Injecting hydrogen into the gas network – a literature search

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Hydrogen injection into the GB gas network is a likely consequence of using excess offshore wind generated electricity to power large-scale onshore electrolysis plants. Government and DECC in particular now have a keen interest in supporting technologies that can take advantage of the continued use of the gas networks. HSE can contribute to the government’s Growth and Green agendas by effectively regulating and safely enabling this technology.

This report will allow HSE to regulate effectively by pulling together scientific and engineering knowledge regarding the hazards of conveying hydrogen/methane mixtures in network pipes and its use in consumer appliances, into a single ‘state-of-play’ report. It enables Energy Division to consider and assess submissions for ‘gas quality’ exemptions to the Gas Safety (Management) Regulations 1996 (GSMR). In particular, the report has examined the following hazards:

- conveyance of H2/CH4 mixtures in network pipes
- use of H2/CH4 mixtures in consumer appliances (domestic/commercial/industrial)
- explosion and damage characteristics (and ignition likelihood) of H2/CH4 mixtures
- effects on odourisation

It identifies that the flame profile in gas appliances will increasingly flatten as hydrogen content rises. For modern appliances fitted with flame failure devices this may cause the appliance to shut down (and default to a safe condition). For some older types of gas appliance (1970s and older) not fitted with flame failure devices there may be an increased risk of flame failure leading to internal gas escapes. At the concentrations of hydrogen in methane likely to be considered by the industry (between 0.5 and 10%) this effect is not significant. Where exemptions for higher concentrations are sought HSE will insist on the identification and modification of vulnerable appliances.

The report concludes that concentrations of hydrogen in methane of up to 20% by volume are unlikely to increase risk from within the gas network for from gas appliances to consumers or members of the public.

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CONTENTS

1 INTRODUCTION ........................................................................................................ 1

2 GAS INTERCHANGEABILITY CRITERIA ............................................................... 2
2.1 Wobbe Number ................................................................................................. 2
2.2 Weaver Flame Speed Factor ........................................................................... 3
2.3 Gas characteristics and national limits ............................................................. 3

3 IDENTIFYING THE HAZARDS ........................................................................... 6
3.1 Fire and explosion ........................................................................................... 6
3.2 Materials and structural integrity issues ......................................................... 14
3.3 Chemical Considerations ................................................................................ 17
3.4 Effect of hydrogen addition to natural gas ...................................................... 21
3.5 Assessment of the size and composition of the UK gas appliance (domestic and commercial) population .......................................................... 24
3.6 Domestic gas appliances ............................................................................... 25
3.7 Assessment of the size and composition of the UK gas appliance population – commercial appliances ........................................................... 29
3.8 Flame detection/supervision devices ................................................................. 32

4 CONCLUSIONS .................................................................................................... 36
4.1 Fire and explosion ........................................................................................... 36
4.2 Materials and structural integrity issues ........................................................... 36
4.3 Chemical considerations ................................................................................ 36
4.4 Domestic and commercial appliances ............................................................. 37
4.5 Hazard and risk summary table ...................................................................... 38

5 REFERENCES ......................................................................................................... 39
EXECUTIVE SUMMARY

Objectives

The aim of this literature review was to examine the potential effects that hydrogen enriched natural gas may have on those parts of the existing gas network that could carry the gas mixture. The potential impacts on domestic and industrial gas burning appliances and equipment have also been considered.

Main Findings

There is a long history of the transportation of hydrogen at pressures below 20 barg across the world with few operational issues occurring over many decades. Historically in the UK, the gas distribution network successfully conveyed town gas containing significant proportions of hydrogen.

There is little evidence to suggest that materials used for the low pressure distribution system will undergo degradation due to the injection of hydrogen into the natural gas network. In particular, there is no evidence that pipes and fittings made from polyethylene (PE) will be adversely affected.

Safe use of gas appliances depends on the Wobbe Number (WN) of the gas supplied matching the calibration of the gas appliance burner(s).

Modern, CE marked, naturally aerated appliances appear to be able to burn hydrogen-enriched natural gas available in the UK safely at up to 20% v/v without modification.

It is not expected that the fire and explosion hazards arising from the ignition of accumulations of mixtures of natural gas and hydrogen (up to 20% v/v) from unintentional escapes will be significantly more severe than for leaks of natural gas alone.

The effectiveness of odorising compounds used in the natural gas network, to make gas escapes more easily detectable by members of the public, is unaffected by the injection of hydrogen.
Recommendations

This review has found that injection of hydrogen at concentrations of 20% v/v or less is unlikely to have a deleterious effect on the gas network and most appliances.

What is less certain from the work done to date is whether the inclusion of hydrogen would have any long term effects on appliances. The gas mixture at the higher end of the hydrogen injection range would possibly encourage the flame to light back and settle on the burner, permitting overheating or degradation of the burner potentially causing issues with burner operation. Long term testing of appliances with higher levels of injected hydrogen will be necessary to investigate whether or not this is likely.
1 INTRODUCTION

Injection of hydrogen into the natural gas network is seen as a way forward in creating a more sustainable energy mix in the UK. The proposal is to feed hydrogen, produced by the electrolysis of water using excess or off peak electricity, into the existing gas network. This would act as a transport route and storage mechanism for the hydrogen. Hydrogen would be injected into the network at the manufacturing site, mixing with the natural gas. Hydrogen would then be extracted at various downstream points, to be utilised for hydrogen powered engines or fuel cell applications.

This literature review examines the potential effects that hydrogen enriched natural gas may have on those parts of the existing gas network that could carry the gas mixture. Also considered are the potential impacts on domestic and industrial gas burning appliances and equipment.
GAS INTERCHANGEABILITY CRITERIA

The principal acceptability criteria for the quality of distributed gases is that they give reasonably similar heat inputs, good flame stability, reliable ignition and complete combustion. Other factors to be taken into account in relation to gas appliances are sooting, flame lift and light-back. These acceptability criteria, as practically applied to appliances, are visited in further sections.

2.1 WOBBE NUMBER

The Wobbe index was developed to provide the principal criteria for enabling prediction methods of interchangeability of different gases in distribution systems and in end use appliances based on gas composition. The Wobbe Number (WN) was adopted to be the main combustion related property, as it indicates the effect of gas composition changes on appliance heat input with a constant pressure gas supply and is therefore useful in comparing gaseous fuel mixtures.

WN is defined as:

\[ W = \frac{\text{Gross calorific value}}{\sqrt{\text{Relative density}}} \quad (\text{MJ/m}^3) \]

Equation 1

An early diagrammatic system for predicting gas interchangeability was developed by various authors. This was a two dimensional diagram in which a corrected WN (corrected to accommodate varying gas compositions) was plotted against the combustion potential of the (town) gas related to the burning velocity (1) (2) (3).

As the longevity of natural gas supplies to the UK came into question in the 1980’s, and with the prospect of having to use gas from other sources with potential quality differences, the question of gas interchangeability was revisited. A three dimensional diagram was developed (4) to address inherent inaccuracies of the previous method. This new method proposed reducing the composition of the gas to a four component equivalent. Practically, it introduced a third axis, on which was plotted the percentage mole fraction of hydrogen in the gas composition. This analysis is obviously of benefit when considering the proposed injection of hydrogen into the UK gas infrastructure.
2.2 WEATHER FLAME SPEED FACTOR

The flame speed of various gas compositions is also important when designing appliance burners to avoid flash back. The Weaver flame speed factor is used in these predictions.

The Weaver flame speed factor is defined as the percentage ratio between the laminar flame speed of the gas of interest and that of hydrogen. Thus, hydrogen has a value of 100.

The Weaver flame speed factor, $s$, is defined as:

$$ s = \frac{x_i F_i}{A + 5x_n - 18.8x_0 + 1} $$

Equation 2

where

- $x_i$ is the mole fraction of the combustible component, $i$
- $x_n$ is the mole fraction of the inert components
- $x_0$ is the mole fraction of oxygen in the gas
- $A$ is the theoretical (stoichiometric) air per unit volume
- $F_i = \frac{\text{burning velocity of component } i \text{ in a stoichiometric air mixture} \times (A_i + 1) \times 100\%}{\text{burning velocity of hydrogen in a stoichiometric air mixture}}$
- $A_i$ is the theoretical (stoichiometric) air per unit volume for component $i$.

2.3 GAS CHARACTERISTICS AND NATIONAL LIMITS

The characteristics and conveyance of natural gas through the UK national gas pipe distribution network are regulated by the Gas Safety (Management) Regulations 1996 (5). Within the guide to the regulations, the prescribed characteristics of the gas in the UK are given (6).

In the UK, under normal conditions (emergency conditions allow for a temporary widening of the WN band to ensure supply), the limits of supply (as defined by the WN) are:
Natural gas falls into the second family of gases defined in BS EN 437:2003 (7). Within the second family, natural gas Group H, identified for use in the UK, is defined as having a WN range between 45.7 and 54.7 MJ/m³. This is slightly wider than that quoted in the Gas Safety (Management) Regulations 1996.

Table 1 shows the range of WNs of the natural gas used in Europe and the UK. These ranges reflect the characteristics of the localised natural gas used or discovered in or near each locality. Included for contextual purposes are the WN’s for the first and third gas families and LNG imported into the UK.

