen will be provided by an electrolyser. The unit is designed and sized to ensure that minimum summer demand at 0.1% hydrogen level and peak winter demand at 20% can be sustained, based on the operational characteristics of the electrolyser with regard to turn-down and ramp rate.

The unit has a nominal rating of 0.5MWe providing a peak hydrogen delivery of 9.2kg/hr. Modest amount of buffering is provided with the Electrolyser. The electrolyser is supplied in a weather-proof ISO Container.

Demonstration of electrolyser operation in the field under actual variable gas flow conditions provides valuable benchmark data for the industry. Production of hydrogen on demand also avoids significant inventories of hydrogen storage onsite. Furthermore space is limited and additional large tube trailer truck movements on the campus are avoided.

The expectation is that the electrolyser will be used after this project for either (a) ongoing testing beyond HyDeploy at the Keele Site or (b) redeployment on an alternative public network, depending on the outcome of the programme, thus forming the basis for the ongoing pathway for deployment of hydrogen on the network. Should neither of these options be feasible, the supplier ITM has agreed to a buy-back option for the electrolyser; 50% before on-site commissioning, 25% post

Figure C.3.1 ITM Power's Grid Connected Electrolyser in Frankfurt, Germany

on-site commissioning, the proceeds of which will be returned compliant with the OFGEM process for return of funds.

C.3.4 Mixing unit

This will be the first time that a hydrogen mixing unit has been deployed in the UK. NRM Netzdienste Rhein-Main GmbH have supplied two units for use in Germany, and they have provided reference information for this project, including budgetary estimating.

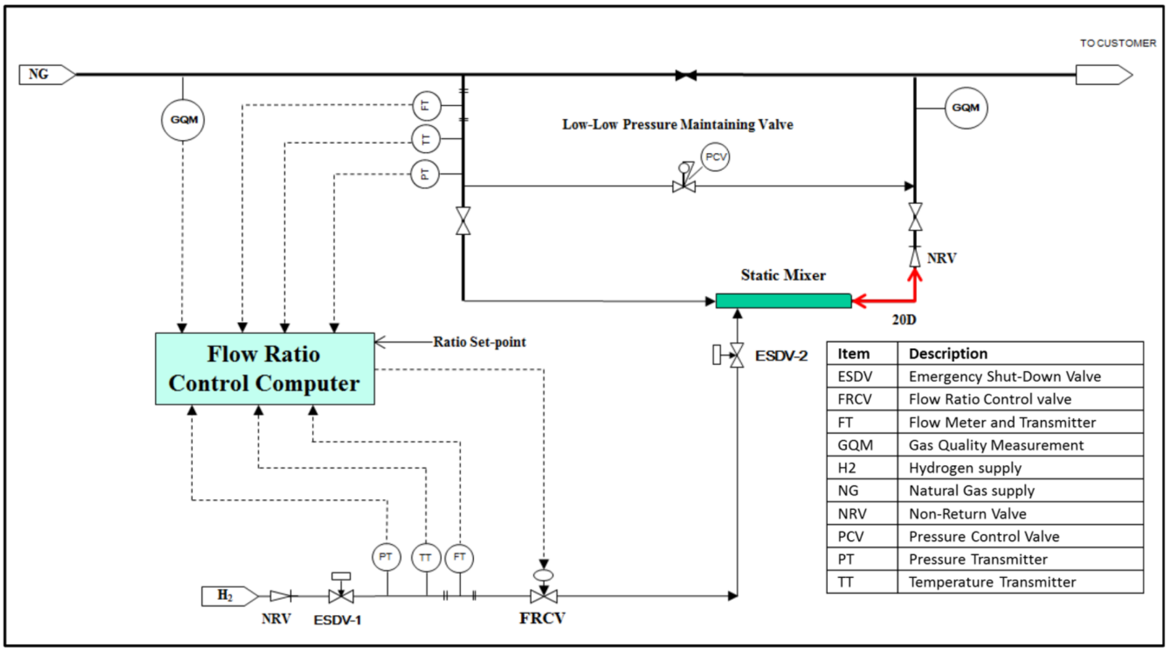
Ensuring that the final design is acceptable to the HSE and suitable for UK operation is an important aspect of this project. Substantial enabling works have already been undertaken to progress this, with a functional specification developed by DNV-GL as part of the HyStart project, from which the following key attributes taken.

The plant configured to guarantee continuity of gas supply to customers regardless of the state of operation of the mixing unit.

It is critical that the two gas are fully mixed prior to injection onto the network. The design is based on a static mixer, as used in Germany, an example of which is shown in Figure C.3.4

Figure C.3.4 Static mixer

Figure C.3.5. shows the single direction gas blending concept gas mixing unit in which hydrogen is blended into the gas grid on a proportional basis. The entire natural gas stream is diverted to the blending unit and the amount of hydrogen limited by a flow ratio control operation.



Item	Description
ESDV	Emergency Shut-Down Valve
FRCV	Flow Ratio Control valve
FT	Flow Meter and Transmitter
GQM	Gas Quality Measurement
H2	Hydrogen supply
NG	Natural Gas supply
NRV	Non-Return Valve
PCV	Pressure Control Valve
PT	Pressure Transmitter
TT	Temperature Transmitter

Figure C.3.5 Mixing Unit Process Flow Diagram

The functionality is described below

Item	**Description and functionality**
Valves	
Non-Return Valve	To force the gas to flow only in a single direction in the GEU. As a minimum one NRV in the Blended gas line and another in the Hydrogen line.
Emergency Shut-Down Valve	At least one will be required on the Hydrogen line to cut off the hydrogen supply into the gas mixer in the event of a major fault.
Flow Ratio Control valve (FRCV)	This valve will be used to control the amount of Hydrogen flowing into the static mixer based on the flow and composition of natural gas from the gas network.
Pressure Control Valve (PCV)	The PCV will ensure continuous flow of gas through the network in the event of a fault that result in a reduced or no flow condition in the GEU.
Isolation valves	Those valves will be used to divert gas from the network and into the GEU. Those valves can also be used to isolate the GEU from the gas network.
Metering	
Natural Gas meter	To measure the gas flow in from the gas network
Hydrogen meter	To measure the amount of hydrogen sent into the gas mixer
Flow Control	
Flow Computer	Flow computer will be used to collect the following data: • Gas quality measurement (Inlet natural gas) • Flow measurement (Inlet natural gas) • Flow Measurement (Hydrogen) This will then be used to control the amount of hydrogen flowing into the gas mixer based on the set-point (e.g. 20% hydrogen)
Gas Quality Measurement	
Natural Gas (Inlet)	This will be used to measure the properties of the natural gas flowing into the GEU. E.g. Wobbe Index, density and Calorific Value
Blended gas (Outlet)	This will be used to measure the gas composition and gas properties of the blended gas to ensure that the blended gas flowing into the network complies within the exemption criteria to GS(M)R.

Control and Safeguarding system

The control system will be designed to run unattended and be fully automatic. Remote monitoring of the site will be available to the Gas Network Operator, the GEU operator and the H2 Generation operator.

The Flow Ratio Control system contains:

1. the measurement elements, (flow, temperature and pressure measurement devices) in both the natural gas and H2 gas streams
2. a processor (Flow ratio Control Computer) and
3. a final element – the flow ratio control valve (denoted FRCV)

Flow, temperature and pressure of the natural gas will be measured and then temperature and pressure corrected to derive the accurate volumetric flowrate of the natural gas. A similar system will also be used for the H2 gas stream such that the volumetric flows of both gas streams will be monitored.

The set point of the controller (pre-set by agreement) will determine the proportion of H2 gas to be supplied into the downstream system. The flow ratio controller will compare the allowable flowrate of H2 with the measured value and the output from controller will modulate the flow ratio control valve to maintain the set ratio.

The Safeguarding system (Emergency Shutdown (ESD) system) is used to minimize the risk to the community, facility, and environment resulting from abnormal operating conditions and/or external hazards. There are three principal objectives;

- To protect the mechanical integrity of equipment and piping systems
- To place the equipment in a safe state when conditions deviate beyond acceptable limits
- To reduce incident severity and risk of escalation in the event of breach of mechanical integrity.

The safeguarding system is independent from the control computer and should be managed via an independent, appropriately rated PLC.

Odourisation

Gas odourisation has been considered in detail in the HyStart NIA. Through laboratory work it has been established that hydrogen does not give rise to a direct masking of odour intensity, or change of characteristics (although it does not rule out the potential for odorant loss through reaction with hydrogen under pipeline conditions). However there will inevitably be a diluting effect. Initial assessments suggest that up to 20%mol Hydrogen this may be acceptable without further odourant, although the upper level is on the cusp. At this stage provision has been made for odourisation of the hydrogen in the gas mixing unit, although further detailed design work would be required to deliver the low flow rates required in this application. More generally, odourisation in the context of hydrogen injection is one of the work streams for the HyDeploy project.

C3.5 Installation Services & Foundational requirements

The Services connections for the installation are provided below:

- 25mm potable water supply with a minimum flow rate of 0.27m^3/hr and pressure of 2barg
- Water effluent capacity at 0.2m3/hr suitable to connect to a foul drain
- Electrical connection at 560KVA supply, 415V, 3 phase (based on 500kW unit with a PF of 0.9)
- Safe oxygen venting
- The electrolyser, mixing unit, valving and pressure regulation will be PLC controlled by with integrated safety channels and telemetry for connection to NGGDs Hinkeley control centre

The Foundation requirements are summarised below

- Slab footings to the electrolyser, gas mixing plant and buffer tank to be min 0.65mm wide and 1.0m deep mass concrete. Electrolyser loading 14 tonne, gas mixing plant no greater than 14 tonne.
- Concrete shall conform to the relevant classes in BS EN 206-1 & BS 8500-2.
    - Concrete reference: foundation
    - Comp. Strength class: c28/35

  - To comply with design class ac-2s/dc-3
  - Max w/c ratio = 0.5
  - Min cement content = 340kg/m3
  - Max aggregate size = 20mm
  - Allowable cement class = iiib+sr
- Reference Foundation designed for assumed allowable bearing pressure of 70kn/m2 onto stiff clay strata as agreed with the engineer. Any soft strata encountered to bottom of proposed footing to be removed and replaced with mass concrete to approved level, concrete to be grade c20.

C.4 Survey & Sample equipment on Network

The Experimental Programme requires extensive monitoring on the network, comprising

- 2 mobile compositional gas measurement units in addition to the two for the mixing unit above
- 10 sample points added to the Keele network
- 10 pipe material test points added to the Keele network

C.5 Billing Arrangements

During the trial it is proposed that the Calorific Value used for the purposes of billing customers will be on a Declared basis, to be agreed with OFGEM and published three months prior to the start on injection. In order to ensure that this is conservative in favour of the consumer, the Declared CV will take account of the lowest CV natural gas to be supplied from the LDZ and the dilution of the maximum level of hydrogen to be used during the trial. Blended gas quality will be measured using the analysis equipment on site as well as periodic laboratory sampling by an accredited facility to confirm that the actual calorific value is in excess of the declared value. Further details can be found in Section 7 of the NIC submission document.

C.5 Experimental Programme Definition

HyDeploy will be the first project in the UK to inject hydrogen into a natural gas grid. In order to deliver the project there needs to be a robust experimental programme and scope of works which will both; (a) Provide the scientific evidence needed to act as the basis of the Safety Gas and to inform an application for an Exemption against the GS(M)R Regulations and (b) Gather scientific evidence from the study to confirm the safety and performance of a hydrogen / natural gas mix when injected into part of the Keele University gas network. This evidence can then be used to justify more widespread trials of hydrogen injection.

The experimental scope of works falls into two main stages; (1) Pre-Exemption scope of works to inform the safety case for injection and (2) Data gathering during trials

C.5.1 Pre-exemption technical scope of works

The following safety and performance issues need to be investigated as part of the pre-exemption work. They should be based on the scientific evidence to give a safe limit for hydrogen injection:

- Safety and performance issues associated with running appliances on a hydrogen and natural gas mixture
- Safety and performance issues associated with long term appliance behaviour
- Safety issues associated with materials embrittlement and leakage from joints on the network
- Safety issues associated with the mixing behaviour of hydrogen /natural gas mix
- Safety issues associated with explosibility of hydrogen / natural gas mix
- Safety issues associated with the appropriate detection of hydrogen / natural gas mix
- Performance issues associated with calorific value of hydrogen / natural gas mix

In addition to the work needed to justify the safety case for injection at Keele, some experimental work is going to be included in the project to look at the effects of up to 100% hydrogen on leak rates within the grid. This work is outside of the scope of the exemption and will be considered under a separate risk assessment overseen by HSL.

The proposed pre-exemption scope of works in more detail is as follows;

1. Assess appliance performance with hydrogen and natural gas mixtures

a. **Literature review**: Including a review of work previously conducted in the area of appliance testing with hydrogen and a justification of the relevance of pre-existing safety and performance data to Keele study.

b. **Laboratory testing:** Offline laboratory testing of a selection of 18 appliances with a variety of burner types which will demonstrate the safety performance of appliances with variable natural gas compositions and additions of different quantities of hydrogen. Eighteen burner types have been selected as being representative of the most well used burner types. This will cover the mix of appliances at Keele. Measurements of CO, CO2 and NOx will be made along with observations of flame picture, flashback potential, temperature of burner head and flame and verification of safe operation of safety devices. Testing will also be undertaken with dynamic changing of wobbe index and / or hydrogen concentration to mimic gas quality on the Keele grid.

c. **Modelling flashback:** Keele University will be using their expertise to run an analytical model to assess the likelihood of flashback with different hydrogen / natural gas mixtures in selected burner geometries.

d. **Baseline Survey of Keele Appliances:** On site testing of appliances, as installed at Keele, to determine both installation integrity and actual performance when using hydrogen and natural gas mixtures. Testing will take place with bottled gases in a range deemed ‘safe’ following laboratory testing. Observations will be taken for CO production, flame picture and leakage. This on site testing is designed to verify the ‘safe’ limit proposed from the laboratory testing.

e. **Appliance repair / replacement:** Any appliances observed to be defective in installation will be repaired or replaced. The Oban study saw very few replacements and Keele is expected to be a better controlled site.

f. **Results:** The results from the laboratory testing, on site testing and modelling work will be reviewed by the scientific team from the Health and Safety Laboratories and recommendations made about safe limits for injection based on appliance performance.

2. Assessment of Long Term Appliance behaviour

a. **Literature Study:** Including a review of any previous studies which have looked at the long term performance of appliances when exposed to hydrogen.

   b. **Laboratory testing:** the addition of hydrogen to natural gas is expected to increase the burning temperature with potential impacts on the longevity of appliance components These impacts will be studied, during a number of laboratory based accelerated appliance tests, using a combination of various temperature measurement and component inspection techniques.
   c. **Results:** The results of these experiments will be reviewed by the scientific team at HSL and recommendations made about longevity of components. This data will be discussed with both Keele University as the host site and with appliance manufacturers.

