Hy4Heat
demonstrating
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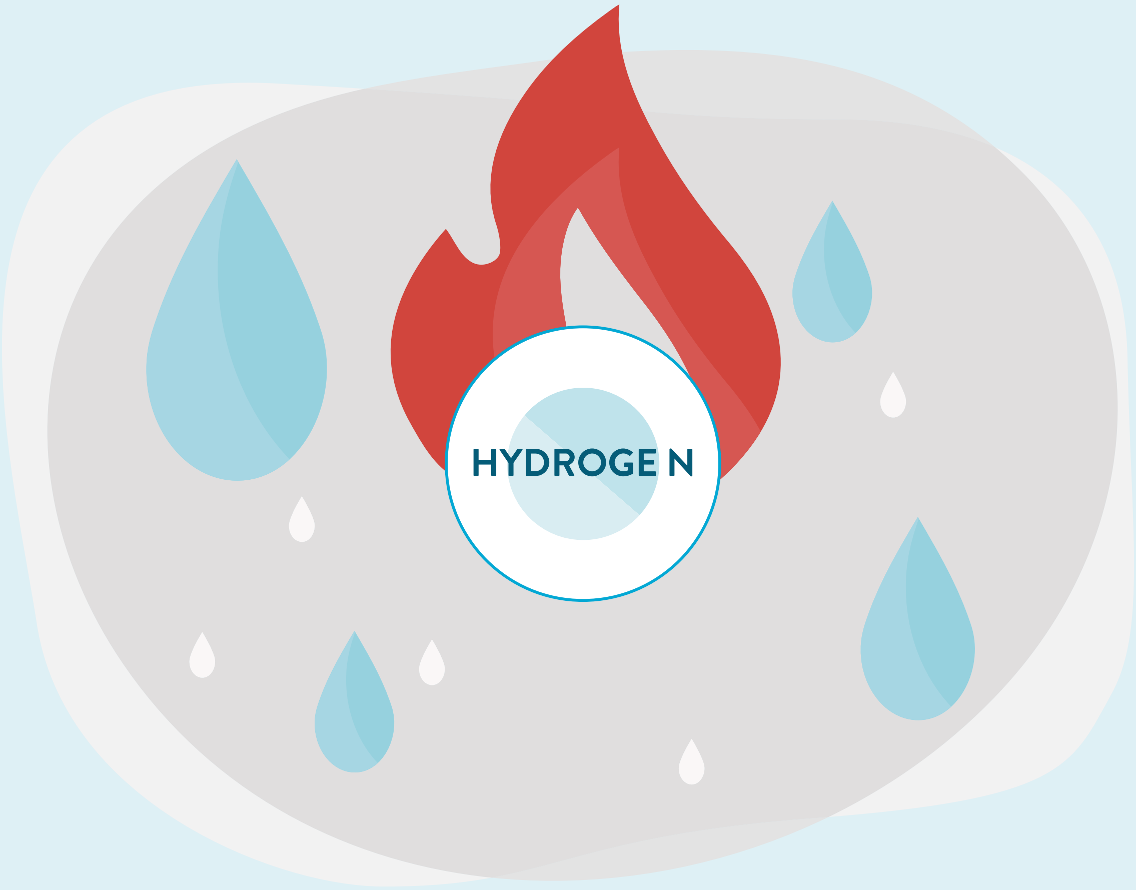
Department for
Business, Energy
& Industrial Strategy

WORK PACKAGE 2

IGEM Hydrogen Standards



IGEM/H/1
Communication 1835

Reference Standard for low pressure hydrogen utilisation

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Reference Standard for low pressure hydrogen utilisation

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CONTENTS

SECTION **PAGE**

1 Introduction 1

2 Scope 3

3 Legal and Allied Considerations 4
- 3.1 Competent persons 4

4 Background 5

5 Characteristics of hydrogen 6
- 5.1 General 6
- 5.2 Combustion characteristics 6

6 Effect on Materials 8
- 6.1 Background 8
- 6.2 Metals 8
- 6.3 Pipework jointing 10
- 6.4 Polymers and elastomers 11
- 6.5 Sealants 11

7 Effect on Application 12
- 7.1 General 12
- 7.2 Building 12
  - 7.2.1 Construction/Building strength 12
  - 7.2.2 Flueing 12
  - 7.2.3 Ventilation 14
- 7.3 Risk assessment 16
  - 7.3.1 Introduction 16
  - 7.3.2 Current Legislation and Standards 16
  - 7.3.3 Effect of Hydrogen on risk assessment 17
  - 7.3.4 Approach to be adopted 18
- 7.4 Hazardous areas 19
  - 7.4.1 Introduction 19
  - 7.4.2 Current Standards and methods 19
  - 7.4.3 Effect of using Hydrogen 20
  - 7.4.4 Approach to be adopted 20

8 Effect on practices 21
- 8.1 General 21
- 8.2 Metering 21

- 8.3 Pipework Design 22
  - 8.3.1 Current standard practice for NG 22
  - 8.3.2 Effects of Hydrogen 23
- 8.4 Pipework Installation 24
  - 8.4.1 Current standard practice and procedures for NG 24
  - 8.4.2 Effects of Hydrogen 24
- 8.5 Appliance Installation 24
- 8.6 Testing, Purging & Commissioning 25
  - 8.6.1 General 25
  - 8.6.2 Testing 25
  - 8.6.3 Purging 26
  - 8.6.4 Commissioning 28
- 8.7 Inspection & Maintenance 28
  - 8.7.1 Inspection 28
  - 8.7.2 Maintenance 29
- 8.8 Identification & labelling 30
  - 8.8.1 Current practice 30
  - 8.8.2 Effects of Hydrogen and approach to be adopted 30
- 8.9 Detection & Response 31
  - 8.9.1 Gas detection instruments 31
  - 8.9.2 Leak detection fluid 32
  - 8.9.3 Emergency response 32

APPENDICES

1 Glossary, Acronyms, Abbreviations, Symbols and Units 33

2 References 35

3 Hydrogen characteristics 43

4 Hydrogen Quality Specification 49

5 Hazardous area classification 50

6 Metering 53

7 Gap Analysis 56

FIGURES

1 Well-mixed gas accumulation room with high level ventilation only 44

2 Layered gas accumulations in a room with high and low ventilation 44

3 Typical dwelling meter components 55

TABLES

1 Suitability of metals for use in hydrogen at less than 2 bar pressure 9

2 Suitability of polymers and elastomers for use in hydrogen at less than 2 bar pressure 11

3 Comparison of physical properties of hydrogen and methane 45

4 Comparison of general combustion characteristics data of hydrogen and methane 47

5 Draft recommendation for a UK Hydrogen quality Standard for heat applications based on existing standards and documents 49

6 Required ACH to achieve Zone 2 NE 52

SECTION 1: INTRODUCTION

1.1 This Reference Standard has been agreed between the IGEM Technical Co-ordinating, Gas Transmission and Distribution, Gas Utilisation, Gas Measurement and Hydrogen Committees, who are responsible for the publication of IGEM Standards.

1.2 This Reference Standard has been developed as part of a Government funded initiative to explore the potential use of hydrogen (see Section 2.2) for use in premises.

1.3 This Reference Standard aims to identify and discuss the principles required for the safety and integrity of Hydrogen installation and utilisation in premises.

This document intends to:

- provide a point of reference for those requiring an understanding of the implications of using hydrogen as a distributed gas in properties
- detail the characteristics of Hydrogen
- detail the comparisons between hydrogen and Natural Gas (NG)
- discuss the safety implications of using hydrogen
- discuss the implications for materials when using hydrogen
- discuss the implications for the installation and use of using hydrogen in domestic & smaller commercial buildings.

This Standard is intended to be a source of reference for any subsequent hydrogen trials and any related IGEM documents.

1.4 Within this document, reference is made to both NG and methane. The composition of NG is predominately methane, however, for theoretical testing purposes, tests are carried out using 100% methane (G20). There should be no significant difference in combustion characteristics between the two gases.

1.5 This Specification makes use of the term "shall" and "should" when prescribing particular requirements:

- the term "shall" prescribes a requirement which, it is intended, will be complied with in full and without deviation
- the term "should" prescribes a requirement which, it is intended, will be complied with unless, after prior consideration, deviation is considered to be acceptable.

Such a term may have different meanings when used in legislation, or Health and Safety Executive (HSE) Approved Codes of Practice (ACoPs) or guidance, and reference needs to be made to such statutory legislation or official guidance for information on legal obligations.

1.6 This Standard can be freely downloaded from IGEM's website www.igem.org.uk.

1.7 Requests for interpretation of this Standard in relation to matters within its scope, but not precisely covered by the current text, is to be addressed to Technical Services, IGEM, IGEM House, 26 & 28 High Street, Kegworth, Derbyshire, DE74 2DA, or e-mailed to technical@igem.org.uk and will be submitted to the relevant Committee for consideration and advice, but in the context that the final responsibility is that of the engineer concerned. If any advice is given by or on behalf of IGEM, this does not relieve the responsible engineer of any of their obligations.

1.8 This document was published in May 2021.

SECTION 2: SCOPE

2.1 This Reference Standard addresses the issues arising from the proposal to use Hydrogen as a gas in domestic and smaller commercial properties to evaluate its potential use as a replacement fuel.

2.2 Hydrogen as referred to in this document, is as per the specification set out in Appendix 4, and therefore does not cover blends of Hydrogen and NG.

2.3 This reference standard covers Hydrogen installations in domestic and small commercial premises downstream of the supplier’s emergency control valve (ECV) and:

- supplier’s meter installation is considered in terms of location, ventilation and general meter installation materials and components but excludes the design and construction of the meter itself
- maximum operating pressure (MOP) of the installation pipework is not exceeding 25 mbar
- supply pressure is assumed to have a MOP of 75 mbar.

2.4 Standards development in the first instance is to consider domestic and smaller commercial gas infrastructure and will exclude the following:

- dual fuel engines
- gas turbines
- any standards related to upstream of the suppliers ECV
- educational establishments
- processes and industrial plant
- multi-occupancy buildings
- large commercial buildings that are considered to have non-domestic appliances
- energy centres and plant rooms with cascade boiler systems
- garages and body shops facilities
- caravan parks and boats, yachts and other vessels
- bottled gas supplies
- gas fire pits, lamps and vehicles
- commercial catering.

2.4 Italicised text is informative and does not represent formal requirements.

2.5 Appendices are informative and do not represent formal requirements unless specifically referenced in the main sections via the prescriptive terms “should”, “shall”.

SECTION 3: LEGAL AND ALLIED CONSIDERATIONS

3.1 COMPETENT PERSONS

Competence in safe gas installation work requires engineers to have sufficient training, knowledge, skills, attitude and experience to perform consistently to current recognised standards. This includes the practical skills and experience to carry out the job in hand safely, with due regard to good working practice. Competence is required to be kept up-to-date, e.g. through on-going training, awareness of changes in law, technology, safe working practice and a commitment to continuous professional development.

Training is required to be provided in line with the recognised industry standard IGEM/IG/1, which will include amendments for the additional requirements to enable engineers to achieve competency in installation, service and repair works that will utilise hydrogen. This could be achieved via a conversion course which is required to be undertaken prior to any work being undertaken on pipework and or appliances that utilise hydrogen.

SECTION 4: BACKGROUND

4.1 In seeking to decarbonise the energy supply sector in the UK, one option is to consider the use of hydrogen gas as a distributed fuel. Studies and trials have been developed to assess the feasibility of hydrogen utilisation. The objectives of these studies and trials are to establish if it is technically possible, safe and convenient to replace methane with hydrogen in residential and smaller commercial buildings and gas appliances. The outcome of the trials will determine whether to proceed to a wider evaluation.

4.2 Existing Standards for the utilisation of NG and Liquefied Petroleum Gas (LPG) have evolved over many years and have benefited from experience and evidence of incidents and near misses. This experience is incorporated into Industry Standards. When considering hydrogen, we do not have the benefit from this experience, so additional detailed scientific knowledge and demonstration will be needed to underpin any new Standards.

Using hydrogen gas imposes several technical challenges when compared to our existing NG/LPG systems. In relation to Standards development for hydrogen gas some of the key challenges are:

- identifying any detrimental effects of hydrogen on materials which will affect the selection and use of pipework, fittings and seals
- quantifying test and acceptance criteria for assessing the tightness of new and existing systems
- defining leakage rates and methodology to enable hazardous areas to be calculated and applied for systems and vent termination
- quantifying combustion, ventilation and cooling air levels for the expected types of appliances and plant
- quantify and mitigate the impact of water vapour with flueless appliances
- identifying any detrimental effects of hydrogen products of combustion (POC) on materials which will affect the selection and use of new and existing flue materials, and terminal location
- addressing design issues associated with capacity reduction due to a lower calorific value
- addressing potential necessary changes to procedures, e.g. purging
- applying Risk Assessment to hydrogen installations
- addressing building strength and construction issues as they may affect building requirements.

Most of these challenges will require some investigation and research work to support and justify IGEM's recommendations and guidance, which could delay the definition of certain principles and practices. Where hydrogen related trials are undertaken it is important that any findings are recorded and incorporated into the relevant Standards.

SECTION 5: CHARACTERISTICS OF HYDROGEN

5.1 GENERAL

Hydrogen is a fuel that combusts in air to form water. The calorific value per unit volume of hydrogen is lower than that for methane (the main component of NG) and this means that greater volumes of gas are required for the same end-user energy requirement.

Hydrogen is a gas that is used widely in industrial plants and is a component of Town gas, but there is no widespread use of hydrogen as a fuel gas for domestic, commercial and industrial applications. Pure hydrogen does not contain carbon and so there is no carbon dioxide (CO_2) production, nor any carbon monoxide (CO), when hydrogen is burned.

More details on the characteristics of hydrogen together with comparisons to methane are given in Appendix 3.

A copy of the draft quality standard is given Appendix 4.

5.2 COMBUSTION CHARACTERISTICS

Hydrogen combustion differs from hydrocarbon combustion in many ways. The air requirement is lower, burning velocity higher, ignition easier and flammable range wider. There are also differences in the flame temperatures and flue gas composition.

5.2.1 Combustion air requirement

The stoichiometric combustion concentration of hydrogen in air (assuming air is made of 21% of oxygen and 79% of nitrogen) is 29.6 vol% with the air content of 70.4 vol% and is represented by the following chemical equation:

$$2\ H_2 + (O_2 + 3.76\ N_2) \rightarrow 2\ H_2O + 3.76\ N_2$$

This is different from methane, as each methane molecule needs two oxygen molecules to react fully as shown in the following equation:

$$CH_4 + 2\ (O_2 + 3.76\ N_2) \rightarrow CO_2 + 2\ H_2O + 7.52\ N_2$$

From a power input viewpoint, for every kilowatt of input power requirement, 0.28 $m^3\ h^{-1}$ of hydrogen is needed and 0.67 $m^3\ h^{-1}$ of air (compared to 0.09 $m^3\ h^{-1}$ and 0.86 $m^3\ h^{-1}$ for methane and air respectively). Thus, any combustion appliance set up to deliver air for methane combustion will be able to provide enough air for hydrogen combustion. There is around 22% decrease in overall combustion air requirement for hydrogen compared to methane.