**Table 1  European area gas WN’s according to EN437:2003**

<table>
<thead>
<tr>
<th>Gas family</th>
<th>Gas group</th>
<th>Gross Wobbe index MJ/m³</th>
<th>Locality*</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>First family</td>
<td>Group a</td>
<td>22.4</td>
<td>24.8</td>
<td>Where still used</td>
</tr>
<tr>
<td>(Town gas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second family</td>
<td>Group L</td>
<td>39.1</td>
<td>44.8</td>
<td>NL, FR</td>
</tr>
<tr>
<td>(Natural gas)</td>
<td>Group E</td>
<td>40.9</td>
<td>54.7</td>
<td>DE, BE</td>
</tr>
<tr>
<td></td>
<td>Group H</td>
<td>45.7</td>
<td>54.7</td>
<td>GB, FR, AT, CZ, DK, ES, FI, GR, IE, IT, NO, PT, SE</td>
</tr>
<tr>
<td>Third family</td>
<td>Group B/P</td>
<td>72.9</td>
<td>87.3</td>
<td></td>
</tr>
<tr>
<td>(LPG)</td>
<td>Group P</td>
<td>72.9</td>
<td>76.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group B</td>
<td>81.8</td>
<td>87.3</td>
<td></td>
</tr>
</tbody>
</table>

* Key

<table>
<thead>
<tr>
<th>AT</th>
<th>Austria</th>
<th>GR</th>
<th>Greece</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BE</td>
<td>Belgium</td>
<td>IE</td>
<td>Ireland</td>
<td></td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
<td>IS</td>
<td>Iceland</td>
<td></td>
</tr>
<tr>
<td>CZE</td>
<td>Czech Republic</td>
<td>IT</td>
<td>Italy</td>
<td></td>
</tr>
<tr>
<td>DE</td>
<td>Germany</td>
<td>LU</td>
<td>Luxembourg</td>
<td></td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>NL</td>
<td>Netherlands</td>
<td></td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
<td>NO</td>
<td>Norway</td>
<td></td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
<td>PT</td>
<td>Portugal</td>
<td></td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
<td>SE</td>
<td>Sweden</td>
<td></td>
</tr>
<tr>
<td>GB</td>
<td>United Kingdom</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each gas appliance is designed and manufactured to be used safely within the range of WN quoted for a particular gas group. For example, the test gases (7) used during the
design and manufacture of an appliance to be sold and used in the UK are shown in Table 2. This shows that the WN range of these test gases is slightly wider (45.66 to 54.76 MJ/m³) than the range shown in Equation 3 and is also wider than the emergency WN range allowed in the Gas Safety (Management) Regulations 1996 (6) of 46.50 to 52.85 MJ/m³.

Table 2   Gas second family, Group H test gases according to BS EN437:2003

<table>
<thead>
<tr>
<th>Gas Group</th>
<th>Test gas description</th>
<th>Designation</th>
<th>Composition by volume (%)</th>
<th>Gross WN (MJ/m³)</th>
<th>Gross Calorific value (MJm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Reference gas</td>
<td>G20</td>
<td>CH₄ = 100</td>
<td>50.72</td>
<td>37.78</td>
</tr>
<tr>
<td></td>
<td>Incomplete combustion and sooting limit gas</td>
<td>G21</td>
<td>CH₄ = 87, C₃H₈ = 13</td>
<td>54.76</td>
<td>45.28</td>
</tr>
<tr>
<td></td>
<td>Light back limit gas</td>
<td>G222</td>
<td>CH₄ = 77, H₂ = 23</td>
<td>47.87</td>
<td>31.86</td>
</tr>
<tr>
<td></td>
<td>Flame lift limit gas</td>
<td>G23</td>
<td>CH₄ = 92.5, N₂ = 7.5</td>
<td>45.66</td>
<td>34.95</td>
</tr>
<tr>
<td></td>
<td>Over heating limit gas¹</td>
<td>G24</td>
<td>CH₄ = 68, C₃H₈ = 12, H₂ = 20</td>
<td>52.09</td>
<td>39.55</td>
</tr>
</tbody>
</table>

¹ Limit gas used only for certain appliance types.
3 IDENTIFYING THE HAZARDS

3.1 FIRE AND EXPLOSION

This section discusses the characteristics that are important in understanding the differences in the hazards associated with an unplanned natural gas / air mixture release compared with a natural gas / hydrogen / air mixture release. Whilst it is recognised that natural gas within the distribution system is a mixture of methane, higher hydrocarbons and other gases, much of the comparison data that is available is for hydrogen and methane, the main component of natural gas. Therefore, unless otherwise stated, the comparisons are made between hydrogen and methane.

Table 3 gives a comparison of the key characteristics of hydrogen and methane.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Methane (CH₄)</th>
<th>Hydrogen (H₂)</th>
<th>Reference</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>0.68</td>
<td>0.09</td>
<td>(8)</td>
<td>At 15°C and atmospheric pressure</td>
</tr>
<tr>
<td>Flammable Range</td>
<td>% vol</td>
<td>4.4 – 17.0</td>
<td>4 – 75</td>
<td>(9)</td>
<td>$FL_{CH₄}$/ $FL_{H₂}$ (ref. Equation 5)</td>
</tr>
<tr>
<td>Limiting oxygen for combustion</td>
<td>% vol</td>
<td>12</td>
<td>5</td>
<td>(10)</td>
<td>$LOC_{CH₄}$/ $LOC_{H₂}$ (ref. Equation 6)</td>
</tr>
<tr>
<td>Laminar burning velocity</td>
<td>m/s</td>
<td>0.4</td>
<td>3.1</td>
<td>(11)</td>
<td>$S_{L,CH₄}$/ $S_{L,H₂}$ (ref. Equation 7)</td>
</tr>
<tr>
<td>Heat of combustion</td>
<td>MJ/kg</td>
<td>50</td>
<td>120</td>
<td>(12)</td>
<td>Lower heating value</td>
</tr>
<tr>
<td>Heat of combustion</td>
<td>MJ/kgmol</td>
<td>800</td>
<td>240</td>
<td></td>
<td>Lower heating value (calculated values from above *)</td>
</tr>
<tr>
<td>Detonation cell size</td>
<td>mm</td>
<td>~ 300</td>
<td>~10</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>Minimum Spark Ignition Energy</td>
<td>mJ</td>
<td>0.21</td>
<td>0.016</td>
<td>(14)</td>
<td></td>
</tr>
<tr>
<td>Electrostatic charge for Ignition</td>
<td>nC</td>
<td>60</td>
<td>10</td>
<td>(15)</td>
<td>Limits for IIA and IIC gases</td>
</tr>
<tr>
<td>Minimum Igniting current ratio</td>
<td></td>
<td>1.0</td>
<td>0.25</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>Maximum experimental safe gap</td>
<td>mm</td>
<td>1.12</td>
<td>0.29</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>Autoignition temperature</td>
<td>°C</td>
<td>600</td>
<td>560</td>
<td>(9)</td>
<td></td>
</tr>
</tbody>
</table>

(Ref. Equation 5)
3.1.1 **Formation of Flammable Atmospheres**

A number of properties of hydrogen / methane mixtures can be approximated using suitable forms of the Le Chatelier Equation employing the properties of pure hydrogen and pure methane.

A number of equations are presented in the following sections. In these equations, the hydrogen content of the fuel, $\lambda$, is defined by:

$$\lambda = \frac{\% \text{ vol.} \text{H}_2}{\% \text{ vol.} \text{H}_2 + \% \text{ vol.} \text{CH}_4}$$

**Equation 4**

### 3.1.1.1 Flammable Range

The flammable range of hydrogen, 4 to 75% volume, is far wider than that of methane, 4.4 to 17% volume. (BS EN 60079-20-1:2010). Despite this difference it has been reported that the lower and upper flammable limits of hydrogen/methane mixtures can be reasonably well calculated using Le Chatelier’s rule (16) (17).

The lower and upper flammable limits of hydrogen / methane mixtures may be calculated using the equation:

$$FL = \frac{1}{\frac{\lambda}{FL_{H2}} + \frac{(1-\lambda)}{FL_{CH4}}}$$

**Equation 5**

where $FL_{H2}$ and $FL_{CH4}$ are the flammable limits of hydrogen and methane shown in Table 3.

### 3.1.1.2 Limiting Oxygen for Combustion (LOC)

There is a significant difference between the limiting oxygen concentration required for combustion of hydrogen and that required by methane, at approximately 5% and 11% respectively. Despite this difference, it is reported that reasonable estimates of the LOC of hydrogen-methane mixtures in air can be made using Le Chatelier’s rule (18). The calculated values for LOC are reported to be equal to the experimental values in some cases, but under predicted by up to 1% vol. in other cases.
The LOC of hydrogen / methane mixtures can be calculated using the equation:

\[
LOC = \frac{1}{\frac{\lambda}{\text{LOC}_{\text{H}_2}} + \frac{(1 - \lambda)}{\text{LOC}_{\text{CH}_4}}}
\]

Equation 6

where \(\text{LOC}_{\text{H}_2}\) and \(\text{LOC}_{\text{CH}_4}\) are the limiting oxygen concentrations for combustion of hydrogen and methane shown in Table 3.

3.1.2 Leakage Rates and Dispersion

The gas flow from a leak, and its tendency to disperse, will depend upon the nature of the leak (geometry and pressure) and properties of the gas such as density, viscosity, diffusion coefficient (in air) and the speed of sound (for choked releases).

3.1.2.1 Density

Methane is lighter than air and hydrogen is about three times lighter than methane. Therefore, the addition of hydrogen to methane results in a mixture which is lighter than methane alone.

3.1.2.2 Diffusion

The diffusion coefficient of hydrogen in air is approximately three times larger than that of methane in air. Therefore, it follows that the addition of hydrogen to methane results in a mixture which has a larger overall diffusion coefficient than methane alone.

