HyDeploy$_2$ Project

HyDeploy$_2$: Winlaton Trial Report // September 2022.

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A Progressive Energy Ltd Report

1.0 Background

Concerns relating to the production of carbon dioxide (CO_2) and its effects on global background temperatures have led to international efforts to reduce CO_2 emissions. One of the main contributors to CO_2 emissions is the burning of fossil fuels in domestic and commercial fuel supplies, especially the burning of natural gas (NG) comprised primarily of methane (CH_4).

HyDeploy$_2$ is a demonstration project funded by OFGEM, Cadent and Northern Gas Networks to establish the feasibility of supplementing NG in the distribution network with hydrogen (H_2), which when consumed, does not produce CO_2. As gas fired heating is used in the majority of UK households, the reduction of carbon dioxide emissions from a country-wide range of locations will allow the UK to contribute positively to a reduction in a gas linked to global warming.

To achieve this reduction in CO_2 emissions, a consortium formed of Cadent, Northern Gas Networks, Progressive Energy, the Health and Safety Executive Science Division (HSE SD), ITM Power and Keele University have worked together to study the feasibility of injection of up to 20% mol/mol hydrogen (20% H_2) into the natural gas supply.

Both the 10 Point Plan and Energy White Paper specifically identify the need to unlock hydrogen blending by 2023. HyDeploy (including HyDeploy$_2$) is the only major technical programme within the UK driving the deployment of hydrogen blends within the gas distribution system, therefore the successful outcome of the broader HyDeploy programme is now crucial to facilitating the delivery of HMG hydrogen policy objectives.

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2.0 Introduction

The HyDeploy project seeks to address a key issue for UK customers and UK energy policy makers: how to reduce the carbon emitted from heating homes. The UK has a world class gas distribution grid delivering heat conveniently and safely to over 83% of homes. Emissions can be reduced by lowering the carbon content of gas through blending with hydrogen. This delivers carbon savings, without customers requiring disruptive and expensive changes in their homes. It also provides the platform for deeper carbon savings by enabling wider adoption of hydrogen across the energy system.

The ultimate objective of the HyDeploy programme is to see the roll-out of hydrogen blends across the GB gas distribution network, unlocking 29 TWh pa of lowcarbon heat - the equivalent of removing 2.5 million fossil-fuelled cars off the roads.

HyDeploy has previously delivered a successful trial demonstrations of repurposing existing UK distribution gas networks (Keele University) to operate on a blend of natural gas and hydrogen (up to 20% mol/mol) showing that carbon savings can be made through the gas networks today whilst continuing to meet the needs of gas consumers without introducing any disruptions.

The ultimate objective of the HyDeploy programme is to see the roll-out of hydrogen blends across the GB gas distribution network, unlocking 35 TWh pa of low carbon heat - the equivalent of removing 2.5 million fossil-fuelled cars off the roads. To achieve this, the next phase of the programme is to address the remaining evidence gaps that had not been covered by the trial demonstration programmes.

The demonstrations have focussed on the low and medium pressure tiers of the gas distribution network (i.e., injecting into a 2 bar gauge pressure network and distributing the blended gas down to the low pressure network and into people's homes and commercial buildings and businesses) and predominantly serving domestic appliances.

The remainder of the HyDeploy$_2$ programme will generate an evidence base for GB's gas distribution network, which includes demonstrating the suitability of using hydrogen blended gas in the fields of industrial and commercial users and the performance of materials, assets and procedures on the higher pressure tiers (i.e., 7 bar gauge operation and above).

This report captures the details of the Winlaton trial and provides a future look to how the UK can transition from successful hydrogen blending trials to roll-out.

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3.0 Executive Summary

HyDeploy had previously delivered a successful hydrogen blended gas trial where up to 20% hydrogen mol/mol was injecting into the private gas network at Keele University, the first of a kind in the UK, providing the lower carbon gas to 100 domestic properties and 50 faculty buildings. Customers received blended gas for a year and continued to operate their existing gas appliances without disruption. The natural next steps of the HyDeploy programme was to address evidence gaps and upscale the trial to a public network involving a more diverse range of network materials (e.g., iron mains pipe) and a wider set of stakeholders (e.g., gas shippers and suppliers).

The village of Winlaton was chosen as the site for the trial as it offered a high degree of variability with regards to materials on the network, appropriate size of network and statistical representation of housing in the UK. The Winlaton trial network consists of 668 properties comprising a school, church and a mixture of domestic housing and is situated in Blaydon near Gateshead. The network is owned and operated by Northern Gas Networks (NGN) who isolated the Winlaton trial network from the wider gas network and installed a dedicated supply pipe to feed the isolated network with blended gas from NGN's Low Thornley compound. The compound hosted the hydrogen storage and blending equipment and the entire trial operated for 11 months.

An exemption to the Gas Safe (Management) Regulations (GS(M)R) was required from the Health and Safety Executive (HSE) to inject up to 20% mol/mol hydrogen into the natural gas network. A scientific programme provided the technical foundation of the evidence presented to the HSE in support of the Exemption application.

The evidence base generated spanned; appliances; gas characteristics; gas detection; and materials/assets, the results of which fed into a quantitative risk assessment (QRA). The key findings from the evidence were; less carbon monoxide was produced when using hydrogen blended gas in existing appliances compared with natural gas, which became more significant for when the appliance was in a fault condition; materials on the network were demonstrated to not incur changes to failure frequencies or consequences, including cast iron; and that increases in explosion overpressure from hydrogen blends were 1.2 – 1.4 times that of methane although the explosion impulse (overpressure x time) was comparable to methane. Taking all the evidence into consideration the results of the QRA determined that the individuals in the trial area were safer with a network operating on the blended gas, compared with natural gas, through the significant reduction of exposure to carbon monoxide.

The 11 month trial showed that pipe and component materials performed well throughout the demonstration, with no increase in component failure frequencies when compared to the historical performance of this network on natural gas.

The 11 month trial showed that pipe and component materials performed well throughout the demonstration, with no increase in component failure frequencies when compared to the historical performance of this network on natural gas. Operational issues were dealt with by NGN using, mostly, business as usual operations and in some cases appropriately amended hydrogen blend procedures, predominantly the use of a new gas detector (available within the current market).

Consumers lie at the heart of the HyDeploy project. The basis of blending hydrogen into the gas network is that it unlocks material quantities of decarbonisation, provides a foundation for deeper carbon savings through hydrogen deployment and achieves these without disrupting consumers. To formally analyse the experience of residents taking part in the trial, HyDeploy worked with a team of researchers, who carried out independent research into customer perceptions of hydrogen and their experiences of the HyDeploy project both before the trial commenced and at the end. Research shed light on customers' feelings towards safety, cost and the effectiveness of hydrogen. Overall residents were found to be positively engaged and receptive to the trial, with a high degree of local support.

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4.0 Safety Case

The key regulatory hurdle that had to be addressed to enable the trial to commence was the 0.1 mol% hydrogen limit imposed by Part 1 Schedule 3 of the Gas Safety (Management) Regulations (GS(M)R). The HSE has the power to grant exemptions to stipulations within GS(M)R if a safety case application can be made that evidences that the proposed changes do not prejudice the health and safety of those impacted by the change. Therefore, an exemption application was made to the HSE to permit conveyance for one year of injection of gases, into the Winlaton Trial network, having a maximum mole fraction of hydrogen of 20%.

The exemption was requested on the basis that a Quantified Risk Assessment (QRA) was able to demonstrate that:

- With respect to conveyance and use of gas, the health and safety of persons likely to be affected by the exemption will not be prejudiced as a consequence of increasing hydrogen mole fraction during the Winlaton Field Trial.

NB: The hydrogen supply and grid entry unit (H2GEU), which includes hydrogen mixing, is geographically separate from the field trial area at a secure location owned and operated by NGN. Risks directly associated with this plant are excluded from the QRA and managed through NGN's existing safety management framework. Risks associated with loss of control of hydrogen blending, which would impinge on the field trial area, were included in the QRA.

4.1 Quantitative Risk Assessment

The QRA is a methodology which allows a numerical assessment of risk to be conducted which expressed the inherent risk position during the trial. Risk was defined as the risk to life due to exposure to carbon monoxide (CO) or as a consequence of fires/explosions. The QRA utilised information from a wide range of sources, including:

a) Technical assessment (i.e., literature review) of the impact of use of hydrogen-natural gas blends on appliance performance.

b) Detailed laboratory testing of a selection of appliances.

c) In-premises verification of satisfactory appliance performance within the field trial area.

d) Technical assessment of the potential for increased leakage, dispersion and flammability characteristics of gas conveyed during the Winlaton Field Trial.

e) Technical assessment of the impacts of the Winlaton Field Trial itself on the materials employed in the field trial area and any requirements needed to demonstrate its fitness for purpose for conveyance of natural gas following completion of the trial.

f) Technical assessment of the detection of hydrogen-natural gas mixtures including position for satisfactory odorization.

A house-to-house (H_2H) survey was conducted to capture appliance information within the field trial area. Simultaneously, faulty appliances or internal pipework leaks discovered during the H2H survey were rectified at the time of the survey. However, the QRA takes no credit for any such risk reduction and so is considered conservative with respect to risk mitigation.

A fault tree was developed using 'AND', 'OR' and 'NOT' logic gates to enable the detailed relationships underpinning gas usage risk to be developed. The fault tree was developed to the necessary level of detail to allow identification of the gas-specific basic events that must combine with environmental, mitigative and human behavior basic events to trigger the chain of risk causality.