5.2.2 Flue gas characteristics

Combustion product mass flow rates are smaller for hydrogen combustion than for methane. For every kilowatt of input power requirement, the overall flue gas mass flow is 0.9 kg h^{-1} compared to 1.2 kg h^{-1} for methane. Hydrogen flue gas mass flow is approximately 24% lower than that for methane. Of this total mass flow rate, the proportion of water content differs for the two fuels. For methane the water mass flow rate is 0.15 kg h^{-1} whereas for hydrogen the water mass flow rate in the flue gas is 0.23 kg h^{-1}. The increased water content of the flue gas impacts on the dew point. For methane the flue gas water dew point temperature is around 60 °C whereas for hydrogen it is 73 °C. This could impact on the amount of condensation in flue gas paths.

5.2.3 Burner design options

Different burner types can be used to combust hydrogen. The high burning velocity, wide flammable range and low ignition energy may influence the burner selection and pre-mixed (or partially pre-mixed) burners may be prone to issues with light-back (flash-back). Nozzle-mixed or diffusion burners are options for hydrogen combustion. Hydrogen is well-suited to catalytic combustion (or surface combustion) systems though purity of the fuel is a concern, as this could impact on catalyst lifetime.

5.2.4 Pollutant emissions

The combustion of hydrogen only produces water as a bulk emission. There is no CO_2 produced as there is essentially no carbon in the fuel. The CO_2 present in air can react to form CO in the flame but the concentrations produced are very low. Hydrogen flame temperatures are slightly higher than those of NG or LPG (under similar air to fuel ratio conditions).

As oxides of nitrogen (NO_x) formation are sensitive to temperature, the higher temperature of the hydrogen flame could lead to increased NO_x emission concentrations. The magnitude of any change is dependent on the burner design and arrangement. Premixed burners may result in lower NO_x emission compared to NG, whereas diffusion flame burners have a tendency to produce higher emission levels. Catalytic combustion of hydrogen could be an option and this removes the potential for NO_x formation.

As NG is odour free, odorant is currently added to the fuel gas network to maintain safety. The current odorant added to NG is Odorant NB, which is a mixture of tertiary-butyl mercaptan and dimethyl sulphide (TBM and DMS). Recent studies (H100) indicate that Odorant NB is suitable for use with hydrogen gas at similar concentrations to that currently added to NG (i.e. 6-7 mg m^{-3}). If another odorant is selected then detailed demonstrations will be required to determine that the public will continue to respond to gas escapes in the same way they do today.

When combusted, Odorant NB will produce a low level oxides of sulphur (SO_x) emission from the sulphur present. Also, as the odorant contains carbon, there will be a small amount of CO_2 produced and this may possibly lead to the production of very low levels of CO in combustion products.

SECTION 6 : EFFECT ON MATERIALS

6.1 BACKGROUND

Extensive literature exists for the use of low to medium carbon, carbon-manganese steels and austenitic stainless steels in hydrogen containing networks. Much of this work pertains to high pressure systems; however this is of limited use when considering the materials used within low pressure (circa 25 mbar) domestic or light industrial systems. The materials currently used in the low pressure domestic and light industrial systems are radically different to those used in high pressure hydrogen industrial and automotive systems.

An extensive review has been conducted of the components and the materials used in domestic and light industrial systems. This has revealed the use of a wide variety of metals, polymers and elastomers. The metallic materials used range from low carbon steels, cast irons, copper, brass, stainless steels, various aluminium alloys and soldered joints. There may also be some lead pipes in older Victorian properties that are still in service. Polyethylene is used extensively for pipework in the distribution network upstream of the meter and polymers and elastomers are used extensively for components and seals in meters, valves and governors.

6.2 METALS

The mechanism for the permeation of hydrogen into metals is complex, but involves a number of stages.

1. Adsorption onto the metal surface.
2. Dissociation from molecular hydrogen to highly reactive atomic hydrogen.
3. Atomic hydrogen diffusion towards low pressure/concentration region.
4. On arrival at the external metal surface, hydrogen atoms recombine and hydrogen gas is released.

Although the mechanism of desorption and permeation of hydrogen in metals is independent of pressure, the effects of hydrogen on the material properties may be affected by the pressure of the system.

If the hydrogen pressure is sufficiently high, gaseous atomic hydrogen will enter the solid metal matrix, to produce secondary physicochemical effects such as material embrittlement or loss of ductility. This is often due to accumulation of atomic hydrogen, or recombined molecular hydrogen at lattice defects, which exist in all metals or at internal inclusions (impurities) within the metal. Metallic materials are prone to embrittlement or loss of ductility, provided that the hydrogen partial pressure is sufficiently high enough to promote these mechanisms. The ability of hydrogen to degrade the material is dependent on several factors including operating pressure, temperature, hydrogen concentration, contaminants, material, microstructure, the nature of a crack front, plastic strain and residual stresses within the material.

For metallic materials, the embrittlement effects are a small change in tensile strength, reduction in ductility (leading to brittle behaviour) and a reduction in fatigue life (see Appendix A2.4 1.).

A review of the metallic components likely to be used within a domestic or light industrial gas system was conducted and the materials are listed in Table 1 along with the likely effect of exposure to hydrogen at a working pressure of up to 2 bar. For most materials, other than low carbon steels and austenitic stainless steels, the effects of long-term exposure to 100% hydrogen has not been studied.

Town Gas, containing less than 50% hydrogen, was in use in the UK during the early to mid-20th century and is still used in Hong Kong. This would suggest that hydrogen does not have a detrimental effect on the various metals in Table 1. There is evidence to indicate that the presence of 100 to 1000 ppm CO and 150-4000 ppm oxygen (O_2), at high pressures of circa 9 MPa , can have an inhibiting effect on the detrimental effects of hydrogen with respect to fatigue in carbon steels (see Appendix A2.4 2.).

The beneficial effect of trace gases on other components in the system e.g. copper, brass etc. has not been demonstrated.

Material	**Suitability**	**Comments**
Cast iron	Possibly OK at low pressures?	[3, 4, 5]. Further data required. Ref 4 state unsuitable for hydrogen service.
High carbon spring material	Unknown	No data found to allow a judgement to be made. Possibly susceptible to premature failure.
Martensitic stainless steel spring material	Unknown	No data found to allow a judgement to be made. Possibly susceptible to premature failure.
316 Stainless steel	Satisfactory	[3, 4, 5]
304 Stainless steel	Satisfactory	Not as good as grade 316 [3, 4, 5]
Carbon steel, e.g. API 5L B	Satisfactory	[3, 4, 5, 6]
Aluminium	Depends on alloy	1000, 2000, 7000 series alloys satisfactory. Dry gas only. [3, 4, 6]
<2.5% Leaded brass	Satisfactory	[3, 4, 5]
>2.5% Leaded brass	Unknown	[3, 4, 5] limited data available for use of higher lead contents above 2.5%. Effect of increasing lead content is unknown.
Chromium plated brass	Unknown	No data found to allow a judgement to be made
Copper	Satisfactory	Oxygen free copper. [3, 4, 7]
Lead free solder	Satisfactory	[3, 4]
Leaded solder	Satisfactory	[3, 4]
Lead	Unknown	No data found to allow a judgement to be made

Note: The reports referenced in this Table, signified by [ ] are in Appendix A2.4.

TABLE 1: SUITABILITY OF METALS FOR USE IN 100% HYDROGEN AT LESS THAN 2 BAR PRESSURE

6.3 PIPEWORK JOINTING

6.3.1 Welding of steel pipes

Low carbon steel pipes with a specified minimum tensile strength of up to 550 MPa may be joined by welding so long as a number of criteria have been met.

1. The carbon equivalent (CE) has a maximum value of 0.43 (see Appendix A2.4 8.).
2. The welds are made in accordance with an approved welding procedure specification to BS EN ISO 15614-1 (see Appendix A2.4 9.).
3. The welds are made by an approved welder, assessed against the requirements of BS EN 9606. (see Appendix A2.4 10.).
4. The welds are visually inspected after welding to BS EN ISO 5817 acceptance category B (see Appendix A2.4 11.).
5. The welds and Heat Affected Zones (HAZs) have a maximum hardness of 250 HB (see Appendix A2.4 8.).

Welding of pipe previously subjected to hydrogen service may be susceptible to hydrogen cracking and need special consideration, such as preheating (for example to 50 °C) and allowed to cool slowly. Welding should be conducted by:

- the TIG process, or
- MMA welding using low hydrogen electrodes in accordance with manufacturer's recommendations and BS EN 1011-2 (see Appendix A2.4 12.).

Pipes shall be visually inspected for cracks after cooling to ambient temperature, ideally after 24 hours as hydrogen cracks may not occur immediately after welding. It is recommended that visual examination is supplemented by magnetic particle inspection (MPI) or dye penetrant inspection (DPI).

6.3.2 Soldered joints

Evidence indicates that soldered joints can be made for hydrogen service. Leaded and lead-free solders can be used so long as a satisfactory gas tight joint is correctly made and tested.

6.3.3 Threaded joints in steel

Threaded joints contain a theoretical leak path for hydrogen along the joint interface, which will need to be leak tested. Joints should not be over-tightened due to the risk of embrittlement, particularly for joints that have been subjected to previous hydrogen service.

6.3.4 Compression fittings

Compression fittings contain a theoretical leak path for hydrogen along the joint interface, which will need to be leak tested. Joints should not be over-tightened due to the risk of embrittlement, particularly for joints that have been subjected to previous hydrogen service.

6.3.5 Press-fit joints

The use of press fit joints has not been demonstrated for hydrogen utilisation and the performance will depend on the choice of materials used in the fitting. Press-fit joints contain a theoretical leak path for hydrogen along the joint interface, which will need to be leak tested.

6.4 POLYMERS AND ELASTOMERS

Polymers and elastomers are primarily hydrocarbon compounds. Studies have been conducted into the effects of hydrogen on various compounds and their compatibility with hydrogen is given in Table 2. Generally, there will be a greater degree of hydrogen permeation through the polymers and elastomers when compared to NG. However, interaction of hydrogen with most polymers does not appear to be a problem.

Repair using squeeze-off and electrofusion techniques have been conducted on hydrogen exposed PE80 pipes and these processes appear to be tolerant to these conditions (see Appendix A2.4 3.).

Material	Suitability	Comments
PE 80	Satisfactory	No known issues. Trial data shows a good response. [3, 13, 14]
PE 100	Satisfactory	No known issues. [3, 14, 15]
Nitrile rubber (NBR or Buna-N seats and seals, valve discs, safety check valves	Satisfactory	[3, 16, 17]
Fluorocarbon rubber (Viton) seals, O rings	Satisfactory	[3, 16, 17]
Compressed asbestos fibre (CAF) gaskets	Satisfactory	[3, 17, 18]
Ceramic PTFE, spindle bearings in check valves	Satisfactory	[3, 19]
Nylon 581, safety check valves	Satisfactory	[3, 17]
Polyurethane, sealant (encapsulant repairs)	Satisfactory	[3, 17]
Polyamide (turbine meters)	Satisfactory	[3, 17]
Polyacetyl (turbine impellors)	Satisfactory, Fair	[3, 20]
Polycarbonate ‘glass’ panels on turbine meters	Satisfactory	[3, 19]

Note: The reports referenced in this Table, signified by [ ] are in Appendix A2.4.

TABLE 2: SUITABILITY OF POLYMERS AND ELASTOMERS FOR USE IN HYDROGEN AT LESS THAN 2 BAR PRESSURE

6.5 SEALANTS

A number of proprietary sealants have been used with NG, LPG and Town Gas. Many sealants are suitable for use with first family gases, however, according to the data available, none of them have been tested for use with hydrogen gas. Therefore, without further detailed assessment, they are not to be used due to the risk of possible chemical reaction with hydrogen. One well-known brand (see Appendix A2.4 21.) contains constituents known to react with hydrogen gas and is therefore not suitable for such use.

SECTION 7 : EFFECT ON APPLICATION

7.1 GENERAL

This Section discusses the general issues affecting the building and its construction by hydrogen installations in domestic and smaller commercial premises.

Note: Multi-occupancy buildings are excluded from the scope.

7.2 BUILDINGS

7.2.1 Construction/building strength

7.2.1.1 *Introduction*

On rare occasions, gas explosions occur within buildings when fuel gas leaks for example from a pipe, fitting, appliance, and comes into contact with an ignition source. Depending upon the gas leak rate and ventilation rate, differing levels of damage may occur from overpressures developing within the building. This may just be localised heat damage, to broken windows and potentially destruction of the building.

7.2.1.2 *Current Standards*

Generally, buildings are designed to be strong enough to withstand expected external forces, such as wind loadings, but are not designed to withstand internal pressurisation due to gas explosions. Typically, domestic buildings and light commercial structures will suffer structural damage when exposed to relatively low overpressures of ca.100 mbar (see Appendix A2.5). Such overpressures can currently occur during an explosion involving NG.

7.2.1.3 *Effects of hydrogen on current standards*

The volumetric leak rate of hydrogen will be greater than NG through a given hole size. The increase for turbulent leaks (as will occur via larger holes) is greater than for smaller, laminar leaks; this is described further in Appendix 3-Section A3.1. The ventilation rate may be increased due to increased buoyancy of hydrogen and this may, to some extent, mitigate the increased leak rate. However, hydrogen also burns faster than NG and so has the potential to generate higher overpressures in explosions. In the absence of published data to the contrary, this suggests that buildings may be subject to greater internal overpressures as a result of internal explosions from ignition of a hydrogen gas cloud, as compared to a NG cloud of the same size, location and equivalence ratio. More discussion is given in Appendix 3.

7.2.2 Flueing

7.2.2.1 *Introduction*

Flueing is required to discharge combustion products outside a property with the aim of ensuring rapid atmospheric dispersion. The flueing process endeavours to discharge combustion products away from the property to prevent re-entry or entry into adjacent properties and to minimise the potential for contact with any pollutants.

Chimneys and flues represent the channels through which combustion products are transferred to outside of a property.

Any chimney or flue shall be constructed of materials suitable for the application and shall be fit for purpose. Where an existing chimney is to be used as a flue, it shall be inspected, cleaned and lined, as required.

The complete flue or chimney system shall be designed to operate without leakage of gases or condensate, and any joints shall be resistant to combustion product gases and condensate.

7.2.2.2 *Current Standards*

Individual flues serving domestic appliances of net heat input not exceeding 70 kW should comply with requirements from BS 5440-1:2008, and other parts of BS 5440.

In addition, non- domestic flues and chimneys should comply with the spirit of requirements set out in IGEM/UP/10 Edition 4, with amendments – March 2016 & February 2017 (Communication 1800 Installation of flued gas appliances in industrial and commercial premises).

BS 5440-1:2008 specifies requirements for the installation of gas appliances to chimneys/flues and requirements for the maintenance of chimneys.

