Opening up the Gas Market

Executive Summary
October 2016

SGN
Your gas. Our network.

How we keep the gas flowing

Glossary

Abbreviation	Term
ALARP	As Low As Reasonably practicable
ASD	Atmospheric Safety Device
BBU	Back Boiler Unit
BEIS	Department for Business Energy and Industrial Strategy
BERR	The Department for Business, Enterprise and Regulatory Reform
BIS	Department for Business Innovation and Skills
BS	British Standard
C_3H_8	Propane
CBA	Cost Benefit Analysis
CE	European Conformity
CEN	The European Committee of Standardisation
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COSHH	Control of Substances Hazardous to Health
CV	Calorific Value
DAF	Dry Air Free
DECC	Department of Energy and Climate Change
DNV GL	Technical advisor to the energy industry
EASEE	European Association for the Streamlining of Energy Exchange
EU	European Union
FWACV	Flow weighted Average Calorific Value
GAD	Gas Appliance Directive
GB	Great Britain
GDN	Gas Distribution Network
GEOTER	GAS (Calculation of Thermal Energy) Regulations

Abbreviation	Term
GS(M)R	Gas Safety (Management) Regulations
HHIC	Heating and Hot Water Industry Council
HSE	Health & Safety Executive
ICF	Incomplete Factor
IGEM	Institution of Gas Engineers and Managers
IGU	International Gas Union
KIWA	Kiwa Gastec
LCNI	Low Carbon Network and Innovation
LNG	Liquefied Natural Gas
MJ/m^3	Megajoule per Cubic Meter
N_2	Nitrogen
NEC	Network Emergency Co-ordinator
NBP	National Balancing Point (GB)
NIC	Network Innovation Competition
NOx	Oxides of Nitrogen
OGM	Opening up the Gas Market
PPM	Parts Per Million
PPR	Project Progress Report
QRA	Quantified Risk Assessment
RD	Relative Density
SDRC	Successful Delivery Reward Criteria
SI	Sooting Index
SIU	Scottish Independent Undertaking
SMSP	System Marginal Sell Price
UK	United Kingdom
VPF	Value of preventing a fatality
WI	Wobbe Index
WWU	Wales and the West Utilities
ZEE	Zeebrugge (Belgium)

Acknowledgements
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The project in numbers and pictures

20+

successful customer and stakeholder engagement campaigns completed

1,787

appliances inspected

1 year

network trial using gases with Wobbe Index outside the GB regulations

1,104
Oban customers

>90%
access rate

18
appliance laboratory tests

7
special appliance tests

47
appliances replaced due to pre-existing conditions

Key conclusions from the Opening up the Gas Market project

Using Oban as a statistical representation of GB, it is estimated that **2%** of the GB appliance population would be classified as **'immediately dangerous'** against the Unsafe Situations Procedure currently.

An upper WI limit of 53.25 MJ/m³ allows **sufficient headroom** for any deleterious unknowns in the field condition of the appliance.

Domestic and small commercial appliances correctly installed, serviced and operated can **safely burn gas** with WI of up to 54.76 MJ/m³.

The interchangeability diagram can be **simplified and updated** to reflect current requirements.

Both the **Sooting Index** and the **Incomplete Combustion Factor** as stated in GS(M)R are no longer valid.

The cost of maintaining the current GS(M)R limits is **grossly disproportionate** to the risk involved in widening the WI limits to 53.25 MJ/m³.

Currently only **10%** of the available LNG can be accepted into the GB gas network without processing. Increasing the WI range to 53.25 MJ/m³ would allow **>90%** of the globally available LNG to be injected into the GB gas network without processing.

No evidence of deterioration in appliance performance was found after one full year operation on gas outside of GS(M)R limits.

CO campaigns that focus **solely on CO alarms** are not the most effective means of reducing CO risk.

Appliance maintenance, servicing and replacement when required produces a **7-fold reduction** in the absolute risk.

There is a **significant incentive** to change the allowable gas quality in GB, specifically the WI, circa £325m per annum for avoided Nitrogen ballasting.