3. **Materials embrittlement and leakage from joints on the Network**
   a. **Literature Study:** There is a good baseline level of literature available for hydrogen embrittlement of steel and a large quantity of work that has been undertaken across the world looking at hydrogen effects on plastics. This existing body of evidence will be reviewed for relevant data to advise on possible material effects that need to be managed as part of the Keele study.
   b. **Laboratory Testing:** For completeness it is proposed to complete some laboratory testing on solder joints and plastic joints where there is thought to be a lack of previous test data. Testing will also investigate time-scales for out-gasing of hydrogen from steels and polymers following the trial.
   c. **Baseline pipe survey and remedial works:** A full baseline condition survey of the Keele network will be completed prior to exemption application. Any identified areas of concern will be subject to remedial works or replacement to ensure there is a robust network available to test on.
   d. **Collate material:** HSL will collate the evidence for material degradation and propose a safe limit for injection in conjunction with any monitoring and mitigation measures needed as part of the safety case.
4. **Mixing behaviour of hydrogen / natural gas mix**
   a. **Desk Based Study:** It is important that the hydrogen is well mixed with the natural gas at the injection point. Detailed specification of this system and its fail safe controls will be completed as a desk based exercise in the first instance, including the consideration of the causes of excessive hydrogen injection, mitigation measures and responses. If well mixed, it is thought that the hydrogen / natural gas mix will likely remain homogenous. An initial desk based study of previous work and first principles assessment of gas properties will look to support this hypothesis. During testing this hypothesis will be confirmed by collecting experimental data.
   b. **Factory Acceptance Testing of Mixing Unit:** Factory acceptance testing will be completed as part of the procurement of the mixing system. This will be overseen by HSL to ensure safety criteria are met. The testing will cover the foreseeable operating throughput range.
   c. **Specification of Instrumentation:** HSL will be responsible for selection of appropriate instrumentation to measure composition, flow and pressure on the network and will work with Otto Simon on installation details.
5. **Fire and explosion risk from hydrogen / natural gas mix**
   a. **Literature review:** A full literature review will consider the explosion characteristics of a blended mixture compared with a pure natural gas mix.
   b. **Review of area classification (zoning), venting and emergency response:** The literature review will inform the need to consider changes to area

classification (zoning), venting, or emergency response procedures on the Keele site and these will be discussed and agreed with Keele.

6. Appropriate detection of hydrogen / natural gas mix

a. **Literature review:** Work will involve a full review of material on odourisation and detection techniques produced as part of an earlier NIA. This will be assessed for relevance to the Keele study.

b. **Selection & training on appropriate detection methods:** A detailed specification and training procedure for use of hydrogen detection equipment on the Keele site will be developed. This will include the re-calibration of existing equipment and the training of site personnel to detect and deal with escapes of hydrogen / natural gas.

7. Appropriate measurement of CV

a. **Monitor parallel workstreams:** The HyDeploy project will in itself not develop new instrumentation to measure composition / flow / pressure and resulting CV for flows in the network. As part of the project the scientific team will however keep abreast of other studies ongoing in this area and the project could potentially act as a test bed for instrumentation developed during this period.

b. **Model validation:** Baseline modelling of the network will be completed by NG at the start of the study along with predicted modelling with hydrogen. Modelling results will be compared with measured results at the end of the study to determine model validity.

8. Training for Keele staff and others

a. Identify key areas of training required for staff at Keele and other personal who will be involved in running / managing / interfacing with the project. The training may be delivered pre or post exemption application as appropriate.

C.5.2 Post-exemption technical scope of works

The following data will be collected and interpreted during the trials:

7. **Repeat baseline checks on appliances:** A proportion of appliances will be revisited to check actual performance against anticipated performance.
8. **Monitor appliance performance:** A number of appliances will also be instrumented during the course of the trial to provide real-time data for the purpose of assessing safety and operational performance. In the case of some of the larger boilers this instrumentation will be linked into the BMS.
9. **On site materials testing:** Materials testing will be ongoing during the trial to inspect for degradation.
10. **Monitoring of composition, pressure and flow:** Mobile equipment will be deployed around the site to measure composition, pressure and flow at a minimum of two simultaneous points on the network. This will act to build up a picture of mixing and flow behaviour for model validation purposes.
11. **Anecdotal evidence of appliance performance:** As part of the study participants will be encouraged to report on appliance performance using a dedicated phone line and website. A number of selected households will also be asked to engage in a more in depth review of appliance performance during the course of the hydrogen injection though monitoring activities and a number of in depth interviews.

12. **Watching brief of other developments:** During the project, a watching brief will be maintained on other relevant developments in this technical area (e.g. developments in gas analysis or instrumentation, potential changes to area classification standards, etc).

The material from the study will be written up and disseminated as both a published scientific report and in journals and at conferences.

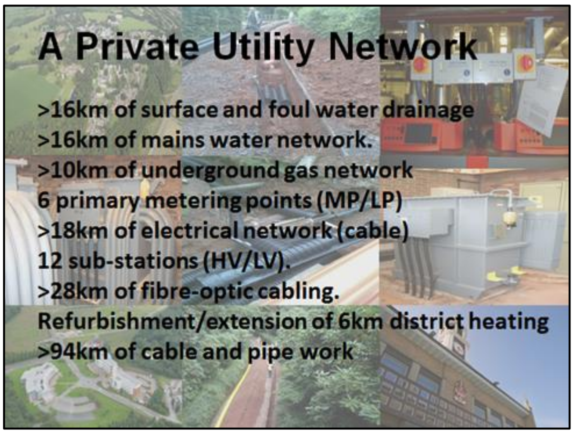
As a final output of the scientific study there will also be a scientific gap analysis reporting in order to inform the next trial on a public network and wider roll out.

Appendix D: Keele University as Host site

Keele University has a key role to play in this project, providing the host site. The University of Keele is the largest campus university in the UK, set in 600 acres, hosting 12,000 people of which some 5000 are resident on the site and has 2.2 million square feet of built environment. As such, it contains a range of uses, including academic, business, commercial, retail, leisure and residential. It has over 90km of private utilities network serviced by its own private utility network to support a wide range of business, academic, residential and leisure users. The campus, therefore, represents a "living laboratory" at the scale of a small town or city district.

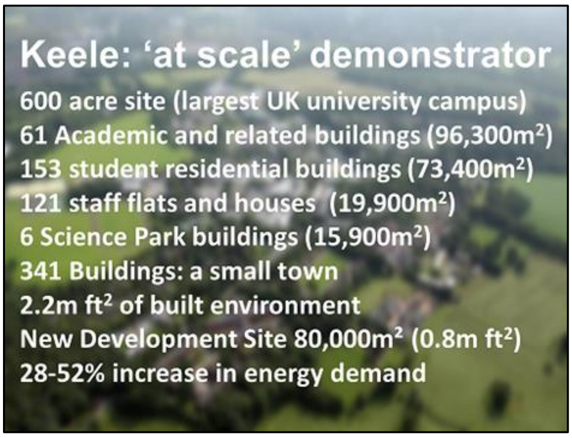
This mix of uses, ownership of a private network, an established range of renewable energy sources and the scale of the campus, allied to the university's expertise in sustainability and green technologies, offers a unique opportunity to develop an at-scale demonstrator for smart energy technologies.

The SEND project is composed of three key elements (i) a capital development programme to convert the existing utilities infrastructure from one optimised to supply to one optimised for research and demonstration, (ii) a programme of smart energy supply chain development working with 217 businesses to appraise opportunities to develop and commercialise new products and services, (iii) a collaborative Research, Development and Innovation product development programme assisting 26 businesses to undertake a three year programme of collaborative product development.



A Private Utility Network

>16km of surface and foul water drainage
>16km of mains water network.
>10km of underground gas network
6 primary metering points (MP/LP)
>18km of electrical network (cable)
12 sub-stations (HV/LV).
>28km of fibre-optic cabling.
Refurbishment/extension of 6km district heating
>94km of cable and pipe work



Keele: 'at scale' demonstrator

600 acre site (largest UK university campus)
61 Academic and related buildings (96,300m^2)
153 student residential buildings (73,400m^2)
121 staff flats and houses (19,900m^2)
6 Science Park buildings (15,900m^2)
341 Buildings: a small town
2.2m ft^2 of built environment
New Development Site 80,000m^2 (0.8m ft^2)
28-52% increase in energy demand

Appendix E: Work undertaken by HSL to define the programme

The following summarises the work undertaken by HSL in order to define and inform the experimental programme proposed

E.1 Appliance performance with hydrogen / natural gas mix

Gas appliances perform differently depending on the quality (characteristics) of the gas that is supplied to them, both in terms of efficiency and in terms of safety (e.g. flame behaviour, carbon monoxide production).

Natural gas that is supplied currently in the UK varies in properties depending upon the source etc, although the Gas quality is regulated by Schedule 3 of the Gas Safety (Management) Regulations (GS(M)R) 1996.

The limits of supply are defined by the Wobbe Number (WN) which is a key parameter in the combustion characteristics of gas. It is defined as:

$$WN = \frac{calorific\ value}{\sqrt{relative\ density}}$$

Under normal conditions, the WN range is:

$$47.20 \leq WN \leq 51.41\, MJ/m^3$$

Emergency conditions allow for a temporary widening of the WN band, whereby:

$$46.50 \leq WN \leq 52.85\, MJ/m^3$$

Schedule 3 of the GS(M)R states that the hydrogen (H_2) content of the supplied gas must not exceed 0.1% v/v.

The addition of hydrogen to natural gas affects the characteristics of the gas in terms of the WN and also its burning velocity and these will influence the performance of the appliances to which it is supplied.

An initial literature review has been carried out to determine available information relating to the safe operation of gas appliances when operated using admixtures of natural gas containing up to 20% hydrogen. This initial search has determined that there is a significant amount of data available, although it will have to be further sifted for relevance to the Keele network.

Therefore, it is proposed to carry out further work before applying for exemption from the GS(M)R for the purposes of the HyDeploy project. This work will include a wider literature review as well as experimental appliance testing. The testing will be carried out on targeted appliances following an appliance survey to be carried out on the Keele site, and will involve laboratory testing for smaller appliances and in-situ testing for larger items. A range of hydrogen concentrations will be included to determine a maximum “safe” level. An initial survey indicates that there are: 121 Boilers for hot water and heating, direct gas fired heaters, 9 water heaters and 7 items of commercial catering equipment (2 twin fryers; combination oven; 6 burner range and oven; over fired grill;

Bratt pan; solid top range oven). In addition there are an unknown number of gas fires and hobs in the 'privately owned' residential properties.

The performance of an appliance also depends greatly upon its design, set-up and state of repair. Therefore, before hydrogen is injected into the Keele network an in-situ appliance inspection programme will be carried out, with aim of checking every appliance on the Keele site. The appliances at Keele university will be tested using bottled gas containing a selected hydrogen concentration, to ensure that existing appliances do not themselves present unsafe conditions, with flame behaviour and carbon monoxide levels being monitored in addition to general observations of installation and condition. A theoretical modelling programme is also proposed, to investigate flame behaviour and provide a deeper scientific understanding of the phenomena.

During the hydrogen injection phase of the HyDeploy project, targeted in-situ re-inspections of appliances will also be carried out.

E.2 Materials Embrittlement and Jointing

An important facet of introducing hydrogen into natural gas as a blend is the effect of hydrogen on the integrity of materials contained within a gas network. These effects are due to the potential for hydrogen embrittlement of the materials within the network and the increased leakage potential from a hydrogen blend. On the Keele network these materials include steels, copper, polymeric materials and solder / jointing materials. Metals can be susceptible to hydrogen embrittlement which is the degradation of the material properties, in particular the loss of ductility and reduced load carrying capacity. It occurs in metals when hydrogen or hydrogen compounds permeate into the lattice structure of the material. Polymers are generally not degraded by the presence of hydrogen through physical or chemical means as they have no lattice. However, hydrogen can diffuse through polymers more easily than metals and it has been suggested that the permeation of hydrogen into PE pipe materials may have an adverse influence on the quality and integrity of subsequent fusion joints.

An initial literature review has revealed a number of gaps in knowledge, relevant to Keele, that require further investigation by further literature reviews or experimental work. The proposed scope of this investigation is shown in Table E.1

Further literature reviews
In depth literature review of the available information and research on the effects of hydrogen on the following materials in particular: Steel, PE, Copper, Solder, Seals
Experimental research activities
Baseline characterisation of network materials
Characterisation of powdered specimens to evaluate sensitivity to hydrogen exposure. Materials to be examined: Steel, PE, Copper, Solder
Tensile testing of selected materials to evaluate effect of hydrogen exposure on mechanical properties of the bulk materials. Materials to be examined: Steel, PE, Copper, Solder Tests to be carried out on samples as manufactured and following exposure to CH_4 / hydrogen mixture and pure hydrogen.
Experiments to study the rate of hydrogen up take and out gassing of selected materials. Materials to be examined: Steel, PE, Copper, Solder
Work to determine potential effects of H2 on jointing/repairs to PE pipe

Further literature reviews
It has been suggested that the permeation of hydrogen into PE pipe materials may have an adverse influence on the quality and integrity of subsequent fusion joints. Review current protocols used at Keele for repairs to current PE pipe network.
Visual / light microscopy examination of examples of fusion joints between PE pipe material exposed to hydrogen /methane mixtures and new PE material. Note: production of fusion weld samples would need to be carried out by other consortium members. Note: fusion joints to be formed by techniques used at Keele.
Tensile testing of fusion joint samples. Specimens to be tested in the following conditions: As manufactured, Exposed to methane, Exposed to methane hydrogen blend, and Exposed to hydrogen Note: fusion joints to be formed by technique usually used at Keele.
Testing of appliance materials – visual inspection and microscopy
Visual and light microscopy inspection of corresponding sets of components exposed to natural gas and natural gas / hydrogen blends. Preparation and analysis of metallography samples as required.
Scanning electron microscopy inspection of corresponding sets of components exposed to natural gas and natural gas / hydrogen blends. Techniques to be used: Imaging, Elemental analysis

Table E.1 Summary of proposed further literature reviews and experimental work

All of the above work would be required before the GS(M)R exemption application.

E.3 Gas Mixing and Detection

HyDeploy will be the first project in the UK to inject hydrogen into a natural gas grid. The hydrogen injection and mixing unit is a key element in this project. The hydrogen will be generated from water by an electrolyser and injected into the natural gas main to obtain a specified, constant hydrogen concentration in the gas stream. Modulating the hydrogen flow as the flow of natural gas varies is clearly necessary for the Keele site since the demand for gas has a wide variation between summer and winter.

The hydrogen is a pure gas and consequently its flow rate could be easily measured and controlled using a thermal mass flow controller. The measurement of the flow of natural gas is more problematic; the pressure in the supply pipe work is low which precludes the use of particular measurement techniques and also the natural gas is a mixture that can quickly change its composition. The attributes of various flow measurement techniques have been reviewed and the information suggests that there is no ideal method for measuring natural gas flow. It appears that a thermal insertion probe may be the best compromise, although this will need to be tested.