BS 5440-1 is applicable to open flue chimneys for Type B [Section 7.2.2.4] gas appliances and room-sealed chimney/flue configurations for Type C gas appliances, each of rated input not exceeding 70 kW net. It is applicable to:

- complete chimney and all chimney components from the appliance connection to the discharge point into outside air
- the installation of gas appliances to existing chimneys that were intended originally for appliances burning other fuels
- chimneys for residential park homes but not to chimneys for leisure accommodation vehicles.

7.2.2.3 *Effects of hydrogen on Current Standards*

BS 5440-1:2008 applies to gas burning appliances utilising first, second or third family gases (as defined in BS EN 437).

Hydrogen combustion characteristics are different to first, second or third family gases, in that the combustion product composition for hydrogen do not contain any CO or CO_2. Combustion pollutant species from hydrogen are mainly associated with NO_x.

Hydrogen combustion characteristics show that water content of the flue is greater than for NG combustion, and this impacts on the dew point temperature.

The greater flue gas water content could lead to a greater degree of pluming (the visible water vapour plume). Appliance designs installation and location should ensure that water vapour does not condense on nearby walls and structures.

7.2.2.4 *Approach to be adopted*

Gas appliances are split into 3 categories in terms of their ventilation requirements:

- Type A – Flueless and take their combustion air from the room and release their (POC) into the room
- Type B - Open flued and obtain their combustion air from within the room and POCs are released to the outside via a flue or chimney
- Type C- Room sealed and take their combustion air from the outside by means of an air intake and release their POCs via a flue.

It is expected that most boilers will be Type C (room sealed) type appliances and discharge through a fanned concentric flue. The degree of pluming will need to be evaluated and studied to determine if it is acceptable in a domestic environment.

Flues from fires will possibly be Type B (open flued) or Type C and again consideration will be needed to the impacts of pluming. It may also be necessary to evaluate the potential impact of any increased flue/chimney condensation.

Cookers are Type A (flueless) but will need to be studied to evaluate whether the potential build-up of water vapour within the kitchen environment is significant.

Ideally, in advance of any trials, the potential impact of the issues stated would have to been assessed prior to any further work. However, since many of the potential issues above would be of concern only in the longer term, it is possible that existing standards could be adapted for use in the initial trial and assessments made during the unoccupied trial, and any corrective action taken for further trials.

Note: Particular care is to be taken to avoid accumulation of a flammable hydrogen/air mixture in chimneys. Appliance manufacturers and installers are cautioned of this risk.

7.2.3 **Ventilation**

7.2.3.1 *General*

Ventilation is required within premises to serve a number of purposes.

It is required for**:**

- provision of fresh air for breathing
- dilution and removal of airborne pollutants and odours (including those released from materials used for construction, decoration and furnishing of a building. Pollutants will vary with the use of the building)
- control of excess humidity
- provision for air for fuel burning appliances
- thermal comfort.

For fuel burning appliances air is required:

- to supply air for the complete combustion of the NG
- to ensure that the POC are diluted and safely dispersed to the outside
- for cooling purposes for controls and casings.

It is worthy of note that there are no ventilation requirements in domestic premises for dilution and removal of potential gas leaks, other than a general requirement not to install pipework in unventilated voids. However, for commercial premises, there is a requirement under the Dangerous Substances and Explosive Atmosphere Regulations (DSEAR).

Ventilation within premises, can be provided by a combination of infiltration (or adventitious ventilation) and purpose-provided ventilation. Infiltration is the uncontrollable air exchange between the inside and outside of a building through a wide range of air leakage paths in the building structure, the air flow driven by wind and temperature differences between the inside and outside of the building. Purpose-provided ventilation is the controllable air exchange between the inside and outside of a building by means of a range of natural and/or mechanical devices. Mechanical ventilation systems will not be designed to handle flammable gases (including NG) and so in the event of a gas leak, ignition within the system could not be ruled out.

Currently, much building ventilation occurs adventitiously, especially in domestic premises, and this meets the requirements for NG usage. Should the requirements differ for hydrogen, building regulations would have to take these changes into account and this may present a challenge, particularly for existing building stock.

7.2.3.2 *Current standards*

The following Regulations and standards are applicable:

- Building Regulations 2010 Means of Ventilation: Approved Document F
- Building Regulations 2010 Combustion appliances and fuel storage systems: Approved Document J
- IGEM/G/11 Unsafe situations procedure.

7.2.3.3 *Effect of hydrogen on the means of ventilation within a building*

In recent years, infiltration ventilation levels have been reduced to minimise heat loss.

Due to the wider flammability limits and increased ignition sensitivity of hydrogen it is necessary to consider whether ignition would be more likely in the event of hydrogen leakage.

There is no requirement for purpose provided ventilation in a building or space which people do not normally enter, or is solely used for storage or is a garage used in connection with a single dwelling. Consideration shall be given to whether specified ventilation requirements are necessary for these spaces, if they contain pipework conveying hydrogen, in order to avoid the accumulation of flammable gas resulting from leaks. This is especially true for small, poorly ventilated spaces (see also Sections 7.4, 8.2 and 8.3).

Consideration shall also be given to whether extra ventilation and/or hydrogen/heat detectors are required to help mitigate against hydrogen leakage from gas meter installations. Gas meter installations may be required to be located outside of the building.

For combustion purposes, hydrogen requires less air for combustion therefore existing calculations for ventilation for the purpose of combustion will be sufficient. However, it will need to be demonstrated as to whether ventilation will be required for the dispersal of POCs for flueless appliances and further research into this area will be required. There will be no additional requirements for room sealed appliances.

As the temperature of the hydrogen flame can be higher than those for NG there is an increased likelihood of NO_x emission levels increasing for flueless appliances (such as cookers). If this proves to be the case, current purpose provided extraction rates for kitchens may require recalculation and manufacturers are expected to provide detailed installation instructions to address this hazard.

Hydrogen is more buoyant than NG and so hydrogen leaks may result in more accumulation at high level. However, both gases would require ventilators and extractors at a high level in the room to avoid flammable accumulations.

7.2.3.4 *Effect of hydrogen on Combustion appliances*

Hydrogen requires less air for combustion than NG and therefore existing ventilation calculations for NG will provide more than sufficient air requirements for combustion. Gas fires utilising NG can use a variety of flue systems, including open flues. It will need to be demonstrated as to whether gas fires utilising hydrogen will be suitable for open flues and twin-walled flue arrangements.

The combustion of hydrogen will produce more water vapour within its flue gas than NG, as a result of this, proximity distances need to be reviewed to prevent nuisance pluming. It will also need to be assessed as to whether the water vapour will be more or less acidic as this could affect deterioration of flue materials.

Flueless appliances (such as cookers and fires) will produce more water vapour in their POC into the room when compared to NG appliances. This could potentially lead to an increase in mould formation within rooms and it will need to be considered as to whether the current Building Regulation requirements for mechanical ventilation requirements are sufficient.

Currently, room sealed appliances do not require compartmental ventilation under the Building Regulations. Compartmental ventilation requirements will need to be revisited once appliances have been developed and the POC have been demonstrated.

Building Regulations currently require houses that contain solid fuel burning appliances to install a CO alarm. There are known cross-sensitivity issues regarding CO alarms and small quantities of hydrogen. Further work, including development of new CO sensors, will be required to overcome this problem.

7.2.3.5 *Approach to be adopted*

Ideally, in advance of any trials, the potential impact of the risk stated would have to be assessed prior to any further work. However, since many of the potential risks would be of concern only in the longer term, existing standards could be adapted and assessments made during trials, and any corrective action taken.

The issues highlighted above will need greater understanding in order to input into a risk assessment (see Section 7.3).

7.3 RISK ASSESSMENT

7.3.1 Introduction

The hazards associated with the supply of NG are controlled via existing procedures and standards. Nonetheless, there remains a residual risk. There are many ways of assessing risk, each one having individual strengths and weaknesses (see Appendix A2.8 1.). Methods range from high-level qualitative risk assessments, to those that are detailed and quantitative. The choice of a suitable approach will depend upon the details of the process/equipment being assessed. The chosen approach is to be suitable, sufficient and proportionate.

7.3.2 Current Legislation and Standards

Health and Safety at Work Act (HSWA), 1974

Under HSWA employers have a legal duty to assess the risks to the health and safety of their employees (and risks to the health and safety of persons not in their employment) to which they are exposed while they are at work.

IGEM/GL/4 Ed 3 Gas system assets – risk management

This standard specifies a framework for risk management of assets associated with gas systems. It covers all activities including design, installation, operation, maintenance, management and providing an emergency service on the assets associated with gas systems. It applies to all fuel gases and is based on HSG65 but with further requirements to make it gas-specific.

IGEM/G/7 Risk assessment techniques

This standard covers hazard identification and includes assessing the consequences of failure along with risk assessment techniques in general and specifically addresses their application in the NG and LPG industries.

The scope also covers activities on systems associated with on-shore storage, transmission, distribution and utilisation of NG and LPG throughout their life cycle; that is design, construction, commissioning, operation, maintenance, de-commissioning and demolition.

Gas Safety (Installation and Use) (Amendment) Regulations 2018

These Regulations specify the requirements for the safe installation and use of gas. Hydrogen is included in these regulations, other than in non-domestic premises. They make reference to the obligations (e.g. under the HSW Act, the Management Regulations, and the Workplace (Health, Safety and Welfare) Regulations), for securing safety of both staff and trainees.

Gas Safety (Management) Regulations (GS(M)R) 1996 Safety Case (HSE Guidance)

GS(M)R requires gas conveyors to develop a safety case for the operation of their network and this is required to be accepted by HSE before any gas is conveyed. GS(M)R currently defines ‘gas’ as any substance in a gaseous state which consists wholly or mainly of methane and the current GS(M)R limit for hydrogen is limited to < 0.1% (molar). Since GS(M)R applies to networks in which the gas conveyed is wholly or predominantly methane it does apply to hydrogen blending below 50% but not to a 100% hydrogen network. Other regulations, notably the Pipelines Safety Regulations 1996 and the Pressure Systems Safety Regulations 2000 will also apply under certain circumstances.

HSE have advised that, in the current absence of bespoke hydrogen regulations, early trials for hydrogen only networks can be effectively and proportionately regulated. At present, under HSWA and other relevant Regulations the duty holder is required to put in place a suitable Safety Management System and to demonstrate the effectiveness of this, so far as is reasonably practicable, by identifying, assessing and managing all risks associated with their undertakings.

7.3.3 Effect of hydrogen on risk assessment

There are a number of properties of hydrogen that may influence the risk that it presents compared to NG including, but not exclusive to, those outlined below:

i. Construction materials may be degraded by interactions with hydrogen as described in Section 6.
ii. Hydrogen will permeate at a faster rate than NG through pipe walls, etc. This is unlikely to be a safety issue unless the permeated gas could accumulate in very poorly ventilated spaces, since the rate at which hydrogen permeates through pipes will be low compared to expected ventilation rates.
iii. Hydrogen has a significantly lower density than NG. For identical leak conditions (i.e. hole size and pressure), a turbulent leak will therefore produce a higher volumetric flow rate of hydrogen as compared to NG. Assuming the resulting gas jet is unobstructed, the flammable cloud will extend further for hydrogen than for NG. However, the lower density of the gas may also increase the ventilation rate of a room due to buoyancy. More discussion is given in Appendix 3.
iv. Hydrogen has a slightly lower LFL than NG, which may result in ignition of leaked gas at a slightly lower concentration than NG.

v. Hydrogen has a significantly higher UFL, which means that hydrogen/air mixtures can be ignited over a wider range of concentrations than NG.

vi. Hydrogen has been shown to be more readily ignited than NG when exposed to a range of ignition sources such as electrical sparks, electrostatic discharges, frictional heating, etc. (see Appendix A2.3 3. and 4.). The potential exposure to such ignition sources are required to be mitigated in areas subject to the requirements of the DSEAR. However, ignition sources in other areas are not controlled and are likely to be capable of readily igniting NG currently. Therefore, the significance of the difference in ignition sensitivity of hydrogen compared to NG would need to be considered in context.

vii. Hydrogen has a lower energy density (i.e. energy per unit volume) than NG. This means that higher volumetric flows of hydrogen would be needed to supply appliances with the required power.

viii. For small-scale releases, pure hydrogen flames emit a lower fraction of their energy in the form of radiated infrared heat than flames of typical hydrocarbon flames, including NG flames. In these cases, for fires of equivalent power, heating of adjacent objects would be less for hydrogen than NG. (5) For larger-scale releases representative of fractured pipeline mains, there is some evidence that the fraction of heat released as radiation in jet fires is similar for hydrogen to NG (6). Hydrogen flames radiate ultraviolet (UV) radiation capable of sunburn-like effects (see Appendix A2.3 7.).

ix. Since the burning velocity of hydrogen is greater than that of NG, stable hydrogen flames may be possible in situations where NG flames would lift off and thereby self-extinguish.

x. Hydrogen burns considerably faster than NG at the same equivalence ratio. If a cloud of hydrogen gas is ignited within a room, or other confined space, the higher burning velocity may result in higher overpressures being generated, causing more damage and, potentially, injury (see Section 2 and Appendix 3 for further detail).

xi. Gas flames can self-accelerate by pre-heating of the unburnt gas mixture as the flame propagates. Hydrogen has a far stronger tendency to self-accelerate than NG and this could further increase explosion overpressures. Similarly, hydrogen has a greater tendency for flames to accelerate from sub-sonic deflagration to detonation than NG.

As a number of these are competing behaviours, a sophisticated understanding of relative risk needs to be developed based on credible evidence to support any overall risk assessment for hydrogen utilisation.

7.3.4 Approach to be adopted

For an unoccupied trial a Hazard Identification (HAZID) approach would appear to be appropriate. This is a high level review of potential hazards, based on checklists, carried out by a multidisciplinary team.

For an occupied trial, a more sophisticated and quantitative approach would be appropriate, such as Quantified Risk Assessment (QRA). QRA involves obtaining a numerical estimate of the risk from a quantitative consideration of event probabilities and consequences. Two commonly used types of risk measure are: individual risk which is defined as the may be expected to sustain a given level of harm; and societal frequency at which an individual risk which is defined as the relationship between frequency and the number of people suffering from a specified level of harm in a given population.

Note: Given the potentially greater damage likely to occur from a hydrogen explosion it is to be expected that additional protection methods may need to be considered, for example excess flow valve, which will shut off in the event of a major leak.

7.4 HAZARDOUS AREAS

7.4.1 Introduction

Under DSEAR, it is necessary to carry out a hazardous area classification (HAC) wherever there is a potential for flammable gas/air mixtures to form (in the case of gas supply in networks this is typically as a result of anticipated potential leaks, or where gases may be deliberately vented). There are some exclusions to the application of DSEAR, such as within domestic dwellings, though it would apply to items such as central boiler houses for multi-occupancy buildings. DSEAR will also need to be considered for any trial that is classed as a place of work.

HAC identifies and classifies areas into Zones within which measures are required to avoid the presence of ignition sources (often requiring the use of ATEX certified equipment).

HAC does not cover releases of flammable gas caused by catastrophic failure such as the rupture of a process vessel or pipeline, component failure and similar rare events that are not predictable. However, measures to avoid such circumstances shall be identified as part of a general DSEAR Assessment.