Increasing the WI to 53.25 MJ/m³ has **negligible impact** on the efficiency, performance and life of domestic or small commercial appliances.

Using Oban as a statistical representation of GB, it is estimated that **4%** of the GB appliance population would be classified as **'at risk'** against the Unsafe Situations Procedure currently.

The Oban Network **safely stored, injected, distributed and utilised** gas with WI ranging from 49 MJ/m³ to 53.2 MJ/m³ during the one-year trial period.

Executive summary

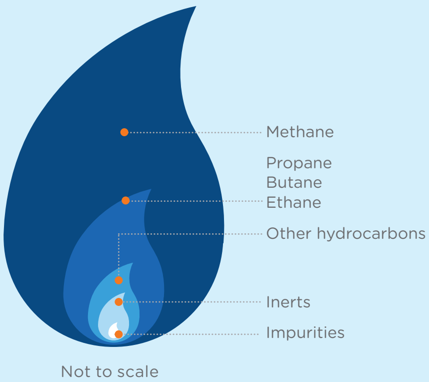
The two key concerns for energy customers are price and security of supply. These concerns along with the global need to reduce carbon emissions, forms the renowned energy trilemma.

With over 80% of peak energy demand supplied by the gas network in Great Britain (GB), it has a very significant role to play in meeting energy needs and the journey to a lower carbon future. Key to this is a flexible distribution network that can adapt to the evolving needs of GB. The 'Opening up the Gas Market' (OGM) project was designed to tackle these issues, by challenging the legislative requirements for gas quality.

GB is now a net importer of gas, with prices and access to supply increasingly depending on international markets. Hence, GB gas prices exhibit volatility, given the short-term and/or spot market conditions.

Gas composition
Although covered by a generic term, 'natural gas' varies in composition, and therefore quality, depending on its source as overall composition can vary in the type and proportion of gas present. While sources of new gas are numerous, GB's specification for gas composition is very prescriptive, therefore restricting the sources of gases that can be used in their pure form and thus limiting the gas market.

Fig. 1 Typical natural gas compositions



Combustion or burning is fundamental to all gas fuelled applications. It is a chemical reaction that occurs producing energy, usually in the form of heat and light. The composition or quality of the gas affects the overall combustion reaction.

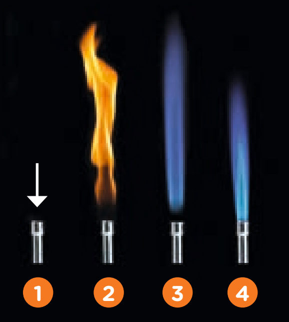
Whilst there are many compositional factors that influence combustion, the Wobbe Index[1] (WI) is arguably the most important parameter in regards to natural gas. The WI is a measure of the amount of energy delivered to a burner and is an indicator of the compatibility between the gas supplied and the burner, often referred to as 'interchangeability'.

Gas interchangeability
A gas that is interchangeable is considered safe to use on a natural gas appliance. It is the ability to substitute one gas for another in a combustion application without materially changing the operational performance of the application (its safety, efficiency or emissions). In GB, the regulations that govern combustion of natural gas are called Gas Safety (Management) Regulations (GS(M)R) 1996. This regulation stipulates the range of WI that should be used in order to ensure safe combustion of natural gas.

All gas-fired equipment is designed to operate within a particular range of WI. If gases outside this range are combusted, this can lead to a range of problems from poor quality combustion through to equipment damage and ultimately dangerous situations. Too high or too low a WI can cause greater emissions of carbon monoxide (CO) through incomplete combustion, as well as other undesirable flame effects.

The GS(M)R WI range was established following test work on appliances carried out in the 1970s and 1980s. Appliance technology has developed significantly since then. This coupled with rising import demand and declining indigenous supply led to the inception of this project with the aim of evaluating and redefining safe WI limits for GB that accommodates more gas sources.

