gasnetworks.ie

Gas Networks Ireland

Injecting green hydrogen blends into Ireland's gas network

Technical and safety feasibility study
December 2022
Revision 1

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Glossary of acyromns and terms

AGI	Above Ground Installation
ALARP	As Low As is Reasonably Practicable
ATEX	Atmosphere Explosible (Explosive Atmospheres regulations)
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
AUT	Automatic Ultrasonic Testing
bar	bar - unit of pressure
barg	Bar Gauge (unit of pressure measurement relative to atmospheric pressure)
BEIS	Department of Business, Energy and Industrial Strategy (UK Government Department)
BSI	British Standards Institution
CAG	Common Arrangements for Gas
CAP	Climate Action Plan
CEN	European Committee for Standardization
CO	Carbon monoxide
CO_2	Chemical symbol for carbon dioxide
CRU	Commission for Regulation of Utilities
CV	Calorific value
DECC	Department of Environment, Climate and Communications
DETE	Department of Enterprise, Trade and Employment
DNV	Det Norsk Veritas
ECA	Engineering Critical Assessment
EU	European Union
GAR	Gas Appliance Regulations (EU regulations)
GB	Great Britain
GDN	Gas distribution network
GERG	The European Gas Research Group
GIA	Gas in air
GO	Guarantee of Origin
GS(M)R	Gas Safety (Management) Regulations (primary legislation applicable to UK)
GTSC	Gas Technical Standards Committee of NSAI
GW	Gigawatt (1 billion Watts)
H_2	Chemical symbol for (molecular) hydrogen
HBICS	Hydrogen blending, injection and control system
HHIC	Heating and Hot Water Industry Council
HSE	Health and Safety Executive – safety regulator for UK
IC	Interconnector
IGEM	Institute of Gas Engineers and Managers (professional engineering institution for gas engineers)
IoM	Isle of Man
ISO	International Standards Organisation
LDZ	Local distribution zone – a term used in GB to describe an area of the network
LEL	Lower explosive limit
LPG	Liquid Petroleum Gas
MAOP	Maximum Allowable Operating Pressure
mbar	millibar - unit of pressure equal to 0.001 bar
MW	Megawatt (1 million Watts)
NI	Northern Ireland
NOx	Nitrogen oxides
NSAI	National Standards Authority of Ireland
NTS	National Transmission System (in GB)
PAS	Publicly Available Specification
PEM	Proton Exchange Membrane (a type of water electrolyser)
PE	Polyethylene (a material for gas pipes)
QRA	Quantitative Risk Assessment millibar - unit of pressure equal to 0.001 bar
RD	Relative density (of a gas)
SNG	Synthetic natural gas
SWSOS	South West Scotland Onshore System
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
USM	Ultrasonic Meter
WI	Wobbe Index – a measure of fuel interchangeability on gas burners

1. Executive summary

Hydrogen is the most abundant chemical in the universe. In its gaseous form it is highly flammable and can be burned to provide heat without releasing carbon into the atmosphere. It can also be chemically oxidised to produce electricity, again without releasing carbon into the atmosphere. Hydrogen can be produced by the electrolysis of water and hydrogen produced using renewable electricity ("green hydrogen") has the potential to allow large amounts of renewable energy to be readily stored, transported and consumed, providing a credible option to replace existing fossil fuel usage and reduce carbon emissions from many sectors of the economy.

Across the EU, the UK and further afield, work is underway to assess the feasibility of blending hydrogen into existing natural gas networks. This has the dual benefit of providing a constant ready-made market for green hydrogen and helps to reduce carbon emissions arising from the use of natural gas. The production, blending and use of green hydrogen can help Ireland achieve its climate and energy security ambitions and will help meet proposed EU ambitions for the development of a European hydrogen economy including hydrogen blending facilitation between Member States.

Action 169 from Ireland's Climate Action Plan 2021 aims to "Develop Renewable Gas in the Gas Grid". One of the steps identified as necessary for delivery of this action is to "test the technical feasibility of safely injecting green hydrogen blends in the gas grid" with a proposed output of a "completed assessment of the impacts on network operation, integrity, and end-users' appliances" by the end of Q4 2022. This action was assigned to Gas Networks Ireland, the operator of Ireland's natural gas network.

To address this action, Gas Networks Ireland assembled an internal cross-functional technical and safety working group assisted by global energy consultancy DNV which, over the course of 2022, undertook a number of technical assessments of its assets, processes, procedures and arrangements and a review of international studies and trials. The main conclusions and recommendations from this work have been taken and set out in this report.

This work included the following objectives:

1. **To evaluate the potential impacts of hydrogen and natural gas blends on Ireland's distribution and transmission network (in Ireland, subsea interconnectors and Gas Networks Ireland's assets in Northern Ireland, Scotland and the Isle of Man).**
2. **To assess the impacts of hydrogen blends on current network operations and the integrity of the gas networks.**
3. **To determine the impacts of hydrogen blends on downstream end-user appliances.**

The technical feasibility study was a high-level initial feasibility assessment of the readiness of the Gas Networks Ireland network for transporting hydrogen/natural gas blends. The findings were very positive and indicate that it will be both safe and feasible to utilise the existing gas network to transport blended hydrogen. However, before injecting hydrogen into the network, further detailed research will be required, particularly in relation to the high pressure transmission network and large industrial, commercial and power generation users. The Safety and Technical Roadmap, along with the recommendations provided in the report, provides next steps including an assessment of the impact on end-users.

1. Executive summary

1.1 Objective One
The potential impacts of hydrogen and natural gas blends on Ireland's distribution and transmission network

Ireland's gas network is one of the most modern in the world and currently supplies natural gas and small amounts (increasing year on year) of biomethane to over 720,000 domestic, commercial, industrial and power-generation customers.

The gas network comprises two systems: The 2,476 km transmission system transports large volumes of gas from the existing entry points at Moffat, Scotland and Bellanaboy, Ireland via high pressure steel subsea interconnectors and onshore pipelines, supplying power stations and very large industrial consumers directly and supplying smaller industrial, commercial and domestic customers via the lower pressure distribution system. The 12,188 km distribution system is predominantly constructed from polyethylene pipe with small amounts of steel and other materials and supplies consumers in urban and sub-urban areas at pressures of up to 4 bar.

A large amount of work, including a number of pilot hydrogen blending projects, has already been undertaken in both the UK and Europe to evaluate the potential for blending hydrogen into natural gas networks.

1.1.1 Objective one - Conclusions

This report has considered the pilot hydrogen blending projects undertaken in both the UK and Europe. In particular, the HyDeploy project (undertaken on two discrete networks in the UK) has successfully demonstrated that hydrogen blends can be safely introduced on the distribution network with no negative impact on either the network itself, or domestic and commercial customers. The evidence generated from HyDeploy, particularly in the area of materials assessment where a significant evidence base has been developed, can be used to support hydrogen blending projects in Ireland. This evidence indicates that up to 20% hydrogen blends will not impact existing materials found on the British gas distribution network.

Ireland's gas distribution network is similar to the British distribution network and is largely compatible with hydrogen blends of up to 20% and even 100% hydrogen with only some modifications required.

This report has determined that Ireland's gas transmission network is also compatible with hydrogen blends, however materials testing is required for around 50% of pipelines on the network to allow current maximum operating pressures to be maintained with hydrogen concentrations of greater than 10%. Some targeted research on certain equipment contained within transmission AGIs and compressor stations will also be required. Across the UK and EU, there are multiple studies already underway testing the compatibility of transmission network equipment (e.g., National Grid HyNTS (FutureGrid), Gasunie programmes, Hydrogen in Gas Grids (HIGGS), GERG and EPRG hydrogen programmes) which will support Gas Networks Ireland in this research.

1.2 Objective Two
The impacts of hydrogen blends on current network operations and the integrity of the gas networks

The injection of different gases into Ireland's natural gas network is not new. Today, biomethane injection into the gas network is taking place and is expected to increase in the coming years. Biomethane (methane produced by anaerobic digestion) is, however, already the main component of natural gas. Blending hydrogen presents a different challenge as hydrogen is not an existing component of natural gas.

Gas Networks Ireland is currently required to demonstrate that the safety risks associated with its natural gas networks both in Ireland and the UK are as low as reasonably practicable (ALARP). The documents through which this demonstration is made are called safety cases and are subject to review and acceptance by the relevant safety regulator in each jurisdiction.

The safety cases set out Gas Networks Ireland's arrangements for managing safety, an assessment of the risks associated with the natural gas networks, and the arrangements in place for controlling those risks so that the overall level of risk is ALARP.

The ALARP demonstration relies, in part, on:

- The identification of, and compliance with, recognised industry standards
- Appropriate equipment, operational procedures and processes
- Risk assessment, including Quantitative Risk Assessment

The introduction of hydrogen to the natural gas network will require a thorough evaluation of the associated risks and a demonstration that the controls put in place maintain the overall level of risk at a level that is ALARP.

1.2.1 Objective two - Conclusions

Standards

The Institution of Gas Engineers and Managers (IGEM) and the European Committee for Standardisation (CEN) are both reviewing the database of relevant industry standards with a view to updating these for hydrogen blends. In addition to this, the National Standards Authority of Ireland, with whom Gas Networks Ireland works closely on the development and refinement of Irish standards for gas, are also tracking the development of hydrogen standards for industrial users.

Whilst further development is needed on these standards for hydrogen blends, standards such as ASME B31.12 for 100% hydrogen have been available and utilised safely within industry for many years. This proven track record is evidence that further standards for blended hydrogen can be safely developed from an existing knowledge base.

Operational processes, procedures, and equipment

Gas Networks Ireland maintains a large suite of operational procedures governing how it designs, builds, operates and maintains the natural gas network. These will need to be reviewed to ensure that the impacts of hydrogen blending are captured and incorporated. In particular, the leak management processes and procedures will need to be updated to reflect the impact of hydrogen blending on the behaviour of internal and external gas escapes to ensure that leaks can be managed safely.

1. Executive summary

Hydrogen, like natural gas, is odourless. A potent smell is currently added to natural gas prior to it entering the Gas Networks Ireland network to ensure leaks can be readily detected. The HyDeploy project has concluded that odour intensity at a distribution level will not be adversely impacted by introducing hydrogen blends up to 20%. As Gas Networks Ireland already inject odorant on the transmission network, this variation will need to be assessed to identify any potential issues associated with the blending of hydrogen at transmission level.

Existing gas detection equipment used by Gas Networks Ireland will need to be modified or replaced to ensure that it accurately measures flammable concentrations of hydrogen/ natural gas. Equipment that is current used to measure carbon monoxide concentrations may also need to be modified or replaced since existing sensors are cross-sensitive to hydrogen.

Natural gas sites are currently zoned under ATEX regulations to identify areas where flammable concentrations of gas might exist and to restrict the presence of ignition sources in those areas. The blending of hydrogen into natural gas is known to impact on the extent of these hazardous areas (zones). Therefore, existing zones will need to be recalculated. As a result, the sinage that currently displays their extent will require replacement. Equipment that is currently used for use within areas zoned for natural gas may require modification or replacement. This is to enable it to be used safely in areas where there is a possibility of hydrogen or a hydrogen/natural gas release.

Operatives working on Ireland's gas infrastructure as part of emergency or maintenance works will likely require additional training to ensure correct application of updated procedures and equipment. Gas Networks Ireland has a Technical Training School and Network Innovation Centre which would be suitable for this purpose.

Similarly, gas installers working on domestic and industrial or commercial pipework, appliances and equipment may require upskilling to ensure that they are competent in relation to the behaviour of appliances and equipment operating on a hydrogen/ natural gas blend.

Risk assessment and safety demonstration

Ensuring that the percentage of hydrogen in the natural gas blend does not exceed allowable limits is a key safety consideration and will require testing as part of the ALARP demonstration.

Hydrogen injection requires careful consideration of flows, pressures, hydrogen quality, control of the mixing process and accurate measurement and monitoring of the blend and its energy content. The strategies to ensure production of a well-mixed blend need to take account of the underlying quality of the natural gas and the potential for the gas to then contain hydrogen up to the allowable limit. Facilities that manage this process are called Hydrogen Blending, Injection and Control Systems (HBICS). Several HBICS suppliers were identified as part of this research.

The consistency and reliability of the blended mixture may also be an important factor, particularly for billing purposes and for some industrial/ commercial and power generation equipment which may be sensitive to variations in gas quality (even within allowable limits).

Although not directly a factor in the assessment of the technical feasibility of safely injecting hydrogen into the natural gas network, the location(s) at which hydrogen is injected into the existing natural gas network will nonetheless need careful consideration as part of a wider national hydrogen strategy. The blending of hydrogen into the natural gas network will also require adaptations to Gas Networks Ireland's current arrangements for managing and operating the network.

Prior to allowing hydrogen onto the natural gas network, a Safety Case (or Safety Cases) containing a thorough evaluation of the associated risks and a demonstration that the controls put in place to maintain the overall level of risk at a level that is ALARP will be required. Much of the considerations and data requirements for such a risk assessment and demonstration are outlined in this report. It is likely that a Quantitative Risk Assessment (QRA) will also be required. Such a QRA was undertaken for the HyDeploy project and indicates that a similar approach is feasible in an Irish context.

For all hydrogen that is blended into the natural gas arriving into the Gas Networks Ireland system at Moffat, Scotland, the safety demonstration must also consider the materials, assets and end user appliances in Northern Ireland and the Isle of Man.

Changes to allowable composition

Currently the allowable limits of the various chemical components present in the Irish natural gas network are set by the Code of Operations and are similar to the limits that are set in the UK under the Gas Safety (Management) Regulations (GS(M)R). Hydrogen is limited in both the Code of Operations and the GS(M)R to 0.1% mol. Therefore, to allow any meaningful quantity of hydrogen to be blended into the network, an increase to this limit will be required.

The UK GS(M)R have recently been reviewed and changes are expected to ensure that gas networks have access to diversified sources of gas to enhance security of supply, whilst continuing to deliver gas to customers safely and efficiently, and to support deep decarbonisation through biogases and hydrogen. Since most natural gas consumed in Ireland comes from the UK, changes to these limits in the UK may have an impact on the gas that is imported into Ireland and will require appropriate adaptation of Irish arrangements to accommodate it.

1. Executive summary

1.3 Objective Three
The impacts of hydrogen blends on downstream end-user appliances

More than 720,000 end-users are connected to Ireland's gas network across the entire economy encompassing domestic, industrial/ commercial and large-scale (e.g. power generation) consumers. With a change from transporting 100% natural gas to natural gas/ hydrogen blends, consideration of end users and their applications is crucial.

Gas quality and its interchangeability are key considerations for the safe operation of gas appliances. For natural gas, the operating ranges and quality are well established and understood. Much work has been undertaken to establish the impact of hydrogen on the operation of natural gas appliances.

1.3.1 Objective three - Conclusions

The combustion characteristics of hydrogen are significantly different to natural gas and the two are not readily interchangeable. It is therefore not possible to operate current natural gas appliances on 100% hydrogen. For example, hydrogen has a lower calorific value (CV) than natural gas (roughly one-third), a much wider flammability range and a higher burning velocity. To operate on 100% hydrogen would hence, require changing or modifying existing natural gas appliances.

Therefore, it is possible to use a blend of hydrogen and natural gas. These mixutres can have similar quality characteristics to natural gas. The blend limit is influenced by the properties of the underlying natural gas and the quantity of hydrogen added.

Blending hydrogen into natural gas impacts on traditional gas quality characteristics. In general, however, the calorific value for hydrogen and any hydrogen/ natural gas blends will always be lower than for natural gas alone and can therefore, impact energy delivery through the network and end-user appliances. In addition, the Wobbe Index[1] decreases with the addition of hydrogen, but the trend is not linear as hydrogen content increases.

In summary, the addition of hydrogen to natural gas lowers the Wobbe index and calorific value and the addition of too much hydrogen could result in a breach of the current acceptable limits of Wobbe Index and calorific value with resulting detrimental impact on appliance performance and so, needs to be carefully controlled.

Gas specifications also form the basis for the manufacturers of end-use equipment such as appliances, burners, furnaces, process plant, gas engines and gas turbines. Meeting these specifications is essential in order to guarantee the performance and maintenance intervals of the equipment.

1 The Wobbe Index is a key parameter for combustion equipment and measures the impact on the thermal output when gas is burned.

The evidence indicates in technical papers on combustion and from the HyDeploy and THyGa studies that the blending of up to 20% hydrogen by volume is acceptable for the majority of domestic and commercial appliances with no impact or end-user changes required. A recent research study by the UCD Energy Institute at Gas Networks Ireland's Network Innovation Centre found that the domestic appliances tested operated safely and effectively with hydrogen blends up to 20%.

However, there may be some equipment, particularly in the industrial, commercial and power generation sectors, that are less tolerant than others. The limits of hydrogen blending for such equipment may not only be influenced by the burner type in the equipment but may also be linked to gas quality limits. Further research and testing are needed to determine the impact of hydrogen blends on industrial, commercial and power generation users and what technical options might exist to safeguard large users if they cannot accept hydrogen blends.

1.4 Other Considerations

This report confirms that injecting green hydrogen into the gas network is technically feasible and can be done safely.

Several other factors which influence the overall approach to hydrogen blending, but which fall outside of the scope of this report, need to be considered as part of a wider national hydrogen strategy.

1.4.1 Hydrogen storage and transportation

Where hydrogen is injected into the natural gas network will likely depend, in part at least, upon where the hydrogen is produced. Since it is unlikely that the optimum location(s) for hydrogen production will coincide with the optimum location(s) for injecting hydrogen into the natural gas network, then that hydrogen must be transported from its point of production to its point of injection. As green hydrogen will be produced from renewable energy sources which, by their nature, are variable, it is also likely that hydrogen storage will be required to help smooth the peaks and troughs of variable production.

Blending of hydrogen into the natural gas network at scale in Ireland will likely require consideration of the storage and transportation of 100% hydrogen which in turn may offer pathways to the direct utilisation of 100% hydrogen.

1.4.2 The metering, billing, regulatory and commercial framework

As with the production of any form of energy, hydrogen producers must be paid for their product and hydrogen consumers must pay both for the product and the costs of transporting it to the point of use. It is important that the production, sale, transportation, storage and usage of hydrogen are commercially regulated in a fair and transparent way. In the case of hydrogen that is blended into the natural gas network, such arrangements must interface with, and may require modifications to, the existing natural gas commercial framework.

1. Executive summary

1.4.3 Hydrogen safety regulation

Although the safety regulatory arrangements for the existing natural gas network are well understood and are anticipated to apply to hydrogen that is blended into it, there is currently no established regulatory framework (other than the occupational health and safety framework) that covers a wider hydrogen value chain from production, transportation and storage through to end-use requirements. Since hydrogen blending into the natural gas network at scale will involve production, storage and transportation of 100% hydrogen, this aspect needs to be determined.

1.4.4 Certification of origin for renewable gas status

Current requirements for certifying hydrogen as renewable differ between the EU and the UK. In the event that hydrogen is transported between Ireland and the UK, either blended into natural gas or transported as 100% hydrogen, it is possible that the hydrogen certified as renewable at its point of production might not be certified as such at its point of use. This could affect both hydrogen imports to, and exports from, Ireland. Efforts should therefore be made to ensure that renewable hydrogen produced in Ireland meets both EU and UK renewable certification requirements.

1.5 Recommendations

Recommendations arising from this work are contained in Section 13 of this report.

1.6 Next steps

This study **recommends the commencement of a pilot hydrogen blending project on the Irish gas network**. Pilot hydrogen blend demonstration projects on Ireland's distribution and transmission networks will help validate the safe operation of the network, end user appliances and equipment.

Pilot blending projects will complement and supplement technical studies and laboratory trials and enable the development at a small scale of the required regulatory safety demonstrations. It will also increase the experience, awareness and confidence in hydrogen blending in an operational environment that can be scaled up to a commercial level as the wider hydrogen value chain matures.

It is recommended that developing the safety assessment strategy for hydrogen/ natural gas blends should commence immediately as a safety demonstration is a prerequisite of any hydrogen blending demonstration pilot(s).

Many of the technical recommendations in this report are relevant and required in advance of the roll out of both pilot projects and any future commercial blending. Pilot projects undertaken both in Ireland and elsewhere will provide a logical framework in which that work can be structured and prioritised and ultimately help ensure Ireland's climate and energy security ambitions.