Additional information and definitions of relevant terms are given in Appendix 5, together with more description of the existing standards and methods.

7.4.2 Current standards and methods

There are several standards, guidance documents and methods in existence; some are gas industry specific while others are more generally applicable.

7.4.2.1 *Gas Industry Standards*

IGEM/SR/25 – "Hazardous area classification of Natural Gas installations"
This Standard applies to all NG installations and complements BS EN 60079-10-1 by providing detailed requirements for the hazardous area classification of permanent and temporary NG installations, thus providing a basis for the correct selection and location of fixed electrical equipment in those areas.

IGEM/UP/16 – "Design for Natural Gas installations on industrial and commercial premises with respect to DSEAR"
This standard follows the principles of IGEM/SR/25 and is intended to provide basic design information to enable designers, and those undertaking risk assessments, to achieve a gas installation that can be classified and maintained as Zone 2 Negligible Extent (NE) (Zone 2 NE).

IGEM/GM/7B – "Hazardous area classification for gas metering equipment"
Like IGEM/UP/16, this document is based on the principles of IGEM/SR/25. It describes specific requirements for well-defined applications.

IGEM/UP/6 Ed 2 – "Application of compressors to Natural Gas fuel systems"
This standard does not give specific guidance on HAC but does advise that IGEM/SR25 be used for this purpose.

7.4.2.2 *Other guidance*

BS EN 60079:10-1 – "Explosive atmospheres. Classification of areas. Explosive gas atmospheres". The most commonly used standard in the UK for determining area extent and classification is BS EN 60079 part 10, which has broad applicability.

Energy Institute Code of Practice, EI15:"Area classification code for installations handling flammable fluids". EI15 is only applicable to systems with a pressure above, or near to, 5 bar and therefore is not directly relevant to low pressure hydrogen supply. It does, however, contain some guidance that could be of use.

Computer based calculation methods are available which provide a scientific mathematical model of a flammable gas jet, developed to provide a more realistic assessment of the releases of flammable gases, in ventilated enclosures or outdoors, in the absence of congestion.

7.4.3 Effects of using hydrogen

Hydrogen has a slightly lower LFL than NG and will exhibit higher volumetric leak rates than NG through given hole sizes. These properties result in hydrogen having larger zones resulting from HAC, or a higher ventilation requirement, than would be the case for NG. Typically, the distance to the LFL will be approximately 3.5 times longer for an unobstructed jet release of hydrogen than for methane, based on a publically available mathematical method by Webster et al.

Hydrogen is also more buoyant than NG and so has an increased tendency to form flammable air/mixtures at high level within rooms (given sufficient gas leakage or insufficient ventilation). Whilst this behavior is less likely to be of concern for situations determined to be of “negligible extent”, it may need further consideration for the purposes of area classification in other circumstances.

Hydrogen is also easier to ignite than NG and the flames can pass through narrower gaps and channels. These properties result in hydrogen being classified as a Group IIC gas, whereas NG is classified as a Group IIA gas (Ref 4). Therefore, the equipment to be used within hazardous areas identified for hydrogen will need to be of a higher standard than currently required for NG installations.

IGEM/SR/25, and the associated standards (IGEM/UP/16 and IGEM/GM/7B) which adopt its principles and methods, are based on modelling of mains NG. There is no simple conversion, for hydrogen, of the current calculations/Tables set out in IGEM/SR/25, IGEM/UP/16 etc., and so a new set of calculations, Tables etc. would be required. The conversion from NG to hydrogen cannot simply be expressed in terms of LFL/leak rate.

Updated ventilation areas will be required for hydrogen in IGEM/GM/7B for meter installations.

7.4.4 Approach to be adopted

Prior to widespread implementation of hydrogen, readily applicable hydrogen-specific area classification standards (covering the same applications as IGEM/SR/25 and associated standards) will be required, as BS EN 60079:10-1 (2009) or published mathematical models may be too complex and inconvenient for designers and installers.

Note: *If a trial site was a commercial premises or deemed to be ‘a place of work’, then DSEAR will apply, even if the installation and appliances are to “domestic” standards. IGEM/SR/25 will not be applicable; application of a more general technique, such as mathematical modelling, could be applied to a simple, one-off installation, although judgement would be required if potential leak points are in highly confined or congested spaces (e.g. with reference to EI15).*

SECTION 8: EFFECT ON PRACTICES

8.1 GENERAL

This Section discusses the general issues that will affect hydrogen installations in domestic and smaller commercial premises.

8.2 METERING

8.2.1 Introduction

Meters are required for the measurement of gas usage and for billing of customers. There are several types of gas meter that could be installed including diaphragm or ultrasonic meters. Meters are required to be able to measure gas usage accurately and reliably. Meters are installed at the connection points between the gas network operator (or transporter) and the customer are the responsibility of the gas supplier (see figure below). Meters are owned/rented by the Meter Asset Manager (MAM) on behalf of the energy supplier.

Meters are required to be installed by an Approved meter installer AMI) who is Gas Safe registered.

8.2.2 Impact of hydrogen on metering

The properties of hydrogen will impact on metering and aspects are noted in the following sub-sections.

8.2.2.1 *Meter functionality*

The only requirements are that the meter does not degrade or leak, and that it accurately measures gas consumption.

Additional functionality (for example a shut off valve in case of excess flow) may be required if there is a safety issue around the use of hydrogen, but this needs to be determined

8.2.2.2 *Meter connections*

Leakage from meter connections remains is a key risk. Meter connections are shall comply with the “Specification for gas meter unions and adaptors” upgraded from the NG specification (BS 746:2014) and “Meter installation fittings” IGEM/GM/PRS/1 2017 for use with hydrogen.

8.2.2.3 *Meter location*

If it is established that there is no additional risk from installing a hydrogen meter to replace a NG meter, the meter location could be the same for either hydrogen or NG.

8.2.2.4 *Meter box*

BS 8499:2017 Specification for domestic gas meter boxes and meter bracket – to be updated to cover hydrogen.

8.2.2.5 *Meter testing*

Meter accuracy testing is required to be undertaken for in-service against an agreed sample plan. For NG meters, in-service testing is undertaken on compressed air. A suitable meter accuracy testing programme needs to be determined for hydrogen meters.

8.2.2.6 *Meter identification*

Hydrogen meters are required to be clearly labelled as "hydrogen only" to avoid confusion with NG meters

8.2.2.7 *Meter installation*

Meters are required to be installed by an AMI as listed on the AMI Register held by SPAA Ltd in accordance with the Supply Point Administration Agreement (SPAA).

8.2.2.8 *Meter degradation*

The long-term impacts of hydrogen on a meter are unknown but may include the degradation of internal meter components (such as the rubber bellows within a diaphragm meter). Hydrogen meter manufacturers need to verify safe operation of the meters within a domestic/commercial application with regards to leakage and degradation.

8.2.2.9 *Physical size of meter*

The calorific value (based on volume) of hydrogen is only one third of NG and most meters measure volume.

It therefore follows that the size of the meter will probably be considerably greater for use with hydrogen.

8.2.3 Approach to be adopted

Certification standards are not currently available for hydrogen meters but it is expected that the principles and approaches taken for NG will be adopted for hydrogen. It is noted that BS 6400 is for 2nd Family Gases and hydrogen does not fall into this category.

Work is underway on suitable the connections, seals, fittings and other infrastructure will be able to be used to support the installation of new hydrogen meters, but a separate Risk Assessment may be required depending on the degree of meter development.

It is recommended that the meter installation is located external to the property.

8.3 PIPEWORK DESIGN

8.3.1 Current standard practice for NG

8.3.1.1 *Pipework schematic*

For non-domestic installations there is a requirement to provide a schematic of the pipework at the meter installation.

8.3.1.2 *Pipework location*

All pipework downstream of the meter outlet can be installed in the following locations being surface mounted, buried or in ventilated spaces.

Currently Installers size internal NG pipework to ensure that the maximum pressure drop between the meter and appliance does not exceed 1 mbar, as per the requirements of BS:6891 and to ensure that the heat requirement from the appliances(s) can be met.

8.3.1.3 *Pipework sizing*

Pipework is sized based on having a maximum pressure drop from the meter outlet to the appliance to ensure the correct pressure at the appliance for the given flowrate. BS 6891 gives flow formulae and tables for different gases (NG and LPG) to enable installations to be correctly sized. Computerised sizing programmes are also available.

8.3.1.4 *Pipework fittings*

Under existing standards the following pipework fittings have been tested and are deemed suitable for use with NG:

- soldered joints
- threaded joints
- compression
- pressed fit fittings
- ground fittings.

8.3.1.5 *Isolation valves*

Simple on/off compression fitting isolation valves suitable for use with NG are to be used at the entry points of each appliance.

8.3.1.6 *Proximity distances*

BS:7671 IET Wiring Regulations covers the requirements for electrical installations adjacent to NG pipes.

It stipulates a gap of at least 25 mm between NG pipes and other services and at least 150 mm between a NG pipe and any electricity meter and distribution cables.

8.3.1.7 *Hidden pipework*

NG pipework buried in floors, located within voids or passing through walls is covered by BS:6891 Specification for the installation and maintenance of low-pressure gas installation pipework of up to 35 mm (R1¼) on premises.

8.3.2 **Effects of hydrogen**

8.3.2.1 *Pipework schematic*

No change to current practice is expected.

8.3.2.2 *Pipework location*

The acceptable location (particularly with respect to pipework in ventilated voids) of pipework will be subject to the outcome of a risk assessment. Internal installation of the above will be subject to the outcome of a risk assessment undertaken to assess the potential increased risk of using hydrogen.

8.3.2.3 *Pipework sizing*

New pipework sizing charts will be required for hydrogen. The differing characteristics of hydrogen may mean that existing NG pipework systems may not be of sufficient size to be re-used with hydrogen, due to the increased flowrates, particularly if the same pressure criteria is used for sizing.

8.3.2.4 *Pipework fittings*

Recommendations on suitable materials for pipework fittings are included in Section 6: Materials. Leak testing of components is recommended to confirm their leak tightness for operation prior to use.

8.3.2.5 *Isolation valves*

Recommendations on suitable materials for valves are included in Section 6: Materials. Performance testing of isolation valves is recommended to confirm their performance prior to use.

8.3.2.6 *Proximity distances*

The proximity distances set out for NG in BS:7671 IET Wiring Regulations need to be updated to cover the requirements for hydrogen.

8.3.2.7 *Hidden pipework*

The requirements for hidden hydrogen pipework (pipework buried in floors, located within voids or passing through walls) will need to be risk assessed.

The risk assessment for NG can be found in BS:6891.

8.4 PIPEWORK INSTALLATION

8.4.1 Current standard practice and procedures for NG

8.4.1.1 NG pipework is required to be installed by a Gas Safe registered engineer, with the appropriate accreditation, in accordance with industry standards.

8.4.1.2 *Applicable standard*

BS 6891 - Specification for the installation and maintenance of low-pressure gas installation pipework of up to 35 mm (R1¼) on premises.

8.4.2 Effects of hydrogen

8.4.2.1 Installation standards will be required to be updated for the installation of hydrogen pipework and Gas Safe Register (or equivalent) engineers accredited for use with hydrogen.

8.5 APPLIANCE INSTALLATION

Appliances are currently installed, as per applicable British Standards and manufacturer’s instructions, by a competent engineer. However, hydrogen appliance installations shall now comply with applicable British Standards (as covered by PAS 4444) and the subsequent manufacturer’s instructions by a competent engineer who has the relevant level of Gas Safe registration for hydrogen appliance installation.

8.6 TESTING, PURGING AND COMMISSIONING

8.6.1 General

An installation shall not be used until:

- installation pipework has been successfully tested to confirm integrity and freedom from leakage
- pipework system had been purged of air and filled with gas
- all appliances connected to the system are commissioned and ready for use.

8.6.2 Testing

It is essential that pipework containing flammable gas does not leak.

It is a legal requirement that pipework is shown to be free of leakage before gas can be introduced.

Additionally, it is recommended practice to carry out tightness tests on an existing system before any work is undertaken and also periodically throughout the system's life to ensure that there is no deterioration in integrity.

8.6.2.1 *Current Standards*

An IGEM suite of Standards covers testing of the various types of installation:

- IGE/UP/1 covers a wide range of installations from small industrial and commercial to large industrial at pressures up to 60 bar. It is primarily for NG and LPG but can be used for certain other flammable gases. It does NOT cover hydrogen as this was not considered to be a widely used commercial gas when IGE/UP/1 was last revised
- IGE/UP/1A is a shortened version of UP/1 for smaller industrial and commercial premises operating at lower pressures up to 60 mbar. Again, it does not cover hydrogen
- IGEM/UP/1B applies to domestic and small non-domestic premises, with a meter of capacity no greater than 16 $m^3 h^{-1}$. Again, it does not cover hydrogen
- IGEM/UP/1C is rather specialised and applies only to meter installations. Again it does not cover hydrogen.

8.6.2.2 *Essentials of tightness testing procedures*

The Standards require that the section of pipework to be tested is isolated both upstream and downstream. The pipework is then pressurised and monitored for a determined period. If there is no loss of pressure, then the pipework is deemed to be gas tight and can be commissioned and used.

Ideally there will be no loss in pressure. The standards do vary in their requirements on this issue, considering the time for the test, the accuracy and readability of the pressure gauges etc.

For example, IGEM/UP1/B requires "no perceptible movement" on the gauge for new installations but a pre-determined pressure loss for certain installations. IGE/UP/1 instead allows a small loss of pressure up to the "gauge readable movement" which varies with the type of gauge.

To comply with IGE/UP/1 it is not required to demonstrate absolute gas tightness. The concept of Maximum Permitted Leak Rate (MPLR) is used. This recognises that a very small leak in a reasonably well-ventilated area is not a serious hazard.

The MPLR is defined in terms of energy release and therefore, in volume terms, is different for different gases with different calorific values. Currently IGE/UP/1 gives data for NG, Town Gas, propane, butane and two commonly used LPG/Air mixtures. (Note the small installations initially being considered for trials are strictly well outside the scope of IGE/UP/1).

8.6.2.3 *Effect on procedures using Hydrogen*

There are a number of differences between the properties of hydrogen and NG that may have an impact on tightness-testing procedures (see Appendix 3). For the same leak size and pressure, the volumetric release rate is greater for hydrogen than NG. However, the release rate in terms of energy is slightly smaller for hydrogen than NG, due to its low calorific value. Whilst this implies that hydrogen fires may be less severe than NG, the potential risks of explosions may be greater for hydrogen (due to the greater volume of gas released, the lower ignition energy, higher flame speed and wider flammability limits of hydrogen).

Hydrogen is not included in IGE/UP/1 (see above) and it will be necessary to calculate the MPLR for hydrogen. IGE/UP/1 Edition 2 states, in Appendix 4.2, that leak rates of concern for tightness testing are assumed to be laminar in nature (and hence will depend upon the gas viscosity). However, even if this is the case, it is still necessary to understand how the leaked gas disperses and accumulates. Work is progressing to establish the values of MPLR for hydrogen.

Whilst the characteristics of NG leaks have been well researched and documented (e.g. RR630 and IGEM/SR/25) this is not the case with hydrogen and there are many questions still to be answered.

