SAFETY AND REGULATORY CHALLENGES OF USING HYDROGEN / NATURAL GAS BLENDS IN THE UK

Jeffrey, K.E.[1], Spriggs, C.[2], McEwen, S.[3], Hooker, P.[4] and Manson-Whitton, C.[5]
[1] Science Division, Health and Safety Executive, Harpur Hill, Buxton, SK17 9JN, UK, kate.jeffrey@hse.gov.uk
[2] Science Division, Health and Safety Executive, Harpur Hill, Buxton, SK17 9JN, UK, catherine.spriggs@hse.gov.uk
[3] Energy Division, Health and Safety Executive, Redgrave Court, Bootle, L20 7HS, UK, stewart.mcewen@hse.gov.uk
[4] Science Division, Health and Safety Executive, Harpur Hill, Buxton, SK17 9JN, UK philip.hooker@hse.gov.uk
[5] Progressive Energy, Swan House, Bonds Mill, Bristol Rd, Stonehouse, GL10 3RF, chris.mw@progressive-energy.com

Abstract

The addition of hydrogen to natural gas for heating and cooking is being considered as a route to reducing carbon emissions in the United Kingdom (UK). The HyDeploy programme (hereafter referred to as HyDeploy) aims to demonstrate that hydrogen can be added to the natural gas supply without compromising public safety or appliance performance [1]. This paper relates to the preparatory work for hydrogen injection on a live site at Keele University closed network comprising domestic premises, multi-occupancy buildings and light commercial premises. The project is based around the injection of up to 20 %mol/mol hydrogen into mains natural gas at pressures below 2 barg. Work streams addressed during the pre-trial preparation included; assessment of material interaction with hydrogen blends for all distribution system components and appliances; understanding of gas appliance behaviour; review of: gas detection systems, fire and explosion considerations, routine and emergency procedural considerations; and the design of a new hydrogen injection grid entry unit. This paper describes the safety and regulatory challenges that were encountered during preparation of the project, including obtaining the necessary regulatory permissions to blend hydrogen gas.

INTRODUCTION: HYDEPLOY SUMMARY

The addition of hydrogen (Hydrogen) to natural gas for heating is being considered as a route to reducing carbon emissions in the UK [2]. HyDeploy aims to demonstrate in a live on-network trial that hydrogen can be introduced to the UK natural gas supply without adversely affecting safety or performance at up to a maximum injection level of 20 %mol/mol Hydrogen The three phases of HyDeploy at Keele University are:

> Phase 1: Identification of possible modifications required to Great Britain (GB) regulatory controls to allow a hydrogen injection trial at up to 20 %mol/mol hydrogen. The trial provided laboratory and field based scientific data to support a quantitative risk assessment (QRA) that demonstrated no deterioration in public safety or appliance function during the planned on-network trials at Keele University.
>
> Phase 2: Installation and commissioning of a new hydrogen production, mixing and injection into the network in preparation for the trial.
>
> Phase 3: Hydrogen injection into an isolated / closely controlled gas network to assess the effect of hydrogen injection. Continued scientific study to fill any knowledge gaps or issues identified during the trial.

Following on from HyDeploy at Keele University a further programme of open network demonstrations are planned as part of HyDeploy 2 [3] to produce evidence for blending hydrogen into natural gas across the UK.

HyDeploy is being delivered through a consortium of Cadent, Northern Gas Networks, HSE's Research and Science Centre (previously HSL), ITM Power, Progressive Energy and Keele University.

UK GOVERNMENT CARBON REDUCTION POLICY

The need for a reduced carbon gas feed such as proposed within HyDeploy is driven by the global context of climate change and the UK commitment to reduce emissions of gases contributing to global warming by 80% from pre-industrial levels by 2050[4]. Concerns relating to the production of carbon dioxide and its proven effect on climate change have led to international efforts to reduce carbon dioxide emissions into the atmosphere. These 'decarbonisation' efforts are also further supported at local levels due to the potential to improve air quality in polluted areas such as large cities. One of the main contributors to carbon dioxide emissions is the burning of fossil fuels in domestic and commercial appliances and equipment, especially that of burning natural gas comprised primarily of methane.