Gas Networks Ireland has the expertise required to support the safe introduction of hydrogen blends and, in time, 100% hydrogen for end user requirements. It is well placed to support and deliver national policy and strategy as we advance the decarbonisation journey for our economy. Gas Networks Ireland has over 40 years' experience in designing, building and operating a safe and reliable gas network and we are confident in our ability to help Ireland transition to renewable gas by utilising our existing gas networks. Ireland has previously transitioned from town gas (large constituent of which was hydrogen) to natural gas in the 1980s. We look forward with confidence that Gas Networks Ireland, as the competent gas operator in Ireland, will again safely deliver the next transition as we move to renewable forms of gas over the coming decade.

Support from the relevant regulatory authorities and a collaborative approach with all stakeholders will be essential to facilitate at first the distribution blending pilot and secondly the wider rollout of hydrogen blending. This approach has been followed for the pilot projects in the UK and EU with great success and there is no reason why it cannot be applied in Ireland.

2. Introduction and background

2.1 Overview of the Gas Networks Ireland network

Gas Networks Ireland builds, develops, and operates Ireland's world-class natural gas infrastructure, maintaining over 14,664 km of gas pipelines and two sub-sea interconnectors.

The Gas Networks Ireland transmission network includes onshore pipelines and assets, the interconnectors and onshore Scotland pipelines and assets. The interconnector subsystem is comprised of two subsea interconnectors between Ireland and Scotland; and two compressor stations in Scotland at Beattock and Brighouse Bay. The interconnector system connects to the GB National Transmission System (NTS) at Moffat in Scotland. It also supplies gas to the Northern Ireland (NI) market via an offtake at Twynholm, Scotland and the Isle of Man (IOM) market through an offtake from the second subsea interconnector (IC2).

From an initial 31km of transmission pipeline in 1978, Ireland's gas network has grown to 2,476 km of high-pressure steel transmission pipelines and 12,188 km lower pressure polyethylene distribution pipelines, as well as Above Ground Installations (AGIs), District Regulating Installations (DRIs) and compressor stations. AGIs and DRIs are used to control and reduce pressures on the network.

The onshore part of Ireland's gas network consists primarily of a ring-main system with spur lines serving various network configurations.

The gas infrastructure is differentiated by the following pressure regimes:

- High pressure transmission infrastructure (steel) which operates above 16 barg and
- Distribution infrastructure (predominately polyethylene) which operates below 16 barg.

The distribution infrastructure is typically operated at two pressure tiers: 4 barg; and less than 100 mbarg for inner city networks.

2.2 Scope of work

During 2022, Gas Networks Ireland carried out a technical feasibility study of safely injecting green hydrogen into the natural gas network. The feasibility study included the following objectives:

1. Evaluate the impacts of hydrogen blends on Ireland's distribution and transmission networks (including subsea interconnectors and Gas Networks Ireland's assets in Northern Ireland, Scotland and the Isle of Man).
2. To assess the impacts of hydrogen blends on current network operations and the integrity of the gas networks.
3. Determine the impacts of hydrogen blends on downstream end user appliances.

To address these objectives, several key tasks were identified and carried out:

- An evaluation of relevant EU and GB studies and demonstration blending projects.
- An assessment of injection options and potential for hydrogen on Ireland's natural gas network.
- A review of Gas Networks Ireland's distribution and network assets.
- A review of Gas Networks Ireland's transmission and network assets.
- A review of interconnector and compressor station assets.
- An evaluation of end use of networked hydrogen / hydrogen blends.
- An identification of standards that require modification / development.
- An assessment of operational impacts on existing procedures and skills.
- A consideration of gas quality.
- An assessment of hydrogen injection facilities.
- Development of a safety assessment strategy.
- Development of a technical and safety roadmap.
- A review of regulatory arrangements.
- An identification of key recommendations.

Figure 2-2-1 Overview of Gas Networks Ireland's Transmission System

2. Introduction and background

It is worth noting that, while the focus of this report is the blending of "green" hydrogen[2], the technical challenges associated with transporting green hydrogen are the same for other types of hydrogen such as blue or grey. Therefore, all the conclusions and recommendations from this report are relevant for all types of hydrogen regardless of their method of production.

2.3 The importance of blending

Introducing hydrogen and hydrogen blends into existing gas networks is now widely recognised across the UK and EU as a potential complementary measure to support decarbonisation and central to the achievement of emission reduction targets and the enhancement of energy security.

Ireland:

- Climate Action Plan 2021 (CAP21) set out an initial target for 1.6 TWh of green gas, including hydrogen, by 2030. CAP21 stated that "scenarios for net-zero emissions by 2050 include a potentially significant role for the use of zero-emissions gases (in particular biomethane and green hydrogen)".
- In July 2022, as part of Ireland's carbon budget programme, sectoral emission ceilings were set, with reductions of 25-75% on 2018 emissions by 2030. At the same time, targets for green gas production increased with a new target for 2 GW of offshore wind dedicated to green hydrogen production and up to 5.7 TWh of biomethane production by 2030.[3]

UK:

- The UK hydrogen strategy outlines that by 2050, 20-35 per cent of the UK's final energy consumption could be made up of hydrogen.[4]

EU:

- The EU's draft Hydrogen and Gas Markets Decarbonisation Package states that 'Transmission System Operators shall accept gas flows with a hydrogen content of up to 5% by volume at interconnection points (by 01/10/2025) between member states'. While Ireland is no longer connected to another EU member state, the UK has signalled that they wish to remain aligned with EU energy policy in this respect.

Given these signals towards a greater role for hydrogen in Europe's and Ireland's future energy system, as the Irish gas distribution and transmission system operator, it is prudent that Gas Networks Ireland explores the opportunities and challenges associated with transporting hydrogen blends in the gas network. This is important for several reasons:

- To help meet Ireland's plans for green hydrogen development and to help Ireland achieve its climate and energy security ambitions.
- To be ready to handle hydrogen blends that may be present at the Moffat entry.
- Point and transported through the subsea interconnectors into Ireland before 2030.
- To meet EU ambitions for hydrogen blending transmission between member states.

The following sections of this report set out and detail the high-level findings of Gas Networks Ireland's assessment.

2 The colour of hydrogen refers to its method of production rather than the actual colour of the hydrogen gas: "Green" hydrogen is produced by the electrolysis of water using renewable electricity. "Blue" hydrogen is manufactured by chemically processing natural gas to produce hydrogen and carbon dioxide; the carbon dioxide is then captured and stored. "Grey hydrogen" is manufactured by chemically processing natural gas or other hydrocarbons to produce hydrogen and carbon dioxide; the carbon dioxide is then emitted to atmosphere.

3 See https://www.gov.ie/en/press-release/dab6d-government-announces-sectoral-emissions-ceilings-setting-ireland-on-a-pathway-to-turn-the-tide-onclimate-change/

4 UK Hydrogen Strategy (publishing.service.gov.UK)

3. Review of UK and EU hydrogen blending projects

This section provides a high-level overview of successful UK and EU pilot hydrogen blending projects within distribution networks. This section also assesses the National Grid's FutureGrid project, which is aiming to develop the evidence base confirming that blends of hydrogen and 100% hydrogen can be safely transported through the GB transmission network.

3.1 Blending projects – Distribution

This assessment looked at evidence gathered from hydrogen blending projects in France, the Netherlands, Germany, Portugal, Denmark and the UK. The assessment observed different network configurations, hydrogen production methods and limits and various end users.

The UK and the EU have made significant advances in hydrogen blending trials in distribution networks over the past five years. In the UK, HyDeploy is successfully blending up to 20% hydrogen to 668 houses, a school and several small businesses. From an EU perspective, a Dutch project completed in 2011 delivered blends in a small distribution network, in Germany blending to two villages of up to 10% hydrogen was successfully completed, and in France a trial of 20% hydrogen blending was delivered to circa 200 new properties.

The Ready for Hydrogen Alliance is a group representing over 90 European gas distribution companies, including Gas Networks Ireland.[5] Their Ready4H2 Project focuses on European distribution networks and has developed a roadmap outlining key actions and milestones for local gas distribution networks from today's various starting points until the common net-zero goal in 2045. The Alliance is developing a roadmap to indicate how gas distribution networks across Europe can transform into Europe's primary hydrogen distribution infrastructure.

A summary of UK and EU successful blending projects is highlighted in Table 3.1 on the following page.

5 https://www.ready4h2.com/_files/ugd/597932_5cf124d563594a39841f9ef83d07c2b7.pdf

3. Review of UK and EU hydrogen blending projects

Table 3.1 Summary of Blending Projects (Table Adapted from Ready4H2)

Project	Evidence
Ameland Dutch Trial, 2011	• Four-year trial delivered to 14 properties. • 5-20% hydrogen blended in the gas network.
GRHYD, 2020	• Residential grid in France with up to 20% H_2 blend, which ran France, 2018- for 2 years, reducing CO_2 emissions by more than 60% and NOx by 40%. • Equipment functioned successfully without issues, and without safety concerns of participating voluntary households.
WindGas, 2012-2016	• Grid blending pilot in Hamburg, Germany which ran for 4 years Germany, from 2012 using H_2 locally produced by electrolysis from wind power. • Successful pilot fed 100,000 m^3 of H_2 into Hamburg grid without complications.
Green Pipeline project, Portugal, 2021-ongoing	• The Green Pipeline Project is a pioneering project in Portugal that, for the first time, will introduce green hydrogen into the natural gas network. • Taking place in a closed network in Seixal, it will distribute a blend of hydrogen and natural gas to around 80 end-users in the residential, non-residential and industrial sectors. • The blend will contain 2% hydrogen initially, and gradually increase to 20% within 2 years.
Hydrogen Injection, Denmark, 2021	• Hydrogen injection in Denmark into an isolated high- and low pressure grid without end users. • Successful 4-month pilot with 15% H_2 showed no emissions or leakages. • Gas grid stations and equipment functioned without issues with a 15% H_2 blend.
HyDeploy, UK, 2019-ongoing	• Phase 1 successfully provided blended H_2 of up to 20% to 100 homes and 30 university buildings. • Phase 2 has been blending up to 20% H_2 for 668 houses, a school and some small businesses in Winlaton. • Further detail on the findings from HyDeploy can be found in Appendix A
THYGA, 2020-2022	• Closing knowledge gaps regarding technical impacts of hydrogen blends on residential and commercial gas appliances. • The project includes the test of 100 appliances with blends of natural gas and hydrogen up to 60%.
HyTest, Ireland, 2021- 2022	• Joint UCD Energy Institute / Gas Networks Ireland project based at the Network Innovation Centre, Citywest, Dublin. • Various domestic appliances tested with blends for hydrogen and natural gas from 2% to 20% hydrogen. • Gas appliances tested were found to operate in a safe and effective manner with the various hydrogen blends.

Note: THyGa is an EU funded scheme that sets out to develop and communicate a detailed understanding of the impact of blends of natural gas and hydrogen on end use applications

Figure 3.1 highlights examples of the current hydrogen blend percentages allowed by certain country's gas regulations.

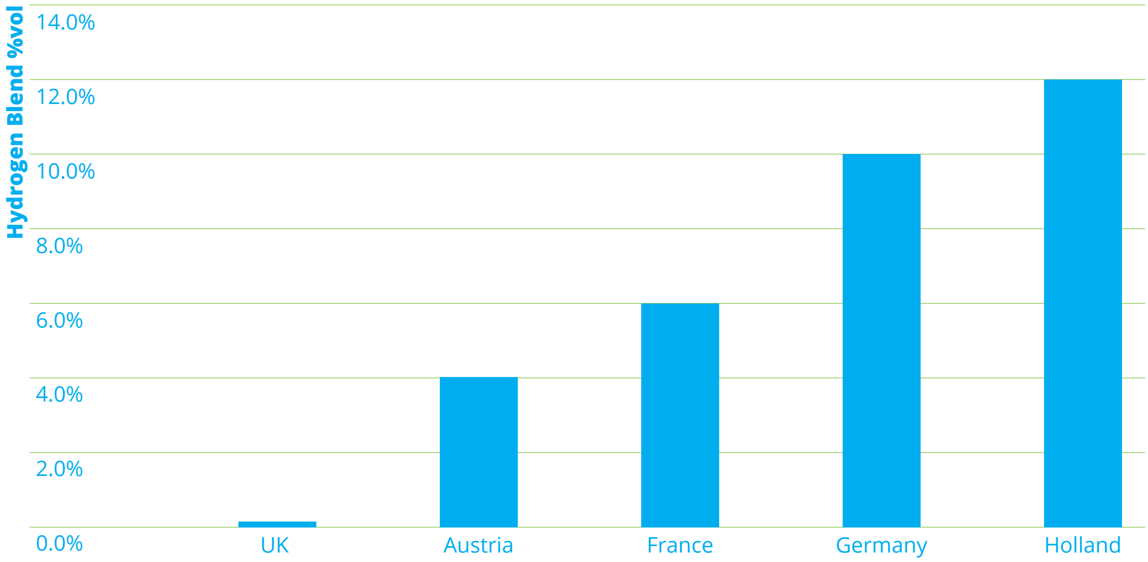

Figure 3.1 Hydrogen permissible limits in UK and selected EU Member States (Source HyDeploy)

The evidence from all of these pilot projects is clear. Injection and transport of up to 20% hydrogen blends in gas distribution networks is both safe and feasible.

Future Grid's Testing Plan includes activities such as; an offline hydrogen testing facility, material permeation testing, flange testing, pipe coating and Cathodic Protection testing, Asset leak testing, fatigue testing , Rupture testing. Future Grids Safety & Risk Management Review covers; Procedure Review, Hazard assessment of the NTS, Quantitative Risk Assessment , Hazardous Area Impact , Overpressure Risk, NGGT Safety Case.

3.2 Blending projects – Transmission

The FutureGrid project led by National Grid is looking into the feasibility of converting the existing GB National Transmission System (NTS) to hydrogen. The project is planning to demonstrate this by building an offline test loop to test, validate and measure the impact of hydrogen through blends of 2, 5, 20 and 100% hydrogen by volume. In addition to this, the project will carry out standalone hydrogen test modules in areas such as fatigue testing and rupture testing. It is important that Gas Networks Ireland follows this project closely as the results will be directly transferable to the Irish transmission system.

3. Review of UK and EU hydrogen blending projects

3.3 Policy Developments

In May 2022, the EU announced details of its REPowerEU Plan to reduce European dependence on Russian fossil fuels. The plan has doubled the target for biomethane from 17bcm to 35bcm by 2030 (compared to the earlier fit for 55 target) and has quadrupled the target for green hydrogen from 5.7MT to 20MT by 2030, with 10MT being produced indigenously within the EU and another 10MT to be imported. The new REPowerEU targets for hydrogen and biomethane, when combined, account for around one quarter of Europe's gas consumption.

Delivering these targets will have a clear positive impact on Europe's energy security, energy system resilience and decarbonisation ambitions. Ireland also increased its ambition for green hydrogen and biomethane in July 2022, with targets of 2GW (dedicated offshore wind capacity) and up to 5.7TWh respectively, announced as part of Ireland's sectoral emissions ceilings. The UK government has committed to making a policy decision on blending in the distribution network by 2023[6]. This will be supported by evidence generated from HyDeploy and a value for money assessment .

In addition, the UK Department for Business, Energy and Industrial Strategy (BEIS), in the consultation on hydrogen transport and storage infrastructure[7], have identified the potential benefit that hydrogen blending may bring to the development of the UK's hydrogen economy BEIS stated:

"By providing a route to market for hydrogen producers during the early development of the hydrogen economy, blending may help to bring forward investment and support its early growth … Even where producers have secured off taker(s) of hydrogen, they may face volatile demand, blending could have value in helping to manage demand volatility by acting as a reserve off taker." BEIS (2022).

3.4 A blending pilot in Ireland

Gas Networks Ireland has carried out an assessment to identify the optimum location for a first of a kind distribution blending pilot on Ireland's gas network. This assessment was independently verified and the process for identifying the optimum location is aligned with industry best practice and follows successful GB hydrogen blending projects.

6 UK Hydrogen Strategy (publishing.service.gov.UK)
7 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1101296/hydrogen-transportationstorageconsultation.pdf

4. Hydrogen blend assets review

This section of the report provides a high-level summary of the suitability of Gas Networks Ireland's assets to transport a hydrogen blend. The review was carried out on:

- Distribution assets
- Transmission assets
- Compressor stations and subsea interconnectors

In 2021, 72% of the natural gas used in Ireland was imported from the UK via the subsea interconnector pipelines which are fed by compressor stations located in Scotland. The transmission network transports the natural gas at high pressure around Ireland before it is reduced to lower pressures for supply to domestic customers and businesses which are connected to the distribution network.

4.1 Distribution Assets

In this section the effects of hydrogen blends are evaluated for the distribution network, which typically operates at pressures between 25 mbar and 7 bar. This evaluation was carried out under international pipeline design codes and hydrogen related safety standards and codes (IGEM TD/1, IGEM TD/13, ASME B31.12-2019 and ISO 15916 standards).

4.1.1 Pipe Materials

While a variety of pipe materials exist on the distribution network, the vast majority of the distribution system is polymer based, chiefly polyethylene (PE) of which the various grades of PE total over 99% of the network. Some small residual amounts of gun barrel material remain, and steel pipe specified to international line pipe standards is also present.

International trials (H21, HyDeploy, Danish Gas Technology Centre) and research have demonstrated that the current grades of polyethylene used in Ireland (PE-80, PE-100) are compatible with up to 100% hydrogen at distribution pressures (up to 10 bar) and that the associated joint fittings give similar performance to that when transporting 100% natural gas. The steel used in Ireland's distribution system pipes is also compatible and can be used with blended hydrogen at the current pressure tiers.

Current hydrogen pipeline standards prohibit the use of cast and ductile iron in gases containing ≥10% hydrogen although research is underway as part of the UK HyDeploy programme to qualify irons at up to 2 bar hydrogen pressure (for a 20% hydrogen blend this would represent up to 10 bar pipeline pressure). A major cast iron replacement programme has been successfully completed on Ireland's distribution network, but it is possible that small sections of residual cast and ductile iron may remain on the network. These will continue to be replaced when identified. To address this risk iron pipe should continue to be replaced when encountered and a risk assessment, informed by test data, should be conducted to show that the failure risk, for any residual iron pipe is acceptable.

Unfortunately, there is no data available on the compatibility of gun barrel material, older polyethylene grades (e.g., PE-A) or reinforced polyethylene (e.g., PE-X). While there is very little gun barrel pipe remaining on the network, it cannot be assured that all of it has been found and replaced before hydrogen blends enter the network. It is therefore recommended that these materials are tested so that an appropriate risk assessment can be carried out. PE-A makes up about 0.25% of the network and PE-X 3.82%, therefore appropriate testing to provide evidence of their hydrogen compatibility is also recommended. Alternatively, if the PE-A can be identified it could be replaced before hydrogen blends enter the network. No new legacy grade materials will be installed in the future.

4. Hydrogen blend assets review

4.1.2 Valve Materials

A variety of valve body materials exist on the distribution network, including polyethylene, cast iron, ductile iron and gun barrel. The iron and gun barrel material are present in valves at pressure tiers up to 4 bar. Steel forgings and castings specified to international line pipe standards are also present.

For valves, similar to what has been reported for pipes, the distribution trials and research have shown that the current grades of polyethylene used in Ireland (PE-80, PE-100) are compatible with hydrogen at distribution pressures of up to 10 bar. The steel used in Irelands distribution system valves is also compatible and can be used at the current pressure tiers.

However, the current hydrogen pipeline standards prohibit the use of cast and ductile iron for pressure containing parts above 10% hydrogen, although research is underway as part of the UK HyDeploy programme to qualify iron valve bodies for up to 7 bar hydrogen. Gas Networks Ireland will use the HyDeploy results to conduct a risk assessment to determine if an iron valve replacement programme is required. The risk assessment will consider both the valve integrity and functionality.

There is no data currently available on the compatibility of gun barrel material or alternative polyethylene grades (e.g., PE-A, PE-X). There are only a small number of gun barrel valves, so their replacement is the preferred option. If replacement is not possible then material testing will be required to determine this materials hydrogen compatibility. PE-A makes up about 0.15% of the valve inventory and PE-X 1.54% and therefore testing to provide evidence of their hydrogen compatibility is recommended. Alternatively, if the PE-A materials associated with valves can be identified then these valves can be replaced before hydrogen blends enter the network. No new legacy grade materials will be installed in the future.

4.1.3 Other materials and components

This study did not assess the compatibility of the internal components within valves and other asset equipment as, in general, failure of such components would cause malfunction rather than a failure leading to a gas release. The exception is the excess flow and relief valves where a failure could lead to a gas release, and these will need to be reviewed in detail before hydrogen blends enter the network.