8.6.2.4 *Approach to be adopted*

Tightness testing depends on knowing what the MPLR is to ensure that this is not exceeded.

For the reasons outlined above, the MPLR for hydrogen is still being established. It may well be that it will need to be based on lower flammability limits (LFL) rather than energy release.

Therefore, it will be necessary to carry out further research work to establish what it is.

It is initially suggested that a conservative approach will be taken. In the interim all installations will be tested as new, as per IGE/UP/1.

In any event, a risk analysis could show that this approach may be acceptable for the early unoccupied tests. For occupied tests an accurate MPLR would need to be clearly established.

8.6.3 **Purging**

8.6.3.1 *Introduction*

Purging requires the safe and complete exchange of the gases within a system whilst minimizing the explosion hazard. Purging can be from air to hydrogen (during commissioning) or from hydrogen to air (during decommissioning).

Purging can be undertaken as follows:

- Directly – where one gas directly replaces the other.
  With Direct purging, the purge velocity is an important characteristic as it can ensure the purge is complete throughout the system and that pocketing and stratification is avoided, and that the size of the flammable mixing zone at the interface between the two gases is minimized
- Indirectly – where an inert gas is used as an interface between the two gases.
  With Indirect purging, the inert gas forms a barrier between the two gases, so a flammable mixing zone is avoided. A regulated supply of inert gas is required and precautions are required in its use are required.

8.6.3.2 *Current Standards*

Purging standards evolved from those developed by British Gas in the 1970's and earlier. Following the break-up of British Gas, domestic purging was moved into BS 6891 before being moved over to IGEM as IGEM/UP/1B. Non-domestic purging was further developed in the late 1980's following British Gas research into the use of direct purging. This then evolved into IGE/UP/1.

The current purging Standard is;

IGEM/UP/1 Strength testing, tightness testing and direct purging of industrial and commercial gas installations

This is the core standard, giving the system limits, methodology, calculations and procedures for undertaking direct purging of NG, LPG and Town gas.

Below IGE/UP/1 are several Standards to cover particular applications:

- IGE/UP/1A for smaller volume (≤ 1 m^3) Industrial & Commercial installations
- IGEM/UP/1B for Domestic and Small Commercial (≤ 35 mm & ≤ 0.035 m^3) installations and meters (≤ U16)
- IGEM/UP/1C for larger meter installations (with outlet isolation present).
- IGEM/UP/1 and IGEM/UP/1A generally require venting into a safe external area with restrictions on purge velocity, clearance volumes and end-point concentrations.
- IGEM/UP1B allows purging into internal areas with specified safety precautions.
  - System ≤ 0.02 m^3 - Unmetered using a cooker hotplate burner
  - System ≤ 0.035 m^3 - Using a temporary burner & using a metered volume
- IGE/UP/1 and IGE/UP/1A also allow purging into well ventilated areas with specified safety precautions.
  - System ≤ 0.02 m^3 - In to an area ≥ 30 m^3 with a max 10%

8.6.3.3 *Effects on procedures using hydrogen*

Due to the higher flame speed and wider flammability limits, purging hydrogen is a more hazardous and complex operation than with NG, for the following reasons:

- greater density difference between hydrogen and air may cause increased pocketing and stratification problems
- wider flammability limits of hydrogen may cause greater hazards in the mixing zone at the interface, especially when purging
- Hydrogen mixtures may have a greater ignition potential within the pipework system
- properties of hydrogen may prevent the practice of venting smaller systems directly into internal spaces.

The use of direct purging may still be possible on domestic and small commercial sized systems by applying agreed procedures based around IGEM/UP/1B, but this still needs to be proven.

On larger systems, higher purge velocities may be required to avoid pocketing and stratification problems and to minimize the size of the mixing zone at the interface.

Further work will be required to quantify the requirements for direct purging of hydrogen systems.

It may be necessary to use indirect purging if the changes to direct purging procedures are too involved or impractical to apply. A requirement to use indirect purging could impose challenges and additional costs, particularly on smaller systems.

Installations will require a suitably valved and sealed vent point to be installed at the extremities of the system.

A suitable hose can be connected to the vent point, which will pass the vented gas to a safe outside area where venting can take place using a mobile vent stack incorporating a flame arrestor, test point and a suitable terminal device. The motive force for the purging process will be supplied by the gas supply pressure (for commissioning) or a suitable air fan (for decommissioning).

Equipment used for purging must avoid the generation of ignition sources (including static) and include suitable flame arrestors.

All purge equipment will need to be cleared of any residual flammable gas immediately after use.

8.6.3.4 *Approach to be adopted*

For occupied trials, equipment and procedures will need to be developed and tested to enable safe indirect purging to be undertaken and for purge gases to be dispersed in a safe area.

Further research is required to develop and test purging methodology for hydrogen before more wide scale occupied trials are started.

8.6.4 **Commissioning**

All appliances connected to a system that has been tested and purged are required to be commissioned for use or disconnected.

Commissioning is required to be in accordance with the manufacturer's instructions, which in turn will comply with applicable hydrogen appliance standards (PAS 4444).

8.7 INSPECTION AND MAINTENANCE

8.7.1 **Inspection**

8.7.1.2 *Current practice*

There is no general requirement to undertake an initial or periodic inspection of a domestic NG installation.

The only area that is covered is where there is a legal requirement (under the Gas Safety (Installation and Use) Regulations (GS(I&U)R)) for Landlords to have annual checks of gas installations in rented properties. This involves a full inspection of the fixed gas appliances at the property, which will include the following:

- check the ECV for let-by and appliances for gas tightness
- check the standing and working pressure at the meter as well as the working pressure at the appliances, if test points are available
- check the burner pressure/gas pressure against the manufacturer’s data plate
- check for the satisfactory provision of all necessary ventilation
- test the flue flow to ensure removal of POC (open flued appliances)
- test the appliance for spillage of POC (open flued appliances, flueless and decorative fuel effect fires (DFE))
- check the combustion CO/CO_2 ratios to ensure they are within the manufacturer’s specification
- check the satisfactory operation of safety devices
- check for physical stability, presence and effectiveness of brackets (where appropriate)
- check for any signs of distress (i.e. evidence of spillage) and/or damage to the appliances (i.e. corrosion to flues/ flue blockages caused by ingress of plants)
- investigate any evidence of unsafe operation and report to the landlord
- test smoke and CO alarms and check they are in date
- issue landlord gas safety record.

For commercial installations, IGEM/UP/2 requires that on completion of an installation, an inspection scheme is drawn up. This would involve a visual inspection and check for leakage using a detector or leak detection fluid (LDF).

Commercial installations also require a DSEAR risk assessment, which would involve a survey of the gas installation.

8.7.1.3 *Effects on procedures using Hydrogen*

There is a lack of evidence of the continued integrity of hydrogen installations in domestic and commercial premises. The effects on procedures using hydrogen include the use of combustion analysers which will monitor oxygen not CO/CO_2 ratio, initially more frequent inspection and testing will be required.

8.7.1.4 *Approach to be adopted*

In the absence of experience and data, it would be pragmatic to require initial and frequent periodic inspection of all trial installations, including private dwellings, covering the same aspects as “landlords safety checks”. Landlord safety checks would still be a legal requirement.

8.7.2 **Maintenance**

8.7.2.1 *Current practice*

For domestic installations, BS 6891 requires that the maintenance of the pipework shall ensure continued safety of the installation.

The GS(I&U)R require that any gas appliance, installation pipework or flue is maintained to a safe condition. Domestic gas appliances should be maintained annually in accordance with manufacturer’s instructions.

For commercial installations, IGEM/UP/2 requires that on completion of an installation, a maintenance scheme is drawn up. Commercial gas appliances should be maintained annually in accordance with manufacturer's instructions.

8.7.2.2 *Effects on procedures using hydrogen*

The new appliances and associated standards being developed should identify any additional maintenance requirements.

8.7.2.3 *Approach to be adopted*

In the absence of experience and data, it would be pragmatic to require a more frequent maintenance program for the appliances used on any trial installations. Periodic inspection of the pipework installation should identify any specific maintenance requirements.

8.8 IDENTIFICATION AND LABELLING

8.8.1 Current practice

Downstream of the ECV, there are currently no discernible features or labelling that identify that a meter, regulator, pipework, valve or appliance operates with a particular fuel gas.

8.8.2 Effects of hydrogen and approach to be adopted

The introduction of hydrogen into UK homes will be undertaken alongside NG and LPG installations, so there will be a requirement to distinguish between the three.

It is recommended that a hydrogen installation is clearly labelled as "HYDROGEN ONLY" on the meter. Consideration shall be given to identification of hydrogen being utilised on the meter box.

Other considerations for the easy identification of a gas meter conveying hydrogen in a domestic environment could take the form of:

- the meter being a specific colour (such as red or blue) and/or
- a generic meter sticker could be developed.

For commercial pipework installations utilising hydrogen, it is recommended that pipework is labelled to enable the identification of the gas being used. Considerations such as those for identification of domestic gas meter installations could also be applied in a commercial environment.

Consideration shall be given for the male and female fitting connecting the hydrogen regulator to the meter to avoid connecting non-compatible regulators.

Emergency responders should have some means of identification to indicate hydrogen may be present.

8.9 DETECTION AND RESPONSE

8.9.1 Gas detection instruments

8.9.1.1 *Current practice*

Gas detectors can be based on different principles and used for different purposes.

They may be either portable or fixed:

- portable detectors are used to investigate and detect gas leaks. They are also used in purging operations
- fixed detectors (not a common requirement, but often found in such places as energy centres and industrial areas) usually measure in the ppm range and are there primarily to act as gas leakage alarms.

The instruments are usually based on infra-red or thermal conductivity principles.

In general, standards for performance are not used, rather manufacturer's declarations and specifications are used.

Existing NG instruments are often cross sensitive to other flammable gases and results may need to be treated with caution. Many instruments are designed to work over rather limited ranges. The widely used Gascoseeker has several scales and can measure from ppm to 100% NG. Such instruments are usually calibrated for a specific gas but may well be cross sensitive to other gases.

8.9.1.2 *Effect on procedures of using Hydrogen*

There should be little change in operations, but the action levels demanded by procedures will obviously be different for a very different type of flammable gas. The outcome of a risk assessment undertaken to assess the potential increased risk of using hydrogen may result in a requirement to install gas detectors in certain situations. Availability of suitable instruments for hydrogen appears to be low at present. This will presumably change if the demand for hydrogen measurement is much increased.

8.9.1.3 *Approach to be adopted*

Lack of suitable gas detector instruments could be a problem.
For purging operations a calibrated portable instrument capable of measuring hydrogen or oxygen, concentrations is required.

For safety monitoring of gas leaks it is essential that small leaks can be detected. It is anticipated that hydrogen will be odorised, but this cannot be totally relied on.

Possibly for the very early tests (particularly unoccupied) the lack of suitable instruments may be tolerated but instruments will be needed for the wider roll out of hydrogen.

8.9.2 Leak detection fluid (LDF)

8.9.2.1 *Effect of Hydrogen on LDF*

LDF is widely used for locating small leaks.

BS EN 14291 is the standard for LDF but its application for hydrogen will need to be verified.

Suitable LDF is currently being tested for hydrogen compatibility.

8.9.2.2 *Approach to be adopted*

Suitable LDF is being tested for approval for its use with hydrogen.

8.9.3 Emergency response

GS(M)R requires that emergency response provision and procedures are in place, and these form part of the Safety Case for gas transporters. This emergency response provision applies to distribution of NG and LPG. The following extract from GS(M)R provides additional detail: "GS(M)R requires an effective emergency response service to be in place to deal with reports of gas escapes, either from the Network or from gas fittings in consumers' premises. The arrangements under GS(M)R should particularly focus on local and domestic situations."

Prior to any trials the suitability of Network operations and emergency response will need to be demonstrated. The gas distribution networks are developing processes and procedures.

Consideration shall be given to issues such as exclusion zones, time to respond, gas detection, firefighting and other aspects of attending a gas emergency. Prior to any occupied trial, a wider range of network procedures will need to be evidenced as safe, including procedures for network repair and maintenance. It is worth noting the point made at the beginning of this document that existing Standards for the utilisation of NG have evolved over many years and have benefited from years of experience and evidence of incidents and near misses. This experience has been incorporated into Industry Standards covering design of network components and operating procedures. When considering hydrogen, we do not have the benefit from this experience, so more detailed scientific knowledge and demonstration will be needed to underpin any new Standards for operation of a hydrogen network.

APPENDIX 1: GLOSSARY, ACRONYMS, ABBREVIATIONS, SYMBOLS AND UNITS

A1.1 GLOSSARY

All definitions except those detailed below are given in IGEM/G/4 which is freely available by downloading a printable version from IGEM's website www.igem.org.uk.

Standard and legacy gas metering terms are given in IGEM/G/1 which is freely available by downloading a printable version from IGEM's website.

A1.2 ACRONYMS AND ABBREVIATIONS

ACoP	Approved Code of Practice
AECV	additional emergency control valve
BSI	British Standards Institution
CO	carbon monoxide
CO_2	carbon dioxide
DMS	dimethyl sulphide
ECV	emergency control valve
GB	Great Britain
GS(M)R	Gas Safety (Management) Regulations
GS(I&U)R	Gas Safety (Installation and Use) Regulations
HSWA	Health and Safety at Work Act
HSE	Health and Safety Executive
IGEM	Institution of Gas Engineers and Managers
ISBN	International Standard Book Number
LDF	leak detection fluid
LFL	lower flammability limit
LPG	Liquefied Petroleum Gas
MOP	maximum operating pressure
NE	negligeable extent
NG	Natural Gas
NO_X	nitrous oxide
POC	products of combustion
RD	relative density
SO_x	sulphur oxide
TBM	tertiary-butyl mercaptan.

A1.3 SYMBOLS

%	percentage
μ	micro.

A1.4 UNITS

ACH	air change per hour
bar	bar
°C	degrees Celsius
g mol^{-1}	gram per mole
h	hour
K	Kelvin
kg m^{-3}	kilogram per metre cubed
kJ	kilojoule
kg	kilogram
kg h^{-1}	kilogram per hour
m	metre
m^3	metre cubed
mbar	millibar

mg	milligram
mg m^{-3}	milligram per cubic metre
mJ	millijoule
MJ	Megajoule
MJ kg^{-1}	Megajoule per kilogram
mm	millimetre
mm^2	millimetre squared
mm^3	millimetre cubed
MPa	Megapascal
mol	mole
m s^{-1}	metre per second
m^2 s^{-1}	metre squared per second
Pa	Pascal
ppm	part per million
s	second.

APPENDIX 2: REFERENCES

This Standard is set out against a background of Legislation in force in GB at the time of publication. Similar considerations are likely to apply in other countries where reference to appropriate national Legislation is necessary. The following list is not exhaustive.

Where British Standards etc. are quoted, equivalent national or international Standards etc. equally may be appropriate.

A2.1 LEGISLATION

This Appendix lists legislation referred to in this Standard as well as some legislation not referenced in this Standard but which may be applicable.