The Clean Growth Strategy (CGS) sets out the agenda for the UK to meet its 2050 emissions targets stating '*Clean fuels such as hydrogen and bioenergy could be used for transport, industry, and to heat our homes and businesses. We need to test how they work in the existing gas network, whether they can fire industrial processes, and how they could be used in domestic appliances*' [5]. As highlighted in this statement, the need to test how the clean fuels can be used with the existing infrastructure is the key to unlocking their potential. With environmental and political drivers moving the case for hydrogen forward, it is important that feasibility and demonstration projects like HyDeploy generate the evidence for the safety, practicality and technology to inform decisions about how to realise the full potential of hydrogen solutions for carbon dioxide emission reduction.

PURSUIT OF AN EXEMPTION TO GSMR FOR A TRIAL: GB GAS QUALITY REGULATION

Gas composition and quality for use on the GBnetwork is defined within the Gas Safety (Management) Regulations 1996 (GSMR) [6]. The regulation governs the conveyance of natural gas (predominantly methane) through pipes in the GB to domestic and other consumers covering four main areas:

1. The safe management of gas flow through a gas network, particularly those parts supplying domestic consumers, with a duty to minimise the risk of a gas supply emergency.

2. Arrangements for dealing with supply emergencies.

3. Arrangements for dealing with reported gas escapes and gas incidents.

4. Specification of the safe composition of gas.

Schedule 3 of GSMR specifies the safe composition of gas that can be used within GB gas networks. The present GSMR limit for hydrogen content of natural gas to be transported in GB is 0.1%mol/mol hydrogen. The objective of HyDeploy is to demonstrate the addition of up to 20 % mol/mol hydrogen, and therefore HyDeploy needed to obtain an exemption against GSMR to extend the acceptable hydrogen concentration above 0.1 %mol/mol.

Schedule 3 of GSMR also defines the Wobbe Number range of the supplied gas (Wobbe Number is a measure of the calorific volume flow) and is a key parameter in the interchangeability of fuel gases, such as natural gas. Wobbe Number is used to design and specify the operating performance of gas appliances. To minimise disruption to users, and to prevent the need to modify gas appliances, HyDeploy would not seek to operate outside the existing WN range specified in GSMR.

Process to Achieve an Exemption to GSMR

GSMR is a permissioning regime and requires gas conveyors to prepare a safety case containing specific information required for any gas feed (defined within Schedule 1 of the regulations) and then have it formally accepted by the GB safety regulator (the Health and Safety Executive (HSE)) before any gas can be conveyed.

In order to receive such an exemption, the conveyor must first justify the need for the exemption and then make a formal submission to HSE based on the best available evidence demonstrating that no additional risks to health and safety are created as a result: this is the route for pursuit of the exemption followed by the HyDeploy consortium.

PIPELINE SAFETY REGULATIONS 1996 (PSR)

While GSMR deals with the management of the gas flow through the GB mains network, the Pipelines Safety Regulations, 1996 (PSR) [7] are concerned with pipeline integrity. The PSR aims to secure safety in the design, construction, installation, operation, maintenance and decommissioning of pipelines. PSR imposes general duties in relation to all relevant pipelines and additional duties regarding major accident hazard pipelines. For the gas transportation and distribution network, major accident hazard pipelines are defined as those operating at pressures in excess of 7 barg. No exemption to PSR is required to progress the project and the network chosen for HyDeploy at Keele operates below 2 barg meaning that it is under the operating pressures considered for major accident hazard pipelines.

WHY THE EXEMPTION WAS AN APPROPRIATE TOOL TO ENABLE THE TRIAL

Exemption was requested from HSE by the consortium against the obligation set out in Regulation 8 of GSMR specifically i.e. "*to convey only natural gas that is compliant with the interchangeability requirements of Part I of Schedule 3 of the GSMR"* with the exemption specifying the 20% mol/mol hydrogen injection level and scoping the exemption solely to the region of the identified, isolated gas network.