Three scenarios were assessed:

- **Scenario 1** – the situation for Great Britain as a whole. This permits model validation by comparison with national statistics for CO incidents and fires and explosions.
- **Scenario 2** – the situation for the trial area network prior to the field trial, i.e., with natural gas conveyed to consumers.
- **Scenario 3** – the situation for the trial area network during the field trial, i.e., with natural gas-hydrogen blends conveyed to consumers. Comparison of overall risk under this scenario with that for Scenario 2 permits assessment of any change in risk and indicates the effectiveness of any mitigation measures employed.

The same fault tree was used in each scenario. Assessment was achieved solely by changing the input probability or frequency data to basic events (appropriate to each scenario) and not by changing the overall interconnection or gate logic. The QRA results comparing Scenarios 1 and 2 are shown in Figure 1 and the comparison of scenarios 2 and 3 are shown in Figure 2 below.

The overall individual risk for the trial area associated with conveyance and use of gas is estimated to be around 90% of that for the GB scenario (Figure 1), when adjusted for population exposed to the hazard. This is because both risk of CO poisoning and fire and explosion are slightly lower for the trial area, which in turn is largely because the overall number of gas appliances per household is lower and the proportion of polyethylene (PE) gas main is higher.

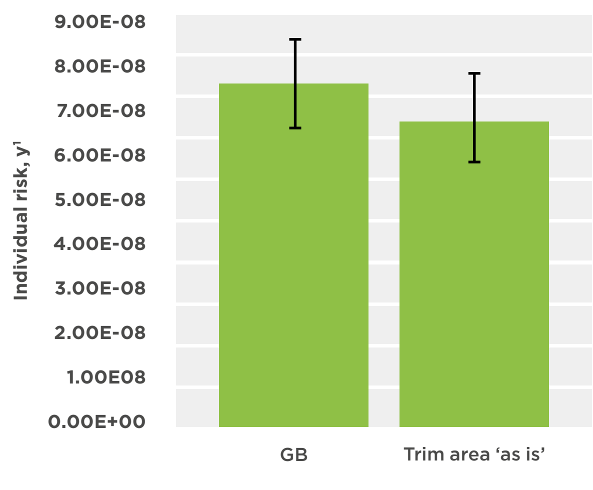

Figure 1: Individual risk of conveyance and use of gas (expressed as million-1.y-1) compared for the trial area and updated GB situation (Scenarios 2 and 1).

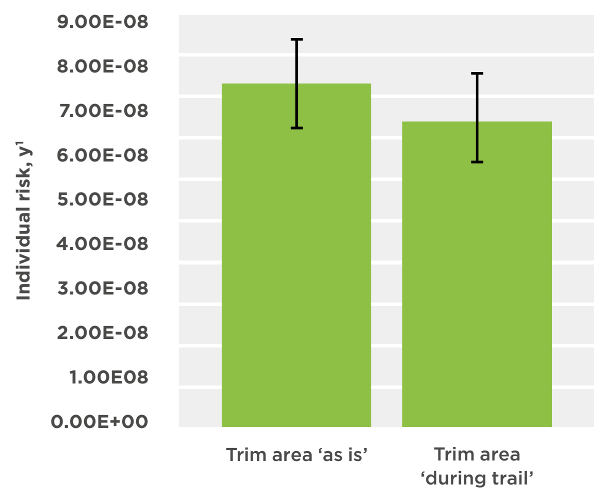

Figure 2: Individual risk (expressed as million-1.y-1) for the trial area before and during the field trial (Scenarios 2 and 3).

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Overall individual risk during the proposed field trial is expected to be low (Figure 2) – in absolute terms around 0.065 $million^{-1}.y^{-1}$ – and this is small in comparison with the range considered to be Broadly Acceptable within the HSE Tolerability of Risk framework for reaching decisions on risks from an activity or process. Individual risk is around three-quarters (78%) of that estimated for the GB population. Overall risk has been reduced by reduction in CO fatalities associated with addition of hydrogen.

The results of the QRA determined that the individuals in the trial area were safer with a network operating on the blended gas, compared with natural gas, through reduction of exposure to carbon monoxide. Given this result, in conjunction with no credit being taken, from rectifying gas safe issues during the H_2H appliance gas safe checks, in determining the risk to individuals "during the trial", it can be inferred that appliance checks are not a necessary requirement to ensure that the safety of an individual is not prejudiced when replacing natural gas networks with blended gas.

4.2 Evidence

A scientific programme provided the technical foundation of the evidence presented to the HSE in support of the Exemption application. The evidence base generated spanned; appliances; gas characteristics; gas detection; and materials/assets. An outline of the key results within each area follows.

4.2.1 Appliances

The objective of the appliances work package was to demonstrate safety assurance of appliance operation at Winlaton and assess key findings for the perpetual use of current UK gas appliances on hydrogen blended gas by investigating the following;

- Safe operation of well-maintained appliances
- CO production in faulty appliances
- CO uptake
- Appliance safety systems
- Application of industry safety standards

The appliances work package consisted of a combination of laboratory based experimentation and in-field inspection and data analysis.

4.2.1.1 Laboratory Testing

HyDeploy1 demonstrated that all UK domestic appliances assessed against the Gas Appliance Directive (GAD, 2009) will function safely and efficiently if correctly commissioned, used and maintained. A wide range of appliances dating back to 1976 (Towns gas switch over) exist in the UK and so an industry appliance review was conducted to review whether aged appliances will be compatible with the hydrogen blended gas. The appliance gas assessment regime for GAD is defined in BS EN 437 which was published in 1994 and 2009. The 2009 edition of GAD introduced one new class of appliance into the acceptance regime (which is not sold in the UK) and therefore it was concluded that the requirements applied in GAD (2009) can be viewed as being the same as those since 1994. Prior to BS EN 437 (1994), the standard in place was BS 4947 which specified very similar testing requirements and since 1976 industry initiatives have led to the removal of old appliances and improvement in the general use of gas within the UK, namely;

- Water heater safety replacement exercise (1986 – 1994).
- Corgi registration scheme for gas installers (1998).
- Gas safety checks for Landlords.
- Building regulations stipulate high efficiency condensing boilers (2005).
- Boiler scrappage scheme (2010).

The net effect of the above mentioned initiatives and improvements have led to a wholescale reduction in the number of poorly performing appliances in the UK. Considering that typical domestic gas appliances have an average life expectancy of 15-20 years; it would be expected that the oldest appliances on the network still in use would be 30 years old i.e., 1990, and therefore given the government led improvement initiatives, property markets and natural appliance life expectancy, the UK population of domestic gas

Energy Minister visit.

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appliances will have moved towards compliance against GAD (1990). Analysis of regulations and timelines in combination with industry expertise suggests that appliances compliant with GAD (2009) are representative of the UK appliance population in the period 1976 – 2019, since the introduction of GAD in 1990 did not drive changes in design. Therefore, the appliances selected for experimental assessment were representative of the UK appliance population.

HyDeploy1 assessed 8 appliance types, HyDeploy$_2$ has focused on generic burner types to cover all domestic and commercial gas appliance configurations in the UK, culminating in 13 different burner types. Burner types were tested with a range of limit gases up to 28.4% hydrogen and across the suite there was generally no change in safety performance. A significant reduction in CO production was observed as well as no changes to the combustion performance, flame supervision devices or appliance acoustics. A minimal change was observed in the delayed ignition overpressure and one appliance type (overhead plaque burner) showed false flameout at 28.4% hydrogen and went in to a cyclic shut down sequence.

The assessment of maloperating or malfunctioning appliances was a key issue to be addressed for the appliances work package within HyDeploy$_2$ to demonstrate that the magnitude of an unsafe environment created by a malfunctioning appliance operating on natural gas does not increase if the malfunctioning appliances operated on hydrogen blended gas. The key concern in this area was poor combustion characteristics leading to high CO output since findings from previous research (Tripartite Gas Quality consultation exercise, GASQUAL – CEN TC234 Working Group 11 "Gas Quality" and SGN's "Opening up the Gas Market" & SIUs) have shown that malfunctioning appliances are the source of CO that leads to fatalities.

Experiments were performed on two central heating boilers to simulate high CO production from the combustion of a malfunctioning appliance. This was achieved by reducing the air intake to lower the stoichiometric ratio of the combustion and hence encouraging high CO production. The experimental results showed that the addition of hydrogen increases the stoichiometric ratio and therefore for a malfunctioning appliance with comparable settings, the malfunctioning appliance will produce significantly less CO whilst operating on hydrogen blended gas than natural gas. This reduction was measured to be between 80-90% for the equivalent malfunction, once embodied within the QRA this reduction in CO production results in a significant reduction of the CO hazard from gas appliances.

The performance of appliance safety systems was tested across a range of gas qualities and showed that flame supervision devices (ionisation devices, thermocouples) operated as required. Oxygen deficiency sensor (ODS) devices were tested during HyDeploy1 with one ODS found to breach the test standard (for a single type of gas fire appliance, the other three types of gas fires tested all performed as required). Subsequent experimentation carried out, both via HyDeploy$_2$ and a separate joint industry project on ODS' has shown that a well operating ODS will operate soundly on all GSMR gases and up to 20 mol% hydrogen.

Industry appliance safety standards were reviewed to assess the suitability of existing installations for blended gas. A review of domestic and commercial regulation, codes and standards downstream of the customer's meter was undertaken. Scenarios where the addition of hydrogen may affect compliance with regulation, codes and standards were identified in conjunction with regards to the relevant properties and behaviour of hydrogen blended gas. A review of the performance of appliance monitoring devices was carried out to understand the compatibility of electronic devices and testing criteria currenting used to assess combustion performance of appliances, this was done using the field data from the 8 appliances installed in the HyDeploy field trial at Keele University currently operating on blended gas.

Keele University Campus.