A2.1.1 Acts

- Control of Pollution Act 1974, as amended
- Environment Act 1995, as amended
- Environmental Protection Act 1990
- Gas Act 1986 (as amended by the Gas Act 1995 and incorporating stand-alone provisions of the Utilities Act 2000)
- Health and Safety at Work etc. Act 1974.

A2.1.2 Regulations

- Dangerous Substances and Explosive Atmosphere Regulations 2002
- Gas Safety (Installation and Use) Regulations 1998, as amended
- Gas Safety (Installation and Use) (Amendment) Regulations 2018
- Gas Safety (Management) Regulations 1996
- Gas Safety (Management) Regulations 1996 Safety Case (HSE Guidance)
- Pipelines Safety Regulations 1996
- Pressure Systems Safety Regulations 2000

A2.1 IGEM STANDARDS AFFECTED BY HYDROGEN (as referenced in this document)

IGEM/G/4	Definitions for the gas industry
IGEM/G/7	Risk assessment techniques
IGEM/G/11	Gas Industry Unsafe Situations procedure
IGEM/GL/4	Gas system Assets- safety management system
IGEM/GM/6	Non-domestic meter installations. Standard designs
IGEM/GM/7A	Electrical connections for gas metering equipment
IGEM/GM/7B	Hazardous area classification for gas metering equipment
IGEM/GM/8 pt 1	Non-domestic meter installations. Flow rate exceeding 6 m^3h^{-1} and inlet pressure not exceeding 38 bar Design
IGEM/GM/8 pt 2	Locations, housings, and compounds
IGEM/GM/8 pt 3	Fabrication, installation, testing and commissioning
IGEM/GM/8 pt 4	Operation and maintenance
IGEM/GM/8 pt 5	Notices and labels
IGEM/IG/1	Standards of training in gas work
IGEM/SR/25	Hazardous areas classification of Natural Gas

IGE/UP/1	Strength testing, tightness testing and direct purging of industrial and commercial gas installations
IGE/UP/1A	Strength testing, tightness testing and direct purging of small low pressure industrial and commercial Natural Gas installations.
IGEM/UP/1B	Tightness testing and direct purging of small liquefied petroleum gas/air, Natural Gas and liquefied petroleum gas installations
IGEM/UP/1C	Strength testing, tightness testing and direct purging of Natural Gas and Liquefied petroleum gas meter installations
IGEM/UP/2	Installation pipework on industrial and commercial premises
IGEM/UP/6	Application of compressors to Natural Gas fuel systems
IGEM/UP/10	Installation of flued gas appliances in industrial and commercial premises.
IGEM/UP/16	Design for Natural Gas installations on industrial and commercial premises with respect to DSEAR.

A2.2 **BRITISH STANDARDS** (abbreviated titles)

BSI/BS-0	Rules for the structure and drafting of UK standards
BS 746	Specification for gas meter unions and adaptors
BS 5440:1	Flueing and ventilation for gas appliances of rated input not exceeding 70kW net (1st, 2nd and 3rd family gases). Specification for installation of gas appliances to chimneys and for maintenance of chimneys.
BS 5440:2	Flueing and ventilation for gas appliances of rated input not exceeding 70kW net (1st, 2nd and 3rd family gases)- Part 2: Specification for the installation and maintenance of ventilation provision for gas appliances
BS 5482	Code of practice for domestic butane- and propane-gas-burning installations.
BS 6400	Specification for installation, exchange, relocation, maintenance and removal of gas meters with a maximum capacity not exceeding 6m3/h. Medium pressure (2nd family gases)
BS 6891	Specification for the installation and maintenance of low pressure gas installation pipework of up to 35 mm(R1/4) on premises
BS 7671	Requirements for Electrical Installations. IET Wiring Regulations.
BS 8499	Specification for domestic gas meter boxes and meter bracket
BS EN 437	Test gases. Test pressures. Appliance categories
BS EN 1011-2	Welding. Recommendations for welding of metallic materials. Arc Welding of ferritic steels
BS EN 1359	Gas meters. Diaphragm meters
BS EN 14236	Ultrasonic domestic gas meters
BS EN 14291	Foam producing solutions for leak detection on gas installations

BS EN 60079-10-1	Explosives atmospheres. Classification of areas. Explosive gas atmospheres
BS EN ISO 5817	Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections
BS EN ISO 9609-1	Qualification testing of welders. Fusion welding. Steels
BS EN ISO 15614-1	Specification and qualification of welding procedures for metallic-Welding procedure test- Part 1: Arc and gas welding of steels and nickel alloys.

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A2.4 EFFECT ON MATERIALS REFERENCES

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11. BS EN ISO 5817: 2014 "Welding – Fusion-welded joints in steel, nickel titanium and their alloys (beam welding excluded) – Quality levels for imperfections"

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2. BS 5540-1:2008 Flueing and ventilation for gas appliances of rated input not exceeding 70kW net (1st, 2nd and 3rd family gases). Specification for installation of gas appliances to chimneys and for maintenance of chimneys.

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8. IGEM/GM/7B – Hazardous area classification for gas metering equipment

9. IGEM/UP/6 Ed 2 – Application of compressors to Natural Gas fuel systems

10. BS EN 60079-10-1 Explosives atmospheres. Classification of areas. Explosive gas atmospheres.

A2.10 METERING

1. BS 746:2014 Specification for gas meter unions and adaptors
2. BS 8499:2017 Specification for domestic gas meter boxes and meter bracket
3. BS:7671 Requirements for Electrical Installations. IET Wiring Regulations.
4. BS:6891 Specification for installation, exchange, relocation, maintenance and removal of gas meters with a maximum capacity not exceeding 6m^3/h. Medium pressure (2nd family gases)
5. BS 6400 Specification for installation, exchange, relocation, maintenance and removal of gas meters with a maximum capacity not exceeding 6m^3/h. Medium pressure (2nd family gases)
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A2.11 PIPEWORK DESIGN

1. BS:6891 Specification for the installation and maintenance of low pressure gas installation pipework of up to 35 mm(R1/4) on premises
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A2.12 PIPEWORK INSTALLATION

1. L56 Safety in the installation and use of gas systems and appliances, Gas Safety(Installation and Use) Regulations 1998
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A2.13 APPLIANCE INSTALLATION

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A2.14 TESTING, PURGING AND COMMISSIONING

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A2.15 INSPECTION AND MAINTENANCE

1. L56 Safety in the installation and use of gas systems and appliances, Gas Safety(Installation and Use) Regulations 1998

2. IGEM/UP/2 Installation pipework on industrial and commercial premises.

A2.16 IDENTIFICATION AND LABELLING

A2.17 DETECTION AND RESPONSE

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A2.18 EMERGENCY RESPONSE

1. L56 Safety in the installation and use of gas systems and appliances, Gas Safety (Installation and Use) Regulations 1998
2. L 80 A guide to the Gas Safety (Management) Regulations 1996.

APPENDIX 3: HYDROGEN CHACTERISTICS

Hydrogen is a colourless, odourless and tasteless gas, less dense than NG and is the most abundant chemical element in the universe. It is an important chemical used in many processes including ammonia and fertilizer production, and hydrogenation of oils in petrochemical facilities.

Hydrogen has three isotopes (hydrogen, deuterium and tritium), and the common form is a stable diatomic gaseous molecule (H_2).

Hydrogen is not toxic but can cause asphyxiation. It is flammable and mixtures of hydrogen in air within the flammable range are explosive.

A3.1 PHYSICAL CHARACTERISTICS

Hydrogen is the lightest known molecule, significantly lighter than methane which in turn is lighter than air. The molecular weight of hydrogen is approximately 2 g mol^{-1}, and this is a factor of eight smaller than methane.

It is a small, light molecule that disperses rapidly in air and has high mobility. The gas density and RD for hydrogen are both around a factor of eight smaller than methane, and this results in increased buoyancy compared to NG.

The diffusion coefficient of hydrogen in air is approximately four times higher than that for methane. Hydrogen will disperse more rapidly in air than methane, leading to more rapid dilution of released gas where diffusion is the main mechanism.

The thermal conductivity and heat capacity of hydrogen are higher than many other gases and this is the rationale behind its use as a coolant in turbogenerators on many steam turbine power plant.

Hydrogen has a lower viscosity than many gases including methane, and as it is a small molecule (with low density) it has a greater tendency to leak through joints, fittings and seals.

The speed of sound for hydrogen is three times greater than that for methane. This characteristic is important as it means that the volumetric flow rate of hydrogen from a hole (a choked, sonic release scenario) would be higher than that for methane.

Table 3 provides information on selected physical properties of hydrogen and data for methane (NG) at ambient, is included for comparison purposes.

Effect of physical properties on leakage rates from low pressure systems (< 75 mbar): as stated above, the viscosity and density of hydrogen are lower than those of methane (NG) and these differences result in larger volumetric leak rates through the same size hole for hydrogen than for methane. For smaller, laminar leaks the flow rate is inversely proportional to the gas viscosity, resulting in the flow rate being approximately 25% higher for hydrogen than for methane. For turbulent leaks (which are typically larger than laminar leaks for realistic leak scenarios) the flow rate is inversely proportional to the square of the gas density. This results in the volumetric leaks rate for hydrogen being higher than methane by a factor of approximately 2.8 times. It is likely that turbulent leaks will dominate the risk profile.

A gas leak will mix with the surrounding air as it exits the hole. Furthermore, all rooms will be subject to some degree of ventilation, even if this is only provided by gaps around windows, doors etc. Therefore, if gas leaks into a room it will to some extent be diluted and eventually it would normally reach an equilibrium concentration within the room. Although the leak rate of hydrogen into a room through a large hole would be up to 2.8 times greater than NG, the low density of the gas may increase the ventilation rate of the room. Increased ventilation of the room would provide some mitigation by diluting the leaked gas and so the final concentration of hydrogen may be less than 2.8 times greater than NG, which could otherwise be expected.

A simple mathematical model by Linden that assumes that the leaked gas forms a well-mixed gas/air mixture (as shown in Figure 1) indicates that the equilibrium concentration of hydrogen would be significantly lower than 2.8 times that of hydrogen. However, the degree to which a low density gas affects the ventilation rate of a room, and hence the equilibrium gas concentration, is a complex subject with other variables such as wind speed, gas release position, etc., having an impact. The gas buoyancy may then not be the dominate driver of ventilation.

Light gases have a tendency to mix with air as they rise, forming a gas rich layer from the top of the room; this behaviour has been observed in experiments (e.g. by Crowther and also by Lowesmith) and also witnessed by gas explosion incidents (as reported by Harris). This is shown schematically in Figure 2. The gas concentration in the layer, as well as the layer depth, will be greater for hydrogen than for NG.

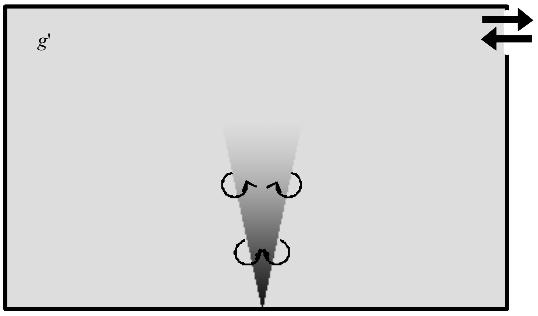


FIGURE 1 WELL-MIXED GAS ACCUMULATION ROOM WITH HIGH LEVEL VENTILATION ONLY

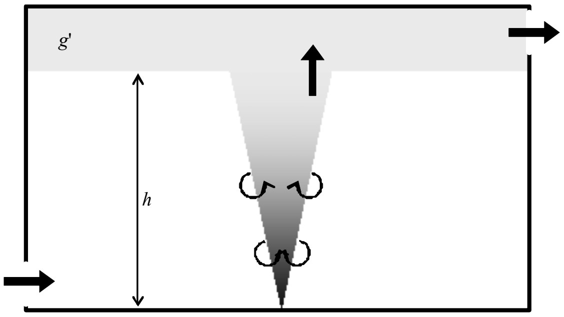


FIGURE 2 LAYERED GAS ACCUMULATIONS IN A ROOM WITH HIGH AND LOW VENTILATION

Characteristic	Units	Hydrogen	Methane (NG)
Molecular weight	g mol^{-1}	2.016	16.042
Boiling point	K	20.4	111.5
Gas density	kg m^{-3}	0.0827	0.659
Relative density (relative to air)	-	0.070	0.555
Diffusion coefficient (in air)	$m^2 s^{-1}$	0.61×10^{-4}	0.16×10^{-4}
Thermal Conductivity	W/(m.K)	0.1875	0.0359
Specific heat at constant pressure	kJ/(kg.K)	14.31	2.23
Specific heat at constant volume	kJ/(kg.K)	10.18	1.71
Specific heat ratio (Cp/Cv)	-	1.405	1.306
Viscosity	μPa.s	8.81	11.02
Speed of sound	m s^{-1}	1294	442

Note: Gas density is calculated at UK metric standard conditions of 15 °C and 101.325 kPa.

TABLE 3 COMPARISON OF PHYSICAL PROPERTIES OF HYDROGEN AND METHANE

A3.2 COMBUSTION CHARACTERISTICS

Hydrogen is a pure fuel and combusts in air to form water. As it does not contain carbon there is no CO_2 production, nor any CO.

On a volume basis the calorific value for hydrogen is approximately one third that for NG. Whereas on a mass basis, the calorific value for hydrogen is nearly three times that for methane.

The Wobbe Number for hydrogen is 45.89 MJ m^{-3}, only about 10% lower than that for methane; the lower volumetric calorific value is compensated by the smaller RD to moderate the overall change in Wobbe Number.

The flammability range for hydrogen is significantly wider than that for methane. Although the LFL is similar, the upper flammability limit (UFL) is significantly higher. The flammable range widens if pressure or temperature is increased, with the greatest impact on the UFL. Hydrogen also exhibits different flammability characteristics as a function of flame propagation direction, and the size of the vessel in which the flammability tests are made. The LFL for a downward propagating flame is higher than that for an upward propagating flame. This variation in the development of hydrogen flames near the LFL has been shown to exhibit complex behaviour with small “balls of flame” or a flame vortex with wrinkling and cellular structures that break up soon after the ignition step, rather than a well-established flame front.

The minimum ignition energy of hydrogen is 0.02 mJ, and this is significantly lower than that for methane. The ignition energy does vary with hydrogen concentration in air, and the minimum value is close to stoichiometric combustion conditions. The autoignition temperature for hydrogen is similar to that for methane.

The burning velocity for hydrogen is about eight times that for NG, for stoichiometric combustion. This higher value can lead to an increased potential for flash-back (light-back) in premixed or partially premixed burners. This may also result in increased damage resulting from the delayed ignition of an accumulation of unburnt hydrogen gas in appliances, or in the event of a gas leak. The accumulation of gas is discussed in Section A.3.1.