3.1.2.3 Speed of Sound

The speed of sound in hydrogen is approximately 2.7 times that in methane. Therefore, the velocity, and hence volumetric flow rate, of hydrogen would be higher in a choked (sonic) release than methane from a hole of the same size and at the same pressure.

3.1.2.4 Leakage Rates

Due to the physical properties of hydrogen compared to methane, the volumetric flow rate of hydrogen will be higher than methane given the same leak size and pressure regardless of whether the leak is at low pressure (19) (20) or is choked flow.

3.1.2.5 Dispersion in the Open Air

In the open air, the lower density and higher diffusion coefficient of hydrogen would aid the dispersion of hydrogen-enriched natural gas.
3.1.2.6 Dispersion within a Vented Enclosure

As part of NaturalHy project, Lowesmith (19) investigated the accumulation of hydrogen/methane mixtures that could be expected within domestic dwellings in the event of a leak. In this work, it was found that the flow rate of gas from a leak increased as the proportion of hydrogen in the gas increased. This would be expected due to the differences in the physical properties of hydrogen and methane, as discussed above. Due to the low pressure of domestic gas supplies in the dwelling (20 mbar) (7), Lowesmith postulated that natural gas could be expected to form a uniform layer above the release point due to its density being lower than air and the mixing with air during the release being poor. This has also been reported by Marangon (21). The work reported by Lowesmith indicated that increasing the hydrogen content results in an increase in the layer thickness and also an increase in the concentration, by volume, of the gas mixture in the layer. It is believed, however, that the tendency to form layers rather than form a more uniform mixture would have been enhanced by the experimental arrangement used, i.e. using two vents in the walls, one low down and the other high up, and wind incident on the bottom vent only. However, it has been reported (22) that wind in the upper vent can overcome the buoyancy-driven ventilation of pure hydrogen and result in a more uniform mixture with a higher average concentration of hydrogen within the volume than when buoyancy dominates. Presumably, a similar effect would be observed with hydrogen/methane mixtures although this would require some further analysis. In the work reported by Lowesmith, there was only a marginal increase in the total fuel concentration within the enclosure when the methane-hydrogen mixture contained less than about 30% hydrogen.

3.1.3 Ignition Sensitivity

It is important to know how sensitive a flammable atmosphere is to ignition as part of a hazard assessment. The influence that added hydrogen has on the sensitivity of methane to common potential sources of ignition is discussed below.

3.1.3.1 Minimum Ignition Energy (MIE)

Experimental data for the minimum ignition energy of methane / hydrogen blends have been reported by Hankinson et al (23). The data indicate that, as expected, the MIE decreases as the amount of hydrogen increases; so the risk of ignition by electrostatic discharges would increase with the introduction of hydrogen. However, it appears that the ignition energy remains above 0.1 mJ for mixtures containing up to 25% hydrogen and 75% methane. This is significant since the maximum equivalent energy of corona discharges, in terms of incendivity, has been reported as being approximately 0.1 mJ (14). The implication of this is that methane-hydrogen mixtures
containing more than 25% hydrogen may be susceptible to ignition by corona discharges, for example those resulting from high electric fields experienced at the top of vents. Coal gas has been shown previously to have been ignited by corona discharges (24); further work would be required to better understand the behaviour of methane mixtures containing more than 25% hydrogen.

3.1.3.2 **Autoignition Temperature (AIT)**

The autoignition temperatures of methane and hydrogen, as measured in standard tests, are very similar at 600°C and 560°C respectively. However, attention should be paid to the difference in behaviour of these gases in relation to contact with hot surfaces (see section 3.1.3.3).

3.1.3.3 **Frictional Ignition**

Proust et al (25) studied the individual ignition of hydrogen and methane by frictional ignition sources. Despite the similarity in the measured AIT of hydrogen and methane, hydrogen is significantly more sensitive to frictional ignition. For example, the applied load on a stainless steel surface subject to rubbing to ignite hydrogen was at least an order of magnitude lower than required to ignite methane. No data have been found for methane / hydrogen mixtures.

3.1.3.4 **Spontaneous Ignition**

Hydrogen is susceptible to “spontaneous” ignition when released into air at relatively low pressure (26). This is also known as diffusion ignition. Methane is far less susceptible to this phenomenon. Recent work (27) shows that the addition of small quantities of methane (5 – 10%) to hydrogen significantly desensitises the gas mixture. Therefore, it would appear to be reasonable to conclude that minor additions of hydrogen to methane are unlikely to result in spontaneous ignition events due to the release of hydrogen / methane mixtures from distribution systems. As the concentration of hydrogen increases towards 100%, however, the potential for spontaneous ignition would become a possibility.

3.1.4 **Area Classification**

Area classification involves the identification of regions where flammable atmospheres may form, and their expected frequency. This gives rise to the designation of zones. Equipment needs to be suitable for the zone in which it is to be used and this will depend upon the nature of the flammable atmosphere. The following material characteristics are considered in identification of suitable equipment; Maximum Experimental Safe Gap (MESG) (see 3.1.4.1), Autoignition Temperature (AIT)
(see 3.1.3.2) and Minimum Igniting Current (MIC), although MIC is becoming somewhat obsolescent.

3.1.4.1 **Maximum Experimental Safe Gap (MESG)**

No data have been found relating directly to the MESG of hydrogen / methane mixtures. However, MESG data are available (28) for town gas and its constituents; methane, hydrogen and carbon monoxide. Town gas containing 57% hydrogen and 16% carbon monoxide has an MESG of 0.57 mm, compared to 1.12 mm for methane, 0.84 mm for carbon monoxide and 0.29 mm for hydrogen. Clearly, a methane mixture containing lower levels of hydrogen would have a larger MESG (see section 3.1.4.3 for further discussion).

3.1.4.2 **Temperature Class**

Both hydrogen and methane are in temperature class T1 due to their high autoignition temperatures.

3.1.4.3 **Information from Standards**

Hydrogen and methane are classed in groups IIC and IIA respectively under the IEC (International Electrotechnical Commission) gas grouping system (groups B and D under the NEC (National Electrical Code) system).

BS EN 60079-20-1:2010 (9) states that natural gas is classified as group IIA provided it does not contain more than 25% v/v of hydrogen. The determination of the gas group of a mixture should **NOT** be calculated from the result of applying Le Chatelier’s Principle to the individual MESG values for the component gases when one of the gases is hydrogen.

Other sources have quoted that natural gas containing up to 30% hydrogen can be treated as group D or IIA (29) (30).

3.1.5 **Consequences of Ignition**

3.1.5.1 **Heat of Combustion**

Although hydrogen has a far higher heat of combustion, by mass, than methane, the low molecular weight of hydrogen means that the heat of combustion by mole (and hence, volume) is actually lower than methane.

This means that the heat of combustion actually reduces when hydrogen replaces some of the methane in a gas / air mixture of the same overall volume concentration. This is manifested in the lower calculated adiabatic pressure rise of explosions in sealed vessels (see section 3.1.7.1).
3.1.5.2 Laminar Burning Velocity

The laminar burning velocity is an important characteristic of a gas / air mixture in that it influences the burning rate and hence rate of pressure rise for an ignited gas / air mixture. The laminar burning velocity of a gas depends upon the gas concentration and will pass through a maximum. The maximum laminar burning velocity of hydrogen is considerably faster (at approximately 3 m/s) than that of methane at approximately 0.4 m/s. The laminar burning velocity of hydrogen-methane mixtures can be estimated fairly well using Le Chatelier’s rule (31).

The laminar burning velocities of hydrogen/methane mixtures can be calculated using the equation:

\[
S_1 p^0 = \frac{1}{\frac{\lambda}{S_{1,H2} p^0} + \frac{1 - \lambda}{S_{1,CH4} p^0}}
\]

Equation 7

where \( S_{1,H2} \) and \( S_{1,CH4} \) are the laminar burning velocities of hydrogen and methane shown in Table 3.

3.1.6 Jet Fires

The ignition of leaking hydrogen / methane may result in a continuous jet fire providing that the flame is stable. As discussed previously, the presence of hydrogen in methane mixtures results in the volume flow rate through a leak being higher. However, at relatively low hydrogen concentrations, the volumetric heat content of the released gas mixture would be lower. A study of large scale hydrogen / methane jet fires (32) indicates that the proportion of radiated heat from a jet fire would decrease as the hydrogen content of the gas increased, although this would be marginal for lower hydrogen concentrations. The report also indicates that the blowout velocity for a methane mixture containing 20% hydrogen would be similar to methane alone (i.e. the flame from an ignited leak of 20% hydrogen / 80% methane would be nearly as likely to lift off and self-extinguish as one of methane alone).

3.1.7 Explosions

Explosions are combustion processes that result in significant pressure generation. They may occur in a sealed vessel, a vessel in which an opening gives some pressure relief, in the open air (if the gas cloud is sufficiently large) or in a gas cloud that is subject to congestion (such as pipes, trees, etc.).
Adding hydrogen to methane will have the following effects, dependant on these explosion modes.

### 3.1.7.1 Sealed Vessels

Explosions involving hydrogen / methane mixtures in sealed vessels have been the subject of a number of reported studies. The work of Salzano (31), carried out in a 5 litre vessel, showed that the experimental maximum explosion pressure remained fairly constant over the range 0 to 100% vol. hydrogen for stoichiometric mixtures, despite the calculated adiabatic pressure rise decreasing with increasing hydrogen content. This is thought to be due to the faster reaction rate, and hence lower heat losses to the vessel and environment, for mixtures containing more hydrogen. The same study concluded that the effect on rate of pressure rise was rather modest unless the hydrogen concentration exceeded 50%, although “modest” appears to be around a factor of 2. For concentrations up to 10%, there is very little change observed.