The identification and evaluation of every material present within all network assets is a large undertaking. The HyDeploy and H21 programmes in the UK are currently undertaking studies which will identify and evaluate every material present across all gas distribution network assets and are expected to publish the results in due course. Gas Networks Ireland will review the results of these studies to determine their applicability to Ireland's gas network. Detailed assessments will then be carried out where gaps are identified between the characteristics of the UK networks and Irish networks.

4.1.4 Other network equipment

Ireland's distribution network contains other equipment such as district and service governors, regulators etc. The pressure containing parts of these assets are constructed with materials found in valves and pipe and so the conclusions from those sections will also apply.

4.1.5 Conclusions - hydrogen blend distribution Assets review

1. The vast majority of Irelands distribution gas network (including all pressure containing assets) are compatible with hydrogen blends or 100% hydrogen. Some replacement programmes and targeted qualification research for residual iron, gun barrel material and some polymer grades are required.
2. UK and EU gas network operators, equipment vendors and research organisations are undertaking programmes of work to identify materials within network equipment and to test for hydrogen compatibility. Gas Networks Ireland will monitor the results of these programmes and apply them to the Irish networks. If this review finds gaps in knowledge for the characteristics of the network, then studies will be initiated to clarify the performance of assets and materials not covered elsewhere.
3. Network equipment contains many different materials used for internal components. Gas Networks Ireland will engage with equipment vendors to ascertain the hydrogen compatibility of their products. If the compatibility is unknown, then the materials present will be identified by a review of relevant technical manuals and surveys during routine maintenance or replacement operations.

4.2 Transmission assets

This section evaluates the effects of hydrogen blends on the gas transmission network.

The transmission network consists of the pipes and other equipment and pipework contained within AGIs such as block valve stations, compressors, and metering stations. This report only considers the hydrogen compatibility of the pipes as a detailed review of all the equipment and valves is only required once it is proven that the pipes are hydrogen compatible and can operate at a pressure sufficient to meet the network's requirements.

Two aspects are considered when assessing hydrogen compatibility of pipeline systems. Firstly, the basic hydrogen compatibility of the pipe materials; and secondly, whether the presence of hydrogen influences the design and operating pressure of the pipeline:

- In respect of the first consideration, the Irish transmission network contains steel grades ranging from API 5L grade B up to grade X-65/ L450. These materials are allowed to transport hydrogen (up to 100%) according to the relevant pipeline design codes, ASME B31.12 and IGEM/TD/1.
- Secondly, the design pressure in hydrogen service is calculated using two code compliant methods. A prescriptive method, which is the base case for IGEM/TD/1 and ASME B31.12; and a more advanced performance-based method. The performance-based calculation is for illustration as it is only available if pipe test data in a hydrogen environment is available, and this data has not yet been generated for Ireland's transmission assets.

The transmission pipes with the specific pipe grade, diameter, and wall thickness combinations; where the current design pressure could not be achieved using the prescriptive methods, have been identified and are listed in Table 4.1 below. All other transmission pipes can be used at the current design pressure according to the prescriptive design method (IGEM TD/1 Supplement 2 and ASME B31.12 method A).

4. Hydrogen blend assets review

Table 4.1 Pipelines that cannot reach design pressures with prescriptive methods

Nominal Diameter	Material	Wall Thickness	Length (km)	Current design pressure (barg)
150mm	API 5L - B	4.78mm	0.193	70
200mm	API 5L - X42	4.78mm	58.158	70
250mm	API 5L - X52	4.78mm	33.671	70
300mm	IS EN 10208-2 - L450	6.10mm	15.506	85
400mm	API 5L – X60	6.35mm	29.621	70
400mm	API 5L – X60	7.11mm	6.234	70
400mm	IS EN 10208-2 - L450	7.11mm	30.132	85
450mm	API 5L – X65	6.40mm	14.669	70
450mm	API 5L – X60	7.14mm	208.612	70
450mm	IS EN 10208-2 - L450	7.10mm	178.309	85
600mm	API 5L – X52	9.52mm	26.132	70
600mm	API 5L – X65	9.52mm	30.804	85
650mm	API 5L – X65	9.52mm	116.889	85
750mm	API 5L – X60	11.10mm	8.966	75 and 85
750mm	API 5L – X65	11.10mm	241.366	85
750mm	IS EN 10208-2 - L450	17.20mm	191.826	145
750mm	IS EN 10208-2 - L450	19.70mm	2.111	(interconnector) 145
900mm	API 5L – X60	11.90mm	12.560	(interconnector) 70
900mm	API 5L – X65	14.30mm	77.210	85
900mm	API 5L – X65	19.10mm	15.076	85
Total			**1,298.045**	

The assessment concludes that Ireland's transmission pipes are compatible with hydrogen. However, further assessments are required (using the performance options of the hydrogen pipeline design codes) on a certain subset of pipes (combination of grade, wall thickness and diameter) to allow them to operate at the current design pressure.

It should also be noted that IGEM/TD/1 includes additional design requirements for hydrogen service, beyond those relating to design pressure described above. Specifically, there are prescriptive limits on the allowable axial stress and a large reduction on the allowable fatigue cycles, which may have a significant effect. These additional requirements will be most significant at above-ground pipework or bends/ tees where thermal expansion can result in high hotspot stresses. Although these issues are likely to be localised, it is recommended that a design review is carried out to determine the number and extent of potential problem areas. A follow-on study is required to assess the hydrogen compatibility of the equipment contained within AGIs. Several international studies are already underway testing the compatibility of transmission network equipment (e.g., National Grid HyNTS (FutureGrid), Gasunie programmes, Hydrogen in Gas Grids (HIGGS), GERG and EPRG hydrogen programmes). Gas Networks Ireland will engage with these programmes to identify if there are unique factors applicable to the Irish networks before undertaking a review of the Irish non-pipe transmission network assets.

4.2.1 Conclusions - hydrogen blend transmission assets review

1. The pipeline steel grades used in the Irish transmission network are all compatible with hydrogen according to international hydrogen pipeline design codes.
2. Approximately half of the transmission system pipe could be used with 100% hydrogen or hydrogen/ natural gas blends at their current design pressure.
3. Transmission pipes requiring qualification testing to allow the current design pressure with greater than 10% hydrogen have been identified. They account for approximately half of the transmission pipe network.
4. A design review will be carried out to identify potential areas where axial stresses may exceed the prescriptive limits in IGEM/TD/1 for hydrogen service.
5. A follow-on study is required to assess the hydrogen compatibility of the equipment contained within AGIs.

4.3 Compressor and interconnector network assets

Most of the natural gas used in Ireland is transported from the UK via subsea interconnector pipelines fed by compressor stations located in Scotland. This section of the report evaluates the effects of hydrogen blends of up to 20% on the Scottish-based compressor stations and the subsea pipelines.

The results of this study indicate that the Beattock and Brighouse Bay compressor station piping, and valves are compatible with hydrogen and in most cases can operate at the current pressures. However, the IGEM/ TD/13 hydrogen supplement (AGI design code) includes additional design requirements for hydrogen service, beyond those relating to hoop stress and design pressure. Specifically, there are prescriptive limits on the allowable axial stress and a large reduction on the allowable fatigue cycles. These additional requirements will be most significant at outdoor above-ground pipework or bends/ tees where thermal expansion could result in high hotspot stresses. Although these issues are likely to be localised, it is recommended that a design review is carried out to determine if such areas exist.

The pipelines between Beattock and Brighouse Bay and from Brighouse Bay to the interconnectors will have limits on operating pressure at blends of more than 10% hydrogen unless materials testing qualifies them to operate at higher pressures.

The subsea interconnectors would both have lower allowable operating pressures if the prescriptive design pressure calculation method were used. A performance-based design method (fracture mechanics/ limit state) design could allow a higher allowable operating pressure, but additional data and materials test work would be required to implement this approach.

4.3.1 Conclusions - compressor and interconnector network assets

Compressor stations:

1. The analysis of the gas-facing piping and fitting materials in Beattock compressor station indicates that all the materials used are compatible with hydrogen service.
2. The materials on a small number of valves at Beattock could not be determined and these will need to be further reviewed before allowing hydrogen to be blended. It is recommended that the valve and elastomer manufacturers and vendors are contacted to obtain more information about these valves.

4. Hydrogen blend assets review

3. In Beattock compressor station some piping design pressures calculated using the TD13 prescriptive approach were found to be below the current design pressure of 93 barg. The current design pressure can be achieved by using a performance based assessment, but materials testing is needed to assess this option.
4. The analysis of the gas-facing piping and fitting materials in Brighouse Bay compressor station indicates that all the materials used are compatible with hydrogen service.
5. For the Brighouse Bay compressor station, all the piping sections' calculated hydrogen design pressures were above the current natural gas design pressure. This is because modern materials with guaranteed fracture control properties were used more extensively in Brighouse Bay compared to Beattock compressor station.
6. Overall, the rotating machinery (turbines and compressors) will be able to operate with blended hydrogen and some modifications will be required for the starting of the gas turbines and tuning for the NOx emissions. The gas turbine enclosure will need to be checked for ventilation and configuration of the gas detectors with the new blended gas composition, however the need for major modification is unlikely.

Pipelines near to compressor stations:

1. The pipelines from Beattock to Brighouse Bay (a 750 mm (nominal diameter) pipeline and a 900mm (nominal diameter) pipeline) have restricted operating pressures in hydrogen service when the prescriptive design method is used. An assessment using the performance-based method (and materials testing) will be needed to allow the current maximum operating pressure of 85 barg to be used once the hydrogen concentration is more than 10%.
2. The onshore sections of the interconnectors leaving Brighouse Bay will have a lower design/ operating pressure in hydrogen service than the current maximum operating pressure if the prescriptive design method is used. For the Interconnector 1 pipeline the decrease is minimal but for the Interconnector 2 pipeline the use of the performance-based design method and thus hydrogen test work will be required to allow it to operate at its original design pressure.

Subsea Interconnectors:

1. Using the prescriptive design method (ASME B31.12 Option A or TD/1), results in a decrease in the Maximum Allowable Operating Pressure (MAOP). To maintain MAOP comparable to today, particularly for the Interconnector 2 pipeline, the analysis indicates that the DNV design code F-101 should be used as a basis and a fracture mechanics design approach (performance-based) will need to be adopted.

4.3.2 Other Considerations

Meters:

Substantial research has been carried out in the EU[8] and UK into the compatibility of domestic and light commercial gas meters with hydrogen / hydrogen blends. Findings from this research indicates that there are no integrity or accuracy issues with a 20% blend of hydrogen. In addition, several large industrial Ultrasonic Meter (USM) meter manufacturers have also stated that their equipment is suitable for a 20% blend. Further compatibility assessments are required for rotary and turbine meter manufacturers.

8 Energies: Domestic Gas Meter Durability in Hydrogen and Natural Gas Mixtures

ATEX:
Blends of up to 20% hydrogen can impact Atmosphere Explosible (ATEX) zoning requirements. The impact on zoning can vary significantly depending on the type of installation. The new IGEM SR25 hydrogen supplement has been developed to help assessment of new and existing infrastructure.

4.4 Recommendations

1. International gas networks, equipment vendors and research organisations are carrying out programmes of work (e.g. HyDeploy and H21) to identify materials within network equipment and to test for hydrogen compatibility. Gas Networks Ireland will review the results of these programmes and apply them to the Irish gas network. Any knowledge gaps identified relating to the characteristics of the Irish gas network, will result in the initiation of further studies to assess the performance of assets and materials not covered internationally. Based on initial assessment, targeted qualification research for residual iron, "gun barrel" material and some polymer grades will be needed.
2. Approximately 52% of the transmission pipeline network will need to be assessed using the performance-based methodology (per ASME 31.12 or IGEM/TD/1) to allow the current maximum operating pressures to be maintained with hydrogen concentrations of greater than 10%. A material testing programme will need to be developed and conducted to inform these assessments.
3. Carry out a design review on transmission and distribution installations to identify potential areas where axial stresses may exceed the prescriptive limits in IGEM/TD/1 and IGEM/TD/13 for hydrogen service.
4. Carry out a study for the equipment contained within transmission AGIs and compressor stations (to allow hydrogen entry). Several studies are already underway testing the compatibility of transmission network equipment (e.g., National Grid HyNTS (FutureGrid), Gasunie programmes, Hydrogen in Gas Grids (HIGGS), GERG and EPRG hydrogen programmes). It is recommended that Gas Networks Ireland engage with these programmes to identify if there are unique factors applying in their network before undertaking the review of the non-pipe network assets.

5. Gas quality and end user implications

5.1 Gas quality and hydrogen

Gas quality and its interchangeability are key considerations for the safe operation of gas appliances. For natural gas, the operating ranges and quality are well established and understood.

Hydrogen is significantly different to natural gas and is not readily interchangeable, so it is not possible to operate current natural gas appliances on 100% hydrogen. However, it is possible to use a blend of hydrogen and natural gas as these mixtures can have similar gas quality characteristics to natural gas. The blend limit is influenced by the properties of the underlying natural gas and the quantity of hydrogen added.

For blends it is important to understand the hydrogen blend limit to ensure that the blend can be analysed accurately to meet the gas quality entry specification requirements for the network, and to ensure that the measurement is suitable for billing requirements.

To provide the background to the differences between hydrogen and natural gas, Table 5.1 compares some key physical and chemical parameters.

As can be seen, hydrogen:

- Is less dense than natural gas.
- Has a significantly wider flammable range with a high Upper Flammability Limit (UFL).
- Has a much faster burning velocity.
- Has a much lower ignition energy.
- Has a lower calorific value compared to natural gas.

Hydrogen blending impacts on traditional gas quality characteristics including Wobbe Index (explained in more detail below), calorific value and relative density. The overall effect of hydrogen is dependent on the quantity of hydrogen present but there are other key factors that also require consideration. For example, the calorific value for hydrogen and any natural gas/ hydrogen blends will always be lower than for natural gas and can impact energy delivery through the network and end-user appliances. In addition, the Wobbe Index decreases with the addition of hydrogen, but the trend is not linear as hydrogen content increases.

Table 5.1 Comparison of characteristics of methane (natural gas) and hydrogen[9]

Property	Unit	Natural Gas (CH_4)	Hydrogen (H_2)
Density	kg/m^3	0.68	0.09
Flammable range	% vol	4.4 – 17.0	4 – 75
Limiting oxygen for combustion	% vol	12	5
Laminar burning velocity	m/s	0.4	3.1
Heat of combustion	MJ/kg	50	120
Heat of combustion	MJ/kmol	800	240
Minimum spark ignition energy	mJ	0.21	0.016
Autoignition temperature	°C	600	560

9 HSE Research Report R1047 "Injecting hydrogen into the gas network – a literature search" JP Hodges, Dr W Geary, Dr S Graham, P Hooker and Dr R Goff (2015 – available from https://www.hse.gov.UK/research/rrhtm/rr1047.htm (accessed August 2022)

In summary, the addition of hydrogen to natural gas lowers the Wobbe number and calorific value and the addition of too much hydrogen could result in a breach of the current acceptable limits of Wobbe Index and calorific value and so needs to be carefully controlled.

5.2 Energy flow and measurement of hydrogen blends

The lower calorific value of hydrogen compared to natural gas means that any change in gas composition through the addition of hydrogen will impact on the energy flow through the gas network. The characteristics of energy flow depend on the operation of the network, but for comparison purposes, if the pressure drop along the pipeline is constant and the flow is steady state, then the energy flow for mixtures of natural gas and hydrogen is shown in Figure 5.1[10] where the 100% value on the y-axis is that for a pipeline operating with natural gas alone.

The addition of hydrogen to natural gas impacts on several key gas quality and interchangeability parameters, network flow capacity and operations, and on combustion characteristics that can influence the stability of burners, combustors and performance of the end-use equipment.

The key factors considered include:

- Energy flow in pipelines.
- Impact on Wobbe Index.
- Impact on burning velocity.

Due to the differences outlined in Table 5.1 between natural gas and hydrogen, new measurement equipment will be required to accurately measure hydrogen blends. This measurement is currently performed using gas chromatographs which take a sample of gas from the network and then analyse the quality of the gas. The analysis is then used

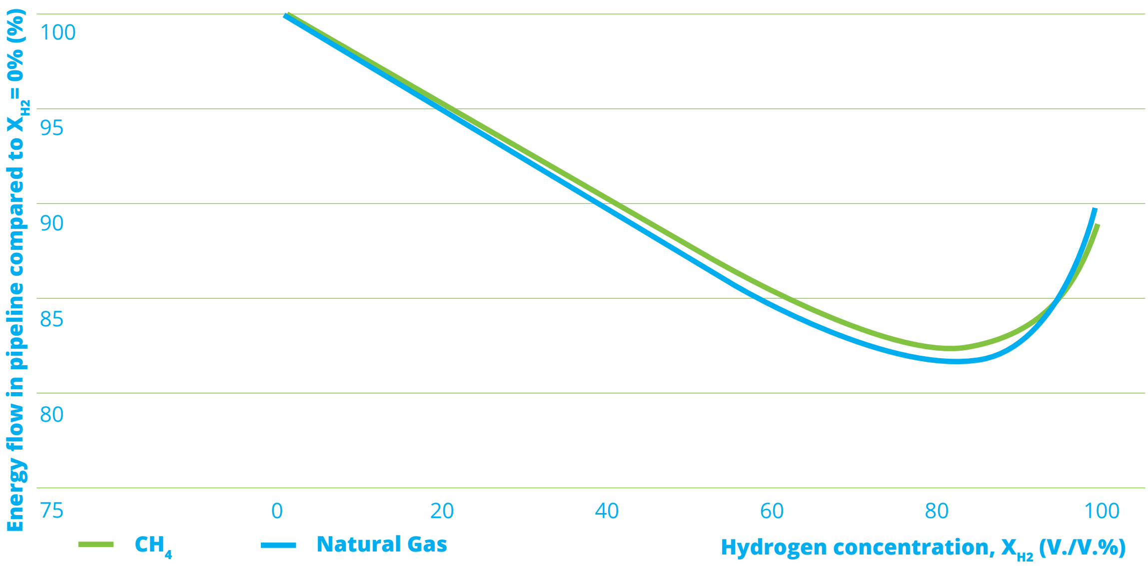

Figure 5.1 Energy flow with variation for hydrogen/ natural g as mixtures (from 100% methane as the normalised level)

10 Quintino, F.M.; Nascimento, N.; Fernandes, E.C. "Aspects of Hydrogen and Biomethane Introduction in Natural Gas Infrastructure and Equipment. Hydrogen 2021, 2, 301–318. https://doi.org/10.3390/hydrogen2030016

5. Gas quality and end user implications

to determine the calorific value of the gas for billing purposes. Older gas chromatographs were designed to operate on natural gas only and can therefore not accurately detect the quality of hydrogen blends.

New technological developments in this field can significantly reduce the costs associated with using gas chromatographs for hydrogen blends and can enable accurate Calorific Value measurement. This has the potential to help support the rollout of blended hydrogen with accurate measurement devices that can be installed across the gas network.

5.3 Hydrogen properties relevant for end-user equipment

Introducing blends of hydrogen into Ireland's gas network will impact on the operation of the end-user combustion equipment. The impact may not solely be a safety consideration, but rather it could be an emissions or efficiency impact and therefore it is important to understand the potential range of effects on the different appliance/ equipment types. Changing the fuel from natural gas to a hydrogen blend could be more challenging in some sectors than in others, but for domestic users there will be little or no impact. In addition, introducing hydrogen blends into the gas network has the benefit of reducing end-user emissions and can help establish a pathway to a cleaner energy future.

For European countries, gas appliances and equipment are certified for use and safety by the Gas Appliances Regulation (EU 2016/426) (GAR(2018)) formerly the Gas Appliances Directive. Currently installed natural gas end-use equipment has been designed, installed, and maintained for a given range of distributed natural gases.

The introduction of hydrogen into natural gas networks changes the chemical and physical combustion properties of the gas delivered which may affect the performance of the end-use equipment. It may result in the equipment operating outside of the range that it was originally designed for.

From a climate action and air quality perspective, lower NOx emissions have been measured when using hydrogen blends in domestic appliances. The presence of hydrogen can also influence the concentration of carbon monoxide (CO) in the flue gas. Several studies have shown that CO emissions decrease when hydrogen is added. This could lead to an additional safety benefit as well as lower carbon dioxide emissions.

Furthermore, the allowable proportion of hydrogen blends in natural gas networks depends strongly upon both the type of appliances installed in the field and the distributed natural gas composition.