Fig. 2 Gas flame effects

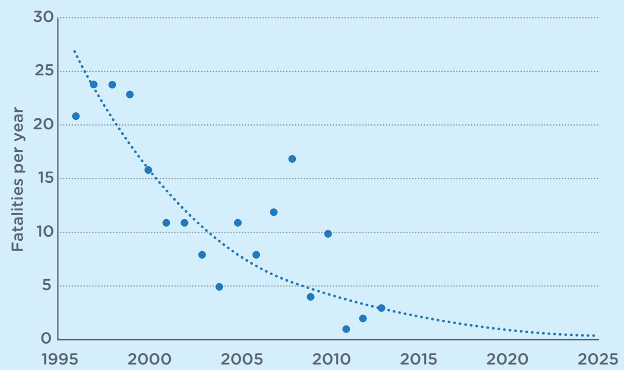


1 Flame light back
2 Incomplete combustion
3 Flame lift
4 Normal combustion

1 At standard reference conditions 15°/15°C.

This project has carried out significant appliance testing to understand the impact of a wider range of WI in terms of appliance performance and safe use. CO is a poisonous gas at certain concentrations, so in considering a change to the WI, it was necessary to evidence whether a change to the limits of the WI will increase the risk of CO poisoning to occupants of the properties where the appliances are being used.

Fig. 3 Fatality trend data to 2025



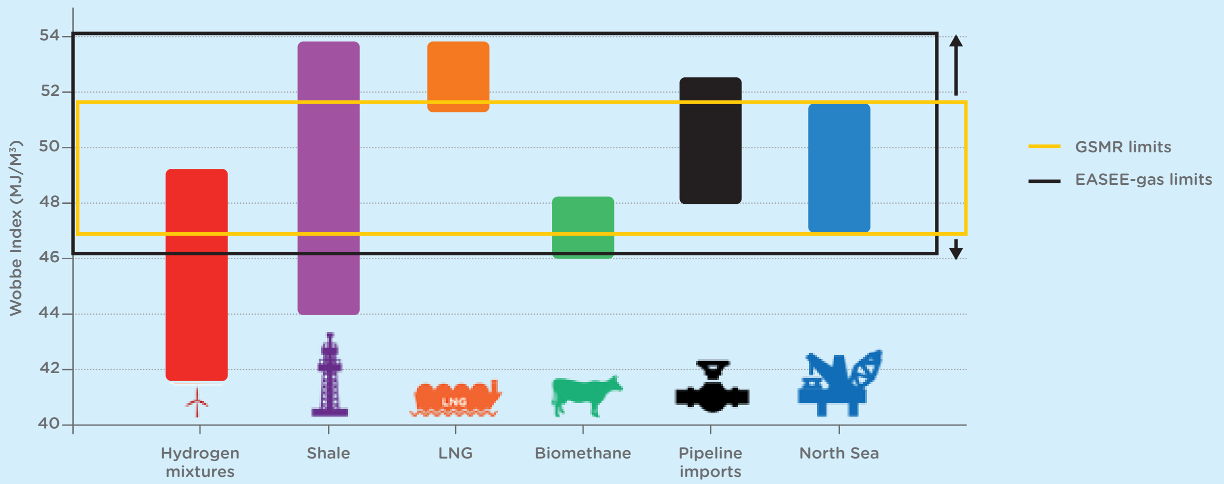
The assumption that numbers of CO incidents are directly proportional to the fraction of appliances with CO levels above an arbitrary level is not demonstrated and could be considered questionable given that CO incidents have continued to fall since records began, despite little change in WI of distributed gas (in fact WI has risen over the period since 1990). The linkage between CO incidents and CO above an arbitrary level is therefore more complex than originally assumed. This suggests that a high proportion of incidents were associated with factors other than gas quality. There is also a lack of a geographical correlation between CO incidents and gas WI. More incidents might be expected in the north of GB where consumers are supplied principally with higher WI St Fergus gas, but this is not the case.