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4.2.1.2 In-field Inspection

A house-to-house (H_2H) data collection survey was carried out to obtain information on gas appliances on the Winlaton trial network for the purpose of having more data to develop the Great Britain (GB) scenario (presented in Figure 1) as part of the Quantitative Risk Assessment (QRA). It was also a good opportunity to conduct gas safe checks on all accessed appliances.

The objective of the H_2H survey was to collect site-specific gas appliance related data for those gas appliances connected to the Winlaton trial network. This data included;

- Appliance type.
- Appliance condition.
- Condition of appliance ventilation.
- Condition of appliance flue.
- Appliance safety device functionality.
- Property type.
- Property ownership.
- Number of CO detectors in the property.
- CO detector functionality.
- Appropriateness of CO detector location within the property.

A team of Customer Care Officers, Gas Safe engineers and utility contractors were led by Northern Gas Networks over a 4-month operation to access the majority of the 668 properties on the Winlaton trial network. Data was collected from two primary sources;

1. Door-to-door visits specifically arranged as part of the H2H survey.
2. Gas Safe certificates provided by the Local Authority (LA) for gas appliances installed within properties owned by the LA.

A standardised survey collection form was used to ensure that the data collection process was the same at all locations and with all engineers. Gas Safe registered engineers used this survey to support a H_2H exercise to access customer properties on the Winlaton trial network, the survey was populated by the engineers once access had been granted by the customer. Concurrent with this, the engineers performed Gas Safe checks on customer's appliances. Data from the Gas Safe certificates received from the LA were digitised and concatenated with the data collected from the H_2H visits to create one dataset survey. Altogether, data for 594 (89 %) of the 668 properties on the Winlaton trial network was accessed. A total of 1208 individual gas appliances were checked and surveyed with 8 appliances having some form of malfunction, 5 appliances having unsatisfactory flueing and 1 appliance having unsatisfactory ventilation. Remedial repairs were undertaken on all substandard gas appliances and installations identified to bring them to compliance with current standards.

Prior to the H_2H data collection, the Communications team and Customer Care Officers (CCOs) at Northern Gas Network (NGN) carried out a comprehensive engagement program with the gas customers on the Winlaton trial network informing customers of the proposed trial and the requirement to carry out the H_2H survey. Where possible, the NGN CCOs would pre-arrange appointments: however, where this was not possible, direct doorstep engagement was undertaken. The former provided a schedule of booked appointments for engineers to carry out the H_2H survey. Utilergy Gas Ltd was employed as the successful tenderer to carry out the H_2H survey and data collection.

Engineers were provided with a handheld device (tablet) to record the H_2H survey information during the survey and also to record the outputs of the appliance Gas Safe checks. Upon completion of the H_2H survey and Gas Safe check, where the appliance passed its check, the engineer would provide the customer with a Gas Safe certificate. However, if the appliance failed the Gas Safe check, then a warning notice would be served and the appliance would be made safe. Where further remedial action was identified, the remedial action was escalated to the dedicated NGN H_2H survey supervisor to take the appropriate rectification actions to make the customers appliance Gas Safe.

Figure 3: Images of house-to-house survey team; planning activity, engaging with customers and a Gas Safe engineer carrying out gas safe check on a customer's gas fire.

4.2.2 Gas Characteristics

The gas characteristics of natural gas containing up to 20 mol% hydrogen, in comparison to natural gas, was an important area of understanding to underpin the quantitative risk assessment and support appropriate supplementary guidance for operational procedures to be developed, where needed. The main findings were as follows:

1. A review of actual natural gas explosion incident reports has been carried out and this has provided useful insight into real-world incident situations. A number of key findings are listed:
   a. Gas explosion incidents occur fairly evenly throughout the year.
   b. The number of gas explosion incidents in each property type was broadly in line with the population of those property types in the UK.
   c. Gas explosion incidents have occurred with a wide range of gas concentrations from lean to rich.
   d. Most ignition sources identified were of a discontinuous nature and often involved human interaction, though there were also ignition sources that could be considered to be continuous.
   e. Many of the ignition sources identified were of a strong, or potentially strong, nature. However, in a significant number of cases the ignition source was not identified and it is probable that these cases included some smaller ignition sources.
   f. In a few cases, evidence of stratification of the flammable dispersion was evidenced after analysis of the damage pattern.
   g. Ten fatalities were registered within the reports reviewed in a time frame of 10 years, which was in agreement with previous estimations RIDGAS and RIDDOR.
2. In considering leak rates, a leak that is laminar in nature with natural gas (NG) will remain laminar when hydrogen is added to the gas; therefore, the leak rate will not increase for this type of leak.
3. Extensive modelling and experimental work showed that gas accumulation resulting from leaks of blend within buildings will be almost identical to that of NG both in terms of layer depth and concentration. Therefore, the likelihood of an accumulation of the blended gas coming into contact with an existing ignition source is unchanged compared to NG.
4. The blend would be expected to be more sensitive than NG, and similar to propane, to ignition by mechanical ignition sources. This is based on correlations of frictional and impact ignition sensitivity with the spark ignition energy, and interpolating between other gases.
5. Consideration of ignition sources of lower ignition potential indicates that these will not dominate the risk profile. Ignition sources with an equivalent energy of a few millijoules or less will either be less frequent, or incapable of causing ignition in some cases.
6. The explosion overpressures resulting from gas mixtures containing 20% hydrogen have been compared with methane, based on the results of published models. Changes in overpressure were found to be in line with expectations from theoretical analysis: for the 20% blend, the overpressure is expected to be between 1.2 and 1.4 times that of methane. The impulse (overpressure x time) of the blended experiments was found to be comparable with methane.
7. A number of questions were addressed relating to a 20% blend following a review of gas network procedures. These covered the following areas:
   a. Maximum permissible leak rate (MPLR); this can remain unchanged.
   b. The minimum purging velocities in mains pipelines should be increased by a factor of 1.14 in order to avoid incomplete purging.
   c. The pressure drop along service pipes; this is expected to remain within the limits currently experienced with natural gas, but could increase by up to 10% in pipes where the flow is in the transitional regime between laminar and turbulent flow.
   d. Separation distances have been reviewed based on the distance required to avoid flammable atmospheres. A conservative approach was adopted for the trial only, and further work will determine the true nature of separation distances. Conservative separation distances for the trial were summarised as:
      i. Low momentum releases: increase distance by 10%.
      ii. High momentum releases: increase distance by 25%.
      iii. The exclusion zone around a Tornado unit: increase by 10%
      iv. Separation distance between underground mains and buildings can remain as current for the Winlaton trial.
      v. The current height of purging vent stacks can remain unchanged.
      vi. As for the previous trial, when carrying out area classification for the blend in the Winlaton trial, the flow rate of gas should be increased by 10% for assessment of inside leaks using SR/25 calculations. Distances for external leaks should be increased by 10%.

The results of the gas characteristics workstream were aggregated to support the Quantitative Risk Assessment and provided a framework for supplementary guidance to be generated for the operational procedures. This ensured any ‘hydrogen effect’ was properly accounted for within the relevant operational procedures to maintain the same level of operational integrity historically experienced by the Winlaton network.

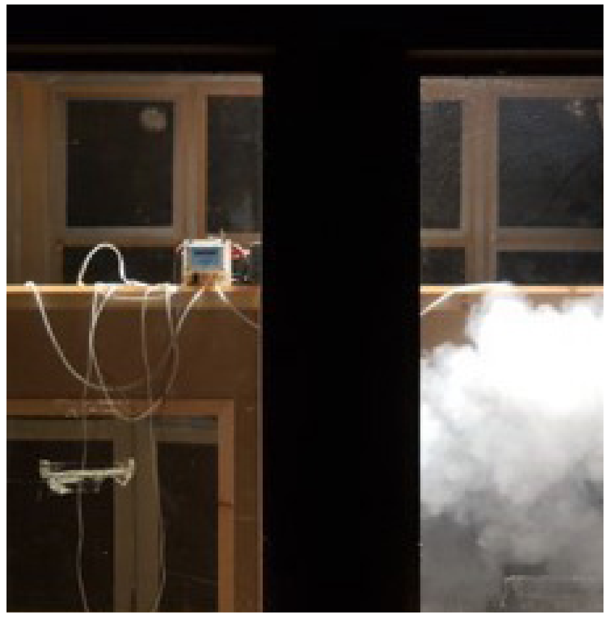

Figure 4: Experimental setup showing how hydrogen blended gas accumulation characteristics were tested.

Figure 5: Image of bespoke container developed to run hydrogen blended gas explosion characteristic experiments.

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4.2.3 Materials and Assets

The interaction of hydrogen with materials is an important area which must be understood when evaluating hydrogen injection. The initial stage in this workstream was to undertake a comprehensive asset register of the Winlaton trial network to evaluate the spectrum of materials for suitability assessment. A total of 1,043 assets were identified on the network encompassing pipelines (mains, services and domestic), meters, regulators, governors and valves. The Winlaton Trial network consisted of both medium and low-pressure pipework with; 639 metres of iron mains, 8,815 metres of polyethylene mains and 106 metres of steel mains. All services to users were either polyethylene, steel or copper. A new Fiorentini governor was fitted on the trial network which regulated the pressure from a 2-barg incoming blended gas stream to a maximum operating low pressure of 75 mbarg.

Extensive assessment was conducted for each material and asset type on the network which comprised a mixture of:

- Literature review.
- Desk-based modelling and analysis.
- Physical experimentation.
- Engagement with original equipment manufacturers.

Through analysis of the above criteria, the susceptibility of materials, present in the Winlaton trial site, to hydrogen degradation was assessed, with consideration of the Winlaton operating conditions (up to 20% H_2 at total blend pressures of 20 mbar – 2 bar). The output of this work was to determine whether there were any components, which have been identified at the Winlaton trial site, which could have a significantly increased risk of failure due to their exposure to hydrogen during the trial.