### 3.1.7.2 Vented Vessels

Experimental large-scale vented explosions of hydrogen / methane mixtures have been reported (19). The experiments were carried out in a 69 m$^3$ vessel in which obstacles were placed between the ignition position and the relief vent. In the same paper, the data were also used to validate a model. The paper concludes that the over-pressures were increased by the inclusion of hydrogen, although the increase was modest for hydrogen contents of up to 20% v/v.

### 3.1.7.3 Open Air

As discussed in section 3.1.2.4 the presence of hydrogen in methane would increase the volumetric leakage rate for a given leak size and pressure. However, at lower hydrogen concentrations in the fuel, say less than 20%, the increase in flow rate is not expected to be large (19). Furthermore, some mitigation would be provided by the dispersion being better than for methane alone and the lower volumetric energy content within the gas cloud.

### 3.1.7.4 Congested Environments

Work was carried out at HSL, as part of the NaturalHy project, in which hydrogen/methane mixtures were ignited in congested volumes and the resulting over-pressures recorded (33). It was concluded that explosion pressures for methane containing 10% hydrogen or less would not be significantly higher than those for pure methane. The experimental data also show only slight increases in the over-pressures
resulting from fuel mixtures containing 25% v/v hydrogen. However, higher hydrogen contents resulted in significantly higher over-pressures.

3.1.8 Deflagration to Detonation Transition (DDT)

The propensity for a burning gas / air mixture to transition from a deflagration to a detonation (DDT) can be correlated to the size of the detonation cells. There is a significant difference in cell size between pure hydrogen (~10 mm) and pure methane (~300 mm). Experimental work on cell widths for hydrogen / methane mixtures in air has been published by Yoshida et al. (34). Although the results of the work were limited by the size of the equipment used, the results indicate that for mixtures containing more than about 50% methane the cell widths were tending towards 100 mm (i.e. 10 times that of hydrogen and similar to that of the common hydrocarbon, propane). Similar results are also reported by Jallais (35). Therefore, it could be concluded that for hydrogen concentrations of less than 50%, the propensity to detonate for hydrogen / methane mixtures would be similar to that presented by common alkane gases.

3.1.9 Summary

Although there are some knowledge gaps relating to the fire and explosion hazards of methane / hydrogen mixtures, the indications are that the differences in the behaviour of methane containing up to 20% hydrogen and that of pure methane are small and unlikely to present a significantly greater hazard in practical situations.

3.2 MATERIALS AND STRUCTURAL INTEGRITY ISSUES

A literature search identified published data related to the issues of material integrity relevant to the injection of hydrogen into the existing natural gas transmission and distribution system. The materials of interest were steels used for the transmission system and steel, cast iron and polyethylene (PE) used in the distribution network.

The search produced approximately fifty papers of some relevance.

The majority of the published literature is in the form of journal papers; however, there were also reports based on two projects (36) (37) specifically undertaken to address the potential issues of using the existing natural gas systems to store and transport hydrogen. In general, there was less detail of the durability of distribution network pipe line materials since the distribution lines operate at a much lower pressure and therefore their integrity is unlikely to be significantly impacted at hydrogen levels that are acceptable for high pressure transmission pipe.
The rationale for the NaturalHy project (37) in terms of materials was, firstly, to assess the impact of hydrogen / natural gas mixtures on the durability of materials that make up the network and secondly, to consider the effects of hydrogen injection on pipeline integrity management.

In terms of durability, experiments were carried out as part of NaturalHy to quantify the effects of hydrogen on the fracture toughness and fatigue crack growth resistance of two commonly used transmission pipeline steels, one of which (X52) is of medium strength and has been used for many decades and the other, higher strength material (X70) of more recent origin. Although the results are interim findings, the data showed that fracture toughness decreased with hydrogen pressure. At a typical transmission pipeline pressure of 69 barg, the toughness could decrease by 30-50%. However, no embrittlement was observed and the mechanical fracture behaviour of both steels remained ductile.

The effects of hydrogen on fatigue behaviour showed that the fatigue threshold decreased and the growth rate, in terms of the Paris curve (38), increased in the presence of hydrogen; however, the effects were strongly dependant on the test conditions and the hydrogen pressure (39). Work carried out under simulated field conditions concluded that a blend of 75% natural gas and 25% hydrogen would be acceptable for the X70 material and that a 50/50 blend would be acceptable for the lower strength X52 material, without degradation of fatigue performance. In addition, tests showed that the number of pipe bursts would not increase with the addition of hydrogen and that hydrogen has no effect on internal pipe coatings. The effects of hydrogen on compression stations were outside the scope of the project and therefore there is a need for additional work. Some work on the effects of an injection of 25% hydrogen at pressure reduction stations has shown that a temperature drop of several degrees might occur (40) although the amount of liquid condensate was somewhat reduced compared with methane alone (41).

In term of integrity management, NaturalHy examined the effects of the number, type, distribution and shape of defects on on-going integrity. This work showed that the effects were minor up to concentrations of 50% hydrogen by volume; however, there was an impact on the acceptable initial crack size especially for axial defects.

Polyethylene is the most commonly used polymer for medium and low pressure distribution systems and the permeability of PE to hydrogen is a specific issue. Transport of hydrogen through polymers is a factor of 6 to 7 times larger than methane. Tests showed that for a given temperature, natural gas and hydrogen retain their molecular permeability, in other words there is no effect of mixing. Nevertheless, the conclusion was that hydrogen losses due to permeation were extremely small.
compared to the leakage from small defects in pipe walls and that leakage rates are insignificant from a safety point of view.

Little literature is available on the aging of PE in hydrogen gas atmospheres; however, NaturalHy concluded that hydrogen had no significant effect.

The National Renewable Energy Laboratory (NREL) report (36) came to broadly similar conclusions to NaturalHy. A number of low strength pipe line steels were reviewed (API 5L, A, B, X42, X46) and it was found that these were not generally susceptible to hydrogen-induced embrittlement under normal operating conditions. It was further concluded that hydrogen-induced failures were not a major concern for steel pipes. The predominant hydrogen damage mechanism for low strength steels has been found to be loss of ductility or blistering (42); failure is by a ductile mode instead of catastrophic brittle fracture. For a range of pipe line steels the resistance to hydrogen absorption decreases with decreasing steel strength (43). Some tests carried out on externally notched pipes (API X52) under hydrogen and methane pressure showed that hydrogen is able to penetrate into the near surface layers and change the local mechanism of fracture (44); however, there was no effect on the strength of notched pipes under the experimental conditions examined.

Carbon and low alloy steels have been shown to have accelerated fatigue crack growth rates and a reduction in endurance limits when exposed to hydrogen at relatively low pressures (42). The accelerated fatigue crack growth is more pronounced at ambient temperatures than at elevated temperatures. The study showed that fatigue thresholds were also reduced.

In terms of pipe line integrity in the presence of defects, the stress generated at a defect and the rate at which a defect can propagate are primary concerns. Sharp, crack-like defects can result in significant stress intensification factors and, under typical pipe line loads, hydrogen can accelerate growth rates. In general, crack and crack-like defects are considered to be more detrimental than corrosion defects when hydrogen is introduced.

For other metallic pipes, including ductile iron, cast iron and copper, it was not thought that hydrogen damage was a factor under the general operating condition of the natural gas distribution system. Furthermore, no major concern was thought to exist regarding the hydrogen-induced aging of polyethylene or polyvinylchloride (PVC). Little information on the degradation of polyethylene in hydrogen has been reported. There is little to suggest that an interaction between hydrogen and PE should be expected; hydrogen does not provide radicals that can cause polymer breakdown. In addition, it was considered that most of the elastomeric materials used in distribution systems were also compatible with hydrogen.
3.2.1 Summary

There is a long history of the transportation of hydrogen at pressures below 20 barg across the world with few operational issues occurring over many decades. Historically in the UK, town gas containing significant proportions of hydrogen has also been successfully transmitted through the distribution network.

Little evidence has been published to suggest that materials used for the low pressure distribution system will undergo degradation due to the injection of hydrogen into the natural gas network.

Current integrity programmes may need to be reviewed when hydrogen is added to the natural gas network. For example, inspection intervals may need to be considered.

3.3 CHEMICAL CONSIDERATIONS

This part of the review explores the potential consequences of introducing hydrogen gas into the natural gas (methane) network with respect to odorants.

3.3.1 Possible Issues related to Odorants;

The introduction of hydrogen may reduce the efficacy of odorants present in the gas stream. This could be envisaged as arising via:

I. Introduction of a large volume of non-odorised hydrogen gas into the gas stream.

II. Adverse reaction of hydrogen with odorants added to the gas stream.

3.3.2 Odorisation of Gas

In the UK, methane is currently odorised by addition of a mixture of tertiary-butylmercaptan, a sulphur containing molecule with a strong repulsive odour, and diethyl sulphide (45). A basic safety requirement in all countries, odorant is added in sufficient quantities so that, at a concentration in air of 20% of the lower explosive limit, the gas is readily detectable by a person with a normal sense of smell. This limit is set out in several international standards, including US 49CFR192.625 “Odorization of Gas” (46). When discussing odorisation, the UK Gas Safety Management Regulations (GSMR) (5) state that “the gas shall have been treated with a suitable stenching agent to ensure that it has a distinctive and characteristic odour, which shall remain distinctive and characteristic when the gas is mixed with gas which has not been so treated, except that this paragraph shall not apply where the gas is at a pressure of
above 7 barg”\). US Standard 49CFR192.625 (47) also describes specific scenarios where combustible gases are exempt from containing odorant, these include:

1. *Where the line transports gas to any of the following facilities which previously received gas without an odorant from that line (before May 5, 1975)*:
   
   I. An underground storage field;
   II. A gas processing plant;
   III. A gas dehydration plant; or
   IV. An industrial plant using gas in a process where the presence of an odorant:
      a. Makes the end product unfit for the purpose for which it is intended;
      b. Reduces the activity of a catalyst; or
      c. Reduces the percentage completion of a chemical reaction.