HSE is an enabling regulator that seeks to support innovation by industry while maintaining health and safety standards for employees and the public. Working under an exemption is an example of how these two elements can be effectively balanced and implemented. While the consortium is in the knowledge gathering, feasibility and trial demonstration stage (or assessing how hydrogen can be utilised at scale within an existing infrastructure) an HSE provided exemption does not require permanent changes to a regulation (e.g. GSMR) to be made. If wide-scale adoption of hydrogen were to be deemed safe and suitable, outputs from projects such as HyDeploy help inform strategic decisions about the use of hydrogen and how regulation change may be required. This link between HSE and emerging research R&D objectives whilst informing regulators of all technical considerations to include in future regulation.

Exemption scope

Early in the project the scope of topics that needed to be covered in the application for an exemption were identified and agreed with HSE (this exemption scope is presented in Figure 1). The schematic identifies all areas that could be impacted by increasing the level of hydrogen within natural gas within the live field trial and the supporting evidence of change / no-change that would be required. The themes identified in the scope consider interdependence of factors such as trial management and procedural review plus the technical work streams. As part of the exemption the consortium produced 42 individual documents with ~ 1400 pages of documentation being submitted for the exemption application.

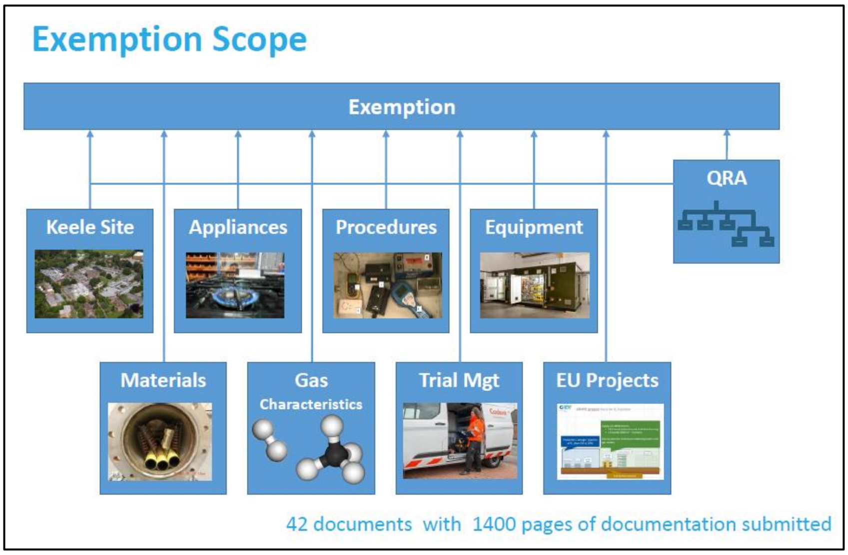

Figure 1. HyDeploy Scope of Evidence for Exemption Application

As part of the exemption the project referred to other EU blending projects to add weight to the overall evidence base.

METHODOLOGY USED FOR THE EXEMPTION APPLICATION: QUANTITATIVE RISK ASSESSMENT (QRA)

A Quantitative Risk Assessment (QRA) approach was used to support the field trial exemption application. The QRA developed for the project aimed to demonstrate that the field trial would not result in a material increase in risk to persons being serviced by the Keele network [8]. In order to draw a comparison of the risk of the live field trial three scenarios were assessed and quantified within the QRA:

- Scenario 1 – the present situation for natural gas within GB as a whole. This permits model validation by comparison with national statistics of, for example, carbon monoxide incidents including fatalities, and fire and explosion accidents.

- Scenario 2 – the situation for the Keele university G3 network prior to the field trial, i.e. with natural gas conveyed to consumers.

- Scenario 3 – the future situation for the Keele university G3 network during the field trial, i.e. with natural gas-hydrogen blends conveyed to consumers.

By comparison of the overall risk achieved by changing to blended natural gas: hydrogen gas against that under the present conditions prior to the field trial an assessment of any change in risk the effectiveness of any mitigation measures could be demonstrated. This method enabled effective comparison of the relative hazards and risk associated with the conveyance and use of blended natural gas: hydrogen gas within the difference scenarios.

Selection of Site for the Live Field Trial – Keele University G3 Network

The HyDeploy live trial was planned to be on an isolated and closely controlled network and the Keele University site controlled by the G3 governor was selected. The site already operates under a Smart Energy Network Demonstrator (SEND) programme and is particularly suitable for the project as it is a self-contained network owned and operated by the University. The site also provided a diverse set of property types including university premises, student accommodation and over 100 residential houses.