The materials evidence generated by HyDeploy1 laid the foundation for the assessment where mechanical property data (elongation, elastic modulus, UTS and proof strength) on numerous materials (metals and non-metals) was gathered by soaking test specimens in 100% hydrogen chambers for 6 weeks at 1.5 barg (Figure 6) followed by mechanical testing. Data was generated for a range of materials including: mild steel, stainless steel, cast iron, brass, copper, and polyethylene. While the experimental parameters were designed to simulate the operating conditions of the HyDeploy1 Keele University gas distribution network, this data is more broadly applicable to the study of the degradation of mechanical properties of metals, when exposed to hydrogen gas environments. The results of which showed that the hydrogen soaking had no impact on the materials' mechanical properties.

In addition to this, the electrofusion procedure to join PE pipe and the mechanical squeeze-off procedure to stop flow within a PE pipe were tested by soaking the PE pipes in 100% hydrogen for 6 weeks at 2 barg pressure before performing the two procedures. Figure 7 below shows images from the PE squeeze-off tests where the PE pipe was squeezed (Figure 7a and Figure 7b), the pipe was then re-rounded (Figure 7c) and then hydrostatic tested (Figure 7d). Once the tests were completed, the samples were cross-sectioned (Figure 7e) to for dye penetrant inspection (DPI) inspection to show evidence of potential stress crack onset and X-ray radiography was used to inspect for mid-wall voids. The figure shows an even colour over the surface of the sectioned area indicating that there was no cracking to the body of the PE during the squeeze-off nor hydrostatic testing. A similar result was observed for the control sample and both the hydrogen soaked and un-soaked control sample passed the test as defined in the controlling standard.

Figure 6: Soaking chamber containing various metallic and non-metallic test specimens for soaking in hydrogen up to 1.5 barg.

Figure 7: Images from PE Squeeze-Off Tests.

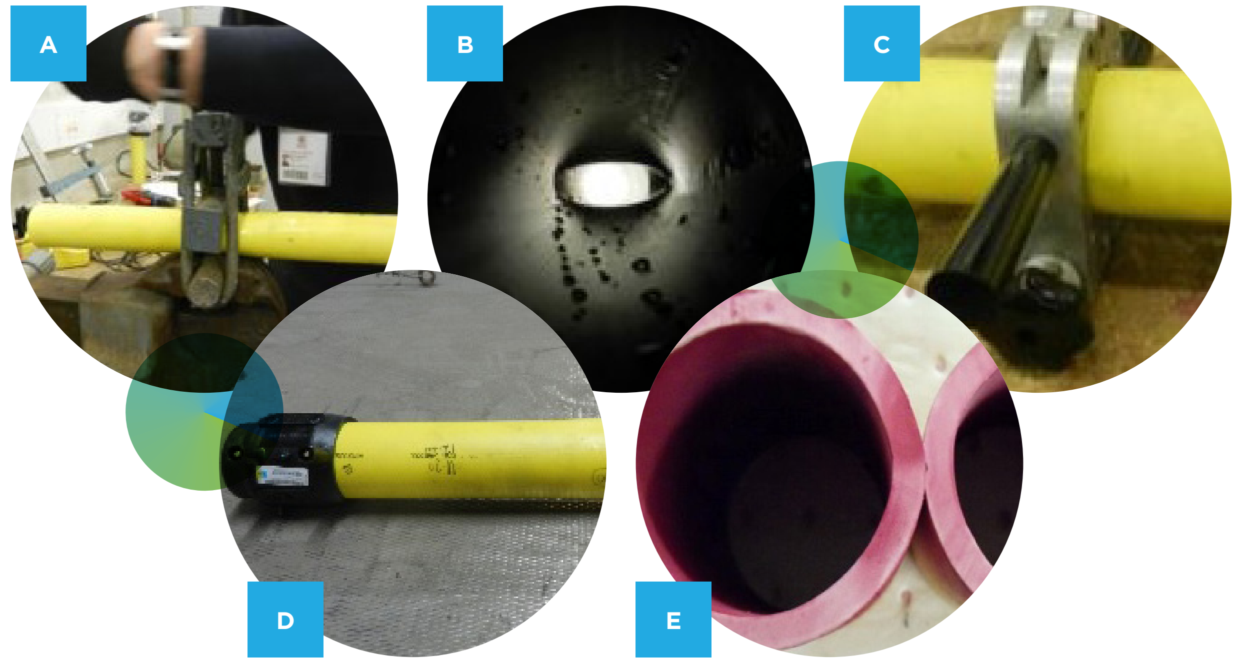
A: External view of pipe being squeezed using a squeeze-off tool.

B: Internal view (pipe inner wall) of pipe as it is being squeezed-off.

C: Re-rounding PE pipe after completion of squeeze-off.

D: PE pipe prepared for hydrostatic testing.

E: Sectioned view of hydrogen soaked PE pipe following hydrostatic testing.



Electrofusion jointing was carried out in both the socket (end-to-end) orientation and as a saddle joint (90° orientation). Within each trial, water-in-water hydrostatic testing was again undertaken with each sample held at 80°C. After testing was completed, all the samples were assessed by X-ray and DPI: Figure 8 shows a sectioned joint. The figure shows the DPI dye trapped within the cut marks from the pipe sectioning. Dye trapped within the curvature of the pipe relates to areas of the weld joint but do not indicate any cracking or damage to the weld. No evidence of stress cracking was found on any of the samples tested and the hydrostatic pressure test was completed successfully to required standards.

Further materials evidence was generated as part of the Winlaton evidence base to reflect materials that were not present on the HyDeploy1 Keele trial network (specifically cast iron) and also to advance the breadth of data in this field by increasing the testing parameters to reflect wider network pressure operations. Both tensile testing and charpy impact tests were conducted on steel, brass and cast-iron materials following soaking in pure hydrogen vessels at 8 barg for different lengths of time (1 week, 4 weeks and 5 weeks). Figure 9 shows images of the pressure vessels used to soak the samples in hydrogen and typical sample geometries for the tensile and charpy impact testing.

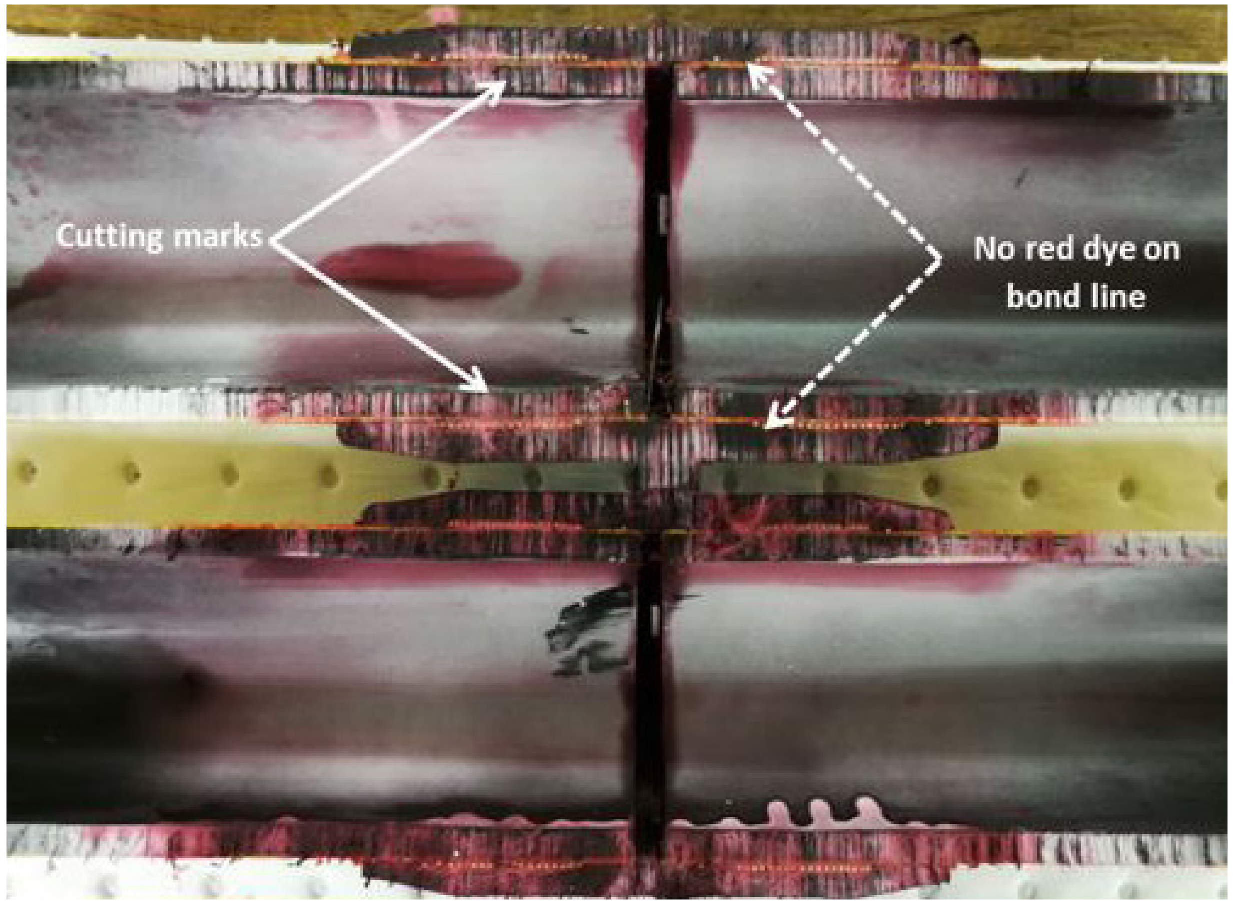


Figure 8: Sectioned view of electrofusion welded hydrogen PE pipe following hydrostatic testing.