There are a number of reasons why the composition of the hydrogen and natural gas mixture supplied to the Keele network needs to be determined, most importantly to avoid high hydrogen concentrations reaching consumers. The composition analysis is required immediately after the injection point and also at other points within the network. Four analysis techniques have been identified for gas composition measurement, each having a drawback that must be accepted or corrected. It may be that a combination of measurement techniques be employed, one providing accurate data and another providing a less-accurate but faster response. Further work is required in this area prior to the exemption application.

It will be necessary to define, as part of the functional specification of the injection and mixing system, acceptable tolerances for the hydrogen injection; this will probably be required before the exemption application is submitted.

Instruments are used at Keele for detecting gas in the event of leaks occurring; fixed site instruments are used to warn of leaks in the plant rooms while estate staff also use portable instrument to survey the university site for gas leaks on a twice yearly basis. Commercially available leak detectors respond differently to natural gas and hydrogen and so some changes may be required. The fixed site instruments, used to warn of leaks in the plant rooms of student residences, will need to be recalibrated with appropriate natural gas and hydrogen mixtures throughout the trial. Alternatively, the detectors could be calibrated for a worst case response, but this may lead to false alarms. For the twice yearly survey of the university site, Keele staff may need to use a combination of the existing detector and a hydrogen sniffer based on a palladium sensor.

Other aspects of gas detectors that need to be considered are:

- Most carbon monoxide sensors are sensitive to hydrogen and so detection of an unburnt mixture of natural gas and hydrogen may be interpreted as carbon monoxide resulting in an incorrect set up for the appliance.
- Gas detecting instruments are used to determine when a pipe or appliance has been flushed with natural gas. A hydrogen and natural gas mixture could give false readings during this type of work, leading to a potential flask back from an appliance.

E.4 100% Hydrogen Equivalent Testing

Although the HyDeploy project is limiting the concentration of hydrogen in network and the appliances to up to 20% v/v, there is interest in taking the opportunity to investigate how an existing natural gas distribution system would perform, in terms of leak tightness, with 100% hydrogen. To this end, it is proposed to carry out leak-tightness tests on; a section of redundant buried gas pipeline, one block of flats and five domestic houses (including internal laterals and risers). A tightness test involves isolating a pipework system or legs of pipework, applying a set pressure and monitoring the pressure over time to determine if leaks are present. The tests will be in accordance with IGEM Utilization Procedure IGE/UP/1 Edition 2, “Strength testing, tightness testing and direct purging of industrial and commercial gas installations”.

There are a number of practical safety issues that need to be considered if 100% hydrogen were to be injected into a live gas distribution, namely the difficulty of ensuring that all hydrogen is purged from the pipelines after the tests and also the difficulties of being able to locate any hydrogen leaked during the tests in a real system where the gas may become trapped in voids etc. Therefore, it is suggested that hydrogen as a test gas is substituted with helium for this programme of work. Helium is a very close approximation for molecular hydrogen in terms of density and buoyancy and diffusion rate (1.4 times slower than hydrogen using Graham’s Law) but has the benefit of not being flammable. It is common place to substitute hydrogen for helium in scenarios such as this without affecting the quality of the experimental data, although it would be necessary to take the difference between hydrogen and helium into account.

E.5 Risk of Fire and Explosion from Hydrogen / Natural Gas Mixtures

It is necessary to consider whether the introduction of hydrogen in natural gas has a significant impact on the fire and explosion risks following an uncontrolled leak of the gas mixture when compared to the existing risks associated with natural gas alone. It is also necessary to consider the fire and explosion risks associated with the hydrogen generation and injection facilities.

An initial literature review has been carried out into the fire and explosion characteristics of natural gas containing hydrogen in order to assess whether sufficient knowledge exists to understand the hazards of accidental, uncontrolled releases or whether further experimental or modelling work is required. Although much of the data that is available is for mixtures of hydrogen and methane, rather than natural gas, it is considered unlikely that the composition of the base natural gas will have a significant effect on the fire and explosion properties in comparison to the changes resulting from the introduction of hydrogen. The initial review indicates that the fire and explosion risks are unlikely to be significantly changed for the gas system at Keele for mixtures containing up to 20% v/v hydrogen. However, there are a number of issues that need to be considered in the risk assessment.

The properties of pure hydrogen are considerably different to natural gas. However, pure hydrogen should only be present in a very limited area of the site. The electrolyser will also generate oxygen which, although not flammable itself, will significantly increase the fire hazard from any combustible material with which it is mixed and so will need to be vented to a safe place. It will be necessary to carry out area classification for the electrolyser and hydrogen injection system. In light of the new and modified hazards associated with the hydrogen injection project, it is recommended that the existing emergency response procedures be reviewed.

In summary, the following work is required.

Before submitting the exemption application, carry out a risk assessment including:

- Confirm that the proposed changes (including hydrogen injection, any changes in gas pressure etc) are unlikely to change hazardous area classification requirements.
- Confirm that large clouds of hydrogen-methane mixtures cannot form, especially in congested areas.
- The existing emergency response procedures should be reviewed, including the inadvertent injection of more than 20% hydrogen into the mains, and considering any additional security concerns.

The following work is recommended during the project:

- It will be necessary to carry out area classification within the hydrogen generation (electrolyser) enclosure, within the mixing enclosure and also to determine the zoning distances around these facilities.
- Determine a suitable location for the venting of oxygen from the electrolyser.
- Consider providing hydrogen awareness training for those who may be involved with the project on the Keele University site.
- Follow developments in the Gas Group classification of methane-hydrogen mixtures. If necessary, plan how this could be progressed with HSL input.

Appendix F: Enabling Work undertaken in the HyStart Project

This technical note provides an overview summary of the scope of work undertaken as part of the Power to gas study and the main findings and conclusions from the study relevant to the HyDeploy project at Keele.

Gas Distribution Network Materials

- Interaction of hydrogen on iron pipe: (i) Limited information available in the literature which may not be directly applicable to hydrogen/natural gas mixtures in a gas distribution network. (ii) Effects on iron mains (and steel mains) at the metallurgical level are likely to be small, but have not been determined. (iii) ISO/TR 15916:2004 states that iron (cast, grey and ductile) are not suitable for hydrogen service though there is no specific guidance on methane/hydrogen mixtures. (iv) clarification of the scope and the applicability of ISO/TR 15916:2004 guidance and ASME B31.12 standards to the proposed hydrogen/methane compositions should be sought from ASME and ISO TC 197.
- Permeation through PE mains will be higher than for natural gas, but likely to be insignificant in magnitude at the operating pressures and concentrations proposed.
- The major source of leakage is from defective mechanical joints in the iron pipe network, through which hydrogen is expected to escape more easily.
- Leakage from the PE network is likely to result from the failure of a joint, regardless of the gas composition.
- There is evidence that leakage through rubber hose can be an issue and this should be investigated further.
- There are also some knowledge gaps with regards to polymers used in in-house installations.
- Current demonstration projects in Europe have operated up to four years. It would be beneficial to have longer term data in service conditions. Accelerated materials testing in hydrogen conditions may also aid this.

Rhinology

- Hydrogen has no direct masking effect but would act as a diluent of the odorant concentration
- Consideration will need to be given to supplementary addition of odorant to compensate for the dilution by hydrogen.
- It is recommended that monitoring of gas odour downstream of injection is carried out at a point where consistent gas flow occurs.

Gas Detection Equipment

- This focused on types that are currently in use by GDNs, but also considers future developments with regard to new IR instruments.
- Both high and low readings are possible from gas detection equipment as well as potential deviations from the true reading.
- It is important that Operations Engineers are aware that hydrogen is present when undertaking the following activities: Purging and Commissioning, Leakage Investigation, Evacuation and Re-entry and Bar-holing.

- All gas detection is impacted by the presence of hydrogen in natural gas, and the effects are dependent on the detection method and the activities that the equipment is used for: (i) Pellistor-type gas detection equipment will respond to the presence of hydrogen in natural gas, but will over-read. For leakage detection this will not compromise safety, but care needs to be exercised if this equipment is used for "Purging and Commissioning" operations, (ii) Infrared gas detection equipment will not detect hydrogen in gas and if hydrogen is present then the LFL, or gas concentration readings will be lower than the "real" reading, (iii) FID type detection equipment uses a small hydrogen flame within the instrument to give sensitive detection for organic compounds (hydrocarbons. As hydrogen is used in to form the flame in the detection device, it is not detected in the analysed gas and as a result the instruments will give "low" readings for mixtures containing natural gas and hydrogen.
- Personal Gas Monitors (PGM) may present additional issues with regard to hydrogen in natural gas. The presence of hydrogen impacts on flammables detection, giving an over-reading.
- If the gas detection equipment has multi-gas detection capability then it must be recognised that the CO and H_2S sensors may give false readings as a small quantity of hydrogen has a significant effect on the electrochemical cells. Repeated exposure to low concentrations of hydrogen may lead to permanent issues with the sensors and the instruments may need to have more frequent servicing and maintenance.
- Additional studies of the ATEX rating for equipment are advised following recent communications by the CEN Sector Forum Energy Management / Working Group

Quantitative Risk Assessment

- This focused on the impact to domestic gas consumers -
- Fault trees have been developed for "risk of fatality due to carbon monoxide poisoning" and "risk of fatality due to gas explosion" for a Base Case reflecting network operation within the current GS(M)R specification and for up to 20 mol% hydrogen.
- Both domestic and industrial gas consumers will be impacted by the addition of hydrogen and relative risk will change for both of these groups.
- Addition of hydrogen will relatively increase the risk of an incident due to gas explosion by an order of magnitude but has a minimal increase of risk relating to CO poisoning. The order of magnitude increase in risk of an incident due to ignition of gas is related to the conservative approach adopted when stepping out from the base case. This approach was necessary due to lack of information available relating to the impact of hydrogen

GS(M)R Exemption – Gas Quality

- A decision needs to be taken on whether the proposed GS(M)R exemption includes derogation for both the hydrogen concentration limit or to extend the approach to include the Wobbe Number range also.
- It is essential to have "live" information on the natural gas quality and the capability to adjust the hydrogen addition (concentration) to meet Wobbe Number limit requirements.

- Based on an historical data evaluation exercise, it is evident that extending the hydrogen addition to 20mol% leads to a significant reduction to Wobbe Number and calorific value, CV.
- Adding hydrogen to a distribution zone (or part of a zone) that is already receiving biomethane may lead to both Wobbe Number and CV concerns
- 10mol% hydrogen would provide a comfortable safety margin to the existing limits, but seeking to secure an exemption to 15mol% or above would be a good option to provide scope for establishing the optimum limit value.

GS(M)R Exemption – Billing

- If the concentration of hydrogen is less than ~3.5 mol% then the CV of the natural gas/hydrogen mixture is likely to be close to the prevailing FWACV. Apart from a GS(M)R exemption for hydrogen content, the injection of low quantities of hydrogen will have a negligible effect on the fairness and operation of the billing system. It will be necessary to document the historical and likely natural gas quality variations in the field trial area as these will determine the maximum quantity of hydrogen that can be injected.
- If the concentration of hydrogen is greater than ~3.5 mol% then the CV of the natural gas/hydrogen mixture is likely to be more than 1 MJ/m^3 lower than the FWACV. Were this to be a public network, this would result in the CV capping of the entire LDZ as gas consumers receiving the low CV hydrogen/natural gas mixture would otherwise be disadvantaged. In this case, a body of evidence would need to be submitted to Ofgem including details of the proposed measurement systems and any mitigation of risks. The current Ofgem-approved gas quality measurement systems are not suitable for natural gas/hydrogen mixtures so approval for the new analysis systems will be required if consumers' bills are to be based on measurements. This approval process has taken many months in the past. Delivering enduring solutions to this issue is the purpose of the NGGD NIC (2016) "Future of Billing", which considers the changes to billing methodology necessary to facilitate adoption of new gases and blends more widely.
- Given the initial trial is on the private network at Keele, then, subject to Ofgem approval, an alternative billing system could be used for this project. This could take a number of different forms including use of a declared or lowest source CV, which could be based on the historical FWACV, designation of a new charging zone or a directly measured CV at the entry point to the affected network.

Gas Analysis

- Gas analysis and measurement equipment exist for determination of hydrogen content in mixtures of hydrogen and natural gas. However, to ensure that any selected equipment is fit-for-purpose a test evaluation programme is required to ascertain the overall performance of both analysers for fiscal purposes and also analysers for control application. This is an important benefit of undertaking this trial.
- For enduring wider deployment, as well as a technical evaluation it is necessary to provide support to Ofgem, through collation of a portfolio of evidence to enable a Letter of Direction to be raised that approves the use of a named analyser for

the measurement of gas composition to calculate CV subsequently used in customer billing. For operation on a public network, consideration will also need to be given to the OFGEM approved Data Collection Software, currently DANINT, which would need to be modified

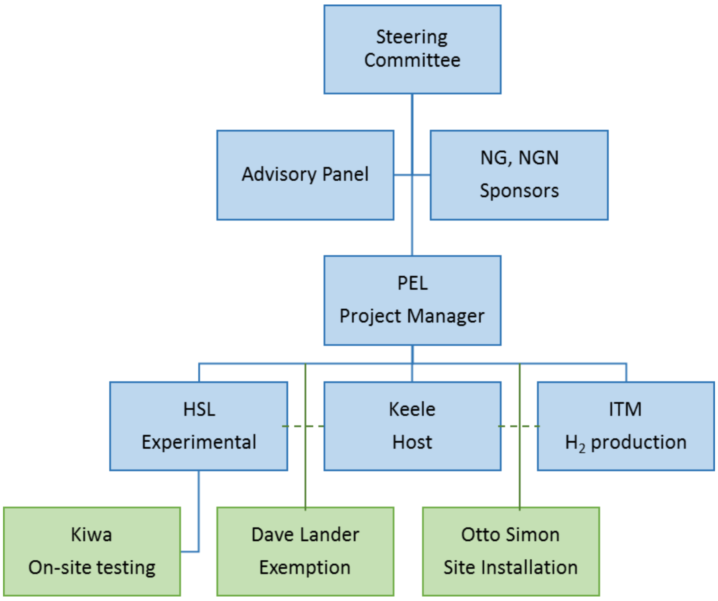
Hydrogen Gas to Grid – Outline Functional Specification

- Proposed design concept in summary incorporates: (i) A single direction gas blending concept gas entry unit, GEU, in which hydrogen is blended into the gas grid on a proportional basis and the entire natural gas stream is diverted to the blending unit, (ii) Amount of hydrogen limited by flow ratio control operation, (iii) Static gas mixing used for hydrogen blending, (iv) For installations where there may be an issue with regard to pressure loss across the metering system, ultrasonic meter(s) would be recommended, (v) Where the maximum pressure loss across the metering system can be greater than 15mbar, ultrasonic, Coriolis and RPD meters could be considered, (vi) Odorant injection volumes should be set to match those of the upstream network, based on the flow of hydrogen via the Flow Ratio Control Valve (FRCV), (vii) An odour monitoring point should be installed downstream of the GEU and further secondary points may be required further downstream in the network, (viii) A minimum of two gas quality measurement points are required: 1) Wobbe Number and CV of incoming natural gas to the GEU and 2) Composition, Wobbe Number, SI, ICF, water dewpoint and CV of outgoing natural gas\hydrogen mixture on the exit of the hydrogen GEU
- A recommended functional specification has been developed incorporating the following: (i) List of Equipment, (ii) Operating philosophy assuming a fully automated system, (iii) Safeguarding systems, (vi) Communications/Telemetry, (v) Odorisation, gas quality measurement and Hydrogen and natural gas metering requirements, (vi) Upstream interfaces, (vii) Safety studies required, (viii) Relevant external and internal standards

Key Conclusions

Whilst the addition of hydrogen to a natural gas distribution network poses many challenges, none are insurmountable and the technology exists to potentially resolve them all. The proposal to undertake a first UK trial on a private network is a sensible approach to enable practical progress to be made in this important area. The acceptable limit value for hydrogen requires careful consideration of a number of factors including but not exclusively with regard to: (i) consumer acceptance, (ii) consumer billing, (iii) appliance safe and efficient operation/performance, (iv) existing natural gas quality ranges at proposed hydrogen injection points (and the day-to-day variability), (v) end-users for the mixed natural gas/hydrogen (eg. Issues remain for use in gas engines, CHP systems, large gas turbines and others), (vi) user demand and load profiles, (vii) impact on gas distribution network operations and safety response.