The diversity of properties, appliances and installation types plus their condition and age made the trial representative of the wider GB network.

New equipment

Hydrogen for the HyDeploy trial will be produced by electrolysis. The hydrogen is blended into the gas network using a Grid Entry Unit (GEU). This was developed specifically for the project and supplied by one of the UK biomethane GEU manufacturers. The functional design specification was developed to deliver and maintain the hydrogen blend in a safe and controlled way onto the network over the range of flow conditions used on the Keele University site.

Customer engagement

Extensive customer engagement led by Keele University with a dedicated customer engagement liaison officer was undertaken to encourage customer engagement. A detailed trial awareness campaign for the project explaining its aims and the impact for participating customers was run in Phase 1, engaging with all customers on the Keele network. The campaign successfully enabled access to over 95% of the properties on site to undertake full gas safe checks and testing of appliances with blended gas in the field using a bottle-based gas mixing system.

Hazard Identification

A hazard identification process reviewed the main areas where an increased amount of hydrogen in natural gas might have an impact on safety or client experience. The following list provides the output from the hazard identification:

- Hazard associated with fires;
- Hazards associated with explosions;
- Hazards associated with incomplete combustion;
- Hazards associated with toxicity / asphyxia;
- Hazards associated with impacts of hydrogen on asset materials, appliances and installations; and
- Hazards associated with new technology.

This analysis was shared with HSE and any credible hazards were subject to detailed analysis, scientific research and quantification using methods such as fault tree analysis.

Credible Hazards Evaluation

Fire and Explosion

The hazard study for fire and explosion undertook statistical comparisons of GB natural gas data to compare the fire hazard associated with natural gas fueled gas appliances to electrical appliances to act as a hazard baseline. The statistics indicated that the greatest cause of fires was due to cooking appliances. From the statistics relating to cooking appliances, it was also indicated that a higher percentage of cooking appliance fires were linked to electrical appliances rather than natural gas. These statistics provided a hazard baseline for appliance fires within GB.

Hydrogen burns markedly differently to natural gas both in flame speed and energy output resulting in different combustion properties: the impact this might have on appliances was assessed. Overall, the evaluation suggested that the presence of hydrogen in a blended gas showed that the potential for fires associated with open flames encountering flammable materials would be no worse than that with natural gas.

A similar evaluation was undertaken regarding explosion risk based on leak rates from the present Keele network into the open air (e.g. via losses at joints, flanges or via other gas-loss permeation routes). The evaluation concluded that leak rates on the Keele site would not be sufficiently large to cause a viable flammable atmosphere to form in open spaces and so could be removed from the study. However, the fire and explosion hazard based on assessment of accumulation of flammable gas mixtures in confined spaces did indicate that this would require further study but could be managed during the trial through increased rates of onsite leak testing and gas detection.

The hazards associated with catastrophic failure of pipelines (such as might occur in any natural gas transmission systems due to corrosion, wear or accidental perforation) was also considered to not be a credible increased hazard due to the similarity of the pipeline failure modes for both blended gas and natural gas plus the low line pressures at which the Keele network operates (i.e. 2 barg maximum).

Incomplete Combustion

A further statistical evaluation of incomplete combustion for the Keele network was undertaken and found to be lower than the wider GB statistics: this was proposed to be due to there being a lower proportion of domestic appliances within the properties for the trial combined with the historically high rate of servicing of the appliances within the properties. Although this indicated that incomplete combustion did not present an additional hazard, it was proposed that it was still a factor that had to be considered when interpreting probability of fatalities, assessing the population at risk and converting probabilities of fatality to frequencies.

New Equipment

In addition to the NG: hydrogen gas mixture being conveyed in the Keele network, the Phase 3 field trial itself would require operation of new equipment for hydrogen production, hydrogen/natural gas mixing and network injection. Similarly, to commissioning of any new process plant, a small but finite risk would be expected to be associated with its operation (e.g. leaks and consequences of hydrogen or hydrogen-NG or loss of control of the management and flow of high-pressure gases etc.). The assessment of this risk was deemed to have been mitigated through design and construction in accordance with appropriate industry build standards.