The fracture energies observed from the charpy impact tests showed an increase in scatter with longer hydrogen exposure, however the scatter was all within the spread of the as-received samples which were un-exposed to hydrogen and thus it could be concluded that the impact energies for the materials were not influenced by the hydrogen charging. The tensile testing of hydrogen exposed samples revealed no discernible difference between the un-exposed and soaked condition with the cast iron data set showing most scatter which is expected of cast iron due to the nature of its microstructure.

Fractographic assessment showed that the presence of hydrogen do not change the failure mechanisms of the materials in that ductile micro-void coalescence fracture of the steel and brass was observed, whereas more of a brittle fracture surface was observed for the cast iron.

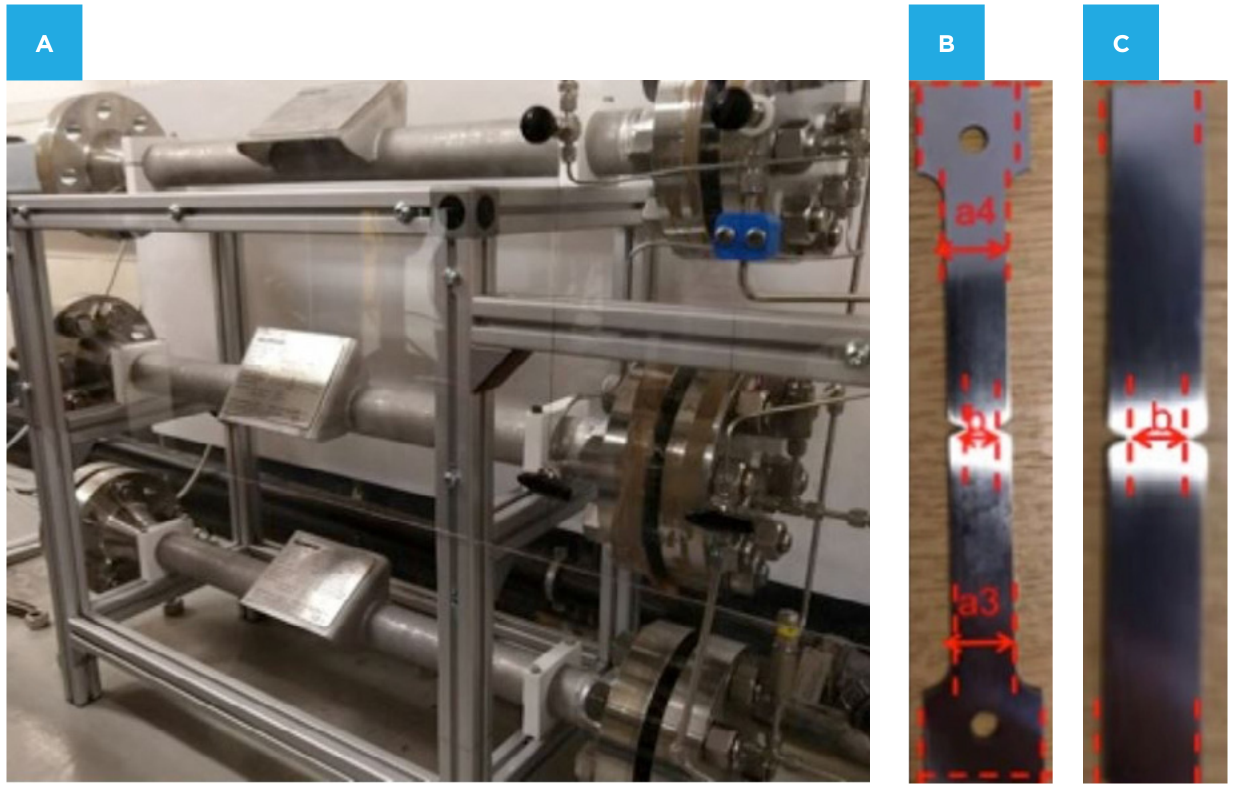


Figure 9: A) Image of 3 pressure vessels used for soaking specimens in hydrogen for various lengths of time at 8 barg. B) Tensile test specimen C) Charpy impact test specimen.

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All metallic materials are susceptible to hydrogen embrittlement under certain environments and operating conditions, the operating conditions expected in the Winlaton trial were mild with respect to conditions under which hydrogen degradation is widely reported (circa 100 bar) and experimental data collected for hydrogen exposed material at pressures reflective of the gas distribution network where these materials are found allied concerns of increases to failure frequencies. Furthermore, the components operating at Winlaton (in governors and pipelines etc.) typically do not experience significant stresses during operation. It was reasonable to expect that materials that are usually considered susceptible to hydrogen embrittlement in other contexts are unlikely to have their mechanical properties significantly degraded during the Winlaton trial. The majority of components have been assessed to be at no significant risk of failure due to exposure during the trial.

Although there are many factors contributing to the failure of elastomeric seals, the most common causes are due to material mis-selection and poor specification, which are linked to human factors and may result in chemical attack due to chemical incompatibility of the seal with the media within a system. Similarly, a second area of concern for the use of elastomeric materials was whether the overall rate of gas permeation would be unduly affected by interaction with hydrogen. The permeation coefficient for elastomeric materials has generally been reported to be much higher than those of polyethylene. However, studies have concluded that the much larger surface area of PE in the GDN compared to that of elastomeric seals would lead to the amount of hydrogen gas going through the pipe walls to be of greater significance than that lost from any permeation through any elastomer in the system. Based on the available data, most elastomeric sealants were assessed to be compatible with hydrogen including coatings because they were not at risk of any mechanical or chemical degradation; and hydrogen permeation was not expected to occur at a significant rate.

Steel springs are a potential risk of fatigue if significantly cycled at high stress amplitudes. The cycling frequency of these springs, however, was expected to be low (in the order of 10s or 100s per day), lending confidence that the risk of increased failure is insignificant.

Cast iron pipes have the possibility of being exposed to traffic loading (i.e. stress cycling) if they run underneath roads. Whilst the loading conditions of these pipes is unknown and although cast irons are inherently brittle in nature, it was reasonable to expect that over the course of the trial, an increased failure rate was unlikely.

As a consequence of these assessments, it was recommended that an increase in materials failure frequency is not likely, however the following components would be monitored or inspected at an increased frequency, during the Winlaton trial:

- Steel springs in governors (checked every four months during the trial, current natural gas operations requires a check every two years)
- Cast iron top/bottom caps in governors (checked every four months during the trial, current natural gas operations requires a check every two years)
- Cast iron pipes and pipeline (above ground leakage survey conducted every day, current natural gas operations requires no above ground leakage surveying of cast iron pipes).

The It was reasonable to expect that materials that are usually considered susceptible to hydrogen embrittlement in other contexts are unlikely to have their mechanical properties significantly degraded during the Winlaton trial.

4.2.4 Operational Procedures

The assessment of appropriate operational procedures to govern the injection of a hydrogen/natural gas blend into Northern Gas Networks' (NGN) Winlaton gas distribution network was a key requirement of the HyDeploy$_2$ project. To perform this assessment the review was broken down into two areas, procedures upstream of the emergency control valve (ECV) these procedures are owned by NGN, and procedures downstream of the ECV, procedures which would be performed by Gas Safe registered individuals. Assessment of the upstream procedures was led by NGN and assessment of the downstream procedures was led by Blue Flame Associates (Blue Flame are an industry expert on downstream gas procedures).

Methodologies were adopted to be able to highlight procedures that could potentially be used on the Winlaton trial network during the hydrogen blended gas injection period and if they were impacted by the changing of the gas within the network from natural gas to hydrogen blended gas. This method determined that for downstream gas procedures a total of 56 gas procedures required expert review, resulting in 80 technical questions to be assessed and for the upstream network a total of 80 gas procedures required expert review, resulting in 266 technical questions to be assessed.

The operational procedures assessment led to a determination as to whether the existing procedure is suitable for hydrogen blend operation, or if an amendment is required.

The assessment took into account the associated experimental and literature research carried out as part of the HyDeploy (Keele Trial) and HyDeploy$_2$ (Winlaton Trial) workstreams such as the assessment of gas characteristics, materials impact, appliance, survey of assets on the Winlaton network and impact of hydrogen blended gas on gas detection equipment. The conclusion of the assessment is that for upstream gas procedures most activity within operational procedures remains unchanged and some procedures which require a technical modification, namely the use of appropriate gas detectors, an increase to separation distances for DSEAR assessments and a 1.14 factor increase to the direct purge velocities. A subset of procedures were recommended for an increased frequency of operation such as leakage surveys and functional checks on the governor. These changes impacted just 12 procedural documents of the 80 that were reviewed and so all the changes were collected into a new procedures guidance document. The new guidance document formed the fundamental part of an appropriate training package and was disseminated accordingly to all relevant operatives that were responsible for the safety, operation and maintenance of the Winlaton network during the hydrogen blend injection period.

The downstream procedures review concluded no change to domestic procedures [and their related competencies] for all IGEM and BSI procedures that underpin Gas Safe natural gas competencies. There are over 100,000 gas safe registers engineers in the UK and they will not need retraining or upskilling to work on appliances receiving a hydrogen blended gas. This review was peer reviewed by IGEM, BSI and appliance manufacturers before being formally communicated to the Gas Safe community via a Technical Bulletin. The Gas Safe community was further engaged with via a dedicated webinar, where nearly 700 engineers attended to ask questions and engage with the project.