In Table 5.2, a selection of physical and chemical properties of natural gas/hydrogen blends are shown.

Table 5.2 Physical and chemical properties of methane/hydrogen blends

CH_4 [mol%] Temperature	H_2 [mol%] Value	Burning Velocity [11]	Adiabatic Flame Limit [K][12]	Gross Calorific [MJ/m^3][13]	Net Calorific [MJ/m^3][14]	Lower Explosive Limit [vol% in air]	Upper Explosive Limit [cm/s] [vol% in air]
100	0	35.0	2,228	37.78	34.01	4.9	15.0
98	2	35.5	2,228	37.26	33.53	4.8	15.2
95	5	36.2	2,230	36.49	32.82	4.8	15.6
90	10	37.6	2,232	35.20	31.62	4.8	16.3
80	20	40.5	2,238	32.62	29.23	4.7	17.9
70	30	44.5	2,244	30.05	26.85	4.6	19.7
0	100	250.0	2,384	12.10	10.22	4.0	75.6

Note 1: the calorific values are for reference conditions of: 15 °C (288.15 K) and 1013.25 mbar (101.325 kPa)
Note 2: the table shows adiabatic flame temperatures for comparison purposes.

5.4 Gas specifications for networks

Any natural gas-hydrogen blend must always comply with the gas specification relating to the individual gas network. If gas composition is already at the lower limit of the gas specifications (such as Wobbe Index), then hydrogen cannot be blended in as it would further reduce the gas quality below these lower limits.

For example, for industrial, commercial and domestic burners, the Wobbe Index[15 16] is an important parameter because the thermal input for most of the end-use equipment is directly proportional to the Wobbe Index. For this reason, the Wobbe Index of the gas should always be within the gas specification.

Wobbe Index is defined as:

$$\text{Wobbe Index} = \frac{\text{Gross CV}}{\sqrt{\text{RD}}}$$

Where RD is relative density of the gas and Gross CV is the volumetric gross calorific value [MJ/m^3].

In summary, gas entering the network is required to meet the Wobbe Index set out in Gas Networks Ireland code of operations Part G17. Blending hydrogen will reduce the Wobbe Index and could have an impact on end-users. Therefore, it is essential to monitor this pre and post hydrogen injection to ensure the Wobbe Index stays within the established Code of Operations limits.

11 Calculated for stoichiometric fuel/air composition using the Premix code of the CHEMKIN II package (Kee, R.J., F.M. Rupley, and J.A. Miller,"CHEMKIN II: A Fortran Chemical Kinetics Package for the Analysis of Gas-Phase Chemical Kinetics," 1989.) and USC II mechanism (Wang, H.,You, X., Joshi, A.V., Davis, S.G. et al., "USC Mech Version II. "High-Temperature Combustion Reaction Model of H2/CO/C1-C4 Compounds,"http://ignis.usc.edu/USC_Mech_II.htm)
12 TECOM: Program for calculation of equilibrium composition (3.04), A.V. Mokhov, November 1997
13 DNV GL Oil & Gas UK, GasVLe: Software package that calculates the properties of gases, liquids and dense fluids (Excell Add-in Version 3.6), DNV GL, https://www.dnvgl.com/services/gasvle-8331, 1985-2016
14 DNV GL Oil & Gas UK, GasVLe: Software package that calculates the properties of gases, liquids and dense fluids (Excell Add-in Version 3.6), DNV GL, https://www.dnvgl.com/services/gasvle-8331, 1985-2016
15 International Organization for Standardization, "Natural gas- Calculation of Calorific values, density, relative density and Wobbe Indices from composition," ISO 6976:2016, International Organization for Standardization (ISO), Rev. Aug.2016
16 International Organization for Standardization, "Natural gas- Vocabulary," ISO 14532:2014, International Organization for Standardization (ISO), Rev.Feb. 2017

5. Gas quality and end user implications

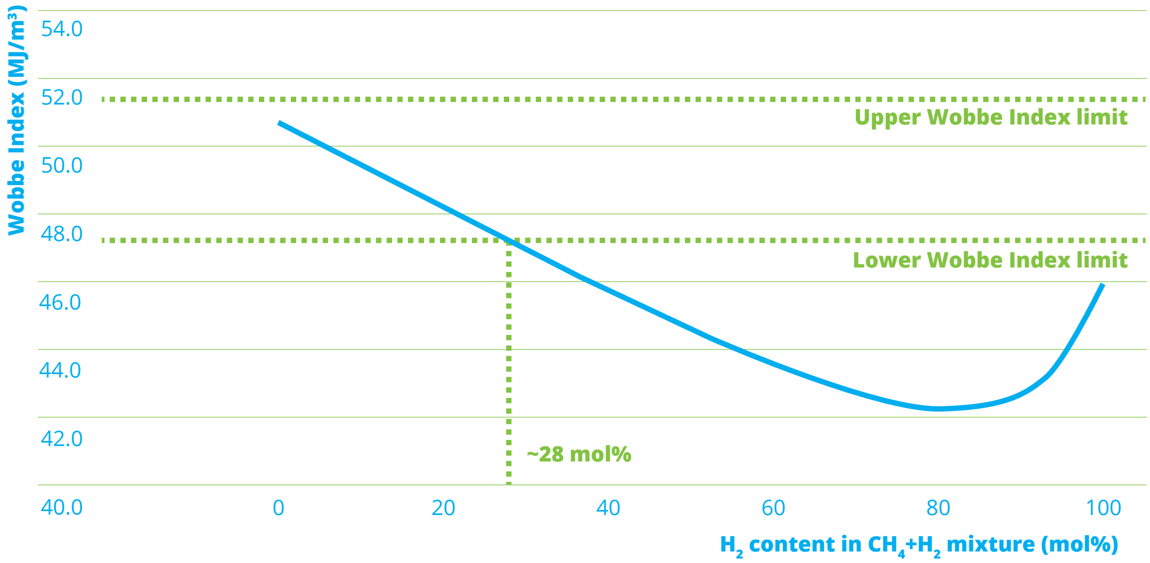

Figure 5.2 Effect of hydrogen addition to methane on Wobbe Index of the mixture.

Note: The Wobbe Index limits are taken from Gas Networks Ireland's Code of Operations Part G Appendix 1[17]

5.5 Testing of blends of hydrogen and natural gas (HyTest)

In 2022 Gas Networks Ireland undertook a joint research project with the UCD Energy Institute to test and demonstrate the safe operation of natural gas appliances using blends of hydrogen. The lead researcher for the project was Dr Ali Ekhtiari of UCD Energy Institute, under Dr Eoin Syron of the School of Chemical and Bioprocess Engineering in UCD and the UCD Energy Institute. The project was supported by Gas Networks Ireland's Gas Innovation Fund.

This project evaluated the safety and operational performance of existing domestic gas appliances with increasing hydrogen concentrations in blends with natural gas (2%, 5%, 10%, 15% and 20% hydrogen).

For a range of natural gas and hydrogen mixtures, this project investigated the calorific value (CV) of the mixture, performed leak and safety testing, evaluated metering accuracy, conducted flue gas analysis, compared flame pictures and checked operating pressure and flow rate variables.

The overall objectives were to assess if:

1. Supplying a mixture of hydrogen and natural gas is a safe, secure and sustainable gaseous fuel for use in the residential market.
2. Domestic end-user equipment continues to operate over the range of hydrogen concentrations tested without any safety or operational issues.

17 See web-site: https://www.gasnetworks.ie/docs/corporate/gas-regulation/PART-G-(Technical)-_(final-clean)-Version-5.03-_.pdf accessed 21 October 2022

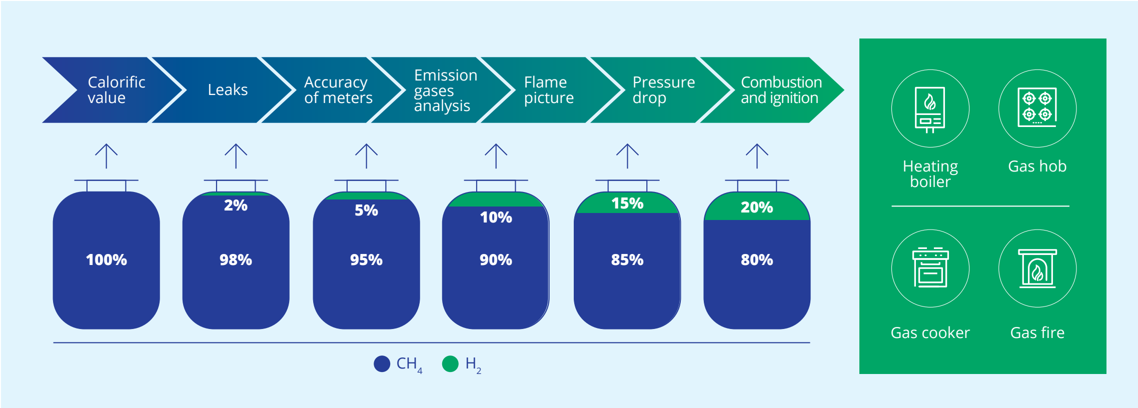

Figure 5.3 Overview of the hydrogen blend and the tests carried out in the HyTest project.

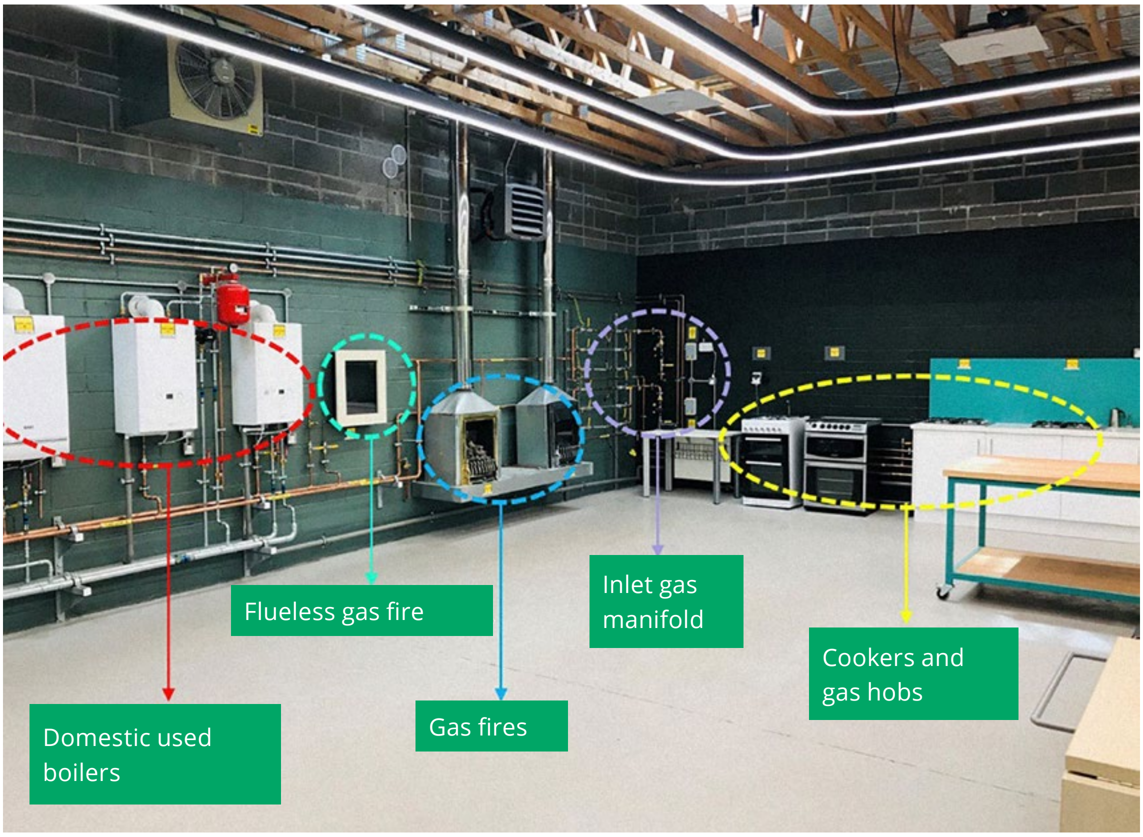

Figure 5.4 The Gas Networks Ireland's Network Innovation Centre

5. Gas quality and end user implications

The conclusion of the project was that hydrogen has the potential to be directly blended and used for domestic end-use. The study showed no significant changes in operational variables such as pressure and flow rate using hydrogen blends. Focusing on the assessment of the safe operation of domestic gas appliances with hydrogen blends (up to 20%), the key findings were:

- The domestic gas appliances tested operated safely and effectively with various hydrogen blends tested ranging from 2% to 20% hydrogen by volume.
- There was a substantial emissions reduction obtained by blending hydrogen with natural gas.
- The average emission reduction found was a 12% reduction in CO_2, a 37% reduction in CO, a 43% reduction in the CO:CO_2 ratio, and a 40% reduction in NOx emissions.
- There were no changes observed in the minimum operating pressure of appliances while burning the hydrogen gas blends.
- No leakage was detected during pre-testing or during operations for all pipework, connections, fittings, and valves at operating pressure.
- The domestic gas flow meter was consistently accurate when used for measuring gas volume flows containing up to 20% hydrogen compared to natural gas.
- The flame motion and colour of the hydrogen gas mixtures stayed similar to natural gas.

For further information on this research project see the report 'Testing of Blends of Hydrogen and Natural Gas (HyTest)' in Appendix B.

5.6 End-user equipment compatibility

Gas specifications also form the basis for the manufacturer of end-use equipment such as appliances, burners, furnaces, process plants, gas engines and gas turbines. Meeting these specifications is essential in order to guarantee the performance and maintenance intervals of the equipment.

The evidence indicates (in technical papers on combustion and from the HyDeploy and THyGa studies) that the blending of up to 20% hydrogen by volume is acceptable for most domestic and commercial appliances. The recent research study by the UCD Energy Institute at Gas Networks Ireland's Network Innovation Centre found that the domestic appliances tested operated safely and effectively with hydrogen blends up to 20%. However, there may be some equipment that are less tolerant than others. Understanding of the limits of hydrogen blending may not only be influenced by the burner type in the appliances but may also be linked to gas quality limits.

The following applications require further consideration:

- Gas engines.
- Gas turbines.
- Industrial and commercial combustion equipment.

Gas Networks Ireland will also evaluate whether "deblending" could be a technical option to safeguard existing large users if they cannot accept hydrogen blends.

5.7 Conclusions

1. Hydrogen blends can be interchangeable but there may be an inherent limit to the hydrogen content.
2. The underlying natural gas quality can impact on the acceptable quantity of hydrogen that can be blended with it.
3. It is likely that the newer, existing gas chromatographs will be able to analyse hydrogen blends. The older gas chromatographs will not be able to measure the blends.

5.8 Recommendations

The following recommendations will help accelerate end-user readiness for hydrogen blending and the hydrogen transition.

1. Monitor developments on projects such as HyDeploy and THyGa as they will provide further clear evidence on the safe operation of combustion equipment when using hydrogen blends for a wide range of equipment sizes and scales.
2. Monitor developments on hydrogen blend projects from the EU, UK and elsewhere. There are some new projects starting that will provide additional information that could support the development of hydrogen blending in Ireland.
3. Further develop the testing facilities at the Network Innovation Centre to study the impact of blends and potentially look to extend the operating range for safe utilisation of hydrogen blends. Provide further studies on emissions, especially NOx and assess if they are compliant with current legislation. Extend knowledge of the impact of blends on efficiency, operability and equipment life.
4. Undertake a live trial demonstration project building on the experience from HyDeploy and other projects, to provide further information on the suitability of hydrogen/ natural gas blends, to complement the technical studies and laboratory trials. The laboratory studies provide the background technical information and detailed results on appliance performance and the live trial will supplement this with longer term impact studies. There is additional benefit and valuable information that can be obtained from a live trial extending the current knowledge regarding combustion equipment and appliances in an operational environment.
5. Continue to gather information on the industrial and commercial combustion equipment installed in Ireland and extend the understanding of the impact of hydrogen blends on existing installations, to establish if upgrades or conversion of equipment is possible, or if replacement or other solutions would be required. Testing and trials of hydrogen/ natural gas blends on industrial and commercial equipment may be required.
6. Further research the gas engine and gas turbine practical limits for hydrogen blends. Examine whether deblending could be a technical option for specific end users.
7. Work with existing gas chromatograph manufacturers regarding the potential upgrade of existing gas chromatographs or options for updated analysis.

6. Standards development

The publication of hydrogen blending standards is currently under development. It is expected that during the next 12-36 months this area will progress significantly given the early activity in this area by the relevant standards bodies in Ireland and further afield.

6.1 Irish and European standards bodies

Standards relating to the safety of the natural gas transmission and distribution networks in Ireland are the responsibility of the Gas Technical Standards Committee (GTSC) in the National Standards Authority of Ireland (NSAI). The GTSC mirrors several CEN Technical Committees, responsible for the development of European Standards including CEN/TC 234 'Gas Infrastructure' and CEN/TC 237 'Gas meters':

- CEN, the European Committee for Standardisation, is responsible for the development of European Standards (EN's) in various sectors, including the gas sector, for the European single market.
- NSAI, as the national standards body for Ireland, is a member of CEN and experts from Gas Network Ireland and other industry stakeholders in Ireland participate on the standardisation committees.

6.2 Existing standardisation work

CEN/TC 234 has completed a review of its standards to determine the updates required to accommodate hydrogen and hydrogen blends on gas infrastructure (including gas quality, gas transmission networks, gas distribution networks, and related safety considerations). This review is summarised in CEN/TR 17797 'Gas infrastructure - Consequences of hydrogen in the gas infrastructure and identification of related standardisation need in the scope of CEN/TC 234' which acts as a guideline for future standardisation work within TC 234.

The GTSC will continue to monitor and contribute to the Standardisation work of TC 234, and other Technical Committees (TCs) as necessary, to ensure safety requirements appropriate to the Irish gas networks are considered appropriately. The GTSC may also, as part of this work, propose the development of national standards and amend existing national standards in line with the changes to European standards and to provide more detailed guidance where necessary for the Irish market, consistent with the published European standards.

The inclusion of hydrogen requirements into all relevant European gas infrastructure standards will take a number of years, but there are published standards from other jurisdictions and within EU member states that may be appropriate for use on an interim basis.

In March 2021 the Gas Safe Register in the UK issued 'Technical Bulletin 159: Natural gas standards when working on domestic installations being supplied with natural gas containing up to 20 vol% hydrogen', which had been developed by BSI, IGEM, HHIC and Progressive Energy. An industry review of standards and competencies as it relates to domestic installations and appliances formed the basis of this technical bulletin. The review demonstrated that no change to domestic natural gas installation standards is required to account for the impacts associated with the introduction of a 20 vol% hydrogen blend within natural gas supplies.

Significant progress has been made on the development of 100% hydrogen standards for end-user utilisation. In June 2022 IGEM updated their reference standards for low pressure utilisation (IGEM/H /1). Work is ongoing on additional standards for both domestic and nondomestic hydrogen installations. In 2021, the British Standards Institution (BSI) updated its standard PAS 4444 for hydrogen-fired gas appliances. IGEM are also working with BSI on a series of additional installation standards for 100% hydrogen which will provide specifications for internal pipework, regulators, fittings and other installation devices and components. The percentage blend of hydrogen / natural gas has an impact on the application of standards to the transmission and distribution network. For example, IGEM Transmission Standards require the partial application of hydrogen requirements for blends but the full application of the hydrogen requirements when the blend percentage exceeds 10% (i.e. blends above 10% are treated as 100% hydrogen). However, for IGEM Distribution Standards blends up to 20% are treated differently from 100% hydrogen.

Whilst further development is needed on standards for hydrogen blends, standards such as ASME B31.12 for 100% hydrogen have been available and utilised safely within the industry for many years. This proven track record has evidenced that further standards for blended hydrogen can be safely developed from an existing knowledge base.

The IGEM and the CEN are both reviewing the standards database with a view to updating these for hydrogen blends. In addition to this, the NSAI are also tracking the development of hydrogen standards for industrial users.

6.3 Developing European blending standards

CEN currently have two standards focussed on hydrogen blends which are currently under approval. These are:

- prEN 17928-1 – Injection stations Part 1: General Requirements.
- prEN 17928-3 – Injection stations Part 3 Specific requirements regarding the injection of hydrogen fuel gas.

prEN 17928-1 provides detail on the functional requirements of stations for the injection of biomethane, substitute natural gas (SNG) and hydrogen fuel gas into gas transmission and distribution systems. The standard describes the general approach including all the relevant functions that can be installed in different configurations. It also applies to refeeding stations that feed such gases back into the upstream gas supply networks.

prEN 17928-3 specifies the functional requirements of stations for the injection of hydrogen fuel gas into transmission and distribution systems. This standard complements part 1 by specifying the technical safety requirements to be observed in relation to the chemical and physical properties of hydrogen fuel gas. The standard also describes how to handle hydrogen measurement during the injection process.