Current arrangements dictate that in order for gases with compositions that sit outside of the GS(M)R WI range to be conveyed and used within GB, expensive gas processing is required to bring them within these specifications. Gas processing is a means of either increasing the WI of the gas by enrichment with propane or decreasing the WI of the gas by dilution with nitrogen (an inert gas). The types and sources of gas that can be used in GB without processing are limited, this ultimately leads to increased costs for the consumer estimated to reach £325m per annum by 2020[2].

If the GS(M)R WI range can be safely widened to accommodate more gas types and sources without processing, this will reduce the costs for the customer and open the market to new sources.

Gas specifications vary for different countries and were set to suit the local gas quality and

Fig. 4 Typical Wobbe Index range of various gas sources



2 Current 2020 forecast estimate of £325m in GB from National Grid (IGEM presentation, 2014).

equipment at the time. GB has one of the narrowest acceptable WI ranges in Europe. This is often a barrier to trade. In Europe there is an ambition to extend and harmonise the WI across all member states called the European Association for the Streamlining of Energy Exchange-gas (EASEE-gas) specification.

Opening up the Gas Market

The Opening up the Gas Market (OGM) project therefore sought to demonstrate whether gas, which meets the EASEE-gas specification but sits outside of the characteristics specified within GS(M)R can be distributed and utilised safely and efficiently in GB.

The limits EASEE-gas proposed are aspirational, but this work coupled with previous studies provided a useful starting point for this project, since the sources of gas seeking injection into the networks are more varied than ever before. This will only be exacerbated in future in pursuit of lower carbon sources, for example the injection of biogas and hydrogen.

For this demonstration project, the aim was to evaluate whether, through statistical sampling, gas appliance installations in GB are capable of burning gases with a wider quality variation, either higher (richer) or lower (leaner) WI than currently permitted in GB. The most important questions are whether this widening of the WI either increases the risk to any person or causes premature deterioration of burner components.

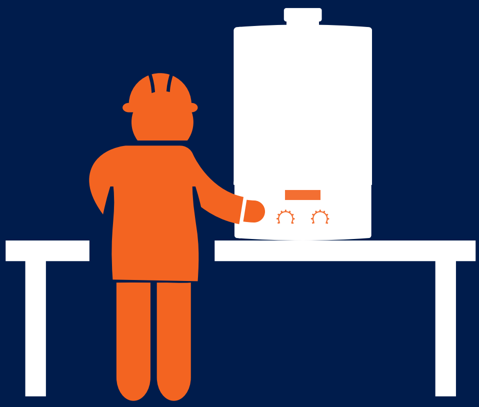
In order to do this, SGN was afforded a unique opportunity to utilise one of the discrete independent undertakings, the Oban gas network. Oban is a town in the Highlands of Scotland and was demonstrated to be statistically representative of GB on a socio-economical level (essentially a microcosm). A demographic study conducted by DNV GL[3] in May 2013 concluded that the 1,104 gas properties with a gas supply in Oban and the appliances within them could statistically represent that of GB in relation to the range of appliance types and models likely to be in use throughout GB. This enabled the findings to be evaluated as a potential solution to be scaled to GB.

The project was broken down into three distinct stages each with its own 'go/no go' stage gate. Each stage gate required a success criterion to be met before moving to the next stage.

Fig. 5 Oban

3 DNV GL Demographic Analysis of Oban for Gas Testing, 2013.

Stage 1 Laboratory testing



In stage 1 a survey of gas appliances in 100 randomly selected properties in Oban was conducted. The survey results provided an understanding of appliance stock in Oban, recording their make, model, condition and manufacturer details. During this time, if any appliances encountered were considered to be unsafe or in need of repair, they were replaced or repaired free of charge.

Laboratory tests

The appliance types present within the appliance survey data were considered typical and representative of the entire appliance population in Oban. This enabled the selection of 18 appliances of various types for laboratory testing using the recognised industry standard test gases over an extended WI range (45.66-54.76 MJ/m^3)[4] that exceeded the current GS(M)R limits.