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5.0 Physical Installation

The Winlaton site was chosen as the site for the HyDeploy$_2$ trial as it was seen as the site that offered a high degree of variability with regards to materials on the network, size of network and statistical representation of housing. The Winlaton trial network is an estate of the wider Winlaton gas network situated in Blaydon near Gateshead. The Winlaton trial network was isolated from the wider gas network and a dedicated supply pipe was installed to feed the isolated network with blended gas from NGN's Low Thornley compound. The compound hosted the hydrogen storage and blending equipment.

5.1 Compound

To determine the compound area, analysis of NGN's network was carried out using the criteria set out in Table 1. NGN's InTEGRel site, also known as the Low Thornley gas depot near Gateshead, was identified as an optimum site to host the compound to allow for the trial network to be in the Winlaton geography. An aerial view of the compound is shown in Figure 10.

Winlaton Estate is in the North East near Gateshead in the constituency of Blaydon. The locations and proximities of the Low Thornley InTEGRel site and the trial network in Winlaton are shown in Figure 11.

Criteria	Basis of assessment
Ease of isolation from wider network.	Limited isolation points required to isolate trial network from other parts of the NG network.
Downstream of, or including Biomethane injection points in trial area.	Challenging to run test if in close proximity downstream from biomethane. Would not run with injection points within trial area.
Minimum scale of commercial buildings.	Must have between 500-1,000 dwellings and ideally some commercial buildings.
Statistically representative range of housing stock.	Dwellings should be representative of UK housing stock.
Mix of steel and plastic pipes.	Sites which contain only one type of iron material and which have only limited steel sections are preferred.
Suitable operating pressures.	Sites which can accommodate the pressure drop inherent in the H$_2$GEU are preferred.
Proximity to sensitive receptors.	Sites which require location of the electrolyser in close proximity to schools or hospitals (etc) are likely to be ruled out.
Presence of IGT's.	Less favourable if IGTs present in the area of the distribution of the blend.
Planning position requirements.	Lengthy and costly planning permission could cause significant risks to the project deliverability.
Location of other utilities.	The compound/electrolyser will require a supply of water and natural gas.

Figure 10: Aerial image of Low Thornley compound.

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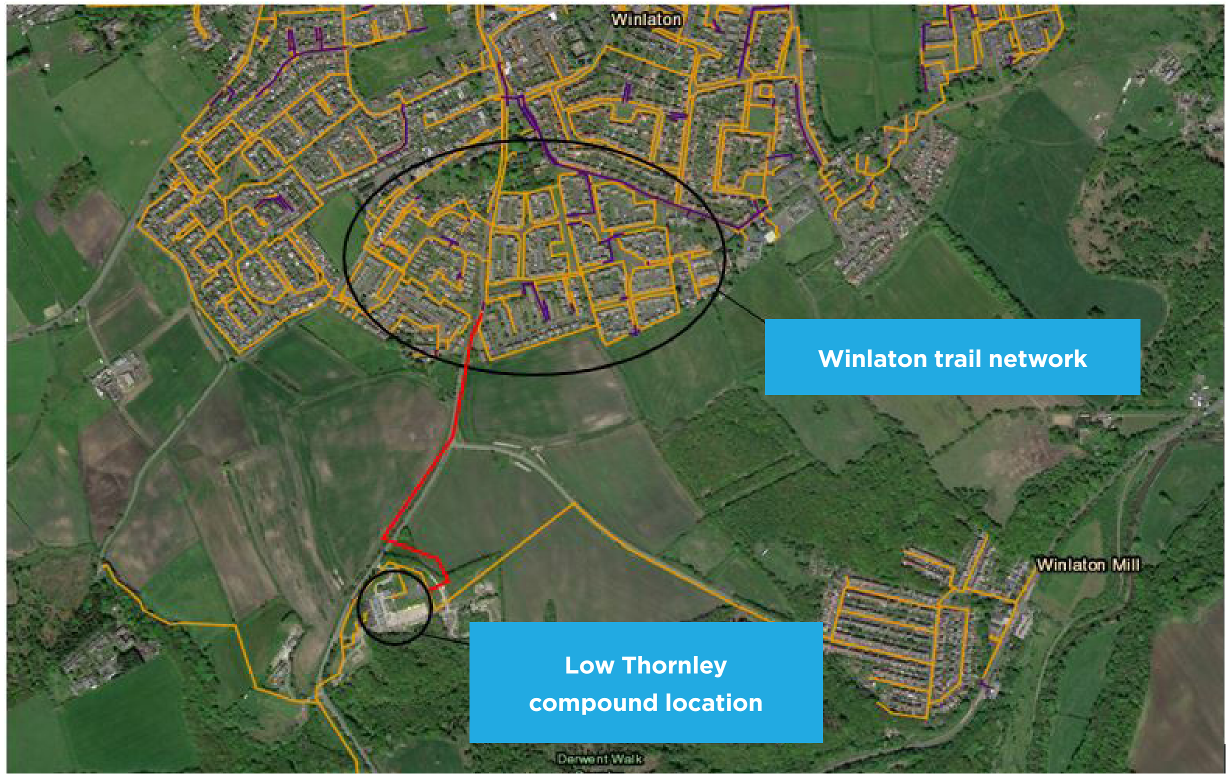

Figure 11: Image showing Low Thornley gas depot (location of compound hosting hydrogen supply and grid entry unit) and the Winlaton trial area. New medium pressure PE pipeline to supply the blended hydrogen is shown in red.

5.2 Hydrogen Supply

Hydrogen was taken from a bulk trailer storage facility housed at the InTEGReL site. The hydrogen supply system comprised of a road trailer unloading and static hydrogen storage facility (Figure 12), designed, constructed, and installed in accordance with industry standards. The purpose of the trial was to demonstrate the distribution and utilisation of hydrogen blends, other programmes are underway to develop bulk low-carbon production. Therefore, the hydrogen supply for the trial was via a supply contract. A mechanical connection and spacing allocation were made for supply at a later date by an electrolyser.

The project made a contribution to a local tree planting project to more than counterbalance the embedded emissions of the hydrogen supply for trial. When rolled out nationally, the hydrogen supply for blending will need to conform with the BEIS low carbon hydrogen standard.

Figure 12: Image of Low Thornley compound highlighting various assets.

5.3 Grid Entry Unit

In order to safely blend hydrogen into the network, a hydrogen grid entry unit (H_2GEU) was required to ensure reliable hydrogen blending at set levels. This was a bespoke unit based on the successful design and operation of the H_2GEU used in HyDeploy1 for the Keele trial. Thyson Technology Ltd was selected as equipment provider and undertook final design and fabrication based on a developed design and specification not too dissimilar to the Keele H_2GEU. The equipment completed fabrication and was initially Factory Assessment Tested (FAT) using inert gases at their facility. This was followed by a Site Assessment Test (SAT) at NGN's Low Thornley site, the H_2GEU can be seen situated in the Low Thornley compound in Figure 12. The unit performed well within the parameters.

The H_2GEU comprised of gas analytical instrumentation and controls to allow the stipulated blend level to be achieved whilst remaining within all other gas quality limits stipulated by GS(M)R and to any process limitations. The unit is specifically designed with gas sampling instrumentation to ensure that hydrogen blends above 20% cannot be blended into the network.

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6.0 Hydrogen Blend Trial

On August 4th 2021, Winlaton, Gateshead became the first community to receive hydrogen blended gas via the existing natural gas network. This was the first time in the UK's history that a publicly operated network transported hydrogen blended gas to customers to use within their existing natural gas appliances.

6.1 Blend Level Management

The hydrogen blend level philosophy determined the necessary steps required to gain confidence in increasing the hydrogen content of the blend and provided a framework to ensure operation within the requirements of the Exemption.

The hydrogen content of the blend was increased in a series of incremental steps up to the permitted level, unless the basis of the Exemption was no longer true regarding:

1. Safe operation of the hydrogen supply equipment and H_2GEU within tolerances of control proven in the FAT.
2. Safe operation of the network.
3. Safe operation of end appliances.

The pertinent data required to allow sufficient confidence to be gained regarding the operation of the hydrogen supply equipment and H_2GEU was developed through the Factory Acceptance Testing (FAT). Key conclusions of the FAT defined safe and reliable control e.g., blend level control tolerance, was used as the basis for review of the process equipment to feed into the internal sanctioning process of hydrogen blend levels.

The project sanctioned an increase in hydrogen level during the proving stage, up to the permitted maximum under the Exemption, subject to:

1. There were no unresolved gas incidents which were attributable to blending.
2. Survey and personal detectors for gas leaks continued to function reliably.
3. Confirming of sound operations by the Commissioning Team.
4. Satisfactory completion of all relevant operation undertakings such as functional checks and leakage surveys.

No inclusion of additional Rhinology or network compositional analysis was included as part of the sanctioning process. This is due to the compelling evidence collected as part of the Keele trial that; hydrogen blending does not distinguishably dilute odorant levels and once blended, the downstream network will always observe a uniform concentration of hydrogen blend.

During the trial, hydrogen injection was increased in accordance to the following reference blend levels:

1. Initial – 2 % mol/mol.
2. Intermediate 1 – 5 % mol/mol.
3. Intermediate 2 – 10 % mol/mol.
4. Final – Exemption limit (minus control tolerance).

This approach minimised the risk of operational issues resulting from transient operations and created the opportunity to profile operations across a range of blend levels. The outrun schedule for achieving the final blend level was a function of meeting the required criteria outlined above. The decision to increase blending level only took place once the criteria had been met and the governance process had been adhered to.

With the learning from the previous trial, the project were able to reach maximum blend rate within 6 weeks of operations at set-point of circa 19 % which fluctuated up to 20 %, but did not breach this stipulated set point, thereby not being in breach of the granted exemption which permitted a maximum of 20 % blended hydrogen to be injected. Maximum hydrogen injection was able to be operated for the majority of the trial duration with only a handful of days of downtime due to maintenance and management of hydrogen resources.