The combustion and consequences of flammable gases leaking into a room or enclosure is a complex issue. This will depend upon many variables, including: leakage conditions and ventilation arrangements; the gas cloud concentration, extent and homogeneity; the position of the ignition source relative to the position of any explosion pressure relief routes; the presence of internal obstacles that would increase the turbulence of the gas cloud. The damage caused to structures is a function of both the pressure and the duration over which it is imposed (i.e. the impulse). It will be necessary to understand the differences in behaviour of hydrogen versus methane in terms of pressure and duration for geometries representing rooms, in combination with the response characteristics of construction materials, in order to assess the difference in risk profile.

Table 4 provides information on selected combustion characteristics of hydrogen and data for methane is included for comparison purposes.

Characteristic	Units	Hydrogen	Methane (NG)
Gross Calorific Value	MJ m^{-3}	12.10	37.78
Net Calorific Value	MJ m^{-3}	10.22	34.01
Gross Calorific Value	MJ kg^{-1}	141.95	55.57
Net Calorific Value	MJ kg^{-1}	119.91	50.03
Wobbe Number	MJ m^{-3}	45.89	50.72
Flammability range (LFL – UFL)	Vol%	4 – 75.6	5 – 15
Stoichiometric fuel % in air	Vol%	29.5	9.5
Limiting oxygen % for combustion	Vol%	5	12
Minimum spark ignition energy (in air)	mJ	0.02	0.29
Maximum Adiabatic Flame Temperature	K	2318	2148
Maximum Laminar Burning Velocity	m s^{-1}	3.1	0.4
Auto ignition temperature	K	833	873
Quenching gap	mm	0.6	2.0

Note: *Wobbe Number and Calorific Value (volume based) are calculated at UK metric standard conditions of 15 °C and 101.325 kPa.*

TABLE 4 COMPARISON OF GENERAL COMBUSTION CHARACTERISTICS DATA OF HYDROGEN AND METHANE

A3.3 OTHER CHARACTERISTICS

Although hydrogen is nominally a single component, pure fuel, large scale production methods may result in minor contamination. Trace concentrations of CO, nitrogen, argon, CO_2 and oxygen may be present. It is anticipated that minimum hydrogen content for pipeline distributed hydrogen will be 98% (see Table 5).

As hydrogen is odourless, it is important for pipeline distributed hydrogen to have an odour added, in the same manner to NG, for safe leak detection and protection of the public through odour detection at concentrations lower than the flammability limit.

The type of odorant for hydrogen has not been finalised at present, but it is anticipated that the same odorant (mercaptan NB) as that for NG will be used in the initial trials.

Hydrogen exhibits a positive Joule-Thomson effect meaning that under adiabatic conditions its temperature increases upon depressurisation, and this is opposite to the effect for methane.

Hydrogen burns with a less visible flame than NG, and in some instances, it is difficult to see the presence of the flame at all. Flame visibility is an important characteristic from a safety and operability viewpoint. Current research is evaluating options for methods that could be used to either colour the flame or indicate the presence of a flame.

APPENDIX 4: HYDROGEN GAS QUALITY SPECIFICATION

Content or characteristic	Value	Rationale
Hydrogen content minimum	98 % (cmol mol^{-1})	This value is a good compromise between hydrogen cost and effects on appliances.
Carbon monoxide	20 ppm (μmol mol^{-1})	A practical engineering limit based on achievable production limits and to meet long term exposure limits HSE EH/40
Hydrogen sulphide content	≤ 5 mg m^{-3} 3.5 ppm (μmol mol^{-1})	These values are taken from GS(M)R:1996 as any detrimental effects would be similar for hydrogen and NG.
Total sulphur content (including H_2S and odorant)	≤ 50 mg m^{-3} 35 ppm (μmol mol^{-1})	
Oxygen content	≤ 0.2% (cmol mol^{-1})	
Hydrocarbon dewpoint	-2 ˚C	Not more than -2°C at any pressure up to 85 bar.
Water dewpoint	-10 ˚C	Not more than -10°C at 85 bar
Sum of methane, carbon dioxide and total hydrocarbons	≤ 1% (cmol mol^{-1})	No detrimental effects to boiler, this limit is to reduce carbon content of the exhaust
Sum of argon, nitrogen and helium	≤ 2% (cmol mol^{-1})	To avoid transporting inert gases with no calorific value in the hydrogen gas (in agreement with ISO/FDIS 14687) and to limit the impact on Wobbe Number (see below)
Wobbe Number range	42 – 46 MJ m^{-3}	Range and percentage variation based on Natural Gas range in GS(M)R:1996 Wobbe Number is calculated at UK metric standard conditions of 15 °C and 101.325 kPa
Other impurities	The gas shall not contain solid, liquid or gaseous material that might interfere with the integrity or operation of pipes or any gas appliance, within the meaning of regulation 2(1) of the Gas Safety (Installation and Use) Regulations 1998, that a consumer could reasonably be expected to operate	

TABLE 5: DRAFT RECOMMENDATION FOR A UK HYDROGEN QUALITY STANDARD FOR HEAT APPLICATIONS BASED ON EXISTING STANDARDS AND DOCUMENTS.

APPENDIX 5: HAZARDOUS AREA CLASSIFICATION

A5.1 DEFINITIONS

Below are definitions for some common terms used in for HAC:

Zone 0	An area in which an explosive air/gas mixture is continuously present or is present for long periods.
Zone 1	An area in which an explosive air/gas mixture is likely to occur in normal operation occasionally.
Zone 2	An area in which an explosive air/gas mixture is not likely to occur in normal operation and, if it occurs, will only exist for a short time.
Primary release source	a release (of gas) which can be expected to occur periodically or occasionally during normal operation. Example: purge vent pipe terminations.
Secondary release source	a release (of gas) which is not expected to occur in normal operation and, if it does, is likely only to do so infrequently and for short periods. Examples: small leaks from flanges, joints etc.
LFL	Lower flammable limit (concentration of flammable gas or vapour in air below which the gas atmosphere is not fammable). Also, sometimes referred to as Lower Explosive Limit (LEL).
V_z	Volume of flammable gas mixture whose average concentration is 0.5 LFL (for secondary release sources).
Zone of Negligible Extent	This is a volume, generally a Zone 2 but could be Zone 1 or Zone 0, that is of negligible size. The volume of flammable gas present does not present a significant hazard and no ATEX certified equipment is required. This is defined by Vz < 0.1 m^3. (Vz < 0.1 m^3 is similar to background concentration of 10% LEL in terms of gas release size).
Background concentration	This is defined as the volumetric flow rate/ventilation rate.
Distance to LFL from release point	This is the distance away from a release point within which the gas concentration is at or above the LFL.

A5.2 FURTHER INFORMATION ON CURRENT STANDARDS AND METHODS

BS EN 60079:10-1 – "Explosive atmospheres. Classification of areas. Explosive gas atmospheres". The most commonly used standard in the UK for determining area extent and classification is BS EN 60079 part 10, which has broad applicability. The current version makes clear the direct link between the amounts of flammable vapour that may be released, the ventilation at that location, and the zone number. It contains a simplistic calculation relating the size of zone to a rate of release of gas or vapour. The standard is applicable to all gases and includes low pressures. However, it also has a UK national forward highlighting technical issues on useful parts of the Standard. It does not deal with indoor releases well and tends to overstate the hazard because of the poor way ventilation is treated. Therefore, it is probably not very useful for hydrogen within buildings. In some circumstances, applying the calculations can result in boilers houses being classified as Zone 2 rather than Zone 2 NE for NG.

Methods exists that can model a flammable gas jet developed to provide more realistic estimates of V_z for releases of flammable gases in ventilated enclosures or outdoors. It calculates V_z for any situation in which the flammable gas cloud volume or extent of the flammable cloud needs to be determined for a release of pressurised gas. The method is applicable to unobstructed free gas jets of virtually any gas, at pressures from low to high, although it has no facility for dealing with releases in confined spaces and deals with congested spaces using a relatively crude approach (consideration of confined and congested spaces are required in IGEM/SR/25). However, the calculations from the software tool can be used together with the approach used within the Energy Institute code of practice, EI15, for confined/congested releases outdoors.

Energy Institute Code of Practice, EI15:"Area classification code for installations handling flammable fluids". EI15 is only applicable to systems with a pressure above, or near to, 5 bar and therefore is not directly relevant to low pressure Hydrogen supply. It does, however, contain some guidance that could be of use.

IGEM/SR/25 – "Hazardous area classification of Natural Gas installations" This Standard applies to all NG installations and complements BS EN 60079-10-1 by providing detailed requirements for the hazardous area classification of permanent and temporary NG installations, thus providing a basis for the correct selection and location of fixed electrical equipment in those areas.

Certain aspects of the design of new plant and equipment can affect significantly the nature and severity of the eventual hazardous area classification. IGEM/SR/25 is not intended to provide design details for equipment. However, compliance with the general principles of design will help minimize the severity of the hazardous area classification.

IGEM/UP/16 – "Design for Natural Gas installations on industrial and commercial premises with respect to DSEAR"
This standard follows the principles of IGEM/SR/25 and is intended to provide basic design information to enable designers, and those undertaking risk assessments, to achieve a gas installation that can be classified and maintained as Zone 2 NE. It is primarily for designers of new industrial and commercial pipework systems, downstream of the primary gas meter installation.

The Standard covers new gas installation pipework, controls and associated gas appliances including appliance connections and pipework with an operating pressure not exceeding 2 bar installed downstream of the primary meter installation in industrial and commercial premises. It may also apply to parts of common pipework within multi-occupancy domestic premises; for example, between pipework risers downstream of the meter installation and also to the central boiler plant.

There are some technical issues related to smaller enclosures in the current version. These have been addressed in the draft of the updated version.

A5.3 EFFECTS OF USING HYDROGEN ON EXISTING IGEM STANDARDS

Updating of IGEM/SR/25 and associated standards (IGEM/UP/16 and IGEM/GM/7B) would require the calculation methods to be converted back from mass flow to volume flow, modelling carried out for hydrogen under the same gas release and ventilation scenarios, and then the calculation methods converted back to hydrogen in terms of mass flow.

The assumption that allowing sufficient air for combustion will provide adequate ventilation is no longer valid for hydrogen, since less combustion air is required for hydrogen and the leak rate through a significant hole would be ca. three times larger for hydrogen than NG.

The assumption that a ventilation rate of two air changes per hour (ACH) will be sufficient to avoid area classification more onerous than Zone 2 NE has been tested for hydrogen for a range of room sizes, gas pressures and hole sizes. This is shown in Table 6, where calculations have been carried out using a publically available mathematical method by Webster et al. It can be seen that hole sizes of 0.025 mm^2 are adequately covered by the 2 ACH rule, whereas 0.25 mm^2 holes may require more ACH to achieve Zone 2 NE for hydrogen, at 25 mbar, in smaller rooms (as highlighted in the Table 6).

Pressure (mbar)	**Hole area (mm^2)**	**Air Change Rate Required (h^{-1})**					
		10 m^3 Room volume		**30 m^3 Room volume**		**100 m^3 Room volume**	
		Natural Gas	**Hydrogen**	**Natural Gas**	**Hydrogen**	**Natural Gas**	**Hydrogen**
25	0.025	0.2	0.6	0.1	0.2	0.0	0.1
	0.250	2	5	0.5	2	0.2	0.6

TABLE 6 - REQUIRED ACH TO ACHIEVE ZONE 2 NE

The distance to LFL (and ½ LFL) is longer for an unobstructed hydrogen leak than it is for NG. For a 25 mbar leak through 0.025 mm^2 and 0.25 mm^2 holes, the distance increases by a factor of approximately 3.5.

An assessment of a domestic situation can be carried out by considering the maximum permissible leak rate (MPLR) given in IGEM/UP/1B. For example, allowing a pressure drop of 1 mbar over 2 minutes for an internal volume of 35 litres (the maximum for the Standard) results in a leak rate of 0.0175 litres per minute (or 0.0011 m^3 h^{-1}). This is equivalent to a hole size of < 0.1 mm diameter at a gas pressure of 21 mbar. For a small room (e.g. 10 m^3 at 0.5 ACH) then the background concentration of gas will be a few percent of LEL for both NG and hydrogen which is well within the limit for definition of Zone 2 NE equivalent, albeit that the hydrogen concentration is approximately three times that of NG.

A better definition of hole sizes to be used for vibrating equipment at low pressure (< 100 mbar) is required in any revised version of IGEM/SR/25, to be consistent with Footnote 3 of Table 1 in UP/16 Edition 1, otherwise Zone 2 assessments may result for hydrogen unnecessarily. IGEM/UP/16 suggests a hole size of 0.25 mm^2 in such circumstances whereas there is no specific guidance for low pressures in IGEM/SR/25, and a hole size of 2.5 mm^2 could be inferred. However, the hole size of 0.25 mm^2 given in IGEM/UP/16 appears to be at odds with guidance on hole sizes available in BS EN 60079:10-1 (2009) and "Classification of Hazardous Locations" by Cox, Lees and Ang (5), where a minimum hole size of 1 mm^2 is stated.

APPENDIX 6: METERING

A6.1 METER TYPES

A6.1.1 Diaphragm meters

Domestic gas meters in the UK are predominantly diaphragm meters.

Diaphragm meters have four measurement chambers. Two by two, the measurement chambers form a section which is separated by using a deformable wall, the diaphragm. Both diaphragms are connected to each other and they lead, via a rotating piston to the counter. By knowing beforehand, the volume of each chamber, we can measure directly the gas volume that passes through the diaphragm meter

The advantages of diaphragm meters are that they are of robust construction, have proven reliability, are low cost when compared to other meter types, can measure low gas flow, have long term accuracy and stability and have long life expectancy.

The disadvantages of diaphragm meters are that they comprise many moving parts, require clean gas to operate effectively, they are restricted to low flow rate applications, unsuitable for mass flow and converting to SMART functionality requires a bolt-on addition (i.e. the SMART functionality is not integral to the meter).

A6.1.2 Ultrasonic meters

Ultrasonic meters can also be used for domestic applications.

Ultrasonic meters measure the speed of gas movement by measuring the speed at which sound travels in the gaseous medium within the pipe.

The advantages of ultrasonic meters are that the turndown ratio is probably the largest of any gas meter, they are accurate, usually within 1%, they are approved for use in custody transfer metering applications and they have good repeatability, high turndown and rangeability.

Ultrasonic meters can also measure accurately at high and low pressure and temperature, are self-diagnosing and once calibrated the meter requires less frequent calibrations. Also, there are no moving parts, therefore long term reliability is improved.

The disadvantages of ultrasonic meters are that they are expensive, they can be disturbed by noise and impacted by dirt and fluids and require a battery replacement after 10-years of operation.

A6.1.3 Other meter types

Other types of meter are unsuitable for domestic applications. Rotary meters give pulsation and high sensitivity, whereas turbine meters can overrun and are sensitive to disturbed flow conditions.

A6.2 CURRENT METERING STANDARDS AND PRACTICES

The current metering standards, codes of practice and procedures cover wide ranging aspects including meter types, installation and testing and these are identified below.

Meters

- BS 6400 – domestic sized gas meters up to 6 m^3 h^{-1}
- BS EN 1359 – diaphragm meters
- Product design specification as set out by the MAM
- BS EN 14236 – Ultrasonic meters
- IGEM/GM/6 Edition 2 or IGEM/GM/8 - For meters exceeding 6 m^3 h^{-1}
- BS 7671 – IEE wiring regulations.