Appendix G: Project Governance & Organogram



A summary of the proposed management structure for the project is shown below. National Grid has a well-developed and proven collaboration agreement, which has formed the basis for two NIC projects to date. This has been reviewed by the project partners and will form the basis for this project.

The governance framework is in place to ensure appropriate oversight and control over key decisions and to delegate authority for scope delivery to a Steering Committee.

The Steering Committee made up of two representatives nominated by each of the project partners. The Chair of the Steering Committee shall be the Project Director for NGGD, 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. Members may participate via tele-conference, video-conference or other technological means when necessary. Should a nominated member become unable to attend the member may appoint an alternate. Any alternate attending for a period of more than two months is to be approved by the Chair.

- The Steering Committee shall provide assurance on, and reports to the partners:
- Safety and environmental management – incidents, loss time injuries, any breaches of environmental controls etc.
- Progress against deliverables and plan – mitigation of issues arising, review of open issues, sanction for closing open issues.
- Review of subsequent plan for coming 6 month period and potential to accelerate activities or manage issues arising.
- Evidence of project task completion and review of achievement of research outcomes.
- Review progress against budget, risks register (proposed inclusion or removal of, change in impact / probability), communications plan.
- Evidence of project milestone progression as appropriate (progression to be tabled at each partner internal sanction bodies as outlined below).
- Vote on whether the project is to progress to subsequent stages.

For the Project programme as outlined here, the parties will ensure that the Steering Committee meets at the project review stages defined in the Project Plan or at least every 2 months or at any other time at the request of any of the Parties to the Project Manager specifying in reasonable detail the reason why the meeting is required.

Meetings of the Steering Committee will be convened with at least twenty one (21) days written notice in advance. That notice must include a standing agenda and additional agenda items on request of any project partner – such requests are to be heard. Minutes of the meetings of the Steering Committee will be prepared by the Project Manager and sent to each of the parties within 14 days after each meeting.

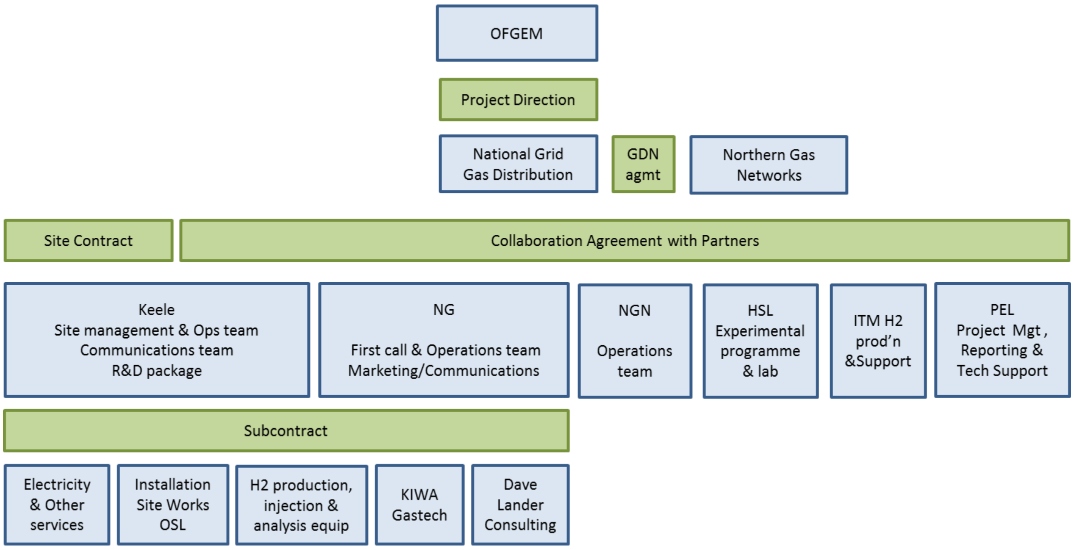
The Project Manager will be from Progressive Energy who will produce monthly reports summarising the progress of the project in accordance to the standing agenda of the Steering Committee, progress concerning research results, and plans to disseminate information / progress beyond the project partners. A copy of the monthly report will be circulated to each member of the Steering Committee with the written notice for the relevant meeting by the Project Manager.

Each partner will have one vote in the Steering Committee. Decisions will be taken by a simple majority of a quorate meeting of the Steering Committee except where a decision necessitates a change to the project plan or a change to the allocation of any funding or change to any contribution. Quorate is defined as including at least one nominated member from each respective partner organisation. In any of those cases, any decision must be unanimous and may only be made where the representatives of all of the partners are present. In a tied vote, the chairman will have a casting vote.

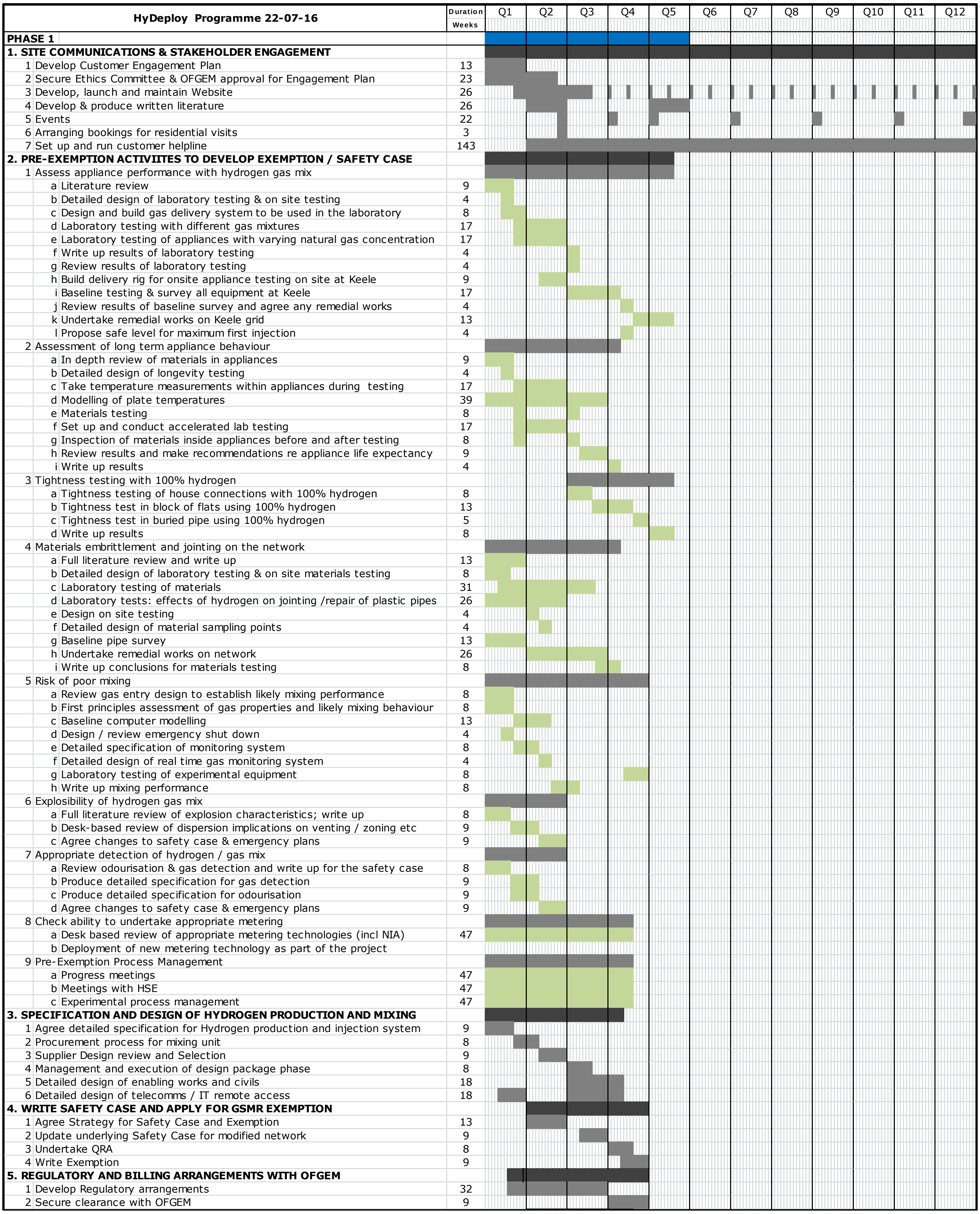
The Project Director for National Grid is accountable for the successful allocation of Milestones and allocation of stage funding under the NIC allowance. The Project Director shall report to National Grid's Distribution Executive Committee progress of each Milestone and sanction for subsequent Milestone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

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.

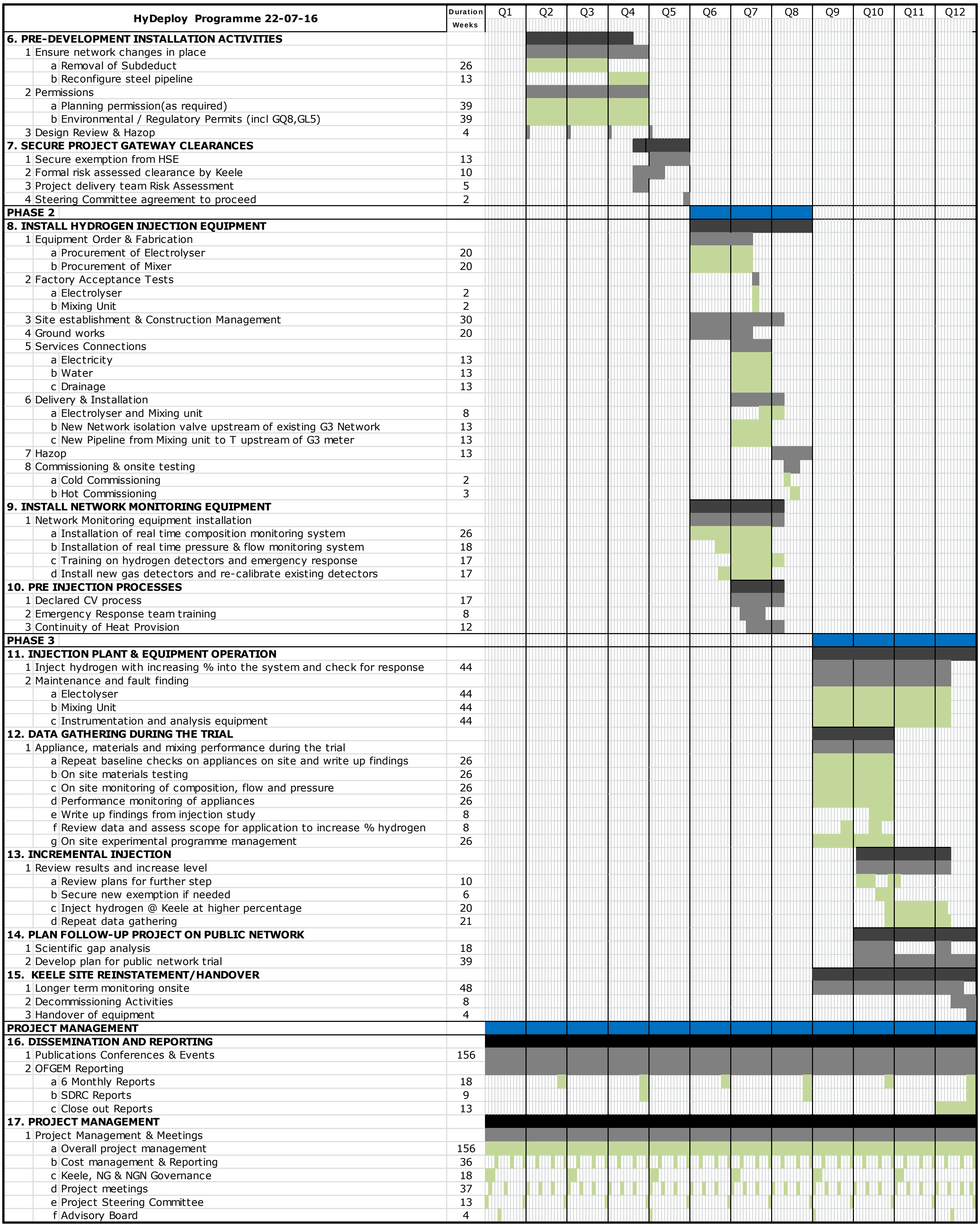
The Project Manager shall commence stage activities upon unanimous agreement to continue to fund the subsequent stage. The Contract structure for the project is shown below