6.2 Network Performance

6.2.1 Gas Escapes

In total there were 24 reported escapes connected to the Winlaton trial network of which eight were false alarms concluding in 'no escape', therefore a total of 16 gas escapes were registered during the trial. In comparison, there were a total of 296 registered escapes between August 2006 and March 2021 at an average of 19 escapes per year. Therefore, it can be concluded that there was no increase in gas escapes during the trial period with hydrogen blended gas operations. This is a promising result given that there will have been an informed population (trial residents) with a heightened sense of detecting and reporting gas escapes appropriately, given that an information campaign was conducted prior to the trial commencement to inform all residents about the necessity and methodology of detecting (through smell) and reporting of gas escapes using the national gas emergency number. Furthermore, daily above ground leakage surveys were conducted for certain sections of the network (see Section 6.2.2.) which would have increased the number of reports, given that the surveys would have picked up permissible leaks (traces values) that would not be typically detected by the public.

6.2.2 Pipelines

Service pipes to properties on the network were made from either PE, steel or copper, and the mains pipes on the network consisted of a mixture of metallic and non-metallic pipelines, with the following split:

- **PE – 8,815 m**
- **Iron – 600 m**
- **Steel – 106 m**

Approximately 600 m of iron mains pipes, located in three different streets, operated with hydrogen blended gas for the 11 month trial at Winlaton. Historically (between 2006-2020), at these locations, there have been 50 public reported gas escapes in 14 years, i.e., 3-4 publicly reported escapes per year. Under normal (natural gas) operations, daily above ground leakage surveys of iron mains is not routine and hence the historic reports were based on public reporting.

For the Winlaton trial, there was a stipulation within the exemption granted by the HSE which required the iron mains to have a daily above ground leakage survey. As such, it was expected that significantly more traces of gas would be detected through these daily surveys compared with the usual method of a member of public detecting and reporting a gas escape. Given the elevated levels of above ground leakage surveys, there were only eight gas escapes associated with the iron mains, seven of which were detected by the daily leakage surveys.

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All eight escapes were dealt with successfully using BAU operations and continued to operate without issues for the remainder of the trial...

Of these eight reports, five were due to leaking joints from loose or corroded bolts (bolts are non-gas facing components and will not have been exposed to the blended hydrogen); one was a corroded stand pipe which was removed and plugged under business as usual (BAU) operations; one was a leaking plug which was renewed and one was a pipe fracture which was repaired with a 4 inch repair clamp under BAU operations. All eight escapes were dealt with successfully using BAU operations and continued to operate without issues for the remainder of the trial, an image of the repaired 4 inch cast iron main is given in Figure 13.

The network commenced blending hydrogen in August and the pipe fracture took place in October. It is not uncommon for iron mains to fail in the onset of winter when the diurnal variation of ground temperature beings to take place. It was the only fracture on the network across 600 m of iron main which operated on the blending gas for 11 months. The fracture took place on the longest section of iron main within the trial which was a 310 m section of 4 inch spun iron serving the full length of the street. Between 2007 and 2020 (13 years) there were 31 reported gas escapes on this street. Of the 31 reported escapes, 23 led to some form of excavation and repair work of the pipeline, and so on average, 1.5 excavations and repairs have been conducted annually on this section of spun iron. Hence, at least one incident leading to an excavation and repair of this 4 inch spun iron pipeline was expected during the trial. As such, it can be determined that the presence of hydrogen blended gas did not increase the failure frequency of the cast iron pipeline throughout the duration of the trial.

Figure 13: Image of 4" cast iron main with a successful repair clamp.

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6.2.3 Meters

No reports of faulty or leaking meters were reported during the Winlaton trial. This provides operational confidence of the integrity of the meters when exposed to hydrogen blends given that similar results were observed during the Keele Trial where there were no reports of gas meter leaks or failures.

6.2.4 District Governor

A new Fiorentini district governor was installed and operated on hydrogen blended gas. This governor was not specifically designed for hydrogen blend operation, it is an 'off the shelf' produce which has been designed for natural gas service but was re-purposed to operate on blended gas. As part of the exemption requirements, quarterly functionality checks were performed on the governor, as the governor contained materials which may be susceptible to hydrogen embrittlement under extreme operating conditions (high cycle fatigue/100 bar service pressure). It should be noted these conditions fall well outside the operating conditions of the governor. In any case, functionality checks were performed, which included a leakage survey every three months, all of which were successful and evidenced no leakage or irregular performance.

6.2.5 Rhinology

At Winlaton, the only rhinology that took place was a monthly check within the governor kiosk which resulted in satisfactory outcomes to reinforce that odour intensity was not diluted by the hydrogen blended gas. The confidence in this minimal regime came from the rhinology results from the Keele Trial. Rhinology testing at six sample points over the blended network was conducted at Keele, at each blend level through the Proving Trial and regularly in the Trial, to provide evidence of satisfactory odour intensity. All additional rhinology tests (conducted at Keele), across all six sample points, at each blend level, demonstrated no perceivable dilution of odour intensity due to the presence of a blend. Two rounds of sampling were undertaken at each blend level with a summary of the rhinology results given in Table 2.

Hydrogen Blend Level (mol%)	Round 1 Results	Round 2 Results
2	All 6 'Satisfactory'	All 6 'Satisfactory'
5	All 6 'Satisfactory'	All 6 'Satisfactory'
10	All 6 'Satisfactory'	All 6 'Satisfactory'
14	All 6 'Satisfactory'	All 6 'Satisfactory'

Table 2: Rhinology results for 6 sampling sites across the Keele trial network.

6.3 Appliance Performance

No additional appliance monitoring was undertaken during the Winlaton Trial as it was deemed unnecessary following the reassuring results achieved during the Keele Trial. A significant appliance monitoring programme was deployed for the Keele trial to provide robust evidence of appliance function throughout the Trial. This programme consisted of the following:

1. Undertaking annual Gas Safe checks and servicing on all appliances within university owned properties and buildings as well as offering free Gas Safe checks and servicing on all privately owned properties, which the vast majority of private householders accepted.
2. Regular combustion checks of specific commercial boilers across three university facilities at each blend level through the Proving Trial.
3. Regular combustion checks with two different flue gas analysers on eight domestic boilers within a dedicated facility at a commercial boiler house on the blended network, the checks were carried out at end blend level through the Proving Trial and within the Trial itself.

Across all of the appliance monitoring performed, the results indicated no increase in appliance failure or performance degradation due to the presence of a hydrogen blend. The failure rates of appliances undergoing the annual Gas Safe checks and servicing was found to be unaffected by the presence of hydrogen blend, and determined by the age and servicing history of the appliance. All combustion checks across each blend levels, for both domestic and commercial appliances, and for both flue gas analysers, were found to be satisfactory – providing strong operational evidence of the performance integrity of appliances operating with a hydrogen blend. Table 3 outlines the combustion results of the domestic gas boilers installed in commercial boiler house being supplied with the hydrogen blend at Keele.

As expected, no appliance failures were reported during the Winlaton Trial that were associated with the gas within the appliance.

Hydrogen Blend Level (mol%)	Boiler 1	Boiler 2	Boiler 3	Boiler 4
2	(CO/CO2)	(CO/CO2)	(CO/CO2)	(CO/CO2)
5	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)
10	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)
14	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)	<0.004 (Pass)

Table 3: Keele University Boiler House appliance test results.

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6.4 Billing

Unlike the field trial at Keele university, the Winlaton trial was carried out on a public gas network, and although the gas network was physically isolated from the surrounding natural gas network, all other aspects of network operation were unchanged. In particular, gas consumers continued to be supplied by different gas suppliers (which had the ability to change during the trial if a customer opted to change energy supplier for example).

Extensive engagement with Ofgem and Xoserve enabled a project-specific gas billing mechanism to be utilised for the trial. The principles of which were to assume gas qualities in the favour of the consumer throughout the trial and to ensure no consumer paid for the hydrogen received through the blend supplied. The system was implemented effectively throughout the trial and administered in accordance with the agreed structure with Ofgem. The process implemented for the trial was a pragmatic solution in favour of the residents, the long-term implications of the energy transition with respect to energy billing is being investigated by separate projects such as the Future Billing Methodology (FBM).

7.0 Customer Engagement

Consumers lie at the heart of the HyDeploy project. The basis of blending hydrogen into the gas network is that it unlocks material quantities of decarbonisation, provides a foundation for deeper carbon savings through hydrogen deployment and achieves these without disrupting consumers. To formally analyse the experience of residents taking part in the trial, and in order to understand how the customer felt throughout the different stages of involvement with the HyDeploy project, from initially hearing about the project through to the end of the blending trial, HyDeploy worked with a team of researchers, who carried out independent research into customer perceptions of hydrogen and their experiences of the HyDeploy project both before the trial commenced and at the end of the blending trial. This builds on similar research carried out linked to the first HyDeploy trial phase at Keele University between 2019 and 2021, where residents were interviewed before and towards the end of the trial.

The Winlaton trial data set comprised 130 survey responses and 11 interviews carried out pre-trial, and 50 survey responses and 9 interviews carried out at the end of the trial. The majority of surveys were carried out by a researcher on the doorstep of residents' houses, with some surveys completed independently online using a link in a letter, and others in hard copy using surveys left by the researcher and subsequently posted to the research team using a stamped addressed envelope. The interviews were carried out by telephone or online.

Survey responses from the pre-trial phase comprised 49% men, 50% women, and 1% non-binary. Survey responses at the end of the trial comprised 51% men, 49% women. The sample was skewed towards the older age group with 69% of pre-trial responses and 60% end-of-trial responses over the age of 60. 63% of pre-trial respondents and 66% of end-of-trial respondents were owner occupiers.