Codes of Practice

- SPAA – Metering Code of Practice.

Regulators

- Essential Requirements of the European Gas Appliance Directive (90/396/EEC) (Now GAR).

Installation ASC Assessment Modules

- CCN 1 Core Domestic Gas Safety Assessment
- CMA 1 Meter Installer Core Gas Safety Assessment
- MET 1 & 2 - Installation Exchange, remove & commission diaphragm gas domestic meters.

Tightness testing

- IGEM/UP/1B - Tightness testing and direct purging of small Liquefied Petroleum Gas/Air, Natural Gas and Liquefied Petroleum Gas installations
- IGEM/UP/1C - Strength testing, tightness testing and direct purging of Natural Gas and LPG meter installations
- BS 746:2014 “Specification for gas meter unions and adaptors”.

Meter box

- BS 8499:2017 Specification for domestic gas meter boxes and meter bracket.

Ventilation

- IGEM/GM/7B, IGEM/GM/6, IGEM/GM/8.

Hazardous area classification

- IGEM/SR/25, IGEM/GM/7A, IGEM/GM/7B.

Electrical

- BS 7671, IGEM/GM/7A.

Meter Index

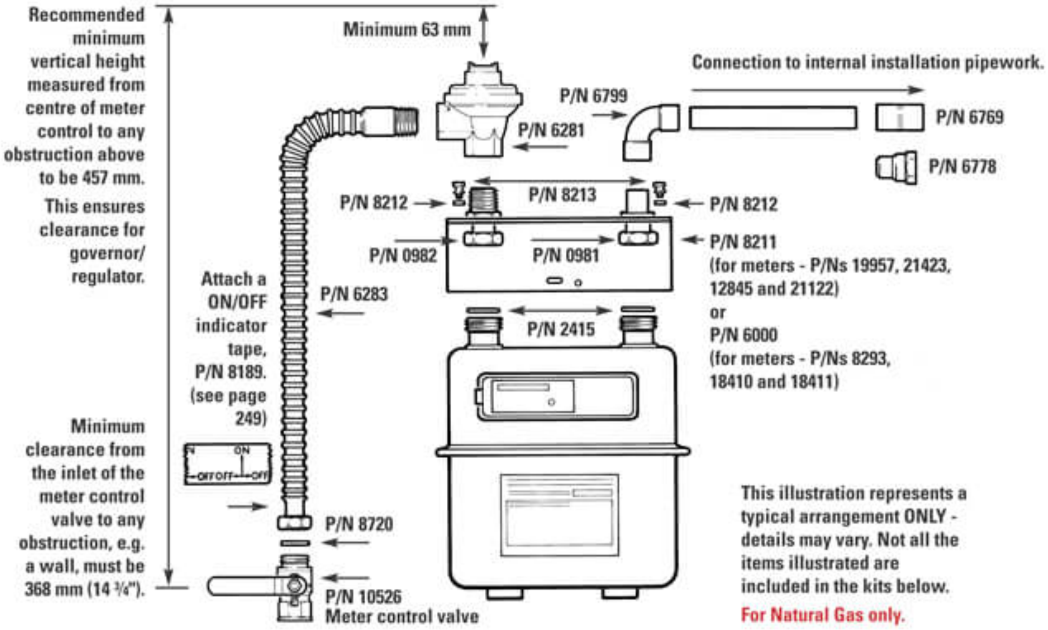
- IGEM/GM/6, IGEM/GM/8.

Access to meter

- IGEM/GM/6, IGEM/GM/8, BS 6400-1 and BS 6400-2.

A6.3 METER COMPONENTS

Meter components (excluding the meter) comprise the regulator, semi rigid connector, washers, fittings etc. (see Figure 3).



Recommended minimum vertical height measured from centre of meter control to any obstruction above to be 457 mm.

This ensures clearance for governor/ regulator.

Attach a ON/OFF indicator tape, P/N 8189. (see page 249)

Minimum clearance from the inlet of the meter control valve to any obstruction, e.g. a wall, must be 368 mm (14 ¾").

P/N 8211 (for meters - P/Ns 19957, 21423, 12845 and 21122) or P/N 6000 (for meters - P/Ns 8293, 18410 and 18411)

This illustration represents a typical arrangement ONLY - details may vary. Not all the items illustrated are included in the kits below.

For Natural Gas only.

FIGURE 3 TYPICAL DWELLING METER INSTALLATION COMPONENTS

APPENDIX 7 : GAP ANALYSIS

This is an example of the gaps identified during the production of this standard. It is to be noted that further evidence may already exist which fills some of these gaps but further gaps could be identified.

Sub heading	Gaps identified
Hydrogen quality specification	Evidence that there are no health effects from trace components from un-combusted gas
Hydrogen quality specification	Evidence that gas detection instruments are fit for purpose and do not suffer from any cross sensitivity. The resulting instrument developed for the sensitive detection of hydrogen gas.
Hydrogen quality specification	Evidence that there are no materials effects (accelerated degradation of metals or polymers) from hydrogen gas and its trace components
Hydrogen quality specification	Quality at the end of the Network, confirmation of the purity of the received gas at the ECV, including any contaminant picked up from the Network
System operating pressures	Confirmation of the operating pressures at the meter outlet.
Competency & Training	Confirmation that suitably trained and assessed operatives are available to conduct trials.
Definitions	Definition of visible flame
Definitions	Definition of ‘hydrogen gas’ ‘100pc hydrogen’ as distributed in the network
Characteristics of hydrogen	Confirmation of visibility of flames and if it will be a requirement
Characteristics of hydrogen	Confirmation as to whether hydrogen will be odorised and the potential name of the proposed odorant
Risk assessment	Analysis of residual risks and confirmation as to whether these are within acceptable limits (un-occupied trial)
Risk assessment	Analysis of residual risks and confirmation as to whether these are within acceptable limits (occupied trial)
Risk assessment	Analysis of residual risks and confirmation as to whether these are within acceptable limits (roll-out)
Hazardous areas	Lack of suitable methodology for application of hazardous areas to hydrogen in low pressure hydrogen installations. There is no simple conversion, for hydrogen, of the current calculations / tables set out in IGEM/SR/25, IGEM/UP/16, IGEM/GM/7B etc. With the exception of V_z calculations for outdoor releases the conversion from NG to hydrogen cannot simply be expressed in terms of LFL/ leak rate

Building strength	Response of building materials to over-pressures from hydrogen explosions will need to be assessed
General room ventilation (subject to availability of appliance types)	Better understanding of ventilation requirements for hydrogen and implications on building regulations is needed. It is unsure if a room that contains a hydrogen gas appliance or pipework will be required to have high level ventilation to allow the dispersal of hydrogen, due to its high buoyancy, in the event of a gas leak. This is in conflict with Approved Document B which requires connecting ventilation to be at low level to reduce the transfer of smoke in the event of fire. So the need, sizing and positioning of ventilators will be required to be reviewed The combustion of hydrogen requires less air, produces more water vapour, less CO and CO_2. So to support combustion, current ventilation may be acceptable. But whilst lower concentrations of CO_2 and CO are produced, there is an increase in water vapour produced, as well as potentially an increase in NO_x emissions into the room (for flueless appliances). Ventilation requirements for these are to be reviewed to migitate a build-up within a room
Ventilation for cookers	The ventilation calculation maybe required to be updated to allow for the decrease in combustion air required for flueless appliances, such as cookers. However, the increase in water vapour content and potentially NO_x emissions, produced by a free standing cooker, in a small room may cause an increase in condensation. This may require an increase in ventilation within the room as there is an increased risk of levels of mould formation on cold walls due to condensation which could constitute a health risk
Ventilation for room sealed boilers	It is unsure as to whether there will be a requirement for compartmental ventilation for cooling purposes of the appliance and this requirement will need to be determined
Ventilation requirements for open and unflued fires (if applicable)	Confirmation of acceptable ventilation provision and flueing methods for fires will need to be reviewed
Proximity distances to flue terminals	Proximity distances for flues will require to be updated, in particular, in cases where flueing could become a nuisance
Building regulations requirements for gas detection	Understanding if CO and hydrogen gas detectors will be required in properties to maintain safety (NB. The CO alarms may be associated with solid fuel installations, as they will not be required for hydrogen combustion)
Emergency response	Demonstrate emergency response network procedures associated with the trial sites are appropriate for hydrogen
Inspection and maintenance	Assess the suitability and frequency of current periodic inspection, maintenance checks and records and would the inspection frequency be required to be increased, as well as whether inspections should now become a requirement

Identification-labelling	Agreed labelling of hydrogen gas meters and pipework, as well as the identification of properties on domestic hydrogen supply
Identification-awareness	Determine what liaison, procedures and records are required to identify hydrogen installations
Combustion, Flueing & Ventilation-NO_x levels	Confirmation of the combustion products and whether they have any effect on materials in the combustion products circuit. Also confirmation of NO_x levels from all hydrogen appliances
Combustion, Flueing & Ventilation -Combustion of trace components	Effects of trace components of hydrogen gas on combustion and emissions from appliances
Combustion, Flueing & Ventilation- Air requirements	Confirmation of air requirements for combustion and comparison with existing air requirements
Water vapour & condensate	Confirmation of amount of water vapour generated from combustion and methods for dealing with this
Water vapour & condensate-pH	Confirmation of pH of flue gas and condensate to determine as to whether there is an increase risk in flue and building material damage from contact with flue products
Water vapour & condensate-pH	Confirmation that the pH of the aqueous condensate will not have any detrimental effect on water treatment plants
Materials & Components-Brass	Many components and fittings are manufactured from brass. One data source found that fittings made from brass with lead contents above 2.5% are not suitable for use with hydrogen. There is a need to confirm this, or test if all fittings used are less than 2.5% lead. Consideration to the loading regime should be given
Materials & Components-Cast Iron	Cast iron valve bodies may suffer loss of strength after exposure to hydrogen. Limited short term tests suggest that this is not the case with low pressures and stresses, however further data is required for longer term use
Materials & Components-Carbon steel springs	Carbon steel springs may suffer premature failure in 100% hydrogen. Particularly in fatigue loading. Springs are exposed to hydrogen in some valves. No data available regarding embrittlement or performance in 100% hydrogen
Materials & Components-Stainless steel springs	Stainless steel springs may suffer premature failure in 100% hydrogen and long term effects will need to be determined. Springs are ferritic or martensitic stainless steels with high tensile strength and yield strength (which is what makes a good spring), therefore they are considered susceptible to hydrogen embrittlement and a reduction in fatigue life
Materials & Components-Lead pipework	Effects of hydrogen on lead pipework strength and leak rate are not known and will need to be determined

Materials & Components-Aluminium alloys	The suitability of aluminium alloys will need to be determined for wet gas service (caused by moisture condensing within the pipe, gas temperature below the dewpoint or ingress of water from a leak)
Materials & Components-Copper	Copper appears to be suitable for hydrogen utilisation, as long as it contains low levels of oxygen. There is a risk of embrittlement if low Oxygen content copper is not used. BS EN 1057:2006 + A1: 2010, does not specify the oxygen content and work may need to be done to determine the optimum oxygen content levels within copper
Materials & Components-Chrome plating	For chrome plated ball valves, there is a theoretical risk of spalling of chrome plating leading to leaks and/or seizure of valve. Work will need to be undertaken to determine if this is the case
Materials & Components-Mechanical fittings	Compression fittings (metal to metal), screwed fittings, pressed fittings etc. there is a theoretical increase in leak rate which will need to be determined
Materials & Components-Sealants	BS EN 751 Part 2 suggests sealants are compatible with 1st Family gases including Town gas (up to 60% hydrogen). Work will need to be undertaken to determine their suitability for 100% hydrogen
Materials & Components-Long term performance	There is a lack of evidence of long term performance of materials with 100% hydrogen
Design and installation of pipework-Isolation valves	Testing will be required on isolation valves (including ball valves to appliances, ECV and AECV) to determine their compatibility with 100% hydrogen
Design and installation of pipework-Pipe jointing	Soldering is identified to be a suitable jointing technique if undertaken correctly. Further understanding to demonstrate leakage on poorly sealed joints may be useful to demonstrate if leaks arising are turbulent or laminar
Design and installation of pipework-Pipe sizing	As hydrogen is less viscous (20% less compared to that of NG). The pipe-sizing table will need to be checked and may possibly require recalculation. This can then be inserted into standard
Design and installation of pipework-Separation distances to electrical cables	Proximity to electrical services will be required to be reviewed (currently covered in BS 7671 and BS 6891). As well as an assessment of any increased risk associated with hydrogen gas pipes
Design and installation of pipework- Tightness test	There is no legal requirement to undertake a gas safety check which includes a tightness test and have a gas safety certificate for a domestic property (other than for Landlords). Is there a requirement for increased frequency / certification of annual integrity checking of pipework?
Design and installation of pipework-Fire protection	Confirmation as to whether any additional fire protection will be required inside a house utilising hydrogen

Design and installation of pipework-Pipework in voids	Review of pipework in voids, including suspended ceilings / floating floors, to make an assessment of comparative risk
Detection & Testing-Gas Detectors	Gas detectors will be required to detect gas leaks in the environment as well as search for specific leaks. Also as part of the purging process, to show either the absence of gas or the presence of gas. The availability of hydrogen detectors suitable for these purposes appears to be limited and suitable instruments will need to be identified and certified for use on the trials. If the hydrogen is not odourised (presumably unlikely) there would be a greater need for hydrogen detectors
Detection & Testing-LDF	Currently common LDF do not seem to be proven with hydrogen
Detection & Testing-MPLR	Determination of MPLR for hydrogen during tightness testing will be required to be determined
Commissioning-direct purging	Direct Purging Fundamentals and Methodology for hydrogen use needs to be developed
Commissioning-indirect purging	Indirect Purging Fundamentals and Methodology for hydrogen use needs to be developed
Metering- Semi Rigid Connector	Tests to be undertaken on the ECV and regulator connections
Metering- Regulator	Tests with manufacturers to consider hydrogen impact on the diaphragm. Potential leakage path through spring thread
Metering- Meter connections	Neoprene washer seals come under BS 746:2014 "Specification for gas meter unions and adaptors" -for gas meter unions the tests specified need to be repeated for hydrogen adaptors" -Torque settings need to be enforced as Hydrogen more prone to leakage that NG
Metering- Meter location	Understanding of relative risk of having internal hydrogen meter box – noting there are several potential leakage points on the meter
Metering- Meter location	Risk of installing hydrogen meters by escape routes to be assessed 'BS 6400 meter shall not be installed on the sole means of escape'
Metering- Meter location	Confirmation of ability to house hydrogen meters in existing meter boxes – consideration needed of size, ventilation, need for closed back, risk associated with recessed meter box etc.
Metering- Meter location	Confirm suitable method for sealing meter outlet to the home to ensure there is no leakage path into home
Metering- Commercial meter	Hazardous area assessment required by IGEM/GM7B currently does not cover hydrogen

Safe limits of for mains pressure	Manufacturers developing appliances to advise on safe limits for mains pressure (if they differ from NG)

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