2. *The combustible gas is hydrogen intended for use as a feedstock in a manufacturing process.*

The fact that hydrogen is often used in processes in which the presence of sulphur-containing compounds would adversely affect a chemical process or catalyst means that hydrogen gas is not routinely odourised. This is due to the fact that the vast majority of odorants contain sulphur. However, acrylate odorants are seeing increased usage, particularly in Germany.

In considering injection of hydrogen into the gas network, the point of introduction of odorant is of key importance. We can assume one of two scenarios described below and summarised in Figures 1 and 2.

![Diagram](image.png)

**Figure 1** Addition of odorant to hydrogen component prior to mixing with pre-odorised natural gas (below 7 barg)
If the hydrogen / methane mixture is going to be burnt as “natural gas” then the presence of odorant does not pose a problem. However, if the gas mixture is to be used in sulphur-sensitive applications or hydrogen will be re-extracted from the pipeline to use in hydrogen-specific applications, sulphur containing odorants will need to be removed prior to use. Examples of sulphur-sensitive applications are processes involving precious metal catalysts and battery fuel cells (48).

3.3.3 Chemical Incompatibility of Hydrogen with Natural Gas Odorants

There are no chemical incompatibility issues of note between hydrogen and the odorising compounds commonly used in natural gas. It can therefore be predicted that hydrogen will behave in an entirely analogous manner to methane with respect to (lack of) interaction with odorants.

3.3.4 Odour Fade

Odour fade or odour loss is a well-known issue where odorising compounds are either adsorbed onto the metal (or plastic) surfaces of pipelines or absorbed via dissolution in liquids (moisture, cutting oil, pipe thread compound) (49) (50) (51). Odour fade is also known to occur in oxidative environments (presence of rust or mill scale) and is more prevalent at higher pressures and low flow situations. It is anticipated that odour fade in hydrogen / natural gas mixtures will be analogous to natural gas only systems.
Odour fade occurs predominantly in new pipelines that have been recently manufactured or not previously used for odorized natural gas. Odour fade can be controlled / limited by passivation or ‘pickling’ of pipeline materials. This process consists of saturating gas lines with odorant by introducing slugs of pure liquid odorant and / or over-odorising the gas entering the line. The process aims to saturate the pipeline material (metal or plastic) prior to its usage with gas containing standard levels of odorant.

3.3.5 Odorant Choice

The most widely used odorants contain sulphur, both mercaptans: tert-butylmercaptan (TBM, 1); iso-propylmercaptan (IPM, 2); n-propylmercaptan (NPM, 3); and sulphides: tetrahydrothiophene (THT, 4); dimethylsulphide (DMS, 5); methylethylsulphide (MES, 6) as shown in Figure 3.

![Figure 3: Sulphur containing odorants](image)

3.3.6 Non-Sulphur Containing Odorants

There are a few acrylate based odorants which are seeing increased use, particularly in Germany (trade name GASODOR-S-FREE (52)). These odorants contain a mixture of methylacrylate (MA, 7) and ethylacrylate (EA, 8) shown in Figure 4 and are reported to have excellent compatibility with pipeline materials and accordingly, much less susceptible to odour loss.
As the smell of acrylates is very different from sulphur containing compounds, a degree of public education is required alongside the introduction of these new odorants to ensure that gas leaks are identified.

3.3.7 Summary

Odorisation of hydrogen gas used in industry is not routine as the vast majority of available odorants contain sulphur that would contaminate chemical processes. However, acrylate odorants are seeing increased usage to avoid such contamination.

There are no chemical incompatibility issues of note between hydrogen and the odorising compounds commonly used in natural gas. Hydrogen will therefore have no deleterious interaction with odorants.

Initial odour fade / loss can be controlled / limited by passivation or ‘pickling’ of pipeline materials.

The injection point of the odorant is important if the hydrogen / methane mixture is going to be used in sulphur-sensitive applications or to re-extract hydrogen from the pipeline to use in hydrogen-specific applications. In this case, sulphur containing odorants will need removing prior to use; or acrylate odorants used.

3.4 EFFECT OF HYDROGEN ADDITION TO NATURAL GAS

Natural gas contains no hydrogen, unlike its predecessor in the UK, town gas, that could contain amounts up to 65% (53).
The addition of hydrogen to natural gas (at least up to ~90% vol.) will cause the WN and hence appliance heat inputs to decrease, given by:

\[ WN_{NG/H2} < WN_{NG} \]

**Equation 8**

The maximum allowable hydrogen concentration in the distributed gas, expressed by the WN of the resultant gas mixture, is given by:

\[ WN_{\text{EN437 group}}^{\min} < WN_{\text{distribution}}^{\min} \leq WN_{NG/H2} \]

**Equation 9**

where;

- \( WN_{\text{EN437 group}}^{\min} \) is the minimum allowable WN according to BS EN 437:2003.
- \( WN_{\text{distribution}}^{\min} \) is the minimum allowable distribution WN in the UK according to the Gas Safety (Management) Regulations:1996.
- \( WN_{NG/H2} \) is the WN of the natural gas/hydrogen mixture.

The maximum concentration limit for hydrogen injection \((H_2)_{\text{max}}\) is therefore reached when the WN of the mixture, \( WN_{NG/H2} \), equals the minimum distribution WN:

\[ WN_{NG/H2} = WN_{\text{distribution}}^{\min} \]

**Equation 10**

European Standard EN437 defines gas families and gas groups, classified according to their WN. Natural gases comprise the 2nd family, with groups H, L and E having the WN ranges shown in Table 1.

For each gas group a reference gas WN is defined as well as a series of “limit gases” (for example, gas family H test gases are shown in Table 4).

These limit gases are necessary to ensure safe appliance operation, as it is insufficient to establish the safe use of a gas by an appliance by a single WN. As may be seen from
Table 4, gas second family H group limit gases have been defined to cover incomplete combustion and sooting, light back, flame lift and burner overheating. Tests for specific appliance types using the test gases (which may include burner overheating tests) are described in the specific Harmonised Standard for the appliance.

Therefore, the limit gases specify the absolute upper and lower WN limits for safe operation of appliances designed and manufactured for the specific gas family and group. The distribution WN’s lie within the range described by the upper and lower WN limits of the limit gases.

The various WN’s described above are summarised in Table 4.

As referred to earlier, the addition of hydrogen to natural gas causes its WN (and therefore appliance heat input) to decrease. Figure 5 illustrates the effects on the WN of adding differing amounts of hydrogen to a Group H gas and a Group L gas (in this case, Groningen gas [shown as G-gas in Figure 5]) (54).

As may be seen from Figure 5, the addition of hydrogen up to approximately 70-80% vol. to natural gas causes the WN to decrease. It is important to ensure that any such
addition does not cause the mixture WN to fall below the minimum values shown in Table 4.

Table 4 Locality UK, 2nd family, Group H. Summary of WN’s

<table>
<thead>
<tr>
<th>WN minimum (MJ-m⁻³)</th>
<th>WN maximum (MJ-m⁻³)</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.2</td>
<td>51.41</td>
<td>Normal conditions¹</td>
</tr>
<tr>
<td>46.5</td>
<td>52.85</td>
<td>Supply emergency²</td>
</tr>
<tr>
<td>45.7</td>
<td>54.7</td>
<td>Group H definition³</td>
</tr>
<tr>
<td>45.66</td>
<td>54.76</td>
<td>Limit gases³</td>
</tr>
<tr>
<td></td>
<td>50.72</td>
<td>Reference gas³</td>
</tr>
</tbody>
</table>

¹, ² A guide to the Gas Safety (Management) Regulations 1996.

3.5 ASSESSMENT OF THE SIZE AND COMPOSITION OF THE UK GAS APPLIANCE (DOMESTIC AND COMMERCIAL) POPULATION

To gain an overall impression of the likely size and make-up of the UK gas appliance population, a comprehensive survey was carried out in 2005 for the Department of Trade and Industry (55). The driving force behind the survey at the time was the realisation that future supplies of raw natural gas from sources such as Russia and LNG imports (56) from the Middle East (with a high WN), that would be needed to top up the existing dwindling gas supplies, would increase the distributed gas WN. Unless the gas is treated, this implies a potential for a deterioration of the combustion characteristics of some UK domestic and industrial appliances.

The data is useful in this particular study in that it categorises the various appliances used in the UK; they are considered in section 3.6.

The data for domestic appliances, shown in Table 5 and projected to 2020, was compiled in a number of ways, from surveys of CORGI registered businesses, through use of existing databases, to information gathered from manufacturers and local authorities. The survey also helpfully determined the total number of appliances that could be affected by the injection of hydrogen into the natural gas distribution system.

The report distinguishes between pre and post GAD (Gas Appliance Directive) (57), implemented in the UK by The Gas Appliances (Safety) Regulations 1995 (5). This is a
key point, as products manufactured after the CE marking required by the regulations are easier to identify. Such products are required to carry an identification (rating) plate that declares (along with other items) the year of manufacture and also the test conditions applied.