Appendix H: Project Gantt Chart



HyDeploy Programme 22-07-16			Duration Weeks
PHASE 1			
1. SITE COMMUNICATIONS & STAKEHOLDER ENGAGEMENT			
1		Develop Customer Engagement Plan	13
2		Secure Ethics Committee & OFGEM approval for Engagement Plan	23
3		Develop, launch and maintain Website	26
4		Develop & produce written literature	26
5		Events	22
6		Arranging bookings for residential visits	3
7		Set up and run customer helpline	143
2. PRE-EXEMPTION ACTIVIITES TO DEVELOP EXEMPTION / SAFETY CASE			
1		Assess appliance performance with hydrogen gas mix	
	a	Literature review	9
	b	Detailed design of laboratory testing & on site testing	4
	c	Design and build gas delivery system to be used in the laboratory	8
	d	Laboratory testing with different gas mixtures	17
	e	Laboratory testing of appliances with varying natural gas concentration	17
	f	Write up results of laboratory testing	4
	g	Review results of laboratory testing	4
	h	Build delivery rig for onsite appliance testing on site at Keele	9
	i	Baseline testing & survey all equipment at Keele	17
	j	Review results of baseline survey and agree any remedial works	4
	k	Undertake remedial works on Keele grid	13
	l	Propose safe level for maximum first injection	4
2		Assessment of long term appliance behaviour	
	a	In depth review of materials in appliances	9
	b	Detailed design of longevity testing	4
	c	Take temperature measurements within appliances during testing	17
	d	Modelling of plate temperatures	39
	e	Materials testing	8
	f	Set up and conduct accelerated lab testing	17
	g	Inspection of materials inside appliances before and after testing	8
	h	Review results and make recommendations re appliance life expectancy	9
	i	Write up results	4
3		Tightness testing with 100% hydrogen	
	a	Tightness testing of house connections with 100% hydrogen	8
	b	Tightness test in block of flats using 100% hydrogen	13
	c	Tightness test in buried pipe using 100% hydrogen	5
	d	Write up results	8
4		Materials embrittlement and jointing on the network	
	a	Full literature review and write up	13
	b	Detailed design of laboratory testing & on site materials testing	8
	c	Laboratory testing of materials	31
	d	Laboratory tests: effects of hydrogen on jointing /repair of plastic pipes	26
	e	Design on site testing	4
	f	Detailed design of material sampling points	4
	g	Baseline pipe survey	13
	h	Undertake remedial works on network	26
	i	Write up conclusions for materials testing	8
5		Risk of poor mixing	
	a	Review gas entry design to establish likely mixing performance	8
	b	First principles assessment of gas properties and likely mixing behaviour	8
	c	Baseline computer modelling	13
	d	Design / review emergency shut down	4
	e	Detailed specification of monitoring system	8
	f	Detailed design of real time gas monitoring system	4
	g	Laboratory testing of experimental equipment	8
	h	Write up mixing performance	8
6		Explosibility of hydrogen gas mix	
	a	Full literature review of explosion characteristics; write up	8
	b	Desk-based review of dispersion implications on venting / zoning etc	9
	c	Agree changes to safety case & emergency plans	9
7		Appropriate detection of hydrogen / gas mix	
	a	Review odourisation & gas detection and write up for the safety case	8
	b	Produce detailed specification for gas detection	9
	c	Produce detailed specification for odourisation	9
	d	Agree changes to safety case & emergency plans	9
8		Check ability to undertake appropriate metering	
	a	Desk based review of appropriate metering technologies (incl NIA)	47
	b	Deployment of new metering technology as part of the project	
9		Pre-Exemption Process Management	
	a	Progress meetings	47
	b	Meetings with HSE	47
	c	Experimental process management	47
3. SPECIFICATION AND DESIGN OF HYDROGEN PRODUCTION AND MIXING			
1		Agree detailed specification for Hydrogen production and injection system	9
2		Procurement process for mixing unit	8
3		Supplier Design review and Selection	9
4		Management and execution of design package phase	8
5		Detailed design of enabling works and civils	18
6		Detailed design of telecomms / IT remote access	18
4. WRITE SAFETY CASE AND APPLY FOR GSMR EXEMPTION			
1		Agree Strategy for Safety Case and Exemption	13
2		Update underlying Safety Case for modified network	9
3		Undertake QRA	8
4		Write Exemption	9
5. REGULATORY AND BILLING ARRANGEMENTS WITH OFGEM			
1		Develop Regulatory arrangements	32
2		Secure clearance with OFGEM	9



HyDeploy Programme 22-07-16	Duration Weeks
6. PRE-DEVELOPMENT INSTALLATION ACTIVITIES	
1 Ensure network changes in place	
a Removal of Subdeduct	26
b Reconfigure steel pipeline	13
2 Permissions	
a Planning permission(as required)	39
b Environmental / Regulatory Permits (incl GQ8,GL5)	39
3 Design Review & Hazop	4
7. SECURE PROJECT GATEWAY CLEARANCES	
1 Secure exemption from HSE	13
2 Formal risk assessed clearance by Keele	10
3 Project delivery team Risk Assessment	5
4 Steering Committee agreement to proceed	2
PHASE 2	
8. INSTALL HYDROGEN INJECTION EQUIPMENT	
1 Equipment Order & Fabrication	
a Procurement of Electrolyser	20
b Procurement of Mixer	20
2 Factory Acceptance Tests	
a Electrolyser	2
b Mixing Unit	2
3 Site establishment & Construction Management	30
4 Ground works	20
5 Services Connections	
a Electricity	13
b Water	13
c Drainage	13
6 Delivery & Installation	
a Electrolyser and Mixing unit	8
b New Network isolation valve upstream of existing G3 Network	13
c New Pipeline from Mixing unit to T upstream of G3 meter	13
7 Hazop	13
8 Commissioning & onsite testing	
a Cold Commissioning	2
b Hot Commissioning	3
9. INSTALL NETWORK MONITORING EQUIPMENT	
1 Network Monitoring equipment installation	
a Installation of real time composition monitoring system	26
b Installation of real time pressure & flow monitoring system	18
c Training on hydrogen detectors and emergency response	17
d Install new gas detectors and re-calibrate existing detectors	17
10. PRE INJECTION PROCESSES	
1 Declared CV process	17
2 Emergency Response team training	8
3 Continuity of Heat Provision	12
PHASE 3	
11. INJECTION PLANT & EQUIPMENT OPERATION	
1 Inject hydrogen with increasing % into the system and check for response	44
2 Maintenance and fault finding	
a Electolyser	44
b Mixing Unit	44
c Instrumentation and analysis equipment	44
12. DATA GATHERING DURING THE TRIAL	
1 Appliance, materials and mixing performance during the trial	
a Repeat baseline checks on appliances on site and write up findings	26
b On site materials testing	26
c On site monitoring of composition, flow and pressure	26
d Performance monitoring of appliances	26
e Write up findings from injection study	8
f Review data and assess scope for application to increase % hydrogen	8
g On site experimental programme management	26
13. INCREMENTAL INJECTION	
1 Review results and increase level	
a Review plans for further step	10
b Secure new exemption if needed	6
c Inject hydrogen @ Keele at higher percentage	20
d Repeat data gathering	21
14. PLAN FOLLOW-UP PROJECT ON PUBLIC NETWORK	
1 Scientific gap analysis	18
2 Develop plan for public network trial	39
15. KEELE SITE REINSTATEMENT/HANDOVER	
1 Longer term monitoring onsite	48
2 Decommissioning Activities	8
3 Handover of equipment	4
PROJECT MANAGEMENT	
16. DISSEMINATION AND REPORTING	
1 Publications Conferences & Events	156
2 OFGEM Reporting	
a 6 Monthly Reports	18
b SDRC Reports	9
c Close out Reports	13
17. PROJECT MANAGEMENT	
1 Project Management & Meetings	
a Overall project management	156
b Cost management & Reporting	36
c Keele, NG & NGN Governance	18
d Project meetings	37
e Project Steering Committee	13
f Advisory Board	4

Appendix I: Risk Register

Category	Risk ID	Risk Description	Impact of Risk	Impact 1-7	Likelihood 0-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Health and Safety	1	Risk of increased CO production	Death and injury to people	7	4	H	Testing of appliances, CO meters	Replacement of appliances or limitation to H2 mixture level	7	1	M
Health and Safety	2	Risk of increased burning temp = degradation over time plate / seals	Possible safety issues	7	4	H	Testing of appliances to propose max safe limit for injection	Long term monitoring or swapping out degraded appliances	7	1	M
Health and Safety	3	Risk of increased pressure drop along line	Loss of hydrogen creates flammable build up	7	2	H	Collate evidence as to likelihood of flammable build up. Testing of installations at Keele.	Repairs to pipework if necessary	7	1	M
Health and Safety	4	Risk of burn back	Catastrophic failure of kit	7	3	H	Testing of appliances to propose max safe limit for injection	Replacement of appliances or limitation to H2 mixture level	7	1	M
Health and Safety	5	Unsafe appliances found at Keele	Unsafe Installation	7	2	H	Appliance checks before injection	Replace if necessary	6	0	L
Health and Safety	6	Small numbers of appliances fail H2 mix at low levels	Could limit all testing	6	2	H	Test all appliances in-situ	Replace if necessary	6	0	L
Health and Safety	7	Long term degradation of Keele grid	Risk of leaks = safety issue	7	3	H	Integrity survey at the end of the study	Plan for ongoing inspection and maintenance agreed	7	1	M
Health and Safety	8	Baseline integrity of network	Hydrogen leakage is greater in weak points in the network	6	2	H	Baseline survey of existing network to identify weak points	Re-work pipework where necessary	6	0	L
Health and Safety	9	Specifying appropriate equipment for mixing	Mixing performance key to safety of system	7	2	H	Careful spec, full HAZOP and safety mechanisms built in	Factory acceptance testing prior to deployment	7	1	M
Health and Safety	10	Risk of high hydrogen entering the system	Unexpected mixture leading to safety issues	6	2	H	Design of mixing control	Sample output mixture regularly	6	1	M
Health and Safety	11	Possibility of flammable build up under and above ground	Safety issue	7	2	H	Better understanding of dispersion from other work	Collate evidence to assess likelihood and develop mitigation and emergency plans	7	1	M
Health and Safety	12	Robustness of instrumentation	Safety risk if critical technologies do not operate effectively	7	2	H	Use of approved and tested equipment	Ensure equipment is approved	7	1	M
Health and Safety	13	Lack of necessary emergency response	Safety issue	6	2	H	Develop appropriate emergency response and provide robust training	Training of emergency teams	6	1	M
Health and Safety	14	Risk of poor mixing	Appliances are subject to varying concentrations of hydrogen	3	3	M	Check appliance performance with hydrogen concentration varying over time	Replace appliances if necessary	3	1	L
Health and Safety	15	Requirements for shut down in the event of hydrogen slug	Safety issue	6	1	M	Detailed consideration of emergency planning		6	1	M
Health and Safety	16	ATEX rating zones may change with the introduction of hydrogen	Safety issue	6	1	M	Review standards and current zoning to confirm this	Allowance for up-rating kit if necessary	6	0	L
Technical	17	Technical solution for mixing unit	Main challenge will be in measuring flow, no known off the shelf solutions	4	3	H	Early consideration and engagement of specialist supplier		2	0	L
Technical	18	Risk of manufacturers not wanting to publicise information on longevity	Project unable to deliver longevity data	2	4	M	Work with industry bodies in terms of benefits of publicising data	Use anonymous data if necessary	2	0	L
Technical	19	Appropriate amount of instrumentation for monitoring the network	Lack of instrumentation = lack of data to demonstrate network performance	4	2	M	Agree appropriate amount of instrumentation	Detailed design	4	0	L

Category	Risk ID	Risk Description	Impact of Risk	Impact 1-7	Likelihood 0-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Technical	20	Risk of access for bottle wagon	Undermines study objectives	4	2	M	Bottle wagon design	Detailed design including long hoses for access	4	0	L
Technical	21	Robustness of instrumentation	Technical/ project risk if credible data not gathered for the project	4	2	M	Use of approved and tested equipment		4	1	L
Technical	22	Data not consistent for network modelling	Unable to validate model	4	2	M	Ensure sufficient quantity and quality of data captured	Regular stage assessment of data achieved; changes as needed	4	1	L
Technical	23	Telecoms and networking to enable remote operation and access to data	Technical challenge of appropriate solution number of parties involved	4	2	M	Early consideration and detailed design	Use Keele on site internet experts 'Internet Central'	2	0	L
Technical	24	Variability in quality of test gases used	Incorrect data collected	4	1	L	Only use accredited suppliers	Test gases before use	4	0	L
Technical	25	Lower NG into Keele than historic range	Limits to highest levels of Hydrogen	4	1	L	Reduced blending during this time	Alter test schedule	4	1	L
Technical	26	Classfiication of drainage water	Extra treatment required if not deemed surface water	2	2	L	ITM to advise early of classification of discharge water		2	0	L
Project	27	Long term degradation of Keele grid	Cost of repair / replacement	5	3	H	Integrity survey at the end of the study	Costs for ongoing inspection and maintenance agreed	5	0	L
Project	28	Risk to high value components on the grid	Loss of grid integrity	5	2	H	Integrity survey at the end of the study	Costs for ongoing inspection and maintenance agreed	5	0	L
Project	29	Specifying appropriate equipment for mixing	Expense of equipment, lead times for equipment	5	2	H	Careful investigation and specification of mixing unit	Apply knowledge to requirement	5	0	L
Project	30	Understanding HSE requirements in terms of exemption process	Risk to granting of exemption / project	6	2	H	Ensure HSE understand project aims and plans	Pre-engagement of HSE with action on feedback	6	0	L
Project	31	Risk of not convincing HSE on evidence to inject	Risk to project delivery	5	2	H	Continuous engagement with HSE		5	1	L
Project	32	Agree size and location of electrolyser, mixing unit and associated storage with Keele	Risk of being unable to install / run	6	2	H	Detailed planning and specification of plant and close liaison with Keele	Provision of suitable space at Keele	6	0	L
Project	33	Risk of equipment vandalism	Cost, delay, safety	5	2	H	Protection arrangements	Construct suitable barriers, locks etc	5	1	L
Project	34	Liability for long term performance of appliances / network	Cost to Keele to replace items	5	2	H	Review likelihood and allow for suitable contingency		5	1	L
Project	35	Delay in customer engagement / ethics Ph1	Delay to Ph2 of programme	4	3	H	Pre-engagement with Keele and customers	Well advanced and planned engagement	4	1	L
Project	36	Risk of ability to access private properties	Unable to continue programme	5	2	H	Provide long enough schedule and use landlord powers	Good PR and customer information	5	0	L
Project	37	Risk of increased burning temp = degradation over time plate / seals	Degraded appliances may need to be replaced	3	4	H	Assessment of appliances at the end of the project	Replace appliances where necessary	1	1	L
Project	38	Delay in electrolyser / mixer installation and commissioning Ph2	Delay to Ph3 of programme	4	3	H	Schedule work carefully	Detailed estimation of resources needed	4	1	L
Project	39	Delay / Budget overrun on network alterations Ph2	Delay to Ph3 of programme	4	3	H	Avoid critical path	Start altertaions asap to keep on programme	4	1	L
Project	40	Risks associated with electrolyser siting	Siting constraints including available space, cost implications	4	3	H	Close liasion with Keele and early detailed design	Early detailed design	2	0	L
Project	41	Booting of G1 gas network needed to deliver req'd flows to G3	Possible network reinforcement with associated time and cost	3	4	H	Early consideration and modelling	Contingenct allowance to be made at bid stage	2	0	L