Both prEN 17928-1 and prEN 17928-3 standards are currently at an "under approval" status with CEN and are likely to be published in the second half of 2023.

In addition to new standards, the CEN 234 working group are undertaking a programme of work to update existing standards for hydrogen and hydrogen blends.

6. Standards development continued

6.4 Implications for blending in Ireland

The currently available hydrogen standard supplements from IGEM and those in the latter stages of the drafting and approvals processes are considered suitable for the short-term solution to support the required update of Gas Networks Ireland's Document Management System (DMS). These standards are likely to be the most comprehensive set of hydrogen blend transmission and distribution standards immediately available.

6.5 Recommendations

1. Assess the utilisation of IGEM standards against the Gas Networks Ireland DMS and existing infrastructure. This approach will then be further assessed within the context of any future planned hydrogen blend trials undertaken by Gas Networks Ireland.
2. Continue ongoing collaboration with NSAI and CEN and regularly source information on draft and published standards to ensure all available approaches can be considered as the hydrogen blend landscape changes.

7. Operational arrangements

Certain existing procedures for the gas distribution and transmission network will need to be amended to enable the safe distribution of a hydrogen blend in the gas network. This section of the report provides a high-level overview of the operational impact hydrogen will have on existing relevant procedures.

7.1 Gas Networks Ireland approach

Gas Networks Ireland has a large suite of procedures for natural gas that will form a solid basis for the revision of procedures to allow for hydrogen blends. Trials within the wider industry are providing the required learning that will allow Gas Networks Ireland to undertake a review and update the procedures contained within its DMS.

In the UK, successful blending trials have been completed by various gas distribution networks and Gas Networks Ireland believe that it also has the capabilities to undertake such trials. It is recommended that a trial is carried out following the same methodology as has been undertaken in the UK. Based on the approach taken and outcome observed, it is expected that the development of a set of procedures for use of hydrogen blends in Ireland is achievable.

7.1.1 Odorisation

HyDeploy has identified that odour intensity at a distribution level will not be adversely impacted by introducing hydrogen blends up to 20%. However, Gas Networks Ireland inject odorant on the transmission network so this variation will be assessed to identify any potential issues associated with the blending of hydrogen at transmission level.

7.1.2 Leak Management

Gas Networks Ireland leak management processes and procedures will need to be updated to reflect the impact of hydrogen blending on the behaviour of internal and external gas escapes to ensure that leaks can be managed safely.

7.1.3 Gas detection equipment

Existing gas detection equipment will need to be modified or replaced to ensure that it accurately measures flammable concentrations of gas in air. Equipment that is current used to measure CO concentrations may also need to be modified or replaced since the sensors that currently detect/measure CO are cross-sensitive to hydrogen.

7.1.4 ATEX zoning and equipment

The blending of hydrogen into natural gas is known to impact on the extent of ATEX hazardous areas (zones). Existing zones will require to be recalculated and the signage that currently displays their extent will require replacement. Equipment that is currently certified for use within areas zoned for natural gas may require modification or replacement to enable them to be used safely in areas where there is a possibility of hydrogen release.

7.1.5 Downstream

Gas installers working on domestic and industrial/ commercial pipework, appliances and equipment may require upskilling to ensure that they are competent in relation to the behaviour of appliances and equipment operating on a hydrogen/ natural gas blend.

7. Operational arrangements continued

7.2 Recommendations

1. Identify options for investing in new gas detection equipment to ensure they are 'hydrogen ready'.
2. Carry out a full assessment of Gas Networks Ireland's procedures to understand how many may be impacted by a blend.
3. Carry out an assessment of how changes to hazardous area zoning could impact transmission and distribution installations.
4. Consideration must be given to any additional training requirements following the review and adaption/development of hydrogen blend procedures and modification/replacement of equipment. Operatives working on Ireland's gas infrastructure as part of emergency or maintenance works, will likely require additional training to ensure correct application of the amended/developed procedures.
5. Undertake research to identify any potential issues on the odour intensity of odourised natural gas associated with the blending of hydrogen at transmission level.

8. Green hydrogen injection facilities

8.1 Hydrogen production from electrolysis

Green hydrogen typically refers to hydrogen produced using renewable electricity. In most of the green hydrogen projects planned within the EU and the UK, the green hydrogen will be generated using a technology called electrolysis. Electrolysis stacks are available at all sizes from laboratory scale up to several megawatt (MW) in capacity with the largest plants varying between 10-100 MW in size (e.g. ReHyne and RefHyne2 projects). Given the rapid scale up in ambition for green hydrogen across the EU, projects deploying gigawatt (GW) scale arrays of units are now being proposed.

The hydrogen produced from electrolysis is of extremely high purity and can be delivered at pressures up to 30 barg. New stack designs are expected to increase this to 70 barg or more in the next few years. A further feature is the ability of electrolysis plants, particularly PEM based ones, to respond rapidly to load changes, and stack lifetime (5-10 years) can be improved if the cells operate at steady conditions.

Potential challenges for an electrolyser-based injection plant are provision of sufficient power and water, likely to be 0.5-1 MW and 3,500-6,500 litres/day for a 1,000-house trial. Therefore, the location of the electrolyser plant must be close to suitable utility supplies and to pipes that can transport the hydrogen to the injection site.

8.2 Green hydrogen injection into gas networks

Hydrogen injection requires careful consideration of flows, pressures, hydrogen quality, control of the mixing process and accurate measurement and monitoring of the blend and its energy content. The strategies to ensure production of a well-mixed blend need to take account of the underlying gas quality of the natural gas and the potential for the gas to then contain up to 20% hydrogen. Facilities that manage this process are called Hydrogen Blending, Injection and Control Systems (HBICS).

Gas Networks Ireland carried out an assessment of injection projects that have successfully demonstrated hydrogen blending. There is sufficient guidance on HBICS to support their safe implementation including considerations for associated operations such as filtration/purification, compression, storage, pressure regulation, metering, mixing, flow ratio control, gas quality, bypass, odorisation, pipework, valves, electrical and ATEX equipment and ancillary equipment within the station. During this research several HBICS suppliers were identified.

For blends up to 20% and for 100% hydrogen, specific hazardous area zoning will be carried out because the hazardous area zones associated with increased percentages of hydrogen have found to be larger than for natural gas alone. There is a method available for completing this zoning using the IGEM SR/25 Edition 2, Supplement 1 (Hydrogen).

Injecting green hydrogen into a natural gas network has been successfully demonstrated in GB by the HyDeploy project at Keele University from 2019 to 2021. The HyDeploy2 project also injected hydrogen into the gas network at Winlaton from August 2021 to June 2022 but in this case grey hydrogen (produced from fossil fuels without CCS) was used.

Both these trials were at small scale with hydrogen being injected at up to 20 vol% concentration into an isolated section of the gas network serving a limited number of customers. This meant that gas appliances connected to the test networks could be tested prior to encountering hydrogen blends. Green hydrogen injection trials have also been undertaken in the Netherlands, Germany and France.

Green hydrogen blending trials are currently under development and underway in Canada and in South Australia.

8. Green hydrogen injection facilities

Figure 8.1 HyDeploy injection facility

8.3 Injection location(s)

- Although not directly a factor in the assessment of the technical feasibility of safely injecting hydrogen into the natural gas network, the location(s) at which hydrogen is injected into the existing natural gas network will nonetheless need careful consideration as part of a wider national hydrogen strategy.
- Hydrogen injected into the transmission network could reasonably be expected to reach all (or at least a very large number of) gas consumers depending on the entry point, including power generation, large industrial/ commercial customers supplied directly from the transmission network as well as smaller industrial/ commercial and domestic customers supplied from distribution networks that are, in turn, supplied from the transmission network.
- Hydrogen injected into the distribution network would only reach those consumers who are fed from the distribution network. Since distribution networks are generally smaller, to achieve hydrogen blending at scale, multiple distribution networks would each require their own injection point(s).
- Hydrogen injected upstream (either in a transmission or distribution network) could prevent the injection of further hydrogen at downstream locations i.e., once the blended gas contains the maximum allowable percentage of hydrogen, no further hydrogen can be added to the gas stream. Similarly, hydrogen injected downstream could preclude the injection of hydrogen at an upstream location.
- The location of the injection point(s) is also dependent upon where the hydrogen is produced. Since it is unlikely that the optimum location(s) for hydrogen production will be coincident with the optimum location(s) for injecting hydrogen into the gas network, then that hydrogen must be transported from its

point of production to its point of injection. The more injection points that exist, the greater the infrastructure required to transport the hydrogen to them for injection into the gas network.

- Ensuring that the percentage of hydrogen in the natural gas blend does not exceed allowable limits is a key safety consideration and will require demonstration as part of the safety assessment. Injection of hydrogen at a point(s) on the gas network where there is an assured mono-directional flow of natural gas may be advantageous in this demonstration and is a further consideration in the selection of suitable injection points.
- The consistency and reliability of the blended mixture may also be an important factor, particularly for billing purposes and for some industrial/ commercial and power generation equipment which may be sensitive to variations in gas quality, even within allowable limits.

8.4 Conclusions

1. 20 vol% hydrogen injection into the GB natural gas system has been safely demonstrated at two locations in GB by the HyDeploy project. One of these trials used green hydrogen.
2. A modification to the Code of Operations Part G Technical (Appendix 1) will be required to permit transport of hydrogen through the Irish gas network.
3. Trials to date in GB have been at small scale and limited to self-contained sections of the gas distribution network which could be closely monitored.
4. Large scale hydrogen injection at transmission system level will need to take account of all users likely to encounter hydrogen and address issues such as mixing with non-blended and non-conventional gases and the effects of potentially variable hydrogen blends on domestic, commercial, industrial and power generation applications. Solutions such as deblending may be needed if large sensitive users are unable to accommodate hydrogen.
5. Diurnal and seasonal changes in gas consumption can lead to a wide range of gas flows in a network which in turn will lead to a wide range of hydrogen injection flows to achieve a particular blending requirement.
6. Ensuring that the percentage of hydrogen in the natural gas blend does not exceed allowable limits is a key safety consideration and will require demonstration as part of the safety assessment.
7. The location(s) at which hydrogen is injected into the existing natural gas network will require careful consideration as part of a wider national hydrogen strategy.

HBICS to further define its process and material requirements and produce a highlevel cost estimate for the facility.

8.5 Recommendations

1. Develop a conceptual design for a Hydrogen Blending, Injection and Control Station.
2. Develop blending procedures to ensure the safe operation of the blending equipment and maintain the consistency and reliability of the blended mixture within allowable limits.

9. Safety assessment strategy

This section of the report describes the safety and risk assessment impacts of introducing hydrogen blends into Ireland's gas networks. It looks at the evidence required to develop the necessary safety demonstrations, gaps in the existing evidence and prospects for how those gaps will be filled.

Although the safety regulatory arrangements for the existing natural gas network are well understood and will continue to apply to hydrogen that is blended into it, there is currently no established regulatory framework (other than the occupational health and safety framework) that covers the wider hydrogen value chain from hydrogen production, hydrogen transportation, hydrogen storage through to end-use requirements. Since hydrogen blending into the natural gas network at scale will involve production, storage and transportation of 100% hydrogen, this aspect needs to be determined.

Gas Networks Ireland has four safety cases in place covering the Irish transmission network, the Irish distribution network, Northern Ireland, and the SWSOS Pipeline System. Safety cases are documents used to demonstrate to all stakeholders that appropriate risk control measures are in place. These documents identify how risks are managed to levels termed ALARP.

A new safety assessment will need to be prepared prior to each stage of hydrogen blending taking place.

The Safety Assessment Development Strategy consists of two aspects:

1. Staged approach to hydrogen blending.
2. Implementation plan.

9.1 Staged approach to hydrogen blending

A staged approach is recommended to the introduction of hydrogen blending as this will gradually increases the complexity of the gas system affected and increase the knowledge and confidence of the system operator. Evidence will need to be gathered to support each of the safety assessments. The Technical and Safety Roadmap in Section 11 of this report outlines timelines for delivery of the relevant safety assessments to support hydrogen blending plans.

9.2 Evidence required for a safety assessment /ALARP demonstration

The gas quality specifications in Ireland, NI, IoM and GB all limit the hydrogen content of gas to 0.1 mol%. The HyDeploy Keele and Winlaton hydrogen blending trial projects successfully applied to the GB HSE for an exemption from this requirement (under the UK's GS(M)R). A similar safety assessment is needed to enable higher hydrogen content for the purpose of blending trials in Ireland, in co-operation with the appropriate safety regulatory authorities.

Based on the HyDeploy Keele and Winlaton trials, a submission to the regulatory authorities could include the following:

1. **Safety Assessment/ALARP Report:** A detailed and systematic demonstration that it is safe to increase the limit on hydrogen content for the purpose of blending trials.
2. **QRA:** Quantitative Risk Assessment for distribution trial including domestic end use of a hydrogen blend.
3. **Network Information:** Data relevant to the trial area should be gathered. In-property surveys may be required.

4. **Gas Characteristics:** Leakage, dispersion and flammability based on the latest research.
5. **Materials:** Review of how materials within the gas distribution network may be affected by contact with hydrogen blends. This may be limited due to the evidence generated from HyDeploy, much of which is outlined elsewhere in this report.
6. **Appliances:** Review of how the local appliance population may be affected by hydrogen blends.
7. **Trial Management:** Governance and operational philosophy.
8. **Procedures**: Review of upstream Customer Isolation Valve (before CIV) and downstream (after CIV) procedures.
9. **Project Review:** Summaries of how similar projects can add to the evidence base.

In addition to the above, the HSE has also produced a document which sets out the 'Evidence requirements for converting a trial area to hydrogen', which states:[18] *"The aim of this document is to provide networks with details of the scope, format and vital thematic areas of evidence that they should submit to provide assurance of safety before operating 100% hydrogen trials"*. Gas Networks Ireland recommend using this document to support a hydrogen blend safety risk assessment for blending projects in Ireland.

9.3 Recommendations

1. Engage with relevant safety regulator(s) to establish and agree the scope, format and evidence that should be submitted to provide the required assurance of the safety of hydrogen/ natural gas blending under the relevant safety legislation in each jurisdiction.
2. Commence evidence gathering for demonstration blending pilot and national safety risk assessments for Ireland's gas network.
3. Conduct a QRA to identify the safety assessment requirements for a distribution blending pilot.

18 Evidence for converting a trial area to hydrogen

10. Regulatory assessment

10.1 Regulatory jurisdictions

Gas Networks Ireland operates in Ireland, Great Britain, Isle of Man and Northern Ireland and this section of the report covers the relevant gas regulations applicable to hydrogen blending in each of the four jurisdictions. Since, in practice, gas is increasingly flowing from Great Britain into the Isle of Man, Northern Ireland and Ireland, Gas Networks Ireland has taken the prudent step of adopting the principles set out in the Gas Safety (Management)

Gas Networks Ireland has reviewed the applicable regulations and requirements of the relevant regulatory jurisdictions outlined in Figure 10.1 opposite to determine if changes are needed for the introduction of hydrogen blended natural gas. The outcome from this regulatory review will inform key research and evidence required to develop Gas Networks Ireland's technical and safety hydrogen roadmap.

Gas Networks Ireland, is the state-owned body which owns, operates, develops and maintains the natural gas network in Ireland. Gas Networks Ireland and its subsidiary Gas Networks Ireland (UK) Ltd hold licences from the regulatory authorities[19]. The independent energy regulator in Ireland is the Commission for Regulation of Utilities[20] (CRU) and they are responsible for economic regulation, gas safety, security of supply and consumer protection. The Utility Regulator (UR) is the regulator in Northern Ireland and the Office for Gas and Electricity Markets (Ofgem) regulates UK operations.

Ireland is also an EU Member State, and it has obligations under EU Regulation 2017/1938[21] to be part of an interconnected and secure European gas system which includes gas quality. However, since the United Kingdom left the EU in January 2020, the Irish gas network is no longer connected to the EU gas market.

10.2 Ireland

Regulatory Compliance Framework - Ireland

Gas Networks Ireland hold the following CRU Licences in Ireland:

- Transmission system operator
- Transmission system owner

UR licence in Northern Ireland

- Gas Conveyance Licence for GNI (UK) Ltd.

Ofgem Licence

- GNI (UK) Ltd interconnector licence.
- Gas Networks Ireland Interconnector licence.

Natural gas meets over 30% of Ireland's energy needs by providing heat and power for more than 720,000 homes and businesses. Also, circa 50% of electricity generation is fuelled by natural gas. Traditionally, natural gas has been supplied by a combination of domestic production and imports from Scotland. By the mid-2020s, 80% of Ireland's gas is likely to be imported and over 90% will be imported from Scotland by 2030.

Maintaining security of supply and decarbonising the gas networks are energy policy objectives for the Irish government. As previously noted, to meet decarbonisation targets, changes are required in the gas quality specification to allow for renewable gases such as hydrogen to enter the Irish gas network.

19 Gas Networks Ireland regulatory compliances are summarised here: https://www.gasnetworks.ie/corporate/gas-regulation/system-operator/
20 Commission for Regulation of Utilities https://www.cru.ie/
21 Regulation (EU) 2017/1938 concerns measures to safeguard the security of gas supply https://eur-lex.europa.eu/eli/reg/2017/1938/oj

Figure 10.1 Regulatory jurisdictions for Gas Networks Ireland assets and operations.

10. Regulatory assessment

In 2008, a Common Arrangements for Gas (CAG) consultation[22] investigated options for a set of common operational arrangements to facilitate a gas transmission system for both Ireland and Northern Ireland as part of the overarching legislative framework set out by the European Commission. The aim was to promote cross border trading and interconnectivity of European gas networks, including the gas networks in Great Britain. In 2009, the Commission for Energy Regulation (now CRU) published its decision paper[23 24] on the Gas Quality Industry group's report. The consultation had concluded that the gas specification prior to 2009 was too wide and the Commission decided to adopt the tighter Gas Safety (Management) Regulations – Schedule 3 used by Great Britain. There were three reasons:

1. **Safety:** Ireland had effectively been operating within the GS(M)R gas quality specification and experience had shown that there were no safety issues associated but there were potential safety issues outside the GS(M)R range. However, the Commission was "*cognisant of the opinions expressed by some members of the group that a range slightly wider than the GS(M)R could be adopted without raising safety concerns.*"
2. **Gas-fired power generation:** Gas quality is an important issue for gas-fired power generators, and it was generally agreed that the Wobbe Index should be brought in line with GS(M)R as a minimum. Rates of change in gas quality were also a concern and these could also be better controlled under the tighter GS(M)R gas quality specification.
3. **Northern Ireland alignment:** Given the rationale that the specification should be narrowed in line with GS(M)R, it made sense to align with the specification in Northern Ireland.

The Commission concluded that gas quality entry and exit specifications to the Irish transportation system (both transmission and distribution) needed to be modified and based on GS(M)R. The Irish network entry specification is now based on GS(M)R and detailed gas quality requirements are set out in the Irish Codes of Operation; these Codes are the highest authority in Ireland for gas quality and any changes of these Codes needs to be approved by the CRU.

Unlike the UK, the Codes of Operation are not primary legislation, and for this reason it should be quicker to change the gas specification in Ireland than in the UK although safety of consumers, employees and the public remain the paramount concern in both jurisdictions.

The Irish gas specifications as set out in the Codes of Operation are shown in Table 10.1 Table 10.1 Hydrogen is currently limited by an explicit statement to 0.1 mol%.

One important difference between GS(M)R and the Codes of Operations is the Irish requirement to odorise the whole system, whereas the GB requirement only applies below 7 bar. Thus, gas leaving Scotland from the National Transmission System is odorised at the Irish interconnector entry point at Moffat.