3.6 DOMESTIC GAS APPLIANCES

This section considers the potential effects of mixing hydrogen with the natural gas supply on domestic gas appliances. Each type of appliance is described and the hazards associated with using a natural gas / hydrogen mixture is examined.

3.6.1 Domestic Boilers

3.6.1.1 Open flue, standard atmospheric pre-mix burner

This burner type is predominately fitted to pre-GAD boilers and, as its name implies, operates with a constant gas pressure (which may be adjustable) and flow, drawing

Table 5 Number of UK Domestic Appliances by Type

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL Domestic Boilers</td>
<td>20365</td>
<td>20890</td>
<td>21200</td>
<td>21142</td>
</tr>
<tr>
<td>TOTAL Pre-GAD Domestic Boilers</td>
<td>6907</td>
<td>3643</td>
<td>1804</td>
<td>802</td>
</tr>
<tr>
<td>TOTAL Domestic fires</td>
<td>11744</td>
<td>10917</td>
<td>10435</td>
<td>10420</td>
</tr>
<tr>
<td>TOTAL Pre-GAD Domestic fires</td>
<td>4719</td>
<td>2159</td>
<td>730</td>
<td>118</td>
</tr>
<tr>
<td>TOTAL Water Heaters</td>
<td>1259</td>
<td>879</td>
<td>754</td>
<td>1023</td>
</tr>
<tr>
<td>TOTAL Pre-GAD Water Heaters</td>
<td>594</td>
<td>269</td>
<td>72</td>
<td>23</td>
</tr>
<tr>
<td>TOTAL Cookers</td>
<td>12565</td>
<td>12649</td>
<td>12699</td>
<td>12728</td>
</tr>
<tr>
<td>TOTAL Pre-GAD Cookers</td>
<td>3687</td>
<td>1479</td>
<td>510</td>
<td>82</td>
</tr>
<tr>
<td>TOTAL Warm air units</td>
<td>398</td>
<td>300</td>
<td>242</td>
<td>196</td>
</tr>
<tr>
<td>TOTAL Pre-GAD Warm Air Units</td>
<td>299</td>
<td>135</td>
<td>49</td>
<td>6</td>
</tr>
<tr>
<td>TOTAL Tumble dryers</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
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<tr>
<td>TOTAL Pre-GAD Tumble Dryers</td>
<td>15</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL APPLIANCES</td>
<td>46389</td>
<td>45693</td>
<td>45388</td>
<td>45567</td>
</tr>
<tr>
<td>TOTAL Pre-GAD</td>
<td>16221</td>
<td>7694</td>
<td>3165</td>
<td>1031</td>
</tr>
<tr>
<td>% Pre-GAD</td>
<td>35%</td>
<td>17%</td>
<td>7%</td>
<td>2%</td>
</tr>
</tbody>
</table>

atmospheric air as necessary for combustion. These burners operate with both conventional and balanced flues. They are a basic type of burner. This type of burner is sensitive to addition of hydrogen to natural gas due to a combination of two factors;
the primary air excess and the initial WN (58). Atmospheric burners used with low Wobbe gas (not at present imported into the UK) are more sensitive to the addition of hydrogen if they have been set-up with test gas G20 (pure methane). Post-GAD appliances designed for use in the UK are tested with the test gases specified in EN 437:3003 (7) shown in Table 2. Note that the light back limit gas (G222) consists of 23% hydrogen (also note the reduced WN). This implies that appliances tested with this gas are capable of operating safely (at least in the short term\(^1\)) with a hydrogen content of \(\leq 20\%\).

Laboratory tests carried out in Denmark as part of NaturalHy’s Work Package 5 on two different types of domestic boiler (standard atmospheric pre-mix burner and balanced flue, fan assisted premix burner) showed that up to 50% volume hydrogen could be added to the natural gas without short or long term problems (59). Above 50% volume hydrogen addition produced overheating of the burner head surface temperature as the flame speed increased and burned back. The conclusion from this work was that residential boilers would be very unlikely to preclude the addition of hydrogen to the natural gas supply.

### 3.6.1.2 Balanced flue, fan assisted premix burner, gas-air ratio valve

This class of boiler is defined here to include pre-mixed fan assisted burners burning in a combustion chamber and heat exchanger, commonly associated with condensing boilers. These boilers were introduced to increase the efficiency of domestic boilers which had, hitherto, been largely constructed with a traditional, natural draught, regular cast iron heat exchanger (see 3.6.1.1). Although these had an almost infinite life provided that the central heating water circuit side had been dosed with an anti-corrosion additive, they only provided efficiencies up to \(\sim 70\%\). The UK government realised the importance of boiler efficiency in the late 1990s, introducing the SEDBUK database (60). This has been a major factor in improving the efficiency of boilers sold in the UK in recent years. From April 2005, all new boilers were required to be condensing unless installers completed a detailed exception report (55).

A gas-air ratio valve controls the fuel-air mix presented to the pre-mix burner. Electronics constantly monitor the heat load required and adjust the gas-air ratio to provide the optimum combustion conditions. These high efficiency appliances are less tolerant to variations in WN, without adjustment (61) (which, in the UK, would need to be made by a Gas Safe Registered engineer).

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\(^1\) Possible limitations to this are; long term impacts which are not known, including the effect of burner heating due to higher flame speeds.
3.6.2 Domestic hobs and ovens

Hobs and ovens use normally aspirated burners with circular hob burners and linear oven burners.

The addition of hydrogen to natural gas would increase the flame speed, causing the flame to burn closer to the gas ring or oven burner.

![Figure 6 Gas ring fuelled by hydrogen enriched natural gas (62), hydrogen content of gas increasing from left to right](image)

In a four year hydrogen injection in natural gas (L gas group) mains study involving domestic gas appliances carried out on Ameland Island in the Netherlands (62), it was found that gas rings behaved as expected, and the flame was maintained up to 20% hydrogen injection. Figure 6, taken from the report, illustrates (from left to right) the increasing flame speed as the hydrogen content increases. Although the effect is subtle, by comparing the upper right to the upper left image (where the effect is more pronounced), the flames tend to shorten and burn more horizontally as the hydrogen content is increased.

3.6.3 Domestic fires

Domestic fires generally use an atmospheric type of burner with the flames impinging on ceramic plaques, bringing them up to red heat which then radiates into the heated space. In addition, convection heating into the heated space is provided by the use of a
heat exchanger above the plaques, removing the heat from the flue gases as they pass safely through to the flue. Conventional flues as well as balanced flues are utilised.

A variant of the gas fire is the decorative flame effect fire. This employs fuel rich, yellow flame, burners to provide a natural looking flame effect together with normally aspirated flames heating ceramic ‘coals’.

The addition of hydrogen to natural gas would increase the flame speed, reducing the yellow ‘flame’ effect.

With a reduction in WN, the heat input would be slightly reduced.

3.6.4 Domestic water heaters
Domestic water heaters predominately use normally aspirated burners with the flames impinging on the low water content heat exchanger through which the water flows on demand.

The addition of hydrogen to natural gas would increase the flame speed, causing the flame to burn closer to the gas burner. This has the potential to cause overheating and possible corrosion of the burner material.

With a reduction in WN, the heat input would be slightly reduced.

3.6.5 Domestic warm air units
Though not as prevalent as ‘wet’ central heating systems, these blown hot air systems utilise a premixed gas burner in a combustion chamber and heat exchanger, over which a circulating fan blows air to be heated and then ducted around the property. The returning cool air is ducted back into the circulating fan.

The effect of hydrogen addition to the gas will be the same as for a similar ‘wet’ boiler (section 3.6.1.1).

3.6.6 Domestic tumble dryers
Domestic gas fired tumble dryers are the exception rather than rule in the UK household (Table 5 – 58000 units and not projected to increase). Although more efficient than their electrical cousin they require a gas supply and flue. They also require fitting by a Gas Safe Registered engineer.

The operation principle is the same as the domestic warm air units and the effect of hydrogen enrichment would therefore be the same.
3.7 **ASSESSMENT OF THE SIZE AND COMPOSITION OF THE UK GAS APPLIANCE POPULATION – COMMERCIAL APPLIANCES**

As an integral element of the 2005 survey referred to in section 3.5 above, the population of commercial gas appliances was also determined. Table 6 shows the results of the survey (55) with projected appliance numbers up to 2020.