Category	Risk ID	Risk Description	Impact of Risk	Impact 1-7	Likelihood 0-5	Pre-Risk Rating	Mitigation	Actions	Impact	Likelihood	Post-Risk Rating
Project	42	Expansion plans at Keele may effect the project	Possible expansion plans may mean connecting into G3 or increasing capacity of G3 during the course of the project	4	3	H	Early consideration and engagement with Keele Estates	Adjust plans as necessary	3	2	M
Project	43	Risk of Keele site insurance being invalidated	Proposed test programme cannot go ahead as planned	6	1	M	Redsign of programme and liaison with insurers	Modified test as necessary	6	0	L
Project	44	Cost of instrumentation – flow, pressure, composition	Significant cost to the project	3	2	M	Careful specification and tendering	Leverage NG buying power and companies looking to validate new technology	4	0	L
Project	45	Change to GSMR regulations	Risk of major disruption / cost to project	4	2	M	Regular liaison with HSE over potential changes to regulations		4	1	L
Project	46	Exemption not granted beyond [10%]	Limit to extendibility of project	3	3	M	Communicate project objective to determine safe level of injection with existing infrastructure - project has not failed if we do not prove above 10%		2	0	L
Project	47	Risk to wider adoption - Keele not fully representative of wider network	Limit to long-term value of project	3	3	M	Design programme and installation to be as applicable as possible	Provide gap analysis at the end of the project as to additional work needed to extend findings to the rest of the network to maximise relevance of the project	3	1	L
Project	48	Risk of not being allowed storage of hydrogen if electrolyser not used	Not able to store quantities of hydrogen needed on site	4	2	M	Design appropriate hydrogen storage and delivery system	Early review of COMAH limits and other regulatory constraints	4	0	L
Project	49	Very low summer flows may affect experimental programme	Delay to Ph3 programme	3	2	M	Design of mixer unit	Arrange programme to take account of summer flows	2	1	L
Project	50	Risk of increased pressure drop along line	Not meet gas regulation standards	2	4	M	Apply for exemption to standards if needed	Apply for exemption to standards if needed	1	1	L
Project	51	Risk of invalidating appliance warranties	Invalid warranties	4	2	M	Review appliance warranties and agree long term maintenance schedule	Compensate for invalidating warranties	2	1	L
Project	52	Delay in customer appliance testing Ph1	Delay to Ph2 of programme	4	2	M	Avoid critical path	leave sufficient overrun time	4	0	L
Project	53	Delay in exemption process Ph1	Delay to Ph2 of programme	4	2	M	Liaise with HSE	Regular meetings with HSE to avoid surprise	4	1	L
Project	54	Electrical supply capacity for electrolyser	Unable to produce hydrogen	4	1	L	Early determination of electrical requirements and need for reinforcement	Include contingency for reinforcement if needed	4	0	L
Project	55	Delay in achieving legal clearances with Keele	Delay to start of programme	5	1	L	Ensure legal requirements are clear and progressed	Emphasis in programme on legal clearance	4	0	L

Appendix J: Project Cost breakdown

HyDeploy Budget			Partner Labour	Direct Costs & Contractors	Total
		Total Cost	3,156,692	4,104,894	**7,261,586**
		Contingency			**372,952**
		GDN mandatory contributions			**763,454**
		NIC Request			**6,871,084**
PHASE 1					
1. SITE COMMUNICATIONS & STAKEHOLDER ENGAGEMENT			220,893	46,000	**266,893**
1		Develop Customer Engagement Plan	67,132	-	67,132
2		Secure Ethics Committee & OFGEM approval for Engagement Plan	16,443	2,000	18,443
3		Develop, launch and maintain Website	41,804	14,000	55,804
4		Develop & produce written literature	29,827	5,000	34,827
5		Events	57,536	25,000	82,536
6		Arranging bookings for residential visits	6,401	-	6,401
7		Set up and run Customer helpline	1,750	-	1,750
2. PRE-EXEMPTION ACTIVIITES TO DEVELOP EXEMPTION / SAFETY CASE			761,850	708,490	**1,470,340**
1		Assess appliance performance with hydrogen gas mix	126,134	374,450	**500,584**
	a	Literature review	18,075	13,950	32,025
	b	Detailed design of laboratory testing & on site testing	7,500	13,950	21,450
	c	Design and build gas delivery system to be used in the laboratory	16,025	12,500	28,525
	d	Laboratory testing with different gas mixtures	-	61,850	61,850
	e	Laboratory testing of appliances with varying natural gas concentration	11,025	15,230	26,255
	f	Write up results of laboratory testing	-	4,650	4,650
	g	Review results of laboratory testing	5,090	-	5,090
	h	Build delivery rig for onsite appliance testing on site at Keele	2,085	47,570	49,655
	i	Baseline testing & survey all equipment at Keele	29,733	124,640	154,373
	j	Review results of baseline survey and agree any remedial works	7,725	25,110	32,835
	k	Undertake remedial works on Keele grid	10,800	55,000	65,800
	l	Propose safe level for maximum first injection	18,075	-	18,075
2		Assessment of long term appliance behaviour	111,595	164,640	**276,235**
	a	In depth review of materials in appliances	12,050	9,300	21,350
	b	Detailed design of longevity testing	13,525	13,950	27,475
	c	Take temperature measurements within appliances during testing	39,690	-	39,690
	d	Modelling of plate temperatures	-	93,000	93,000
	e	Materials testing	19,280	7,000	26,280
	f	Set up and conduct accelerated lab testing	-	41,390	41,390
	g	Inspection of materials inside appliances before and after testing	6,025	-	6,025
	h	Review results and make recommendations re appliance life expectancy	8,975	-	8,975
	i	Write up results	12,050	-	12,050
3		Tightness testing with 100% hydrogen	29,244	18,100	**47,344**
	a	Tightness testing of house connections	9,910	3,380	13,290
	b	Tightness test in block of flats	2,410	3,380	5,790
	c	Tightness test in buried pipe	4,874	6,690	11,564
	d	Write up results	12,050	4,650	16,700
4		Materials embrittlement and jointing on the network	163,630	48,200	**211,830**
	a	Full literature review and write up	36,150	-	36,150
	c	Detailed design of laboratory testing & on site materials testing	11,025	-	11,025
	d	Laboratory testing of materials	68,200	10,000	78,200
	e	Laboratory testing: effects of H2 on jointing /repair of plastic pipes	18,075	1,000	19,075
	f	Design on site testing	12,050	-	12,050
	g	Detailed design of material sampling points	6,025	7,200	13,225
	h	Baseline pipe survey	2,084	-	2,084
	i	Undertake remedial works on network following baseline pipe survey	3,996	30,000	33,996
	j	Write up conclusions for materials testing	6,025	-	6,025
5		Risk of poor mixing	118,062	40,600	**158,662**
	a	Review gas entry design to establish likely mixing performance	17,284	-	17,284
	b	First principles assessment of gas properties and likely mixing behaviour	13,084	-	13,084
	c	Baseline computer modelling	1,391	22,000	23,391
	d	Design / review emergency shut down procedures (hydrogen)	11,676	3,600	15,276
	e	Detailed specification of monitoring system for flow, pressure & H2 %	28,465	3,000	31,465
	f	Detailed design of real time gas monitoring system	12,062	12,000	24,062
	g	Laboratory testing of experimental equipment	22,050	-	22,050
	h	Write up risk of mixing performance and proposed monitoring	12,050	-	12,050

HyDeploy Budget			**Partner Labour**	**Direct Costs & Contractors**	**Total**
6		Explosibility of hydrogen gas mix	28,897	2,000	**30,897**
	a	Full literature review of explosion characteristics including write up	7,375	-	7,375
	b	Desk based review of H2 dispersion: venting / zoning / emergency response	8,408	-	8,408
	c	Agree changes to safety case & emergency plans	13,114	2,000	15,114
7		Appropriate detection of hydrogen / gas mix	29,095	12,000	**41,095**
	a	Review findings on odourisation & gas detection; write up for the safety case	6,025	-	6,025
	b	Produce detailed specification for gas detection	6,025	10,000	16,025
	c	Produce detailed specification for odourisation	5,146	-	5,146
	d	Agree changes to safety case & emergency plans	11,898	2,000	13,898
8		Check ability to undertake appropriate metering	26,185	30,000	**56,185**
	a	Desk based review of appropriate metering technologies (incl NIA)	15,151	-	15,151
	b	Deployment of new metering technology as part of the project	11,034	30,000	41,034
9		Pre-Exemption Process Management	129,010	18,500	**147,510**
	a	Progress meetings	45,498	5,250	50,748
	b	Meetings with HSE	39,953	13,250	53,203
	c	Experimental process management	43,560	-	43,560
3. SPECIFICATION AND DESIGN OF HYDROGEN PRODUCTION AND MIXING			137,662	94,250	**231,912**
1		Agree detailed specification for Hydrogen production and injection system	51,786	23,050	74,836
2		Procurement process for mixing unit	7,725	3,000	10,725
3		Supplier Design review and Selection	20,737	12,200	32,937
4		Management and execution of design package phase	47,447	56,000	103,447
5		Detailed design of enabling works and civils	-	-	-
6		Detailed design of telecomms / IT remote access	9,966	-	9,966
4. WRITE SAFETY CASE AND APPLY FOR GSMR EXEMPTION			23,081	94,000	**117,081**
1		Agree Strategy for Safety Case and Exemption	10,814	30,000	40,814
2		Update underlying Safety Case for modified network	10,061	20,000	30,061
3		Undertake QRA	1,700	35,000	36,700
4		Write Exemption	506	9,000	9,506
5. REGULATORY AND BILLING ARRANGEMENTS WITH OFGEM			138,156	37,500	**175,656**
1		Develop Regulatory arrangements	116,659	18,750	135,409
2		Secure clearances with OFGEM	21,496	18,750	40,246
6. PRE-DEVELOPMENT INSTALLATION ACTIVITIES			34,051	91,450	**125,501**
1		Ensure network changes in place	-	55,000	**55,000**
	a	Removal of Subdeduct	-	-	-
	b	Reconfigure steel pipeline	-	55,000	55,000
2		Permissions	16,282	18,450	**34,732**
	a	Planning permission(as required)	6,207	3,600	9,807
	b	Environmental / Regulatory Permits (incl GQ8,GL5)	10,075	14,850	24,925
3		Design Review & Hazop	17,769	18,000	35,769
7. SECURE PROJECT GATEWAY CLEARANCES			38,440	175,500	**213,940**
1		Secure exemption from HSE	23,662	175,500	199,162
2		Formal risk assessed clearance by Keele	1,518	-	1,518
3		Project delivery team Risk Assessment	13,260	-	13,260
4		Steering Committee agreement to proceed	-	-	-
PHASE 2			-	-	-
8. INSTALL HYDROGEN INJECTION EQUIPMENT			340,837	1,569,093	**1,909,931**
1		Equipment Order & Fabrication	158,385	907,300	**1,065,685**
	a	Procurement of electolyser	155,862	521,100	676,962
	b	Procurement of mixing unit	2,522	386,200	388,722
2		Factory Acceptance Tests	40,456	7,600	**48,056**
	a	Electrolyser	32,320	3,800	36,120
	b	Mixing Unit	8,136	3,800	11,936
3		Site establishment & Construction Management	-	164,000	164,000
4		Ground works	-	187,358	187,358
5		Services Connections	8,386	100,000	**108,386**
	a	Electricity	3,762	50,000	53,762
	b	Water	2,312	25,000	27,312
	c	Drainage	2,312	25,000	27,312

HyDeploy Budget			Partner Labour	Direct Costs & Contractors	Total
6		Delivery & Installation	8,386	158,000	**166,386**
	a	Electrolyser and Mixing unit	3,762	28,000	31,762
	b	New Network isolation valve upstream of existing G3 Network	2,312	65,000	67,312
	c	New Pipeline from Mixing unit to T upstream of G3 meter	2,312	65,000	67,312
7		Hazop	10,094	4,800	14,894
8		Commissioning & onsite testing	115,131	40,035	**155,166**
	a	Cold Commissioning	17,870	12,740	30,610
	b	Hot Commissioning	97,261	27,295	124,556
9. INSTALL NETWORK MONITORING EQUIPMENT			59,045	403,000	**462,045**
1		Network Monitoring equipment installation	59,045	403,000	**462,045**
	a	Installation of real time composition monitoring system	23,460	358,000	381,460
	b	Installation of real time pressure & flow monitoring system	6,660	30,000	36,660
	c	Training on hydrogen detectors and emergency response	26,452	5,000	31,452
	d	Install new gas detectors and re-calibrate existing detectors	2,474	10,000	12,474
10. PRE INJECTION PROCESSES			16,014	51,250	**67,264**
1		Declared CV process	4,250	11,250	15,500
2		Emergency Response team training	11,764	-	11,764
3		Continuity of Heat Provision	-	40,000	40,000
PHASE 3			-	-	-
11. INJECTION PLANT & EQUIPMENT OPERATION			102,265	260,511	**362,776**
1		Inject hydrogen with increasing % into the system and check for response	102,265	260,511	362,776
2		Maintenance and fault finding	-	-	**-**
	a	Electolyser	-	-	-
	b	Mixing Unit	-	-	-
	c	Instrumentation and analysis equipment	-	-	-
12. DATA GATHERING DURING THE TRIAL			160,320	125,010	**285,330**
1		Appliance, materials and mixing performance during the trial	160,320	125,010	**285,330**
	a	Repeat baseline checks on appliances on site and write up findings	4,073	31,560	35,633
	b	On site materials testing	42,175	-	42,175
	c	On site monitoring of composition, flow and pressure	28,542	13,200	41,742
	d	Performance monitoring of appliances	28,270	56,000	84,270
	e	Write up findings from injection study	37,050	-	37,050
	f	Review collected data and assess scope for increasing the % hydrogen	5,360	24,250	29,610
	g	On site experimental programme management	14,850	-	14,850
13. INCREMENTAL INJECTION			734	218,990	**219,724**
1		Review results and increase level	734	218,990	**219,724**
	a	Review plans for further step	-	18,750	18,750
	b	Secure new exemption if needed	-	30,000	30,000
	c	Inject hydrogen @ Keele at higher percentage	-	170,240	170,240
	d	Repeat data gathering	734	-	734
14. PLAN FOLLOW-UP PROJECT ON PUBLIC NETWORK			95,428	-	**95,428**
1		Scientific gap analysis	26,575	-	26,575
2		Develop plan for public network trial	68,853	-	68,853
15. KEELE SITE REINSTATEMENT/HANDOVER			24,013	111,000	**135,013**
1		Longer term monitoring onsite	3,826	87,000	90,826
2		Decommissioning Activities	18,155	24,000	42,155
3		Handover of equipment	2,033	-	2,033
PROJECT MANAGEMENT AND DISSEMINATION			-	-	-
16. DISSEMINATION AND REPORTING			314,136	27,500	**341,636**
1		Publications Conferences & Events	90,867	19,500	110,367
2		OFGEM Reporting	223,269	8,000	**231,269**
	a	6 Monthly Reports	84,284	8,000	92,284
	b	SDRC Reports	84,424	-	84,424
	c	Close out Reports	54,561	-	54,561
17. PROJECT MANAGEMENT			689,767	91,350	**781,117**
1		Project Management & Meetings	689,767	91,350	**781,117**
	a	Overall project management	251,166	-	251,166
	b	Cost management & Reporting	131,894	-	131,894
	c	Keele, NG & NGN Governance	1,518	-	1,518
	d	Project meetings	197,141	73,450	270,591
	e	Project Steering Committee	78,103	16,300	94,403
	f	Advisory Board	29,945	1,600	31,545
Total					**7,261,586**

Appendix K Project Partner's Summaries and CVs

National Grid

National Grid is an international electricity and gas company based in the UK and north-eastern US. We play a vital role in connecting millions of people safely, reliably and efficiently to the energy they use. Supplying 3.4m customers' electricity and 3.6m customers' gas in the US and 11m customers' gas in the UK. Operates the gas and electricity transmission systems in the UK.