22 Common Arrangements for Gas discussion paper https://www.uregni.gov.UK/files/uregni/consultations/CAG_Operations_OC.pdf
23 Commission for Energy Regulation paper on a single approach to gas quality(draft) https://www.cru.ie/wpcontent/uploads/2009/07/cer09035.pdf
24 Commission for Energy Regulation Common Arrangements for Gas Final Report on the Requirementsfor a Single Natural Gas Quality Standard for Northern Ireland and Ireland CER/09/037 https://www.cru.ie/wpcontent/uploads/2009/07/cer09037.pdf

Table 10.1 Gas Networks Ireland gas entry specification based on schedule 3 of GS(M)R

Gas component/property	Entry/exit specification	Note
Hydrogen sulphide	Max 5 mg/m³	Same as GS(M)R
Total sulphur (including hydrogen sulphide)	Max 50 mg/m³	Same as GS(M)R
Hydrogen	Max 0.1 mol%	Same as GS(M)R
Oxygen	Max 0.2 mol%	Same as GS(M)R
Water content	50 mg/m³	Not GS(M)R which uses a dew point criterion for water and hydrocarbon content
Wobbe Index at standard metric reference conditions: combustion at 15 °C, volume at 15 °C and 1.01325 bar	47.2 to 51.41 MJ/m³ (real, gross, dry)	Same as GS(M)R
Incomplete combustion factor	Max 0.48	Same as GS(M)R
Soot index	Max 0.60	Same as GS(M)R
Gross calorific value at standard metric reference conditions: combustion at 15 °C, volume at 15 °C and 1.01325 bar	36.9 to 42.3 MJ/m³	Not contained in GS(M)R
Carbon dioxide	Max 2.5 mol% - limit will not be considered breached if the total inert in the gas is low in the opinion of the Transporter.	Not contained in GS(M)R
Contaminants	Max 2.5 mol% - limit will not be considered breached if the total inert in the gas is low in the opinion of the Transporter.	Similar to GS(M)R
Odour	Gas delivered shall have no odour that might contravene the obligation of the Transporter to transmit gas which possesses a distinctive and characteristic odour. Where the Transporter requires gas to be odourised, the gas shall be odourised in accordance requirement only applies with the following below 7 barg specification: Odour intensity of 2 Olfactory degrees on the Sales Scale (Ref – IGE/SR/16/1989), or such other specification determined by the Transporter acting as a RPO.	Not GS(M)R – different wording and odorant
Delivery temperature	1 to 38 °C	Not GS(M)R specification
Organohalides	Max 1.5 mg/m³	Not GS(M)R specification
Radioactivity	Max 5 Becquerels/g	Not GS(M)R specification
Ethane	Max 12 mol%	Not GS(M)R specification
Wobbe Index	46.50 to 52.85 MJ/m³	Emergency gas quality parameter
Incomplete Combustion	< 1.49 Factor	Emergency gas quality parameter

10. Regulatory assessment

Figure 10.2
Gas quality specification in schedule 3 of GS(M)R (image credit: HSE)

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SCHEDULE 3 — Regulation 8

CONTENT AND OTHER CHARACTERISTICS OF GAS

PART I

REQUIREMENTS UNDER NORMAL CONDITIONS

1. The content and characteristics of the gas shall be in accordance with the values specified in the following table.

Content or characteristic	Value
hydrogen sulphide content	$\leq$5 mg/m^3;
total sulphur content (including H_2S)	$\leq$50 mg/m^3;
hydrogen content	$\leq$0.1% (molar);
oxygen content	$\leq$0.2% (molar);
impurities	shall not contain solid or liquid material which may interfere with the integrity or operation of pipes or any gas appliance (within the meaning of regulation 2(1) of the 1994 Regulations) which a consumer could reasonably be expected to operate;
hydrocarbon dewpoint and water dewpoint	shall be at such levels that they do not interfere with the integrity or operation of pipes or any gas appliance (within the meaning of regulation 2(1) of the 1994 Regulations) which a consumer could reasonably be expected to operate;
WN	(i) $\leq$51.41 MJ/m^3, and
	ii) $\geq$47.20 MJ/m^3;
ICF	$\leq$0.48
SI	$\leq$0.60

2. The gas shall have been treated with a suitable stenching agent to ensure that it has a distinctive and characteristic odour which shall remain distinctive and characteristic when the gas is mixed with gas which has not been so treated, except that this paragraph shall not apply where the gas is at a pressure of above 7 barg.

3. The gas shall be at a suitable pressure to ensure the safe operation of any gas appliance (within the meaning of regulation 2(1) of the 1994 Regulations) which a consumer could reasonably be expected to operate.

4.—(1) Expressions and the abbreviations used in this Part shall have the meanings assigned to them in Part III of this Schedule.

(2) ;ICF and SI shall be calculated in accordance with Part III of this Schedule.

1

10.3 Great Britain (GB)

The gas quality specification in GB is set out in Schedule 3 of the Gas Safety (Management) Regulations[25] which is enforced by the HSE who publish a guide to the regulations[26] (See Figure 10.2 for supply under normal conditions and Figure 10.3 for supply under emergency conditions). See over for further information.

10.3.1 Proposed changes to schedule 3 of GS(M)R

In 2020, the Gas Quality Working Group at IGEM[27] proposed changes to S chedule 3 of GS(M)R to ensure the gas networks have access to diversified sources of gas to enhance security of supply, whilst continuing to deliver gas to customers safely and eff iciently, and to support deep decarbonisation through biogases and hydrogen. It proposed that this would be achieved by:

- Accessing diverse gas resources from across the North Sea including both UK CS and the Norwegian sector.
- Enabling cost efficient LNG imports.
- Helping to secure UK gas supplies from domestic and imported sources.
- Reducing gas processing emissions.
- Being complemented in the near future by a hydrogen quality standard, to allow hydrogen to be blended, without additional legislation.

Figure 10.3 Gas quality specification during a gas supply emergency (Image credit: HSE)

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PART II

REQUIREMENTS FOR GAS CONVEYED TO PREVENT A SUPPLY EMERGENCY

1. The requirements of the gas referred to in regulation 8(2) and (4) are—

(a) WN—

(i) $\leq$52.85 MJ/m^3, and

(ii) $\geq$46.50 MJ/m^3; and

(b) ICF$\leq$1.49,

and in all other respects the gas shall conform to the requirements specified in Part I of this Schedule, as if those requirements were repeated herein.

2.—(1) Expressions and abbreviations used in this Part shall have the meanings assigned to them in Part III of this Schedule.

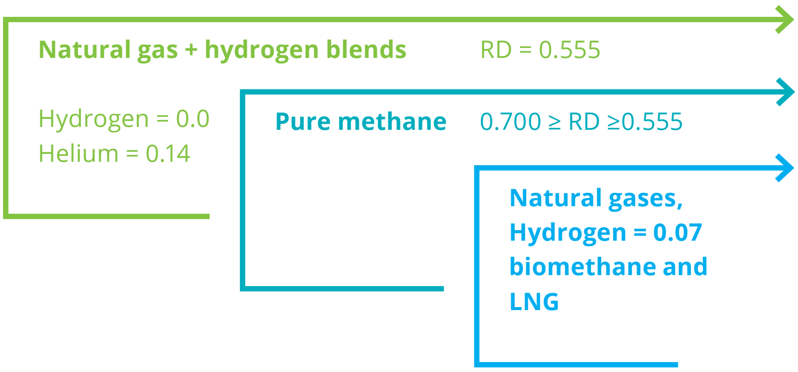
(2) ICF and SI shall be calculated in accordance with Part III of this Schedule.

25 Schedule 3 of the Gas Safety (Management) Regulations https://www.legislation.gov.UK/UKsi/1996/551/schedule/3/made
26 HSE Guide to the Gas Safety (Management) Regulations 1996 https://www.hse.gov.UK/pubns/books/l80.htm
27 IGEM Gas Quality Working Group https://www.igem.org.UK/technical-services/gas-quality-working-group/

10. Regulatory assessment

The GS(M)R are primarily intended to ensure the safety of the public and Schedule 3 of the Regulations is the baseline for the changes. Safety will continue to be the primary aim of the proposed new gas quality standard. The proposed changes are:

- Widen the Wobbe Index range to the existing emergency limits.
- Extend the current GS(M)R class exemptions for oxygen in biomethane to a general 1 mol% oxygen limit at ≤38 barg for all gas sources.
- Simplify the GS(M)R interchangeability diagram with limits on Wobbe Index and relative density only. The incomplete combustion factor, soot index and lift index would be removed and replaced with an upper relative density of 0.700. The relative density limit would enable an increase in hydrogen content at a later stage but the explicit limit of 0.1 mol% hydrogen would remain for the time being. No minimum relative density limit is proposed – the only way to reduce relative density below 0.555 (the value for methane) is by the addition of hydrogen (or helium)[28].



- Move GS(M)R Schedule 3 into a new IGEM standard to create a framework for future changes.

The HSE carried out a consultation, which closed in March 2022[29], and is now considering the options and conducting a cost benefit analysis for GB. The report is likely to be published by the end of 2022, but parliamentary time will be needed to change the specification. However, the HSE has indicated that it is minded to:

- Accept the reduction of the lower Wobbe Index to the current lower emergency limit and to reject the increase in the upper Wobbe Index limit.
- Accept the change to the oxygen limit to 1 mol% oxygen at ≤38 barg for all gas sources.
- Accept the change to the interchangeability diagram.
- Reject the move from UK legislation to an IGEM standard.

Gas Networks Ireland is a member of IGEM and is a stakeholder in the HSE consultation.

10.4 Isle of Man

The Isle of Man conducted a review and consultation on gas regulations in 2021[30]. This covered the Gas Safety (Installation, Use and Management) (Application Order) 2021 which will apply the Gas Safety (Installation and Use) Regulation 1998 currently in effect in Great Britain. These regulations place duties on gas businesses and operatives, landlords and people who use gas appliances. The Order also applies the Gas Safety (Management) Regulation 1996 which places duties on gas transporters including network operators, shippers and terminal operators. In particular, schedule 3 (Regulation 8) describes the "Content and other Characteristics of Gas" and these are the same as Schedule 3 of the GS(M)R that apply in GB.

28 Note that the Marcogaz range of 0.555 to 0.700 is not compatible with hydrogen content greater than zero. The relative density of methane with 0.1% (molar) hydrogen, which is currently allowed under GS(M)R, is 0.554.
29 HSE consultation https://consultations.hse.gov.UK/hse/cd291-revision-gas-safety-management-regulations/
30 Isle of Man Government Gas Safety Regulations Consultation https://consult.gov.im/environment-food-and-agriculture/gas-safety-regulations/

A review of the commercial regulatory agreements for gas supply was carried out in 2019[31] and concluded that Manx Gas should establish a new voluntary regulatory agreement that conforms to UK regulatory best practice.

The impact of hydrogen has been investigated[32] and found to be largely compatible with hydrogen distribution with the exception of several critical components:

- The high-pressure pipeline that brings natural gas to the Island from the Scotland Ireland IC2 interconnector.
- The high-pressure pipeline that carries gas from Glen Mooar to Douglas.
- The high-pressure pipeline that supplies the Combined Cycle Gas Turbine at Pulrose.
- LPG storage tanks and road tankers are currently rated for LPG only.

The technical assessment of the Isle of Man network does not appear to be publicly available. There are references only to emails and it may be prudent to carry out another technical assessment as the understanding of hydrogen compatibility is rapidly developing and a more conservative approach is likely to be recommended. None of the gas boilers on the Island are compatible with 100% hydrogen but are likely to be acceptable for a 20% hydrogen blend. Those parts of the network that were reported to be compatible with hydrogen have a lifetime of 60+ years.

10.5 Northern Ireland

Gas regulations in Northern Ireland come under the Northern Ireland Statutory Rules:

- The Gas Safety (Installation and Use) Regulations (Northern Ireland) 2004[33].
- The Gas Safety (Management) Regulations (Northern Ireland) 1997[34]. Both sets of regulations are essentially the same as those in effect in GB with hydrogen limited to 0.1% mol.

Interestingly, the oxygen content proposed by IGEM has already been accepted[35] and 1 mol% oxygen content is admissible in Northern Ireland at pressures ≤38 barg for all gas sources. This is to promote the injection of biomethane into the network as a decarbonisation measure.

10.6 Interconnectors

The interconnectors delivering gas from Scotland to the Isle of Man, Northern Ireland and Ireland are not covered by GS(M)R. Safety regulation s covering their operation and maintenance are covered in the current Gas Networks Ireland safety cases. Economic regulations are covered by the CRU.

Under the current regulations, changes to gas quality will be assessed as part of the safety case. In the case of hydrogen content, this will include an analysis of the compatibility of the assets with hydrogen, hazardous areas etc. but there is no requirement to comply with a particular gas specification.

10.7 Recommendations

Continue to liaise closely and engage with the UK on proposed changes to the gas quality parameters under the Gas Safety (Management) Regulations and further understand how changes to GS(M)R could impact on the safety of Gas Networks Ireland infrastructure and end users in Ireland, Northern Ireland and the Isle of Man.

31 Chief Minister's Gas Regulatory Review Committee (February 2019) https://www.gov.im/media/1364390/2019-02-15-chief-ministers-gasregulatoryreview-committee-report-final-approved-1822019.pdf
32 Impact of hydrogen on the Isle of Man gas grid https://www.gov.im/media/1368072/appendix-19-gas-grid.pdf
33 Gas Safety (Installation and Use) Regulations (Northern Ireland) 2004 https://www.legislation.gov.UK/nisr/2004/63/contents/made
34 Gas Safety (Management) Regulations (northern Ireland) 1997 https://www.legislation.gov.UK/nisr/1997/195/contents/made
35 Oxygen content in Northern Ireland https://www.hseni.gov.UK/news/gas-safety-management-regulations-ni-1997-class-exemption

11. Technical and safety roadmap

To introduce a blend of hydrogen into Ireland's gas network, several technical and safety implications need to be assessed. Figure 11.1 identifies key steps that need to be met as part of a phased implementation plan to achieve this. The roadmap is split into technical and safety lanes for both the distribution blending pilot and the wider network blending roll out. It also includes other external key milestones and timelines that will impact the introduction hydrogen into the Irish gas network.

A key for the milestones is provided below.
- Indicative timeline
- Other key dates

The duration of each task is estimated based on the review of international experience related to hydrogen blending. However, these timelines may be extended or shortened depending on the following:

- New evidence generated from industry.
- Level of research required.
- Interaction with the regulatory authorities.

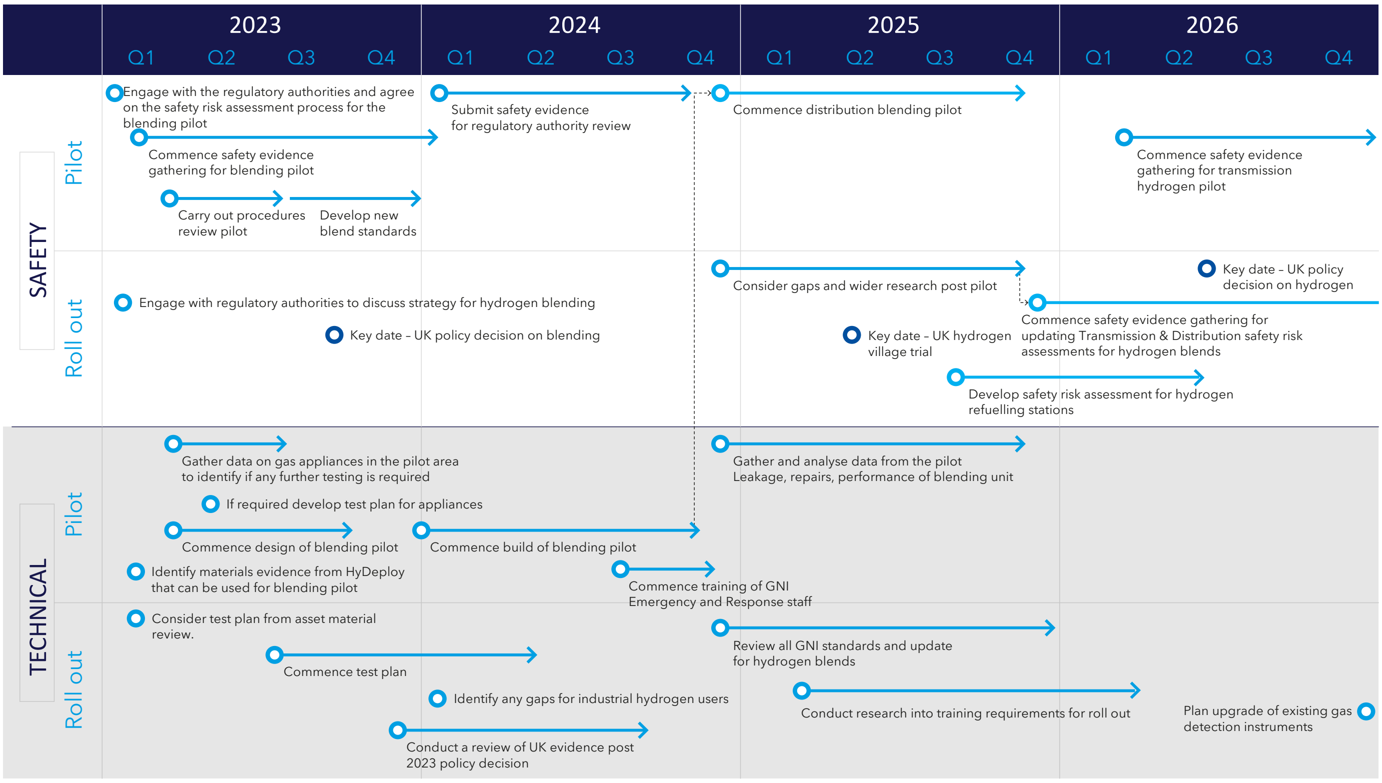


Figure 11.1 Gas Networks Ireland Technical and Safety Hydrogen Roadmap

12. Conclusions

In 2022, Gas Networks Ireland has carried out a 'Technical and safety feasibility study of injecting green hydrogen blends into Ireland's gas network'.

The technical feasibility study was a high-level initial assessment of the readiness of the Gas Networks Ireland network for transporting hydrogen/ natural gas blends. The findings were very positive and indicate that it will be both safe and feasible to utilise the existing gas network to transport blended hydrogen. Prior to injecting hydrogen into the network, further detailed research will be required, particularly in relation to the high pressure transmission network and large industrial, commercial and power generation users. The Safety and Technical Roadmap, along with the recommendations provided in the report, provides next steps including an assessment of the impact on end-users.

This report is an essential first step in progressing to a blending pilot and wider roll-out strategy for hydrogen blending.

There remain **critical work programmes** that must be completed before Gas Networks Ireland can inject hydrogen into the gas network. Recommendations from each chapter are provided and should be prioritised to expedite the delivery of a distribution blending pilot.

Key findings from each of the areas assessed:

Safety assessment development

To enable a change to the code of operations, evidence is required to satisfy the relevant regulatory authorities that hydrogen/ natural gas blends can be safely carried in the same way that natural gas is transported today.

UK and EU research

Successful green hydrogen injection projects have been completed in the UK and EU. Gas Networks Ireland will identify where evidence generated through these projects can be used to support the approach to hydrogen blending in Ireland.

Asset Review

A large proportion of Ireland's gas network can be used to transport hydrogen blends. However, further qualification through existing design standards and materials testing remains.

Standards and operational procedures

A comprehensive review of Gas Networks Ireland's standards and procedures is required to identify what changes may be required for hydrogen blends.

End Users

The vast majority of domestic end users will experience no change to their behaviours or impact on their appliances. However, hydrogen blends will have an impact on industrial processes and some industrial/ commercial equipment may need to be upgraded to accommodate a hydrogen blend.

Gas Quality

Introducing hydrogen into natural gas will affect the quality of the gas as the CV and Wobbe Index will be reduced. However, there are benefits as they lead to a reduction on CO_2, NOx (in some cases) and CO emissions.

Green hydrogen injection

Hydrogen injection has already taken place in a number of different locations across the UK and EU. However, the national strategy for green hydrogen needs to be explored to understand practical issues such as metering, storage and injection locations.

Regulatory

The GS(M)R is in the process of being updated in the UK, but changes to the hydrogen content are not included. However, this could change in the future and Gas Networks Ireland will monitor this closely.

12. Conclusions

Pilot project(s)

This study **recommends the commencement of a pilot hydrogen blending project on the Irish gas network**. Pilot hydrogen blend demonstration projects on Ireland's distribution and transmission networks will help demonstrate the safe operation of the network and the safe operation of end user appliances and equipment.

Support from the relevant regulatory authorities and collaboration with all stakeholders will be essential to facilitate at first the distribution blending pilot and secondly the wider rollout of hydrogen blending. This approach has been followed for the UK pilot projects with great success and there is no reason why it cannot be applied in Ireland.