Table 6  Number of UK Commercial Appliances by Type

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YEAR (2010 and onwards projected)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Commercial Boilers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL Natural draft &lt;20kW</td>
<td>653</td>
<td>533</td>
<td>434</td>
<td>354</td>
</tr>
<tr>
<td>TOTAL Natural draft 20-100kW</td>
<td>333</td>
<td>272</td>
<td>222</td>
<td>180</td>
</tr>
<tr>
<td>TOTAL Natural draft &gt;100kW</td>
<td>62</td>
<td>51</td>
<td>41</td>
<td>34</td>
</tr>
<tr>
<td>Total natural draft boilers &gt;20kW</td>
<td>395</td>
<td>323</td>
<td>263</td>
<td>214</td>
</tr>
<tr>
<td>TOTAL Fan forced &lt;20kW</td>
<td>131</td>
<td>251</td>
<td>350</td>
<td>430</td>
</tr>
<tr>
<td>TOTAL Fan forced 20-100kW</td>
<td>127</td>
<td>188</td>
<td>238</td>
<td>279</td>
</tr>
<tr>
<td>TOTAL Fan forced &gt;100kW</td>
<td>75</td>
<td>87</td>
<td>96</td>
<td>104</td>
</tr>
<tr>
<td>Total fan forced boilers &gt;20kW</td>
<td>202</td>
<td>275</td>
<td>334</td>
<td>383</td>
</tr>
<tr>
<td><strong>Commercial Catering</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL Domestic Cookers [in a commercial environment]</td>
<td>121</td>
<td>121</td>
<td>121</td>
<td>121</td>
</tr>
<tr>
<td>TOTAL Domestic Cookers [in a commercial environment] Pre-GAD</td>
<td>40</td>
<td>24</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL “Commercial” equipment</td>
<td>1216</td>
<td>1216</td>
<td>1216</td>
<td>1216</td>
</tr>
<tr>
<td>Total Pre-GAD cooking appliances</td>
<td>40</td>
<td>24</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Total cooking appliances</td>
<td>1297</td>
<td>1313</td>
<td>1327</td>
<td>1334</td>
</tr>
<tr>
<td><strong>Commercial Misc</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL Cabinet heaters</td>
<td>61</td>
<td>58</td>
<td>58</td>
<td>59</td>
</tr>
<tr>
<td>TOTAL Cabinet heaters (Usually floor) Pre GAD</td>
<td>15</td>
<td>9</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL Unit heaters</td>
<td>149</td>
<td>148</td>
<td>151</td>
<td>157</td>
</tr>
<tr>
<td>TOTAL Unit heaters (Usually roof) Pre GAD</td>
<td>25</td>
<td>15</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL Black radiant tubes</td>
<td>275</td>
<td>273</td>
<td>248</td>
<td>200</td>
</tr>
<tr>
<td>TOTAL Plaque heaters</td>
<td>125</td>
<td>110</td>
<td>92</td>
<td>69</td>
</tr>
<tr>
<td>Total commercial misc Pre-GAD</td>
<td>40</td>
<td>24</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Total commercial misc</td>
<td>610</td>
<td>589</td>
<td>549</td>
<td>485</td>
</tr>
<tr>
<td><strong>TOTAL APPLIANCES</strong></td>
<td>2504</td>
<td>2500</td>
<td>2473</td>
<td>2416</td>
</tr>
<tr>
<td><strong>TOTAL PRE-GAD</strong></td>
<td>80</td>
<td>48</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td><strong>% Pre-GAD</strong></td>
<td>3.2%</td>
<td>1.9%</td>
<td>1.0%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>
3.7.1 Commercial gas appliances

This section considers the effect of mixing hydrogen with the natural gas supply on commercial gas appliances. Each type of appliance is considered in detail.

3.7.1.1 Commercial gas boilers – natural draught

In common with its domestic relation, some commercial natural draught boilers employ an atmospheric natural draught burner to heat the water circulating through the heat exchanger. This type of burner is being phased out on efficiency grounds, but due to its longevity, many remain in service (as shown in Table 6). Adding hydrogen to the supplied natural gas will have the same effect as for domestic boilers of this type. Problems associated with flame burn back and potential overheating of the burner may arise with higher additions of hydrogen. Options for adjustment here are limited to jet pressure adjustment, with the knock-on effect of down rating the appliance.

3.7.1.2 Commercial gas boilers – fully pre-mixed

Again, in common with its domestic relation, increasing numbers of new, or replacement, commercial fully pre-mixed boilers employ a fully pre-mixed burner to heat the water circulating through the heat exchanger that usually surrounds the burner forming a combustion chamber. This arrangement increases the efficiency, especially when combined with condensing technology. A gas-air ratio valve finely controls and continuously alters the combustible mixture of gas and air according to inputs from flame sensors, oxygen sensors or flow meters, to provide the exact conditions for efficient burning.

This type of boiler should be capable of being adjusted to accommodate any reasonable change in the range of WN to avoid the flames retreating to the burner and overheating it.

3.7.1.3 Commercial gas boilers – fan forced draught

Fan forced draft boilers are almost exclusively found in the commercial sector, although some large domestic boilers also employ this principle of operation. The boiler injects a stream of gas into the blast of air coming from the fan blower (63). This device is generally referred to as a ‘package burner’ as it can be ‘bolted on’ to a variety of heat exchangers. The mixing takes place where the air and gas streams meet – there is usually a plate or perforated burner head to aid mixing and to stabilise the flame entering the combustion and heat exchanger chamber.
This type of boiler should be adjustable to accommodate any reasonable change in the range of WN to avoid flame burn-back by altering the gas rate or aeration requirements.

3.7.1.4 Commercial cookers

These use normally aspirated burners with circular hob burners and linear oven burners.

The addition of hydrogen to natural gas would increase the flame speed, causing the flame to burn closer to the gas ring or oven burner.

3.7.1.5 Cabinet heaters

Floor mounted cabinet heaters are generally fired using a fan forced draught package burner and should be able to be adjusted to a different gas quality fairly easily (55).

3.7.1.6 Unit heaters

These are similar to cabinet heaters and may be floor or roof-mounted. They use a naturally aspirated or a package burner to circulate hot air to the heated space via a heat exchanger. They are usually open flued, although there is a trend towards room sealed appliances. Again, they should be readily adaptable to a different gas quality (55).

3.7.1.7 Black radiant tubes

Commonly associated with factory situations, these high level mounted heaters provided instant localised heat in working areas (e.g. machine shops) and employ a mechanically aspirated burner. As such, they should be adjustable for a different gas specification, although the industry has some concerns in this area (55). Due to efficiency savings demanded of the sector, these heaters are deprecated.

3.7.1.8 Plaque heaters

Radiant plaque heaters are generally flue less and are installed above head height to provide localised heating. Being naturally aspirated, these units are susceptible to changes in WN although they are generally installed with a dedicated gas governor that would allow some adjustment (55).
3.7.1.9  Gas turbines

A combustion system particularly sensitive to variations in gas composition is the lean premixed gas turbine. Gas is mixed with high pressure and temperature air and the resultant expanding flames impinge on the turbine blades. Unwanted spontaneous ignition before reaching the burner and flashback of the flame into the burner can both have potentially disastrous effects on the integrity of the machine. At the other extreme, flame blowout is equally unwanted, and even partial flame lift can result in undesirable acoustic instability. A particular concern regarding ignition is the presence of hydrogen; since this gas ignites easily, there is concern that even small quantities of hydrogen in natural gas would be catastrophic for turbine behaviour. To illustrate this apprehension one major turbine manufacturer allows only traces of hydrogen in the fuel gas, while another manufacturer allows only 8.5% of hydrogen (64).

3.8  FLAME DETECTION/SUPERVISION DEVICES

All gas appliances employ some form of flame detection and / or supervision device. As far as these devices are concerned domestic appliances fall into two groups. The first group includes the ‘simpler’ gas fires, hobs and ovens which, as a minimum (Post GAD), employ a flame failure device and/or an oxygen depletion device to monitor the flame health.

The second domestic group are predominately boilers. This group employs more sophisticated flame management techniques, akin to those found in the commercial boiler sector.

Similarly, as far as gas safety controls are concerned, commercial gas appliances fall into two basic groups. Commercial boilers, however, use more sophisticated gas safety controls, commensurate with the complexity of their construction and operation.

Here we consider the effect of mixing hydrogen with the natural gas supply on gas safety controls. Each type of control/sensor is considered in detail. As there is some overlap between the domestic and commercial application of these controls they are considered here as one group, without distinction.
3.8.1 Infra-red

Infrared will penetrate smoke or dust. Addition of hydrogen to the natural gas supply will not adversely affect this device’s sensitivity or capability to detect flame.

3.8.2 Ultraviolet (UV)

Short wave UV will not penetrate smoke or dust. UV detection is effective with almost any clean fire. Any burner flame that will characteristically cause smoke or fuel particles to be present between the flame and the sensor makes satisfactory UV detection problematical. Addition of hydrogen to the natural gas supply will not adversely affect this device’s sensitivity or capability to detect flame.

3.8.3 Visible light

Visible light detection of flames depends on the light sensor and control circuitry recognising the ‘flame flicker’ produced by the flame. The ‘flicker’ effect distinguishes the flame from any background visible light, such as that produced from glowing embers or heated furnace parts that constantly radiate (65). As gas flames do not have strong radiation in the visible wavelengths (whereas oil and coal flames do), this type of sensor has limited application in gas safety controls. As (pure) hydrogen burns with a clean, clear flame its addition to natural gas would only make visual detection more difficult.

3.8.4 Ionisation/rectification

As molecules in and around the flame envelope collide with each other, the collision force liberates some of the outer electrons from the atoms that form the products of combustion molecules. These free electrons and associated positive ions can allow a small current to be conducted through the flame. This phenomenon is used to detect flame by applying a voltage across two electrodes placed in the flame. The current passed is rectified by the flame; the control circuitry monitors the rectified current.

A stable flame is required, as movement of the flame away from the electrodes would prevent the conduction process and would be detected as flame failure. Thus, addition of hydrogen to the natural gas supply could adversely affect this device’s sensitivity or capability to detect flame by altering the flame trajectory.
3.8.5 Thermoelectric valve (Thermocouple)

Thermocouples are usually used to monitor pilot lights on gas appliances. The bi-metallic probe is positioned so that its tip is immersed in the pilot flame. When metals are heated they produce a voltage (Seebeck effect). Joining two carefully selected metals at the probe tip generates a greater voltage (than one metal) that can be used to hold open a spring loaded electromagnetic gas valve. Flame failure prevents voltage generation, allowing the valve to close, shutting off the gas supply to the burner.

A stable flame is required, as movement of the flame away from the probe tip would prevent the voltage generation process and be detected as flame failure, closing the attached electromagnetic gas valve. Thus, addition of hydrogen to the natural gas supply could adversely affect this device’s sensitivity or capability to detect flame by altering the flame trajectory.