TECHNICAL REVIEW PROGRAMME

Overview of Technical Programme

The objective of the technical programme was to use laboratory-based testing, literature and procedural review, and onsite bottle-based, mixed gas trials to generate the evidence base to feed into the QRA and Trials Management activities. The technical programme was fundamental to the demonstration that the use of blended gas within the Keele network would not prejudice health and safety. To make this demonstration, scientific work focused on two main areas:

- Scientific analysis and testing to justify data for the Quantitative Risk Assessment (QRA) aimed at demonstrating the safety of gas distribution at Keele relative to GB.
- Scientific evidence to underpin procedural assessment to demonstrate the continued suitability or amendment of existing gas industry procedures including emergency procedures.

The high-level technical programme is outlined in the schematic within Figure 3. Each section in the figure was proposed to provide more detail on a few of the work strands to provide examples of the types of activities and outline results are detailed below.

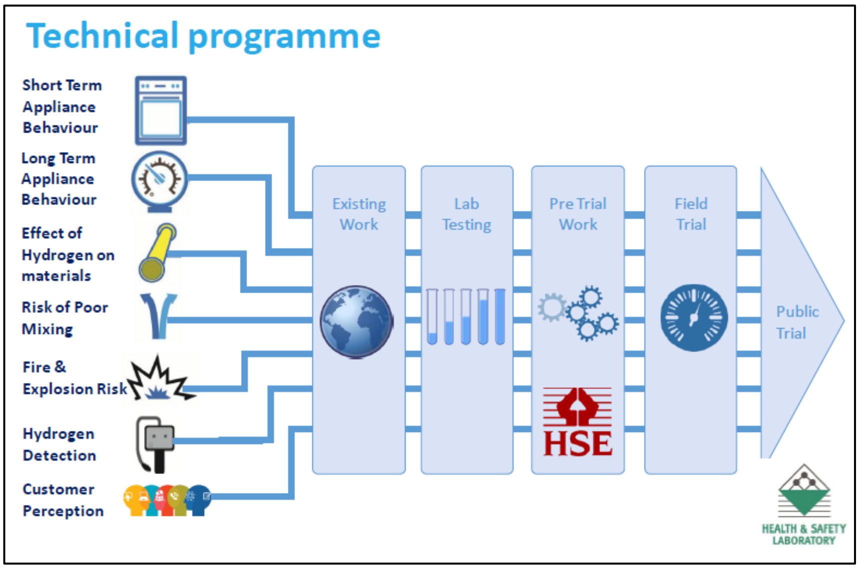

Figure 3. Overview of the Technical Programme for Phase 1 of HyDeploy

PRELIMINARY LITERATURE REVIEW: THEORETICAL PRINCIPLES / HYDROGEN CHARACTERISTICS

A preliminary literature review of the fundamental properties of hydrogen and hydrogen: natural gas blends were undertaken. In summary the review identified the following areas for further investigation in relation to the impact of blend gas on:

- Likelihood of flammable atmosphere forming in light of changes to the volumetric release rate on hydrogen and its flammable range.
- Ignition risk due to a slightly lower ignition energy and wider flammable range.
- The probability of harm to the public by any explosion in relation to changes in overpressure caused by the increase in place speed.
- The volumetric energy density of the blended gas being lower than natural gas.
- Carbon monoxide and carbon dioxide production within combustion products (e.g. within flue gases).
- Potential for hydrogen embrittlement of materials.
- Sensors used for gas detection.

In response to this assessment a full scientific programme was developed which included:

- Appliance behaviour testing: short-term, long-term and on-site testing;
- Effect of hydrogen on materials;
- Risk of poor mixing;
- Fire and explosion risk;
- Hydrogen detection techniques; and

- Customer perception.

Examples of the techniques employed during the technical programme and the results of the work are provided in the sections below.

Short Term Appliance Performance Testing

The appliance testing programme conducted extensive assessment of the short-term behaviour of appliances operating on natural gas enriched with hydrogen in a laboratory environment. Appliances such as gas hobs, gas fueled fires and boilers were tested with a range of test gases ranging from low percentages of hydrogen up to 80-90% hydrogen blends. The rationale for testing appliances at higher levels of hydrogen blends than is planned in the Phase 2 trial was to understand the upper limit of appliances performance with hydrogen blends. The appliance performance was evaluated across attributes such as: composition of combustion gases; light back; flame temperatures; appearance; operation of safety devices; efficiency; noise; sooting; delayed ignition; and ionization current.