Gas Networks Ireland is the competent national transmission and distribution gas system operator. It is ready to take the technical lead to safely introduce hydrogen blends on our existing gas networks. Our organisation has over 40 years' experience in designing, building and operating a safe and reliable gas network and we are confident in our ability to support the next transition to hydrogen blends. Gas Networks Ireland will progress the recommendations outlined in this report. Delivery of the Roadmap and recommendations will be done in consultation with our stakeholders. Support from the regulatory authorities will be critical in preparing our networks for the transition to hydrogen blends and 100% hydrogen in the years ahead.

13. Recommendations

Key recommendations from the report have been collated and categorised below.

13.1 Safety

1. Engage with relevant safety regulator(s) to establish and agree the scope, format and evidence that should be submitted to provide the required assurance of the safety of hydrogen/ natural gas blending under the relevant safety legislation in each jurisdiction.
2. Commence evidence gathering for demonstration blending pilot and national safety risk assessments for Ireland's gas network.
3. Conduct a QRA to identify the safety assessment requirements for a distribution blending pilot.

13.2 Assets

1. International gas networks, equipment vendors and research organisations are carrying out programmes of work (e.g., HyDeploy and H21) to identify materials within network equipment and to test for hydrogen compatibility. Gas Networks Ireland will review the results of these programmes and apply them to the Irish gas network. Any knowledge gaps identified relating to the characteristics of the Irish gas network, will result in the initiation of further studies to assess the performance of assets and materials not covered internationally. Based on initial assessment, targeted qualification research for residual iron, "gun barrel" material and some polymer grades will be needed.
2. Approximately 52% of the transmission pipeline network will need to be assessed using the performance-based methodology (per ASME 31.12 or IGEM/TD/1) to allow the current maximum operating pressures to be maintained with hydrogen concentrations of greater than 10%. A material testing programme will need to be developed and conducted to inform these assessments.
3. Carry out a design review on transmission and distribution installations to identify potential areas where axial stresses may exceed the prescriptive limits in IGEM/TD/1 and IGEM/TD/13 for hydrogen service.
4. Carry out a study for the equipment contained within transmission AGIs and compressor stations (to allow hydrogen entry). Several studies are already underway testing the compatibility of transmission network equipment (e.g., National Grid HyNTS (FutureGrid), Gasunie programmes, Hydrogen in Gas Grids (HIGGS), GERG and EPRG hydrogen programmes). It is recommended that Gas Networks Ireland engage with these programmes to identify if there are unique factors applying in their network before undertaking the review of the non-pipe network assets.

13.3 Gas quality and end-user implications

1. Monitor developments on projects such as HyDeploy and THyGa as they will provide further clear evidence on the safe operation of combustion equipment when using hydrogen blends for a wide range of equipment sizes and scales
2. Monitor developments on hydrogen blend projects from the EU, UK and elsewhere. There are some new projects starting that will provide additional information that could support the development of hydrogen blending in Ireland.
3. Further develop the testing facilities at the Network Innovation Centre to study the impact of blends and potentially look to extend the operating range for safe utilisation of hydrogen blends. Provide further studies on emissions, especially NOx and assess if they are compliant with current legislation. Extend knowledge of the impact of blends on efficiency, operability and equipment life.

13. Recommendations

4. Undertake one or more live trial demonstration project(s) building on the experience from HyDeploy and other projects, to provide further information on the suitability of hydrogen/ natural gas blends, to complement the technical studies and laboratory trials.
5. Continue to gather information on the industrial and commercial combustion equipment installed in Ireland and extend the understanding of the impact of hydrogen blends on existing installations, to establish if upgrades or conversion of equipment is possible, or if replacement or other solutions would be required. Testing and trials of hydrogen/ natural gas blends on industrial and commercial equipment may be required.
6. Further research the gas engine and gas turbine practical limits for hydrogen blends. Examine whether deblending could be a technical option for specific end users.
7. Work with existing gas chromatograph manufacturers regarding the potential upgrade of existing gas chromatographs or options for updated analysis.

13.4 Standards

1. Assess the utilisation of IGEM standards against the Gas Networks Ireland DMS and existing infrastructure. This approach will then be further assessed within the context of any future planned hydrogen blend trials undertaken by Gas Networks Ireland.
2. Continue ongoing collaboration with NSAI and CEN and regularly source information on draft and published standards to ensure all available approaches can be considered as the hydrogen blend landscape changes.

13.5 Operational Arrangements

1. Identify options for new gas detection equipment to ensure they are hydrogen ready.
2. Carry out a full assessment of existing procedures to understand how they will be impacted by a hydrogen blend.
3. Carry out an assessment of how changes to hazardous area zoning could impact transmission and distribution installations.
4. Consideration must be given to any additional training requirements following the review and adaption and/or development of hydrogen blend procedures and modification and/ or replacement of equipment. Operatives working on Ireland's gas infrastructure as part of emergency or maintenance works, will likely require additional training to ensure correct application of the amended and/or developed procedures.
5. Undertake research to identify any potential issues on the odour intensity of odourised natural gas associated with the blending of hydrogen at transmission level.

13.6 Green hydrogen injection

1. Develop a conceptual design for a Hydrogen Blending, Injection and Control Station (HBICS) to further define its process and material requirements and produce a high-level cost estimate for the facility.
2. Develop blending procedures to ensure the safe operation of the blending equipment and maintain the consistency and reliability of the blended mixture within allowable limits.

13.7 Regulatory

1. Continue to liaise closely and engage with the UK on proposed changes to the gas quality parameters under the Gas Safety (Management) Regulations and further understand how changes to GS(M)R could impact on the safety of Gas Networks Ireland infrastructure and end users in Ireland, Northern Ireland and the Isle of Man.
2. Determine the safety and commercial regulatory arrangements for hydrogen production, storage, transportation, sale and usage.
3. Consider the EU and UK requirements for renewable certification for green hydrogen in relation to hydrogen imports to, and export from Ireland.

13.8 Strategic

1. Develop a national hydrogen strategy that considers the full end-to-end hydrogen value chain, including the production, storage and transportation of 100% hydrogen, where hydrogen might be injected into the natural gas network, and possible pathways for the direct utilisation of 100% hydrogen.

Appendix A HyDeploy outputs

Output	Evidence generated
Materials	The HyDeploy[36] project has developed evidence through phase one and phase two of the programme. Exploring a range of materials and the potential impact, these include: • Mild and carbon steels • Stainless steels • Copper alloys • Cast iron • Aluminium • Plastics • Elastomers • Other material – hard chromes, zinc plating and lead. This research identified some potential issues with cast iron pipe and steel springs in district governors. However, further research is being conducted to fully address the concerns in these areas. It is envisaged that when the HyDeploy programme has been completed all materials that are likely to appear on the gas distribution network will have been assessed.
End users	**Domestic[37]**: Successful demonstration of domestic gas appliances operating on a blend of 20 mol% hydrogen has been completed in both phase one and phase two of HyDeploy. This was supported by comprehensive laboratory testing which demonstrated that appliances sold after 1976 in the UK were compatible with 20 mol% hydrogen with no safety or performance issues identified. This is because all appliances sold after 1976 still comply with current gas appliance regulations such as the Gas Appliance Directive (GAD(2009) and the gas appliance regulations (EU 2016/426) (GAR (2018)). Furthermore, the project also identified that with the addition of 20 mol% hydrogen CO emissions reduce, this is particularly pronounced when the appliance is faulty. **Industrial and Commercial[38]**: This is an area of the project that will be addressed over the next 12 months. The project has successfully demonstrated several industrial and commercial applications can continue to be carried out under a blend of hydrogen up to 20% with further practical trials planned for the future.
Standards and procedures	An extensive and robust method for assessing potential impacts on existing gas distribution procedures was conducted under HyDeploy phase two (standards & proc.) A new management procedure for the trials was created to ensure procedures were updated with relevant information such as the increase in dispersion distances. Further, research is ongoing to address the GDN's whole procedural library to identify what changes need to take place. In addition to this, The Institute of Gas Engineers and Managers (IGEM) are also implementing changes to their documents so that they are 'blend ready'. In addition to network procedures, HyDeploy also reviewed downstream procedures and determined that there are no changes required and that existing equipment can be used to carry out functional checks of gas appliances. This is documented in the Gas Safe bulletin 157[39] .

36 HyDeploy2: Materials Assessment for the trial at Winlaton
37 HyD eploy2: Appliance Testing Summary and Interpretation
38 HyDeploy hydrogen blending trial at Pilkington UK on Vimeo
39 Technical Bulletin 157 – CO, CO_2 and combustion ratio checks using an electronic combustion gas analyser (ECGA) when carrying out works on a natural gas appliance being supplied with natural gas containing up to 20 vol% hydrogen (registeredgasengineer.co.UK)

Output	Evidence generated
Gas Characteristics	The research generated under HyDeploy[40] has developed the learning and understanding of the differences between hydrogen and natural gas. Some highlights from the research are outlined below: • Laminar leaks on natural gas will remain laminar with hydrogen blends. This means that the leak rate will not increase for this type of leak. • Accumulation of gas in buildings resulting from leaks is practically identical to that of natural gas. • The blend will be slightly more sensitive to ignition. • The overpressure from a gas explosion containing 20% hydrogen will result in an overpressure between 1.2 and 1,4 times that of natural gas. Further outputs from this research can be found in the HyDeploy gas characteristics reports [41].
Gas Detection	There are two aspects of gas detection that have been considered by HyDeploy 1. Impact of hydrogen on the odour intensity [42] 2. Impact on gas detection instruments [43] The impact on odour intensity is negligible. Hydrogen does dilute the odour intensity but not to the levels that impact the 'satisfactory' smell attributed to natural gas. This was demonstrated by desktop studies and practical demonstration through the Keele trial. HyDeploy phase one identified that existing gas detection equipment will be negatively impacted by introducing hydrogen blends of up to 20% in the gas. This is due to the CO element of the equipment being identified as cross sensitive to hydrogen. In addition to this, the flammable gas sensor that measures ppm, LEL and GIA used across the GDN's were also adversely impacted by hydrogen. To facilitate a trial the HyDeploy project identified two pieces of detection equipment that would be used during the live trial period. • GMI GS700: This was selected as it did not have a CO alarm incorporated and it could be easily calibrated to measure a 20% blend of H_2 to give reliable readings for ppm. LEL and GIA • Drager X: AM 5000 was selected as the device's CO alarm could be compensated to consider the additional signal of hydrogen and therefore remove spurious CO readings with Hydrogen blends.
QRA	The QRA[44] is the overarching process for demonstrating to the regulator that hydrogen blends can be as safe as natural gas. HyDeploy's QRA demonstrated that hydrogen can be introduced into the public network without any increased risk to the public.

40 HyD2-Rep05-V01-Gas Characteristics
41 HyD2-Rep05-V01-Gas Characteristics
42 HyD2-Rep05-AppE-V01
43 HyD2-Rep07-V03-Procedures
44 HyD2-Rep02-V04-QRA

Appendix A HyDeploy outputs

Output	Evidence generated
Metering and Billing	**Billing**: The GB billing systems operate under the Flow Weighted Average Calorific Value (FWACV) regime. This is where an average CV is taken from a Local Distribution Zone (LDZ). The CV is monitored across the LDZ by gas chromatographs. The current billing regime has implications for hydrogen blending, because hydrogen has 1/3 the energy on a volumetric basis of natural gas. So, if hydrogen is added to natural gas the CV decreases. To overcome this, the HyDeploy project utilised a 'declared CV' where a value was used that assumed a worst-case 20% H_2 24 hours a day, 7 days a week. This would ensure that customers were not over-paying for the duration of the trial This scheme whilst practical for the trial is not an enduring solution and projects such as future billing methodology are exploring long term options for updating the current regime. **Metering**: The materials programme for HyDeploy assessed the possible impact that hydrogen blends could have on domestic meters. The assessment determined that there were no integrity issues and that all domestic meters could operate safely on 20% H_2. Further work to define the accuracy of domestic meters is almost complete. National Engineering Laboratories worked with the HyDeploy team to determine all the possible domestic meters that are likely to be installed on the existing gas distribution network. A testing plan was then defined to determine the accuracy of meters using existing standards. Early indications are that accuracy of domestic meters will be within the existing tolerance.

Appendix B HyTest Report

November 2022

UCD DUBLIN | Gas Networks Ireland

Testing of Blends of Hydrogen and Natural Gas (HyTest)

Short Report

Dr Ali Ekhtiari,
Dr Eoin Syron,
Mr Liam Nolan,
Mr Paul O'Dwyer

The project has received innovation funding from Gas Networks Ireland's Gas Innovation Fund under grant agreement No. 2010-021

Appendix B HyTest Report

Introduction

Green hydrogen is currently gaining a lot of global attention as a possible way of achieving a net zero carbon energy system. The future scenario where all our energy needs are provided by renewable electricity backed up by a carbon free gas fuel is compelling. However, society still needs to find a way to transition to this future scenario. Incorporating and blending green hydrogen into the gas networks is an immediately accessible near term solution for storing and transporting renewable energy. Ireland already loses over 11%[1] of renewable electricity generated due to electrical network transmission and balancing issues, and given the future plans to harness both on-shore and off-shore wind resources, curtailment is expected to increase in the future. Blending green hydrogen into the gas network can also provide an existing outlet/demand for renewable energy developers and green hydrogen producers who wish to be first movers in the green hydrogen sector. In order to prepare for this, Gas Networks Ireland teamed up with University College Dublin (UCD) Energy Institute to demonstrate the safe and reliable operation of residential end-user devices connected to the Irish gas network over a range of hydrogen concentrations from 2% to 20%. Measured parameters included the heating value, flue gas analysis, flame temperature and flame picture, pressure drop, minimum operating pressure, and safety and leak tests. All work was carried out at the recently refurbished Network Innovation Centre, Gas Networks Ireland, Brownsbarn, Citywest, Dublin and the UCD Integrated Energy Lab.

Hydrogen

The majority of hydrogen used in the world today is generated from fossil hydrocarbons; alternative carbon free sources are available and becoming ever more cost competitive. Hydrogen is often classified into different colours to identify its source.

Grey hydrogen is produced when natural gas is used as the feedstock for reforming methane using steam to produce hydrogen.

Blue hydrogen is the term given to hydrogen produced through the steam reforming of methane when the associated Carbon dioxide (CO_2) produced is captured and stored via Carbon Capture and Storage (CCS).

Green hydrogen is hydrogen produced without the release of CO_2. Typically this is through the use of renewable electricity for the electrolysis of water.

Comparison of hydrogen and natural gas

The chemical, physical and thermal properties of hydrogen and methane are compared in table (1). Values are given for the gas phase at 288 K (15˚C) and 1 atm. When hydrogen is blended with natural gas, the gas mixture has different properties than either pure methane or pure hydrogen.

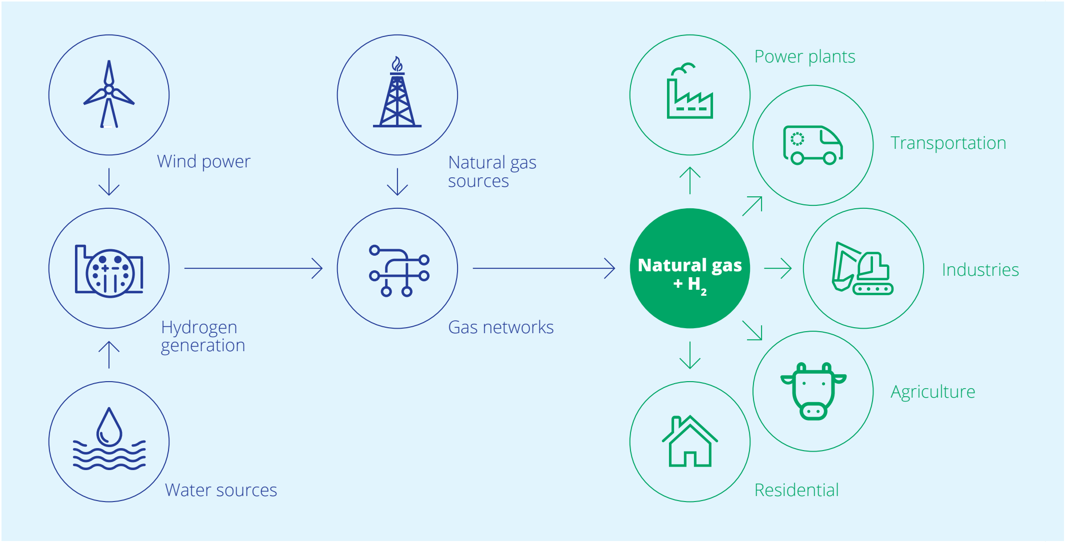


Figure 1. Schematic of Green Hydrogen process from production, injection into the pipelines to be used by different end-users.

1 EirGrid, "Annual Renewable Energy Constraint and Curtailment Report 2020"

Table 1. Hydrogen and methane thermodynamic properties.

Values are given for the gas phase at 15˚C and 1 atm.

Item	Unit	Hydrogen	Methane
Molecular weight	g/mol	2.016	16.04
Specific gravity		0.069	0.55
Specific volume	m^3/kg	12.1	1.52
Absolute viscosity	centipoise	0.009	0.011
Adiabatic combustion temperature	˚C	2100	1950
Calorific value (CV)	MJ/ m^3	Gross: 12.1	Gross: 37.8
		Net: 10.2	Net: 34
Wobbe index	MJ/m^3	Upper: 48	Upper: 54
		Lower: 41	Lower: 48
Gas constant - R	J/kg.C	4126	518.28
Boiling point	°C	-252.75	-161.64
Critical temperature	°C	-240	190.56
Critical pressure	MN/m^2	1.3	4.6

Natural gas-hydrogen blends

Depending on the pipeline materials and engineering standards, 100% pure hydrogen can be transported in the distribution pipelines and existing polyethene distribution pipelines can accommodate blends of up to 20% Volume per volume of hydrogen without any undue safety concerns. However, there are thousands of devices connected to the gas network in homes and businesses across Ireland, and any potential impact on their operation by the addition of hydrogen into the gas network needs to be considered.

Overview of the project

This project evaluated the safety and stability of the gas supply and device operation with increasing hydrogen concentrations (2-20%).

For a range of natural gas and hydrogen mixtures, this project investigated the calorific value (CV) of the mixture, performed leak and safety testing, evaluated metering accuracy, conducted flue gas analysis, compared flame pictures and checked operating pressure and flow rate variables. Post-1996 gas appliances, including six condensing boilers, two gas fires, two gas cookers and two gas hobs, were tested in accordance with the Gas Appliance Directive/Regulations[2]. The overall objectives were to assess if:

1. Supplying a mixture of hydrogen and natural gas is a safe, secure and sustainable gaseous fuel for use in the residential market.
2. Domestic end-user equipment continues to operate over the range of hydrogen concentrations tested without any problem.

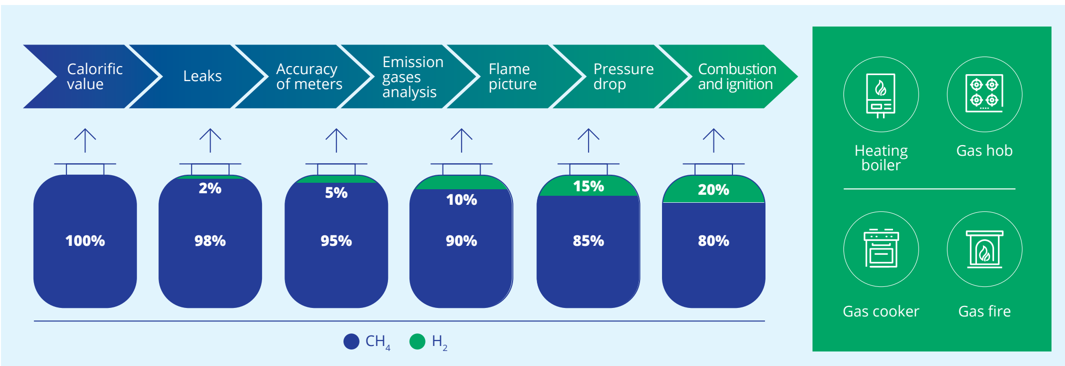


Figure 2. Overview of the hydrogen blend and the tests carried out in the HyTest project.

2 Gas Appliance Directive (GAD) 2009/142/EC and Gas Appliance Regulation (GAR) (EU 2016/426)

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Figure 3. Appliances; (a) six condensing boilers, (b) an 18-year-old gas cooker, (c) a gas hob.

All appliances were serviced and commissioned before testing. The full-service assessment was done in line with the gas installation standard. After testing each boiler's gas emissions, the boilers were operated in continuous mode for a period of one hour.