Lorna Millington is Design Manager, National Grid, 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.

Andy Lewis is Future of Gas Portfolio Manager, National Grid. He works within the Innovation Team at National Grid Gas Distribution 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. Before working at National Grid, Andy worked for Westminster City Council and was responsible for the energy services for 22,000 homes and the development of heat networks within the council's boundaries.

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.

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. The campus effectively forms a small town, with shops, residential accommodation, student halls of residence, a chapel and a large science park for which the University owns and operates all the utilities.

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. At the University of

Manchester he led projects into Grid-Scale Storage and an EU – China research collaboration project across 5 countries and 8 research institutions.

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 Rachel Smith has worked for ITM since 2002 when the company was created, completing a variety of roles including Research Scientist, Head of Science and Operations Manager. Rachel is responsible for grant project management, providing an effective interface between ITM and funding bodies. Rachel was appointed to the company board as an Executive Director in 2015.

Dr John Newton, C.Eng 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. From 2002-2008 John was an independent assessor for the DTI's New & Renewable Energy Programme.

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 an energy project: project screening and selection, project definition and optimisation, contracting (including feedstock, EPC, and power purchase contracts), consenting, project financial evaluation, financing, construction, commissioning, operations, maintenance, and venture management. PEL has extensive experience in multi-partner project management, and has partnered in two other NIC programmes.

Dr Chris Manson-Whitton is a Director of Progressive Energy a company focused on Project Development encompassing both conventional and new technologies. Chris also delivers technical due diligence and trouble-shooting services for investors, technology providers and public bodies in the energy sector. His work encompasses biomass, waste and carbon capture & storage projects. Recent activities include the development of a Bio-SNG Pilot and demonstration Projects under the NIC programme. He is on the industry advisory panel for the SUPERGEN bioenergy research hub.

Charles Eickhoff MA CEng has a broadly-based technical and commercial background in the power industry in the UK and Europe. His roles have included being responsible to Board level for both regulated and non-regulated electricity and gas businesses where risk management and cost control are critical. He is experienced in project development in low-carbon ventures, and has managed participation in several EC–funded collaborative projects.

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 experiments both in nuclear applications and the safe use of hydrogen as a new fuel.. At our Buxton site, we have developed considerable expertise in safely carrying out testing to establish baseline measurements, as is required within this programme of work. **Input into Regulations, Codes and Standards**: Over the last 15 years HSL has undertaken and been part of a major experimental and research programme into the hazards and risks associated with retailing hydrogen. Since 2004 HSL have represented the UK on the **International Energy Agency Hydrogen Implementing Agreement Task 19**. This is a network of hydrogen experts from all over the world whose overall goal is to reduce or eliminate safety-related barriers to the widespread commercial adoption of hydrogen energy systems.

Catherine Spriggs: Masters 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, varying in value from tens of thousands of pounds to hundreds of millions of pounds. She joined the Health and Safety Laboratories in 2012 and works in the Major Hazard team managing scientific research projects for commercial clients predominantly in the aerospace, defence and energy sectors.

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. Since joining HSL in 2009 Phil has been involved in hydrogen research including: ignition by corona discharges, spontaneous ignition due releases from pressurised storage, the behaviour of liquid hydrogen spills, and the dispersion, deflagration and jet fire characteristics of hydrogen gas in enclosures. Phil was a contributing author of the HSE Research Report HSE RR1047 on hydrogen addition to natural gas.

Dave Hedley: B.Eng. (Hons.) Electrical and Electronic Engineering, PGD Computer Science. David's career at HSL started with work on gas detection instrumentation, including the design and build of a battery powered portable Gas Chromatograph. This was followed by research work on gas explosions and mitigation measures. In recent years David has worked on hydrogen safety, predominantly for Sellafield Ltd. on chronic hydrogen production from legacy nuclear waste.

Jonathan Hall: Masters of Engineering, AMIMechE. Jonathan is an aerospace engineer with over 6 years of experience in the Major Hazards Unit at HSL, specialising in flammable dusts, gases and vapours. This role includes the construction of experimental rigs, performing incident investigation research, undertaking programs of testing and writing of scientific papers. Recent hydrogen research projects include; liquid hydrogen transport spills, high-pressure surface releases, enclosed deflagrations, jet fires and ignition energy testing.

Wayne Rattigan: BSc (Hons) Applied Chemistry. Wayne has been part of the Explosive Atmospheres team for over 7 years with a focus on dust explosion hazards and testing. In addition he has spent much of the last 6 years working on large scale experimental programmes relating to hydrogen hazards: ETI (ongoing)– prediction of explosion behaviour in CCGTs running on high hydrogen fuels; Sellafield – predicting and mitigating explosion behaviour of hydrogen releases inside nuclear silos.

Appendix L Stakeholder Engagement to date

Stakeholder	Engagement
HSE	A series of 4 face to face meetings with members of the project team, including senior staff from HSE. The full programme scope and proposed evidence base has been shared with them to ensure that the relevant elements are included. The approach of using the Keele network as a first trial is strongly endorsed.
IGEM	Discussions regarding the principles of the project in light of their current work to provide the evidence base for widening gas quality.
HHIC	Heating and Hot Water Industry Council represent the appliance manufacturers. Face to face meeting and provided a letter of support through the EUA in Appendix M
Boiler Manufacturers	Round table meeting with ITM & HSL including Worcester Bosch, Vaillant & Baxi. Constructively engaged and supportive of the project
GERG	The European Gas Research Group has been championing the role of hydrogen for many years. Discussions with their Secretary General between ITM, Progressive and NGGD.
SGN/WWU	The project team has engaged with both other GDNs throughout the development of the project. They have provided a letter of support
DECC	Face to face meeting with officials, and a wider one-to-one discussion with the Chief Scientist regarding the role of hydrogen in delivering low carbon heat
British Gas	British Gas Innovation manager involved in the project at the outset, and although he has now left British Gas, they continue to support the project as demonstrated by their letter of support.

Appendix M: Letter of Support

Keele
University

21 July 2016

To: Andrew Lewis, National Grid Gas Distribution
Adam Madgett, Northern Gas Networks

Dear Andrew & Adam

Re: HyDeploy Application to the Network Innovation Competition

Keele University is proud to be one of the leading universities in the UK for sustainability and intends to be at the forefront of the fight to combat climate change, and *'promote environmental sustainability in all that we do'*, one of the 6 aims of the University strategy.

Keele University owns and operates the entire utility infrastructure on our campus and as part of our commitment to sustainability, and to help the UK meet its carbon reduction target, we are developing this infrastructure in order to provide an at-scale, integrated energy-vector Smart Energy Network Demonstrator (SEND). This has been made possible by our own investment to date with proposed future investment from the University and funds prioritised by our Local Enterprise Partnership (LEP).

Collaborating with National Grid Gas Distribution and Northern Gas Networks would provide an exciting opportunity for us to realise our vision for the campus as an internationally-leading demonstration site for new technologies. The potential to work with you and your partners to test the injection of a hydrogen blend into the gas grid provides a customer focused solution to the decarbonisation of low carbon heat and is therefore exactly the type of initiative the SEND has been established to enable.

As a research-led university, the proposed collaboration with Keele University would provide a body of practical, referenceable data which is an essential pre-requisite to enable deployment of this low carbon solution and will offer an opportunity for our researchers and students to underpin research with real-world impact.

We wish you every success in the development and submission of the bid and we look forward to working with you to developing our plans for collaboration.

Yours sincerely

Dr Mark A. Bacon
Director of Engagement & Partnerships

Director's Office
Directorate of Engagement & Partnerships
T: 01782 733644
E: m.bacon@keele.ac.uk
Keele University Science & Innovation Park, Staffordshire, ST5 5NH

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

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

20th July 2016

To Andrew Lewis - National Grid, Adam Madgett - NGN

Subject : HyDeploy Application to the Network Innovation Competition: letter of support

GERG, the European Gas Research Group, is a research and development organisation that provides both support and stimulus for the technological innovation necessary to ensure that the European gas industry can rise to meet the technological challenges of the new century. It was founded to strengthen the gas industry within the European Community and it achieves this by promoting research and technological innovation. Established as a network to enable exchange of information between a select group of specialist R&D centres to avoid duplication of effort, it has grown steadily to around 30 members whilst retaining and expanding its original aims. Its priorities are networking, technical information exchange, and the promotion and facilitation of collaborative R&D.

We recognise that the UK has committed to challenging low-carbon targets, and also that the UK has world class networks with enormous potential for future adaptation. Adaptation of this grid by the injection of a hydrogen blend provides a customer focused solution to the decarbonisation of low carbon heat.

We understand that NGGD and NGN are seeking to undertake a project to enable this decarbonisation solution. This will be the first UK practical introduction of hydrogen into a live gas network since the transition from town gas. We understand the key focus of this work will be to establish the practical level of blending which does not require modification to the network or appliances. By providing the evidence base to the HSE you are seeking to undertake a practical demonstration of such a hydrogen blend on the network at Keele University and provide a body of practical, referenceable data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

This is a project we are particularly interested because GERG and its European member companies have been leading a number of important initiatives which establish road maps for introduction of hydrogen into our natural gas networks. Projects include HIPS (hydrogen in pipeline systems), HIPS-NET, and the European Power to Gas Platform. We work closely with policy makers at European level to ensure that the potential for the use of existing gas networks in providing a vital route to a decarbonized future energy system is recognized, and that appropriate Innovation actions are initiated to enable this set of future options.

GERG is prepared to participate on an advisory panel to ensure that key stakeholder views represented by our members are present in the delivery of the programme and its outcomes

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

Yours Sincerely,

R Judd

Robert Judd
Secretary General, GERG

Committee on
Climate Change

Mr A Lewis
National Grid Gas Distribution
Brick Kiln Street, Hinckley
Leicester LE10 0NA

Dr David Joffe
Team Leader
Committee on Climate Change
7 Holbein Place
London SW1W 8NR
david.joffe@theccc.gsi.gov.uk
020 7591 6102

4th August 2016

Dear Andy,

HyDeploy Application to the Network Innovation Competition

The Committee on Climate Change (CCC) is a statutory advisor to the Government and the Devolved Administrations under the Climate Change Act. We recommend the level of UK emissions targets ('carbon budgets'), analyse how they can be met and monitor progress towards meeting them.

The UK has committed stringent low carbon targets, which will require substantial, and possibly near-complete, decarbonisation of heat supply over the period to 2050. We also have an existing gas grid of high quality and wide coverage, and are interested in whether this can be adapted or repurposed to support low-carbon heat or whether the need to decarbonise heat will lead to it being decommissioned.

We understand that NGGD and NGN are seeking to undertake a project to enable this decarbonisation solution, which will be the first UK practical deployment of hydrogen onto a live gas network since the transition from town gas. We understand the key focus of this work will be to establish the practical level of blending which does not require modification to the network or appliances. By providing the evidence base to the HSE you are seeking to undertake a practical demonstration of such a hydrogen blend on the network at Keele University and provide a body of practical, referenceable data which is an essential pre-requisite to enable wider deployment of this low-carbon solution.

This is a project we are interested in because heat decarbonisation is a large challenge, and it is very important over the next few years to understand better the range of options for reducing emissions. We have a particular interest for solutions pertaining to properties on the gas grid, moving customers away from gas boilers looks like a real challenge.

We are currently doing a deep dive on heat decarbonisation, for publication in the autumn, but this is an area that will need pro-active development over the next few years to reach a stage where strategic decisions can be made over the appropriate path(s) for heat decarbonisation and what that implies for infrastructure development/repurposing.

We would be happy to sit on the advisory panel, subject to time availability, for this project to ensure that our views and interests can be represented in the delivery of the programme and its outcomes.

I wish the project every success.

Yours sincerely,

David Joffe

Dr. David Joffe, Team Leader, Committee on Climate Change

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www.wwutilities.co.uk

F.A.O. Andy Lewis
National Grid Gas Distribution
Brick Kiln Street
Hinckley
Leicester
LE10 0NA

28 July 2016

Dear Andy

RE: HyDeploy Application to the Network Innovation Competition

Every day at Wales & West Utilities, our team of more than 1,300 skilled and dedicated colleagues do their very best to keep our 7.5 million customers safe and warm, with gas connections and a gas supply they can rely on combined with a level of service they can trust.
We launched Wales & West Utilities in 2005, and since then we have worked hard to build our impressive and established reputation for delivering excellent customer service with safety, reliability and value for money at the heart of everything we do.

We recognise that the UK has committed to reducing greenhouse gas emissions by 80% by 2050 and WWU believes that this will best be achieved by using and decarbonising our gas grid. Decarbonisation by the injection of a hydrogen blend will be critical to achieving this.

We understand that NGGD and NGN are seeking to undertake a project to enable this decarbonisation solution. We understand the key focus of this work will be to establish the practical level of blending which does not require modification to the network or appliances. We believe that this project is of critical importance to the future of the UK gas grid. The practical demonstration of a hydrogen blend on the network at Keele University will provide referenceable data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

WWU is supportive of this work because recent studies that have been commissioned demonstrate that decarbonising the gas grid is the most cost effective way of meeting our carbon reduction targets. However this will require a hydrogen blend to be injected into the grid. We need to understand the impact this will have on appliances, networks and consumers. This project is a vital step in improving our understanding.

We look forward to seeing this project develop and the conclusions it reaches.