The limit testing work demonstrated that the 20% mol/mol hydrogen: natural gas blend was well within the operating limits of the appliances tested. This work provided confidence that during the trial there will be no additional hazards or increased risks associated with the use of hydrogen blend gas with domestic and commercial appliances within the 20% mol/mol hydrogen blend limit.

Long Term Appliance Performance Testing

The short-term appliance testing provided confidence that appliances could be used safely during the one-year live field trial on the 20 v% mol/mol hydrogen: natural gas blend. To extend the data set beyond the one-year trial period, a study of longer-term effects from using hydrogen enriched fuel in appliances that could become evident after the trial concluded. The two areas of consideration were:

- The chemical degradation of components as a result of exposure to hydrogen.

- The thermal degradation resulting from exposure to temperatures above the design specification of the materials.

In order to understand these, an assessment exercise was undertaken to determine which components may be affected by long-term exposure and use with a blended gas: this was conducted in consultation with the UK gas appliance industry to ensure widest possible assessment. The trial at Keele is supported by the UK bolier manufacturers. A collaborative decision was made to initiate long-term testing of appliances during the live field trial at Keele to gather evidence that could predict any long-term effects. An appliance test facility was set-up at Keele to measure changes in flue gas composition, component wear / degradation and thermal output / transfer efficiency. Once completed, test data relating to this work will be detailed in future submissions to ICHS where possible.

Onsite Appliance Testing and Assessment

The rationale for the onsite appliance assessment was to understand the age and condition of all appliances within the properties that would be included in the live trial. An additional aim to the onsite appliance assessment was to bring each poorly maintained or damaged appliance found on-site to suitable Gas-Safe condition by replacement or qualified maintenance. In combination, this would reliably improve the level of safe operation for all appliances under assessment within the trial. This improvement programme positively impacts the QRA specifically for the assessment of incomplete combustion hazards due to improved appliance operation and the fire and explosion hazards due to limiting the likelihood of leaking appliances.

Effect of Hydrogen on Materials Performance Within Gas Network

The material composition of all assets in the test area on the Keele network was recorded during a site asset survey resulting in 1087 items being identified. This survey found that there were three main types of pipework materials used on the Keele network; steel, copper and polyethylene (PE80). The effect of hydrogen enriched natural gas on each of these materials plus materials found in components (e.g. cast iron) and other materials found downstream of the meter (e.g. solder) in terms of longevity and function was assessed due to its importance for the safe operation during the trial. The assessments included literature review combined with specific tests. The mechanism for material degradation was established during this assessment, with this understanding an evaluation of the operating conditions for the trial was made and established that it would be unlikely that the trial conditions would give rise to the materials degrading via this mechanism. There was no data to support this evaluation, so a series of small-scale tensile tests were performed over a six-week period. The overall assessment indicated that all test materials assessed demonstrated safe use for the planned one-year trial.

Effect of Hydrogen on Repair Materials on Gas Network

Work to identify pipeline repair techniques present on the Keele site (or likely to be used) during the duration of the trial was undertaken. Each repair methodology was reviewed, and agreement was reached as to whether operational changes would be required for any of the techniques. The study concluded that the procedural aspects of the repair processes did not require change but additional control mechanisms such as additional studies into gas detector function might be required.

Ignition Energy / Ignitable Concentration

This work explored methods to determine the range of viable ignition sources (e.g. naked flames, electrical switches etc.) and gas concentration combinations where ignition could occur. Understanding the environments where ignition would occur enabled a comparison with natural gas and an evaluation of whether the risk had, increased, decreased or stayed the same. A model for predicting ignition probability from gas composition based on the model by Mathurkar [9] was developed. The work established that for lean mixtures the difference between the ignition behaviour of natural gas and the hydrogen blend was small.