Results

Calorific value and Wobbe Index

The calorific value is the heat produced by the combustion of a unit of fuel gas. To determine the calorific value of each gas mixtures, the gas flow rate to the boiler was measured as well as the water flow rate and the change in temperature through the boiler. Additionally, the time taken for each gas mixture to boil a known volume of water on a gas hob was measured. The given heat to water can be calculated by differentiating the inlet and outlet temperature of the water in the boiler. The calorific value of the gas is the heat transferred to the water divided by the volume of gas burned. Table (2) shows how calorific value and Wobbe Index (WI) change using different hydrogen blends.

Table 2. Gross calorific value (GCV) and Wobbe Index of hydrogen blends.

	From a gas chromatograph		
Gas blends	**GCV [MJ/m³]**	**WI [MJ/m³]**	**Relative density**
2% H_2	38.5	50.1	0.59
5% H_2	37.8	49.8	0.57
10% H_2	36.4	49.1	0.54
15% H_2	34.8	48.5	0.51
20% H_2	33.2	47.6	0.48

There is an approximate 15% drop in GCV using the 20% hydrogen blend compared with the natural gas. The Wobbe Index, calculated from the calorific value and the specific gravity of the gas, is an indicator of the interchangeability of fuel gases between gas burners. Figure (5) outlines the value of WI and GCV for the different blends. The Gas Quality Specification in the Irish Code of Operations requires the WI of natural gas at entry points to be between 47.2 and 51.4 MJ/m³ (the vertical dash lines in figure 5). All blends tested up to 20% hydrogen were within this existing WI threshold, which was an important indicator for the safe performance of the gas

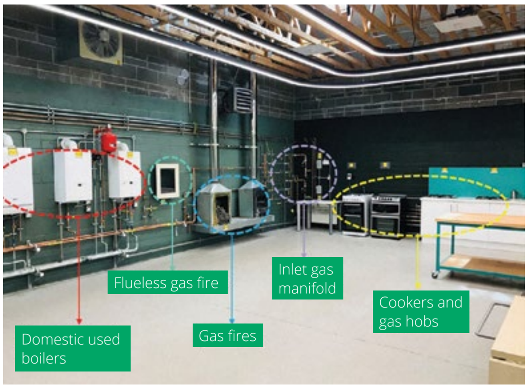

Figure 4. Network Innovation Centre facilities for testing renewable gases.

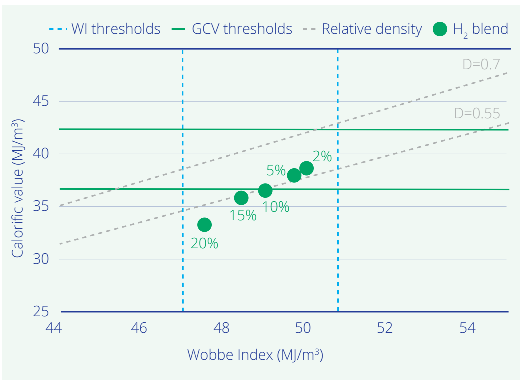

Figure 5. Calorific value and Wobbe Index of natural gas and hydrogen blends from HyTest.

Table 3. Hydrogen blends composition analyses using gas chromatography.

	Composition volume fraction [%]				
Composition	**2% H_2**	**5% H_2**	**10% H_2**	**15% H_2**	**20% H_2**
Hydrogen	1.99	4.71	9.15	15.1	21.1
Methane	91.1	88.7	84.9	79.5	73.6
Ethane	3.63	3.48	3.05	2.85	2.64
Propane	0.88	0.83	0.67	0.63	0.58
iso-Butane	0.22	0.22	0.207	0.194	0.18
n-Butane	0.16	0.15	0.131	0.123	0.115

NOTE: The gas composition results from the chromatograph show that the hydrogen concentrations were not exact, e.g. the hydrogen concentration for the test gas bottle labelled 20% H_2 was 21.1%.

appliances tested during the project. The Code of Operations requires a GCV between 36.9 and 42.3 MJ/m^3. Blends of 10% hydrogen and above were found to be below the lower GCV threshold. This is consistent with a decreasing energy content by volume of the blended gas as the percentage of hydrogen increases. Similar figures for the WI and GCV were achieved in the practical approach (the measurements).

Table (3) shows the composition fractions in the test gas bottles. These figures are tested and recorded in the lab using gas chromatography certified by INAB (Ireland National Accreditation Board) under ISO/IEC17025.

Boiling time of 1 litre of water:

The time it takes to boil one litre of water in steel kettles on the gas hobs for natural gas, and the hydrogen blends were plotted in figure (6). The flow rates of natural gas and hydrogen blends to the gas hobs were constant (0.003 m^3/min). The boiling time for natural gas is 349 seconds (00:05:49), while for 20% hydrogen is 398 seconds (00:06:38). The time difference between natural gas and 20% hydrogen blend is 49 seconds, about a +12% increase in time.

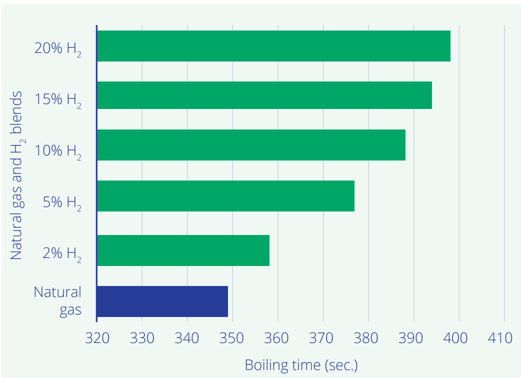

Figure 6. The recorded boiling temperature of one litre of water using different hydrogen blends and natural gas.

Leak and safety tests

The procedures for pressure leak testing (soundness test) are outlined in the national gas installation standards[3] and provide a method to test possible leaks in connections and fittings of a gas pipe by measuring static gas pressure over a specific time. For testing the existing installations of the test facility for each hydrogen blend, the following procedure was implemented:

Pressure leak tests include measuring the pressure decay in the gas pipe, in which both ends are closed.

- Ensuring all appliance isolation valves are open.
- Pressurise the pipe to the working pressure (~20 mbar).
- Allow a minimum of 2 minutes of stabilisation.
- Check the pressure transmitter/gauge and note the exact reading and time.
- After a minimum of 2 minutes, recheck the pressure transmitter/gauge.
- If there is no pressure drop, the leak test is passed.

The gas flows into the test section at an operating pressure of about 20 mbar. Then, by closing both ends of the pipe, all fittings, connections, and valves can be tested over 4 minutes. Both lines "A" and "B" were tested for this work package. There was no loss in pressure during the test for all gas mixtures and natural gas.

Metering with blends

This test compared the consistency of the metering performance of blends for a typical domestic gas flow meter (diaphragm gas meter) by comparing it with a thermal mass flow meter (Bronkhorst FG-111AC) connected in series. The thermal mass flow meter would be considered a highly accurate metering device with an error of less than ±0.5%.

As shown in table (4), for the baseline case with flows of natural gas, a deviation between the two meters of 0.00026 m^3/min (2%) was established. Comparing the two-meter readings (domestic and thermal mass flow meters) for the various hydrogen blends up to the 20% hydrogen blend shows no significant change in this deviation over the course of the

3 Irish standard I.S 813 Domestic Gas Installations

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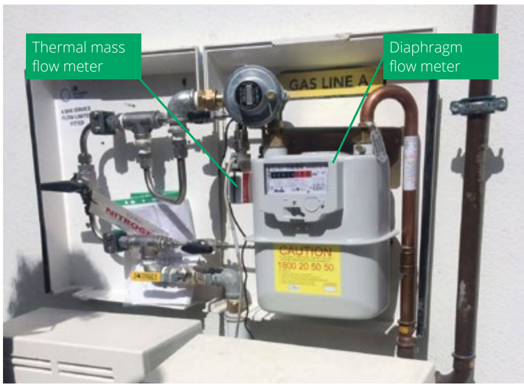

Figure 7. Flow meters are configured in series at the inlet point of the test installation.

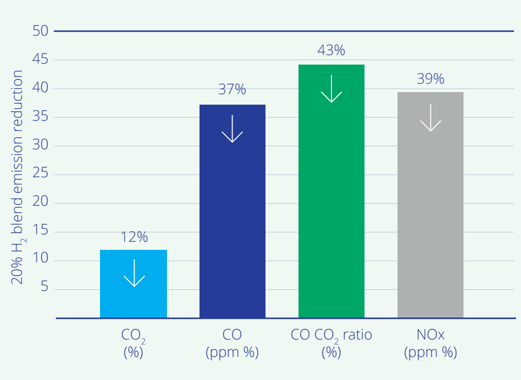

Figure 8. Average percentage reduction in emissions measured for the boilers tested with 20% hydrogen blend.

testing (ranging from 1.3% to 2.2%). The deviation of readings between the flow rates was 0.00026 m³/min (2%) for natural gas compared favourably with the 0.00022 m³/min (about 1.7%) result recorded for the 20% hydrogen blend.

Table 4. The deviation between meter readings: current installed domestic flow meter versus thermal mass flow meter.

Gas blends	Deviation (m³/min)	Deviation (%)
Natural gas	0.00026	2.0%
2% H_2	0.00016	1.3%
5% H_2	0.00019	1.5%
10% H_2	0.00021	1.8%
15% H_2	0.00020	2.2%
20% H_2	0.00022	1.7%

Gas emission analysis

Flue gas emission from the hot water boilers was recorded using a gas emission analyser (MRU OPTIMA 7) and is summarised in Table 3. The recorded data shows that there was a decrease in Carbon Dioxide (CO_2), Carbon Monoxide (CO) and Nitrogen Oxides (NOx) with increasing hydrogen concentration in the gas mixture.

Table 3 shows the gas emissions measured and the recorded average temperature of the exhaust gases produced by the boilers operating at maximum load, when burning different hydrogen blends. Figure (8) shows the average percentage reduction in emissions for various hydrogen blends with the boilers running at maximum load settings.

Table 3. Average flue gas emissions of boilers tested in the laboratory operating at maximum load.

Hydrogen blends (%)	Max. temp (C)	Max. CO_2 (%)	Max. CO (ppm)	CO:CO_2 (%)	NOx (ppm)
Natural gas	62.5	9.5	56.5	0.0006	22.2
2% H_2	61.4	9.3	57.2	0.0005	21.8
5% H_2	62.3	9.0	53.3	0.0005	17.8
10% H_2	62.8	8.8	46.7	0.0004	16.7
15% H_2	62.2	8.6	40.2	0.0004	15.5
20% H_2	62.7	8.4	35.5	0.0003	13.5

The change in emission from burning 20% hydrogen blends during this test is compared with 3 other international tests. HyDeploy project (Hydrogen test project in the UK), the H_2NG project (testing hydrogen blends in France) and the EU-funded ThyGA project (Testing Hydrogen admixture for Gas Applications). A comparison is shown in table (5). The figures for the H_2NG[4] are specific to the old Guillot boiler. The boiler in the THyGA project is a premix boiler.

All projects report reduced CO_2, CO and NOx concentrations in gas emission from boilers using 20% hydrogen blends. THyGA and the HyTest (Gas Networks Ireland/University College Dublin joint) project recorded NOx emission reductions of 43% and 40%[5], which are comparable. The CO_2 reduction recorded is nearly the same figure, about 12%, while this number for the HyDeploy project is 16%[6]. Furthermore, HyTest and THyGA projects reported a 37% and 42% CO reduction. When 20% of natural gas (volumetric value) is replaced by hydrogen, the energy value of a volumetric unit of the gas blend decreases by about 14%. Based on this energy density reduction, the quantity of CO_2 emissions reduction for a larger gas volume of equivalent energy to 100% natural gas is expected in the region of 7%.

4 GRHYD, "The first power to gas H_2 in France (H_2NG)," 2021.
5 THyGA, "Testing Hydrogen admixture for Gas Applications - Market segmentation of domestic and commercial natural gas appliances," 2021.
6 M. Pursell, "HyDeploy: Summary of Gas Appliance and Installation Testing," Health and Safety Laboratory, 2018.

Table 5. Emission reductions measured using 20% hydrogen blend.

20% H_2 blend compared to natural gas	CO_2 reduction	CO reduction	$CO:CO_2$ reduction	NOx reduction
HyTest (Gas Networks Ireland and UCD)	11.8%	37.2%	43%	40%
HyDeploy	16%	28%	32%	22%
THyGA report	decrease	42%	~39%	43%
H_2NG report	12%	20%	~15%	57%

Minimum operating pressure

For each gas appliance, the minimum pressure requirements were determined to maintain operation/combustion over the range of gas blends. The pressure in the gas line was slowly decreased until the appliance stopped working; the minimum operating pressure of each appliance was then noted.

As figure (9) shows, there are no marked differences in the minimum operating pressure of appliances burning hydrogen blends. It cannot be specified that by blending hydrogen, the minimum operating pressure is declining due to an increase of minimum pressure in some appliances, i.e. gas fire no. 2, the wall heater, boilers no. 4 and 5. The minimum operating pressure belongs to gas hobs and gas cookers with less than 1 mbar operating pressure (about 0.3 mbar still working). The operating pressure data from the 20% hydrogen blend compared to the natural gas show that there is no definite decrease/increase of minimum operating pressure while burning a 20% hydrogen blend in domestic appliances. It cannot be considered that the minimum operating pressure decreases or increases while using hydrogen blends.

Flame pictures

The ability to see the natural gas flame is an important safety feature, as it can trigger a visual fire alarm or alert an individual to a gas fire. A pure hydrogen flame is known to burn without a distinct colour. Therefore, it is important to determine the effect of hydrogen addition on the visibility of the natural gas flame. Pictures of the various blended gas flames have been taken under controlled lighting conditions to determine how much the addition of hydrogen influences the flame's colour and visibility.

No changes were observed in flame pictures during the burning of hydrogen blends and natural gas. Figure (10) shows the photographs of the flame using a simple laboratory Bunsen burner. Photographs of the cooker during the operation were taken during burning natural gas, and 20% hydrogen is shown in figure (11). The flame picture for hydrogen blends appears the same as 100% natural gas flame; therefore, there are no safety concerns.

Pressure drop tests

Blending hydrogen with natural gas impacts the physical parameters of the gas flowing in the pipe and the energy delivered per unit volume. To test if there was a significant impact on the pressure drop of gas flowing the pressure loss over a 10 meters length of domestic gas pipeline. A maximum pressure drop of 0.2 mbar occurred when a 20% hydrogen blend was flowing in the pipeline.

Conclusion

Hydrogen has the potential to be directly blended and used in distribution pipelines for domestic use. Blending green hydrogen reduces greenhouse gas emissions and helps in decarbonising gas networks. However, due to hydrogen's lower energy content, when hydrogen is blended with natural gas, the energy content per unit volume decreases.

The main objective of this project was to ensure that domestic appliances can operate safely and effectively with hydrogen blends up to 20%. This study shows no significant changes in operational variables such as pressure and flow rate using hydrogen blends. Gaseous emissions were reduced when

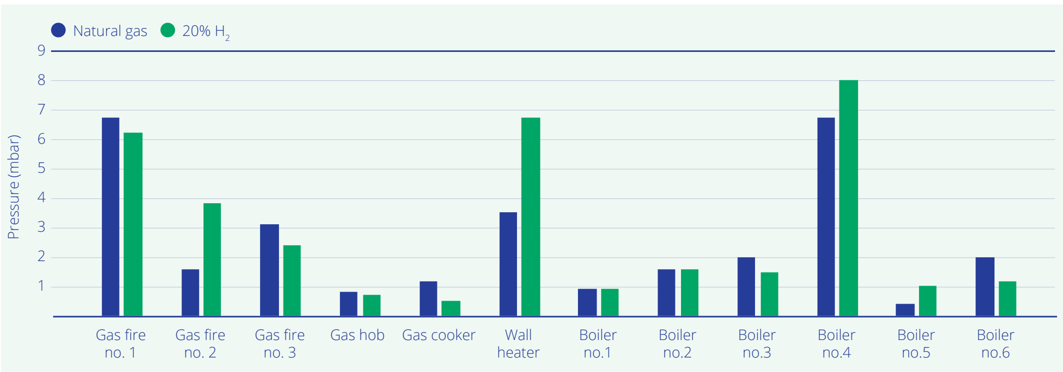

Figure 9. Minimum operating pressures in all appliances.

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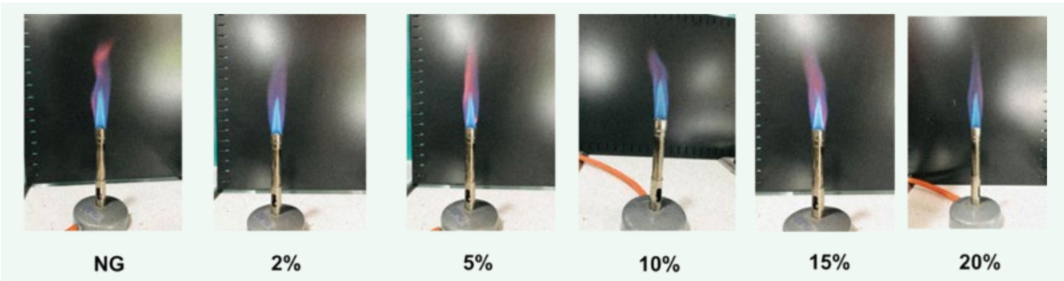

Figure 10. Flame pictures are taken from burning different hydrogen blends and natural gas.

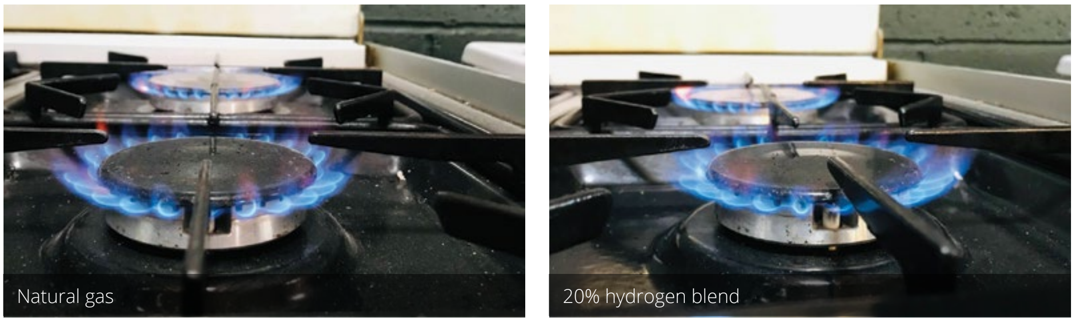

Figure 11. Gas cooker flames for the natural gas and a 20% hydrogen blend

using hydrogen blends, by on average 12%, 37%, and 40% reductions in CO_2, CO, and NOx, respectively, when burning the 20% hydrogen blend. There was a 15% reduction in Gross Calorific Value for the 20% hydrogen gas blend. All blends tested up to 20% hydrogen were within the existing Wobbe Index thresholds. There were no observed perceptible changes in the operation of the appliances using hydrogen blends, and current domestic meters demonstrated compatibility with hydrogen blends for volume measurement.

Following the works carried out for the project, focussing on the assessment of the safe operation of domestic gas appliances with hydrogen blends (up to 20%), the key findings are:

- The domestic gas appliances tested operated safely and effectively with various hydrogen blends tested ranging from 2% to 20% hydrogen by volume.
- There was a substantial emissions reduction obtained by blending hydrogen with natural gas.
- The average emission reduction found was a 12% reduction in CO_2, a 37% reduction in CO, a 43% reduction in the $CO:CO_2$ ratio, and a 40% reduction in NOx emissions.
- There were no changes observed in the minimum operating pressure of appliances while burning the hydrogen gas blends.
- No leakage was detected during pre-testing or during operations for all pipework, connections, fittings, and valves at operating pressure.
- The domestic gas flow meter was consistently accurate when used for measuring gas volume flows containing up to 20% hydrogen compared to natural gas.
- The flame motion and colour of the hydrogen gas mixtures stayed similar to natural gas.

Next steps and recommendations

Future potential projects and areas of interest

- Testing of higher than 20% hydrogen blends and testing 100% hydrogen.
- Testing industrial and commercial end-users' equipment, including investigating the impact of the Wobbe Index variations and compensating for the reduction in energy per unit volume by controlling the gas flow rate.
- Testing renewable hydrogen and biomethane blends with natural gas considering gas emission and gas quality.
- Leakage and safety testing considering equipment long-term material compatibility with hydrogen.
- Further research of the natural gas customer appliance populations in the domestic and industrial / commercial sectors.

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