3.8.6 Interrupted thermoelectric valve (interrupter)

This operates in the same fashion as the thermocouple but with the addition of an electrical switch (such as an over-heat thermostat) between the thermocouple tip and the attached electromagnetic gas valve. This allows an electrical safety interlock to be placed in series with the thermocouple.

Again, addition of hydrogen to the natural gas supply could adversely affect this device’s sensitivity or capability to detect flame by altering the flame trajectory.

3.8.7 Vitiation sensing device (atmosphere sensing device, ASD)

Vitiation in gas terminology refers to the contamination of the fresh primary air needed to mix with the gas for correct combustion. This contamination usually comprises combustion products that are drawn into the appliance should the flue become compromised and they are not released safely into the atmosphere.

In use, primary air to supply the pilot flame is initially drawn in through an aeration port. This allows a stable pilot flame to be precisely directed onto the sensing device’s thermocouple tip, characterised by a blue flame. If the air required for combustion becomes contaminated (i.e. the atmosphere lacks oxygen) the flame will burn with a yellow flame (incomplete combustion) and move away from the thermocouple tip as the combustion characteristics alter. The tip will cool and will no longer provide enough voltage to hold the gas valve open, shutting down the appliance.
Addition of hydrogen to the natural gas supply could adversely affect this device’s sensitivity or capability to detect oxygen deficiency (vitiation) by altering the flame’s combustion characteristics.

### 3.8.8 Liquid expansion valve

This control device is used to monitor the circulating water temperature in boilers, shutting off the boiler burner’s gas supply when the set temperature is reached. It is used together with other control devices to manage the boiler heat output.

A phial connected via a length of capillary tubing to bellows in the gas valve shuts off the gas supply at a pre-set temperature when the liquid contained within the phial, tubing and bellows expands on heating.

This device will be unaffected by the addition of hydrogen to the gas network.

### 3.8.9 Electrical thermostat

A variation of the liquid expansion valve, the expanding liquid in the phial instead operates an electrical switch that in turn is usually used to operate a solenoid operated gas valve.

This device will be unaffected by the addition of hydrogen to the gas network.
4 CONCLUSIONS

4.1 FIRE AND EXPLOSION

Although there are some knowledge gaps relating to the fire and explosion hazards of methane / hydrogen mixtures, the indications are that the differences in the behaviour of methane mixed with up to 20% hydrogen and that of pure methane are small and unlikely to present a significantly greater hazard in practical situations.

4.2 MATERIALS AND STRUCTURAL INTEGRITY ISSUES

There is a long history of the transportation of hydrogen at pressures below 20 barg across the world with few operational issues occurring over many decades. Historically in the UK, town gas containing significant proportions of hydrogen was successfully transmitted through the gas distribution network.

Little evidence has been published to suggest that materials used for the low pressure distribution system will undergo degradation due to the injection of hydrogen into the natural gas network.

Current infrastructure integrity programmes may need to be reviewed, however, when hydrogen is added to the natural gas network. For example, inspection intervals may need to be considered.

4.3 CHEMICAL CONSIDERATIONS

Odorisation of hydrogen gas used in industry is not routine as the vast majority of available odorants contain sulphur that would contaminate chemical processes. However, acrylate odorants are seeing increased usage to avoid such contamination.

There are no chemical incompatibility issues of note between hydrogen and the odorising compounds commonly used in natural gas. Hydrogen will therefore have no deleterious interaction with odorants.

Initial odour fade / loss can be controlled / limited by passivation or ‘pickling’ of pipeline materials.

The injection point of the odorant is important if the hydrogen / methane mixture is going to be used in sulphur-sensitive applications or to re-extract hydrogen from the pipeline to use in hydrogen specific applications. In this case, sulphur-containing odorants will need removing prior to use; or acrylate odorants used.
4.4 DOMESTIC AND COMMERCIAL APPLIANCES

The addition of hydrogen into the UK natural gas network would have potential effects on all appliances connected to it. The range and type of appliances are huge, as are their propensity to be affected in different ways by the addition of hydrogen into the gas stream.

Safe use of gas appliances depends on the WN of the gas supplied matching the calibration of the gas appliance burner(s). Dealing with any potential difference in gas quality standard caused by hydrogen injection leads to two possible choices:

- Sufficient flexibility is available at the appliance burner for correct combustion; this will allow gas specifications to be widened, or
- Flexibility at the appliance burner is limited; hence, gas specifications must be narrowed.

It would appear from the literature that modern (CE marked) naturally aerated appliances would be able to burn hydrogen-enriched natural gas available in the UK (H group gas) safely at up to 20% v/v without modification.

Addition of hydrogen to a high WN gas appears to have less effect on the flame picture\(^2\) than the same addition to a low WN gas.

Other appliances, with tighter tolerances, may be able to safely operate with some minor adjustments of gas and/or aeration rates. There will remain a few appliances from the UK town gas conversion to natural gas programme (pre-GAD) that will not be able to operate safely on a hydrogen enriched natural gas supply. These appliances will require identifying and then either be converted or withdrawn from service (which, in the UK, would need to be carried out by a Gas Safe Registered engineer).

Gas turbines are particularly intolerant to the addition of hydrogen and sensitive to the hydrogen level, with one major manufacturer reported setting an upper limit of 8.5% volume hydrogen, with another allowing only a trace in the fuel supply.

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\(^2\) Flame picture – the appearance of the appliance flame. By observing the flame picture, a trained gas engineer can swiftly determine (in the first instance) if the combustion is efficient and safe. Generally, if a natural gas flame is a blue colour and not lifting from the burner, then there is good combustion. If the flame picture shows a lazy, yellow, flame then this indicates poor combustion (as there is not enough oxygen to allow complete combustion) with the likelihood of carbon monoxide (CO) production. The use of a combustion analyser to determine actual CO levels is required by UK law.
4.5 HAZARD AND RISK SUMMARY TABLE

The known hazards and risks accompanying the addition of hydrogen to natural gas are presented in Table 7, together with the current knowledge levels and associated risk controls.

Table 7 Summary of associated hazards and risks of adding hydrogen to natural gas supplies

<table>
<thead>
<tr>
<th>Issue</th>
<th>Hazard</th>
<th>Risk (after controls applied)</th>
<th>Knowledge level</th>
<th>Risk controls</th>
<th>Report section cross reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas Networks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas interchangeability</td>
<td>Low</td>
<td>Low</td>
<td>Full industry understanding of WN implications</td>
<td>Regular quality testing of supplied gas</td>
<td>2</td>
</tr>
<tr>
<td>Natural gas / hydrogen mixture (up to 20% v/v) release - fire and explosion hazards</td>
<td>Medium</td>
<td>Low</td>
<td>Good understanding of effect of hydrogen addition</td>
<td>Gas network well maintained</td>
<td>3.1</td>
</tr>
<tr>
<td>Upper limit of hydrogen addition (% vol)</td>
<td>Medium</td>
<td>Low</td>
<td>Full scale tests on domestic gas appliances show no apparent problems with addition of ( H_2 \leq 20% ) vol.</td>
<td>Gas appliances well maintained and adjusted</td>
<td>3.6</td>
</tr>
<tr>
<td>Transportation of hydrogen affecting infrastructure materials</td>
<td>Low</td>
<td>Low</td>
<td>Full industry understanding of hydrogen effects on materials, together with historical experience.</td>
<td>Inspection regimes</td>
<td>3.2</td>
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<tr>
<td><strong>Hydrogen transport / Fuel Cell Industry</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur containing odorants affecting processes or catalysts</td>
<td>Low - medium</td>
<td>Low – medium (fuel cells only)</td>
<td>Full industry understanding of effect on fuel cells</td>
<td>Unknown</td>
<td>3.3.2</td>
</tr>
</tbody>
</table>
5 REFERENCES


37. Florisson, O. *NaturalHy: Preparing for the hydrogen economy by using the existing natural gas system as a catalyst*. 2010.


Injecting hydrogen into the gas network – a literature search

Hydrogen injection into the GB gas network is a likely consequence of using excess offshore wind generated electricity to power large-scale onshore electrolysis plants. Government and DECC in particular now have a keen interest in supporting technologies that can take advantage of the continued use of the gas networks. HSE can contribute to the government’s Growth and Green agendas by effectively regulating and safely enabling this technology.

This report will allow HSE to regulate effectively by pulling together scientific and engineering knowledge regarding the hazards of conveying hydrogen/methane mixtures in network pipes and its use in consumer appliances, into a single ‘state-of-play’ report. It enables Energy Division to consider and assess submissions for ‘gas quality’ exemptions to the Gas Safety (Management) Regulations 1996 (GSMR). In particular, the report has examined the following hazards:

- conveyance of H2/CH4 mixtures in network pipes
- use of H2/CH4 mixtures in consumer appliances (domestic/commercial/industrial)
- explosion and damage characteristics (and ignition likelihood) of H2/CH4 mixtures
- effects on odourisation

It identifies that the flame profile in gas appliances will increasingly flatten as hydrogen content rises. For modern appliances fitted with flame failure devices this may cause the appliance to shut down (and default to a safe condition). For some older types of gas appliance (1970s and older) not fitted with flame failure devices there may be an increased risk of flame failure leading to internal gas escapes. At the concentrations of hydrogen in methane likely to be considered by the industry (between 0.5 and 10%) this effect is not significant. Where exemptions for higher concentrations are sought HSE will insist on the identification and modification of vulnerable appliances.

The report concludes that concentrations of hydrogen in methane of up to 20% by volume are unlikely to increase risk from within the gas network for from gas appliances to consumers or members of the public.

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