Analytical Review

Various gas-dispersion models and simulation were undertaken to assess the behaviour of a hydrogen blended gas under different conditions. Scenarios studied included:

- Volumetric release rate through small and large pipe perforations;
- Dispersion distance to LFL;
- Gas stratification distribution and accumulation;
- Ignition;
- Jet fire; and
- Over pressure from vented explosion.

Each of the scenarios shown above were used to inform a review of all standard gas procedures used on the Keele network plus to provide supporting data for the overall QRA.

Procedural Review

A procedural review was undertaken for all of the activities relating to the network at Keele. The procedural assessment considered the following specific areas to determine whether modification to the procedures for local control on the Keel network would be required during the trials:

- Search areas and exclusion zones may need to be modified for blended gas mixtures due to changes in dispersion distances.
- Whether gas detection alarm and action levels required modification due to the change in LFL.
- Whether or not purge procedures needed to be modified due to the wider flammability limits of blended gas mixtures.
- Whether tightness testing procedures, maximum permitted leakage rates and tightness test durations need to be modified.
- Whether area classification and location of equipment in DSEAR assessments would need change.

The review found that the majority of the procedures did not need to change for the trial but those areas where procedures did require change fell into three categories:

- Where additional inspection would occur during the trial e.g. leakage tests.
- Where trial design mitigated the need to look at specific procedures e.g. building proximity distances.
- Procedures that would need to need to change due to specific scientific issues e.g. gas detection due to cross sensitivity of carbon monoxide detectors to hydrogen gas.

The procedural review fed into the trials management work package highlighting where procedural changes or additional monitoring will be needed and how these would be managed.

QRA: SUMMARY OF PRELIMINARY ASSESSMENT

The output from the QRA was that the current risk at Keele with natural gas is one-third of that for the wider GB due to there being fewer appliances per household and a higher appliance servicing frequency being applied. For the HyDeploy blended gas trial at Keele the QRA concluded that risk from carbon monoxide reduced due to increased surveillance of appliances and the fire and explosion risk remained comparable. The overall risk during the field trial is expected to be low and decrease slightly as appliance population mitigation and internal leak mitigation measures where employed.

LESSONS LEARNED – PROVIDED BY PROGRESSIVE ENERGY

Progressive energy is the lead project management contractor for HyDeploy and have provided the following information about lessons learned from following the above exemption process.

Overview: A strong regulatory framework is not an impediment when planning a first-of-a-kind live gas trial. Extensive and constructive engagement with the regulator (HSE) throughout Phase 1 and the exemption process enabled useful discussion and positive progress resulting in the exemption being granted swiftly within around 4 months. The exemption application underwent detailed challenge and review with over 140 clarification questions submitted. Strong and probing questions enabled due consideration of the evidence base.

Exemption Process - Overall project lessons and attributes: The level of evidence required by the regulator to evidence the safety case should not be underestimated. Foundational evidence has been developed for HyDeploy, and for future, wider hydrogen adoption. The project is held in high regard by stakeholders in the GB and internationally and has added to the knowledge base for blended gases.

Technical: The technical programme and the technical insights it brought fed into the management of the complexity of the project. A wide range of different work threads were undertaken both simultaneously and iteratively to focus much of the work to provide robust evidence for 'no change'. To prove a "no change" position was found to be more arduous than justifying a specified change.

Procedure: All applicable procedures were comprehensively reviewed and assessed for the Exemption finding that the changes necessary to procedures were relatively limited. Demonstrating that existing procedures are safe and suitable is a considerable task - even if the final outcome does not appear significantly different. Operational deliverability & training is key. The use of a collaborative forum of operational knowledge combined with analytical science is invaluable.

QRA: The detailed 200 plus gate and event QRA is central to the exemption application. Historical gas industry data is not always as detailed as would be ideal. The most challenging task was translating core scientific findings into quantitative data for QRA. As planned for the Keele trial, conservative positions on inputs were taken, especially where evidence was currently more limited. For the HyDeploy 2 studies, the evidence base will need to be extended to allow risk assessments to be more precisely drawn.

Customer Engagement (Public / commercial gas users for the trials): Learning from best practice, the project achieved excellent customer engagement. A dedicated customer liaison officer, passionate about the project and addressing customer needs was key to the success. Positive client feedback and good access to properties was achieved. Don't underestimate the time and effort needed to communicate the project to customers. Issues are often not directly "project" related but due to outstanding, historical client situations. The timing of any engagement is very important.