These 18 appliances were selected by each class (cooker, local space heater, boiler or commercial catering equipment) in combination with additional criteria such as manufacturer, product type, flueing, control type, age and condition. They were tested extensively in laboratory conditions by Kiwa Gastec, across the full EASEE-gas range and in various simulated scenarios, including but not limited to no ventilation, poor maintenance and mal-operation.

The laboratory tests concluded that for an appliance that was originally correctly designed, and has been installed and serviced according to manufacturer's recommendations there was no deterioration in appliance performance in terms of safety and efficiency due to the variation in WI up to 54.76 MJ/m^3.

To allow for any deleterious unknowns in the field condition of the appliance, an element of safety termed 'headroom' was introduced. These could include low voltage (for appliances requiring electrical supplies), high or low gas pressure, uncharacteristically large differences in temperature of the combustion air and the natural gas or sub-optimal performance of the Oxygen Deficiency Sensors fitted to modern gas fires.

Following discussions with appliance manufacturers, a reduced upper limit of 53.25 MJ/m^3 was proposed to account for the 'headroom'.

4 At reference conditions 15°/15°C.

Additional tests

Additional laboratory work identified by and designed in collaboration with boiler manufacturers was carried out to investigate the effects of increased WI on appliance component life. Nearly all appliance manufacturers do not foresee an issue with more rapid burner aging resulting from higher WI, but the work did give manufacturers an opportunity to bring to attention the need for appliance servicing (especially after extended periods of operation). The test program established that internal component lifetime will not be materially affected by increasing gas WI of the supply and supports the assertion that no effect is expected upon boiler life.

Additional laboratory test work carried out demonstrated that it would be possible to adjust and operate the boilers tested on a gas supply network within a WI range between 48.00-53.00 MJ/m³ with only modest effects on CO production (i.e. ±2.50 MJ/m³ from a central point of 50.50 MJ/m³). Theoretically at least, outside this range, extreme adjustment (either low or high) fed with extreme opposite WI gas (either high or low) can lead to substantial increases of CO in the flue products. The likelihood of this is considered very low due to the Thermal Energy Regulations whereby biomethane plants add propane to the gas in order to meet the Flow Weighted Average Calorific Value (FWACV) of the network.

This compensates for the dilution effect the Biomethane would have on the FWACV which, in practice, means the WI of the Biomethane is likely to fall within the safe appliance adjustment zone.

If changes are proposed to the management of CV within networks going forward, this potential issue should be considered in detail.

Implications for the interchangeability diagram

Additional laboratory tests found that the original method used for calculating the Incomplete Combustion Factor (ICF) over-predicts the true ICF for today's appliances. The tests in this project confirmed that for today's appliances, WI as a sole parameter is appropriate provided Relative Density (RD) is limited to no more than around 0.70.

Laboratory testing in this project also demonstrated that limiting relative density to 0.70 limits propensity for significant sooting. The current Sooting Index (SI) limit value of 0.60 is based on visual assessment of the discolouration of ceramic radiants of gas fires commonly on use at the time (1970/80s). Sooting at this level is not a safety consideration and only becomes of concern only when considering excessive deposition – in the flues of flame-effect fires, for instance.

Replotting the Interchangeability Diagram in terms of WI and RD has only a minor impact on the diagram because RD is a good proxy for equivalent (N_2 + C_3H_8). The results from the laboratory tests in this project have confirmed that for today's appliances, WI as a sole parameter is appropriate provided RD is limited to no more than 0.70. It is therefore recommended that the Interchangeability Diagram can be simplified and updated to reflect current requirements.

Stage 2 Field testing at customers' properties

Stage 2 began in November 2014. The aim of stage 2 was to test all gas appliances in-situ at customers' proprieties in Oban on different WI gases. A total of 903 properties with 1,787 appliances incorporating 2,524 burners were inspected, the majority tested using three different test gases, the same ones used in appliance certification testing[5]. Bespoke portable testing vehicles were designed and constructed to allow these gases to be transported and used efficiently and safely.