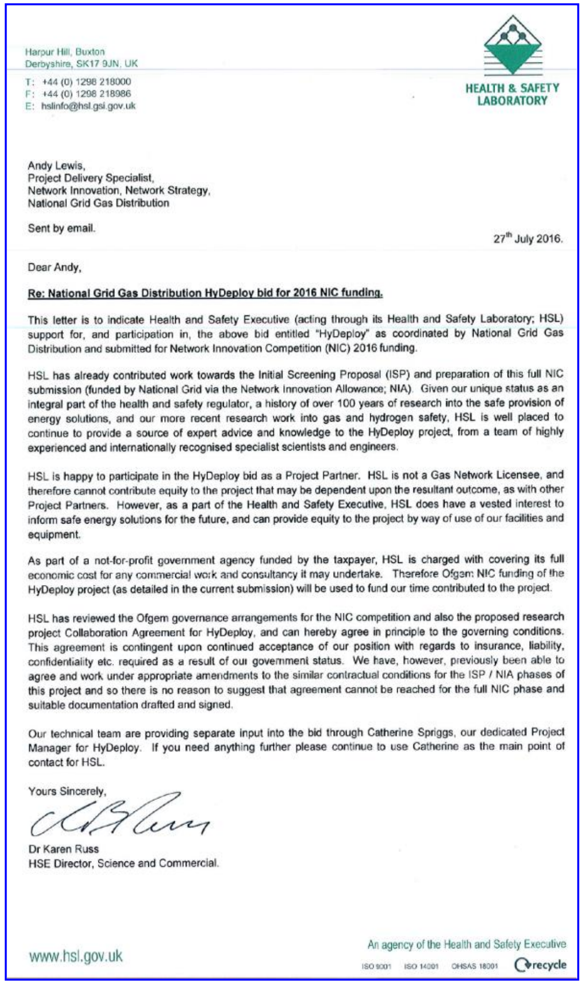
Smell gas? Call us!
Arogli nwy? Ffoniwch ni!
0800 111 999

Institute of Customer Service

Wales & West Utilities Limited
Registered Office:

Yours sincerely

Steven Edwards
Director of Regulation and Commercial



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HEALTH & SAFETY LABORATORY

Andy Lewis,
Project Delivery Specialist,
Network Innovation, Network Strategy,
National Grid Gas Distribution

Sent by email.

27th July 2016.

Dear Andy,

Re: National Grid Gas Distribution HyDeploy bid for 2016 NIC funding.

This letter is to indicate Health and Safety Executive (acting through its Health and Safety Laboratory; HSL) support for, and participation in, the above bid entitled "HyDeploy" as coordinated by National Grid Gas Distribution and submitted for Network Innovation Competition (NIC) 2016 funding.

HSL has already contributed work towards the Initial Screening Proposal (ISP) and preparation of this full NIC submission (funded by National Grid via the Network Innovation Allowance; NIA). Given our unique status as an integral part of the health and safety regulator, a history of over 100 years of research into the safe provision of energy solutions, and our more recent research work into gas and hydrogen safety, HSL is well placed to continue to provide a source of expert advice and knowledge to the HyDeploy project, from a team of highly experienced and internationally recognised specialist scientists and engineers.

HSL is happy to participate in the HyDeploy bid as a Project Partner. HSL is not a Gas Network Licensee, and therefore cannot contribute equity to the project that may be dependent upon the resultant outcome, as with other Project Partners. However, as a part of the Health and Safety Executive, HSL does have a vested interest to inform safe energy solutions for the future, and can provide equity to the project by way of use of our facilities and equipment.

As part of a not-for-profit government agency funded by the taxpayer, HSL is charged with covering its full economic cost for any commercial work and consultancy it may undertake. Therefore Ofgem NIC funding of the HyDeploy project (as detailed in the current submission) will be used to fund our time contributed to the project.

HSL has reviewed the Ofgem governance arrangements for the NIC competition and also the proposed research project Collaboration Agreement for HyDeploy, and can hereby agree in principle to the governing conditions. This agreement is contingent upon continued acceptance of our position with regards to insurance, liability, confidentiality etc. required as a result of our government status. We have, however, previously been able to agree and work under appropriate amendments to the similar contractual conditions for the ISP / NIA phases of this project and so there is no reason to suggest that agreement cannot be reached for the full NIC phase and suitable documentation drafted and signed.

Our technical team are providing separate input into the bid through Catherine Spriggs, our dedicated Project Manager for HyDeploy. If you need anything further please continue to use Catherine as the main point of contact for HSL.

Yours Sincerely,

Dr Karen Russ
HSE Director, Science and Commercial.

www.hsl.gov.uk

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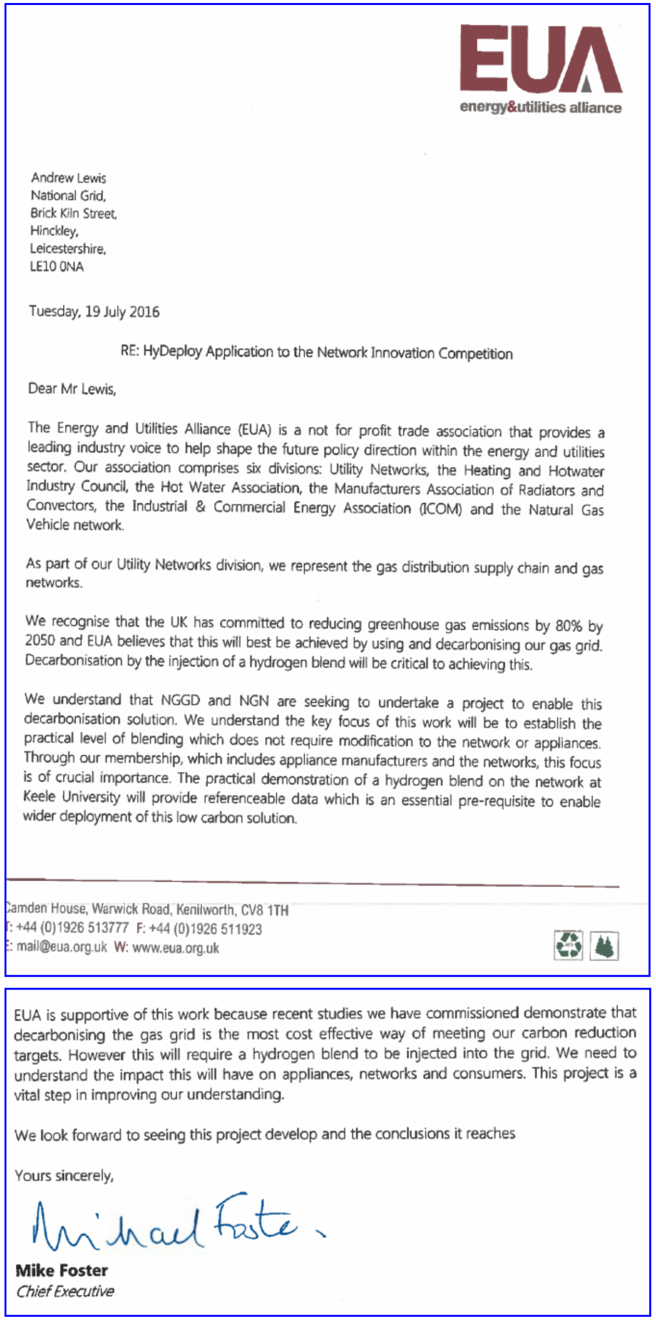

EUA
energy&utilities alliance

Andrew Lewis
National Grid,
Brick Kiln Street,
Hinckley,
Leicestershire,
LE10 0NA

Tuesday, 19 July 2016

RE: HyDeploy Application to the Network Innovation Competition

Dear Mr Lewis,

The Energy and Utilities Alliance (EUA) is a not for profit trade association that provides a leading industry voice to help shape the future policy direction within the energy and utilities sector. Our association comprises six divisions: Utility Networks, the Heating and Hotwater Industry Council, the Hot Water Association, the Manufacturers Association of Radiators and Convectors, the Industrial & Commercial Energy Association (ICOM) and the Natural Gas Vehicle network.

As part of our Utility Networks division, we represent the gas distribution supply chain and gas networks.

We recognise that the UK has committed to reducing greenhouse gas emissions by 80% by 2050 and EUA believes that this will best be achieved by using and decarbonising our gas grid. Decarbonisation by the injection of a hydrogen blend will be critical to achieving this.

We understand that NGGD and NGN are seeking to undertake a project to enable this decarbonisation solution. We understand the key focus of this work will be to establish the practical level of blending which does not require modification to the network or appliances. Through our membership, which includes appliance manufacturers and the networks, this focus is of crucial importance. The practical demonstration of a hydrogen blend on the network at Keele University will provide referenceable data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

Camden House, Warwick Road, Kenilworth, CV8 1TH
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EUA is supportive of this work because recent studies we have commissioned demonstrate that decarbonising the gas grid is the most cost effective way of meeting our carbon reduction targets. However this will require a hydrogen blend to be injected into the grid. We need to understand the impact this will have on appliances, networks and consumers. This project is a vital step in improving our understanding.

We look forward to seeing this project develop and the conclusions it reaches

Yours sincerely,

Michael Foster.

Mike Foster
Chief Executive

1st August 2016

IGEM
Institution of
Gas Engineers & Managers

Mr Andy Lewis
Project Delivery Specialist
National Grid
Hinckley Operational Centre
Brick Kiln Street,
Hinckley
LE10 0NA

Dear Andy

RE: HyDeploy Application to the Network Innovation Competition

The Institution of Gas Engineers & Managers (IGEM) is a chartered professional body, licensed by the Engineering Council which serves the wide range of professionals in the UK and the international gas industry through Membership, events and a comprehensive set of Technical Standards.

We recognise that the UK has committed to reducing greenhouse gas emissions by 80% by 2050 from the 1990 levels and IGEM believes that this can best be achieved by using and decarbonising our gas grid. Decarbonisation by the injection of a hydrogen blend can be part of a critical and significant pathway to achieving this target.

IGEM works closely with all the gas distribution networks to support their innovation projects. In particular we understand that NGGD and NGN are seeking to undertake a project to enable the decarbonisation of the gas grid. We understand the key focus of this work will be to establish the practical level of blending which does not require modification to the network or appliances. We believe that this project is of critical importance to the future of the UK gas grid. The practical demonstration of a hydrogen blend on the network at Keele University will provide empirical data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

IGEM is supportive of this work as recent studies that have been commissioned demonstrate that decarbonising the gas grid can play a significant role in meeting our carbon reduction targets. However, as this project will require a hydrogen blend to be injected into the grid we need to understand the impact this will have on appliances, networks, consumers and standards. This project is a vital step in improving and building on our understanding.

We look forward to seeing this project develop and the conclusions it reaches.

Yours sincerely,

Sarb Bajwa
Chief Executive Officer

cc David Parkin, Director, Network Strategy, National Grid

Institution of Gas Engineers & Managers
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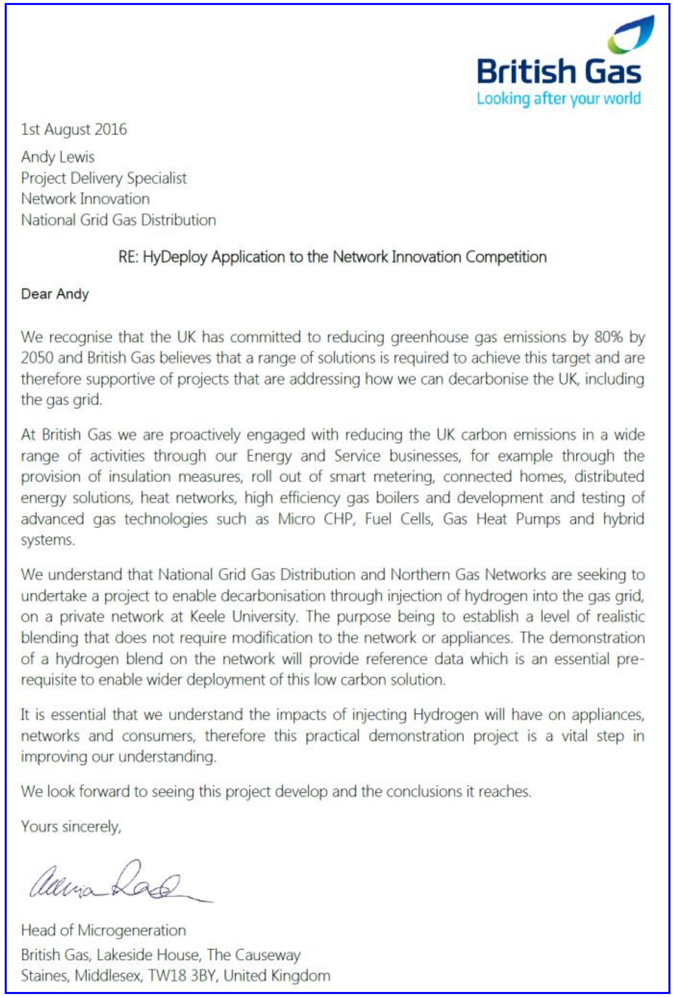

British Gas
Looking after your world

1st August 2016

Andy Lewis
Project Delivery Specialist
Network Innovation
National Grid Gas Distribution

RE: HyDeploy Application to the Network Innovation Competition

Dear Andy

We recognise that the UK has committed to reducing greenhouse gas emissions by 80% by 2050 and British Gas believes that a range of solutions is required to achieve this target and are therefore supportive of projects that are addressing how we can decarbonise the UK, including the gas grid.

At British Gas we are proactively engaged with reducing the UK carbon emissions in a wide range of activities through our Energy and Service businesses, for example through the provision of insulation measures, roll out of smart metering, connected homes, distributed energy solutions, heat networks, high efficiency gas boilers and development and testing of advanced gas technologies such as Micro CHP, Fuel Cells, Gas Heat Pumps and hybrid systems.

We understand that National Grid Gas Distribution and Northern Gas Networks are seeking to undertake a project to enable decarbonisation through injection of hydrogen into the gas grid, on a private network at Keele University. The purpose being to establish a level of realistic blending that does not require modification to the network or appliances. The demonstration of a hydrogen blend on the network will provide reference data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

It is essential that we understand the impacts of injecting Hydrogen will have on appliances, networks and consumers, therefore this practical demonstration project is a vital step in improving our understanding.

We look forward to seeing this project develop and the conclusions it reaches.

Yours sincerely,

Head of Microgeneration
British Gas, Lakeside House, The Causeway
Staines, Middlesex, TW18 3BY, United Kingdom

nationalgrid
National Grid House,
Warwick Technology Park,
Gallows Hill,
Warwick,
CV34 6DA.

Mr Andy Lewis
Brick Kiln Street,
Hinckley,
LE10 0NA.

27th July 2016

Dear Andy,

Re: HyDeploy Application to the Network Innovation Competition

National Grid Gas Transmission (NGGT) is the sole and operator of gas transmission infrastructure in the UK.

We recognise that the UK remains committed to reducing greenhouse gas emissions by 80% by 2050. Decarbonisation of the gas networks by injection of a hydrogen blend will be critical to achieving a cost effective solution to meet this target. We are therefore supportive of Hydeploy as a project to enable this. The practical demonstration of a hydrogen blend on the network at Keele University will provide data and new learning which is an essential pre-requisite to enable wider deployment of this low carbon solution. The project is complementary to the work NGGT are looking to undertake in this area, focussing on demonstrating hydrogen injection in gas transmission pipelines and at gas transmission pressures.

We look forward to seeing this project develop and will be keen to share in the learning.

Yours sincerely,

Tamsin Kashap

Tamsin Kashap
Gas Transmission Innovation Manager