Team: The team needs to be well formulated, with a wide range of complementary skills so as to deliver high quality work effectively. The marriage between scientific rigour and practical experience is critical for success. Communicating assessments of complex risk profiles effectively through organisations is important and must be clear to various types of stakeholders. Internal project reporting processes provide visibility to enable informed decisions. Collaborative engagement with other projects enabled sharing of information and best practice, avoiding duplication and improving outcomes.

CONCLUSION

An exemption to GSMR has been granted for the novel HyDeploy live field trial and Keele University based on sound science and a range of practical, theoretical and simulation studies. The exemption has enabled the HyDeploy project to progress towards a live field trial. The field trials aim to demonstrate that natural gas containing hydrogen at a level above that normally permitted by GSMR but still within the Wobbe Index limits of the regulations can be safely and efficiently conveyed within the gas network. This work is needed to inform decisions on the feasibility and strategy for wider deployment of natural gas containing hydrogen in the gas transmission and gas distribution systems of the UK as a potential pathway to meet the UK 2050 decarbonisation targets. The process of pursuit of a time-limited exemption to regulation has been shown to provide an effective mechanism to enable critical innovation demonstration projects to take place without prejudicing the health and safety of conveyors and consumers.

In order to gain the exemption to GSMR, an application based on a detailed QRA underpinned by a robust evidence base is required: this evidence base has been built from an extensive technical programme made up of literature review, application of theoretical principles, experimental testing and on-site testing and monitoring. Using the methodology outlined above, the HyDeploy team have been able to justify the need for an exemption and use evidence to demonstrate that no additional risks to health and safety will be created as a result during the live field trial.

DISCLAIMER AND ACKNOWLEDGEMENTS

This report and the work it describes was undertaken by HSE's Research and Science Centre under contract to Cadent and Northern Gas Networks. Its contents, including and opinions and /or conclusion expressed, or recommendations made, o not necessarily reflect policy or views of the Health and Safety Executive.

We would like to thank OFGEM, the funding body of the innovation project HyDeploy, for their support. Also, we would like to thank the partners of HyDeploy, in particular Cadent Gas, Northern Gas Networks and Progressive Energy for their help and expertise.

REFERENCES

[1] OFGEM, "NIC Submission," [Online]. Available: https://www.ofgem.gov.uk/publications-and -updates/gas-nic-submission-national-gris-gas-distribustion-hydeploy. [Accessed 7 February 2018]

[2] R. Judd, D. Pinchbeck (2016) Hydrogen admixtures to the natural gas grid, Compendium of Hydrogen Energy, Vol. 4. Hydrogen Use, Safety and the Hydrogen Economy. P165 – 192. Woodhead Publishing.

[3] OFGEM, "NIC Submission." [Online]. Available: https://www.ofgem.gov.uk/system/files/docs/2018/11/2018nic-decision-docuement-final.pdf [Publication date 29th November 2018]

[4] Committee on Climate Change (CCC) (2008) The Climate Change Act [Online] The National Archives, Available: http://www.legislation.gov.uk/ukpga/2008/27/section/1

[5] The Department for Business Energy and Industrial Strategy (BEIS). (2017) The Clean Growth Strategy, Leading the way to a low carbon future, UK Government Publications, [Online]. Available: https://www.gov.uk/government/publications/clean-growth-strategy

[6] Health and Safety Executive (HSE) (1996) A guide to the Gas Safety (Management) Regulations, ISBN 978 0 7176 1159 1, http://www.hse.gov.uk/pubns/priced/l80.pdf

[7] Health and Safety Executive (HSE) (1996) A guide to the Pipelines Safety Regulations, ISBN 978 0 7176 1182 9, http://www.hse.gov.uk/PuBns/priced/l82.pdf

[8] Issac, T. (2019) HyDeploy: The First Hydrogen Blending Deployment Project, Clean Energy, Vol3, Issue 2, pages 114 – 125.

[9] Mathurkar, H. (2009). Minimum ignition energy and ignition probability for Methane, Hydrogen and their mixtures, Doctoral Thesis, Loughborough University.