7.1 Findings

Overall residents were found to be positively engaged and receptive to the trial, with a high degree of local support. As would be expected with any project of this type there are a diversity of views, below is an outline of the broad findings from the research carried out.

7.1.1 Support for taking part in the Winlaton trial

66% of pre-trial survey respondents and 78% of end of trial survey respondents were pleased to be part of the HyDeploy project. The pre- and end-of-trial interviews and surveys included references to pride in being part of a trial, the need for projects like this to tackle greenhouse gas emissions, and the positive feelings of contributing to environmental action but without needing to do anything.

INTERVIEWER:
"How do you feel about Winlaton being chosen as the trial area for the UK for this project?

INTERVIEWEE:
"This might sound corny, but privileged."
(Pre-trial, WIN8)

"To be honest I thought, I'm so pleased that you're doing something to help the environment. That was the main thing."
(End-of-trial, WPT1)

"Just as long as it doesn't actually affect my bill in any shape or form [...] As long as that is not affected at all, I really don't [have] any issue whatsoever. I think it's a good experiment."
(Pre-trial, WIN7)

"It's an easy way to do your little bit without noticing any difference, basically"
(End-of-trial, WPT4)

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7.1.2 Concerns, reassurance and trust

Where concerns about being part of the project were given, these concerns included safety, possible effects on appliances, cost implications, lack of option about taking part and the effectiveness of hydrogen as a solution to climate change.The data suggests that residents were largely reassured of any concerns by the time the trial started, gaining reassurance from the information provided and opportunities to have queries answered by members of the project team. There were high levels of trust that the trial would be safe and it would not be occurring if there were safety risks.

"I think the fact that they've done safety checks, I think that reassures an awful lot of people ... Because it just shows that safety was the number one step before anything else happened." (Pre-trial, WIN1)

"I think it's fine. I've got no complaints at all. They've kept us informed. I've said, they've sent us letters and we went up to the club, saw the layout of the plans and everything." (Pre-trial, WIN11)

7.1.3 Positive experiences of the trial and a lack of disruption

At the end of the trial both the survey responses and interviews show that customers experienced no difference in their gas supplies.

"But everyone I've spoken to, it's made no difference to their usage of gas. It's nothing wrong at all with it. Everything's just the same" (End of trial, WPT1)

"I mean there's been absolutely no changes for us. Everything's been run smoothly. There's not been any issues or anything. So it's been fine, yes." (End-of-trial, WPT3)

"To be honest with you, I barely even know the project's taking place. There's been no disruption at all" (End-of-trial, WPT6)

7.1.4 Desire to continue with blended hydrogen

At the end of the trial 70% of survey respondents would have liked to have continued to have received blended hydrogen, while 22% had no feelings about the end of the trial, and 9% were happy no longer be receiving blended hydrogen.

"I think it's sad that it is coming to an end because if you've got something that works why aren't you just continuing it?" (End-of-trial, WPT1)

"Well, I'm saddened, because I would like to continue with hydrogen" (End-of-trial, WPT2)

7.1.5 Support for hydrogen

There was broad support for the general role of hydrogen in the UK energy supply, with this support increasing by the end-of-trial. 51% of pre-trial survey respondents were supportive of hydrogen being increasingly used in the energy supply, this number was increased to 78% of survey respondents at the end-of-trial. While 22% responded that they 'did not know' before the trial started, only 2% gave this response at the end-of-trial.

7.1.6 A pathway to social acceptance of 100% hydrogen

At the end of the trial, respondents were asked about whether they would be willing to have 100% hydrogen in their home, after being informed that this would involve some level of disruption. 46% of survey respondents said yes, 30% said maybe or that they were unsure, and 12% said no. Where respondents gave a positive response, this was due to this being seen as a positive step to address climate change, although most answers were caveated often with the need for further reassurance about the effectiveness of hydrogen as a solution, that it was safe and that the cost was not borne by the householder. Several residents stated that their positive views of 100% hydrogen had been influenced by taking part in the HyDeploy blending trial, suggesting that blended hydrogen may have a role towards acceptance of higher percentage use of hydrogen in the home.

7.1.7 Positive indirect consequence of the trial

There were positive indirect consequences of the HyDeploy communications, with some individuals saying that they had become more aware of the environmental impacts of home gas use, with some customers even saying that this had led to reduced energy use.

"It's just made me more self-aware of the environment and of the impact it has for the long term" (End-of-trial, WPT2)

7.1.8 Implications to future rollout of hydrogen blending

The results of this research mirror the findings from the Keele University trial despite the very different demographic of the customers involved. As the only UK blending trial, this research has provided a unique insight into how the public might react to a wider rollout of blended hydrogen in the home. The results suggest that the public can be broadly supportive of hydrogen in the home because of the perceived positive environmental implications, albeit not at the expense of the householder. Although some initial concerns around safety in particular are likely, customers can be reassured, but this does require careful planning of communications and ensuring access for customers to have queries addressed on an individual basis. Blending hydrogen, may pave a way to social acceptance of the use of 100% hydrogen, although there is need for more reassurance around safety, the genuine, full life-cycle environmental savings, and a requirement for costs not to be borne by households.

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8.0 Looking Forwards

The HyDeploy consumer trials have successfully demonstrated that hydrogen blends can be used practically and safely to decarbonise homes. Hydrogen blended gas was provided to 820 buildings (both residential and commercial) across two separate trials, with no disruption to the consumer or their appliances. The final phase of the project is focused on completing the evidence base necessary to enable the use of hydrogen blends across the gas distribution network. This principally relates to the use of hydrogen blends within industrial and commercial settings, as well as the distribution of hydrogen blends in higher pressure pipework:

i. The industrial and commercial analysis consists of a series of technical and regulatory assessments, including industrial trials across a number of end user settings (glass, ceramics, consumer goods and baked products). The ultimate output of this programme will be a comprehensive impact assessment of the UK's industrial baseline with respect to the introduction of a hydrogen blend. The results of which will be incorporated into the final risk assessment of the project.

ii. The materials and assets programme will utilise well-established experimental and analytical techniques, utilised previously in the project, to assess the performance impacts of assets that exist within the intermediate and high pressure tiers of the gas distribution network. This will involve further experimental analysis, supported by desk top analysis, and leveraging results from other projects undertaking similar activities.

The completion of these workstreams will enable an evidence base to be developed to unlock the use of hydrogen blends throughout the gas distribution network, where the ultimate output will be a holistic risk assessment representative of the GB gas distribution network and all associated end users.

The full evidence base of the HyDeploy project, inclusive of the two consumer trials, industrial trials and non-trial evidence will be developed into an evidence pack for the HSE and BEIS. The structure of the evidence has been informed by the HSE's assessment of the safety determinations necessary to enable BEIS to undertake a policy decision on 100% hydrogen. The intend of this evidence pack is to provide the enabling evidence to amend the hydrogen limit within Schedule 3 of GS(M)R from 0.1 mol% to 20 mol% for the gas distribution network.

The safety assurance process outlined above will feed into the overall BEIS process of enabling hydrogen blending, as outlined in the 10 Point Plan and UK Hydrogen Strategy. This process is contingent upon a positive economic assessment, where blending represents good value-for-money, as well as safety assurance. BEIS have committed to making the hydrogen blending policy decision by the end of 2023 and are currently on track to deliver the economic case for blending by mid-2023. Following this decision, it is expected that a regulatory process will follow to make any amendments to GS(M)R. Assuming a positive policy decision, It is likely that blending outside a bespoke exemption regime will be possible from the mid-2020s.

2023

Work with industry to complete testing necessary to allow up to 20% blending of hydrogen into the gas distribution grid for all homes on the gas grid.

Figure 14: Hydrogen blending within the Ten Point Plan.

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9.0 Conclusions

- HyDeploy has demonstrated lower carbon heat can be delivered safely through blended hydrogen networks.
- Robust evidence has shown that blended hydrogen is safe and effective in a domestic setting.
- Established that blended gas is safer than natural gas, through reduction of carbon monoxide when operating appliances with blended gas.
- Customers in 668 properties successfully received hydrogen blended gas for 11 months and safely operated their existing natural gas appliances throughout the period of the trial.
- Pipe and component materials performed well, there was no increase in component failure frequency when compared with historical natural gas operations on this network.
- Operational issues were dealt with by NGN using, mostly, business as usual operations and in some cases appropriately amended hydrogen blend procedures (i.e., new gas detectors)
- Gas Safe domestic procedures remain unchanged for hydrogen blended networks – which means that registered Gas Safe engineers (circa. 120,000 in the UK) do not require new training to deliver the services that they currently provide.

The project team

HyDeploy2 is being delivered by the HyDeploy consortium, which has technical expertise and practical experience. The partners are:

Cadent Gas (formerly National Grid Gas Distribution) is leading HyDeploy2. They own and operate four of the eight gas distribution networks in the UK, including the West Midlands.

Northern Gas Networks is partnered with Cadent to deliver HyDeploy2. They own and operate the gas distribution network in the North East, Northern Cumbria and much of Yorkshire.

Keele University is providing learning from the first HyDeploy trial and providing continuity of consortia through the HyDeploy2 trials.

HSE Bespoke Research and Consultancy is the consulting arm of the Health & Safety Executive. They will be providing the scientific evidence which will support the safety case for the public trials.

ITM Power manufacture integrated hydrogen energy solutions.

Progressive Energy is an independent UK clean energy company. It will be supporting the management of HyDeploy2 through development and implementation.

In addition to the core project partners the project is supported by a number of key companies:

Kiwa specialise in gas testing. It is carrying out offsite testing on a range of common household appliances to inform the project, and will lead the gas safety appliance checks on the campus.

Dave Lander is an internationally recognised expert in gas quality and safety and co-ordinated the Exemption application to the HSE.

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