Bespoke test rig

Field tests

Combustion performance was recorded and analysed for every appliance on each test gas. Appliances that were found to have pre-existing faults or were in poor condition upon arrival were serviced and/or fixed, or where appropriate, replaced for free under the project.

The results from the field testing confirmed that appliances correctly installed, serviced and operated can safely burn gas with WI of up to 54.76 MJ/m^3.

This corroborated the findings of the stage 1 laboratory tests (refer to Figures 6 and 7).

Appliance health

Due to the statistical representativeness of Oban and the high level of access achieved, an insight into appliance health was obtained on a scale not seen since conversion from town gas to natural gas.

Of the appliances tested in Oban, 94% fell into the category as correctly installed, serviced and operated. The remaining 6% were considered 'At Risk' or 'Immediately Dangerous', as per the Gas Safety (Installation & Use) Regulations and the guidance given in the Gas Industry Unsafe Situations Procedure[6].

5 G20 (WI 50.72 MJ/m^3), G21 (WI 54.76 MJ/m^3), G23 (WI 45.66 MJ/m^3).
6 https://www.gassaferegister.co.uk/media/1774/tb_001_-_gas_industry_unsafe_situation_procedure_-giusp-_edition-71.pdf

Fig. 6 Average CO emissions vs Wobbe Index by appliance type (flued)

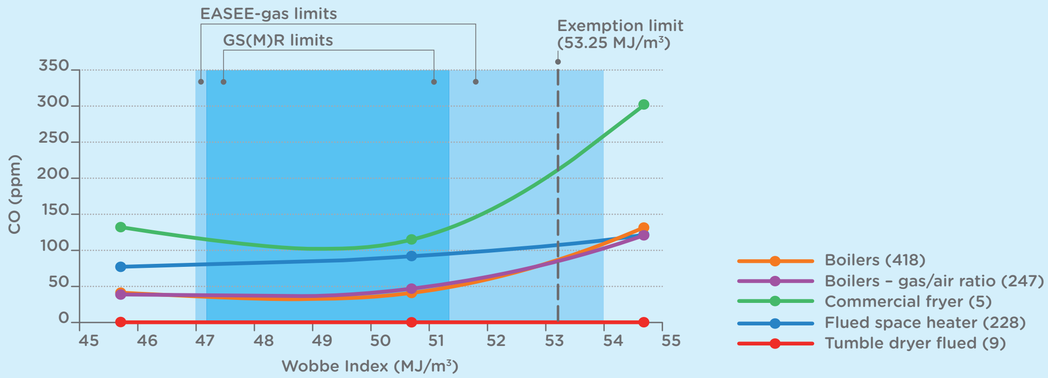
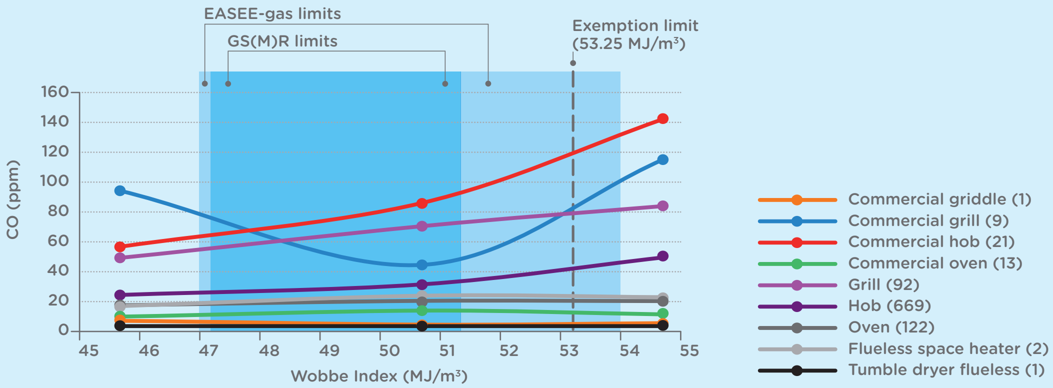


Fig. 7 Average CO emissions vs Wobbe Index by appliance type (flueless)



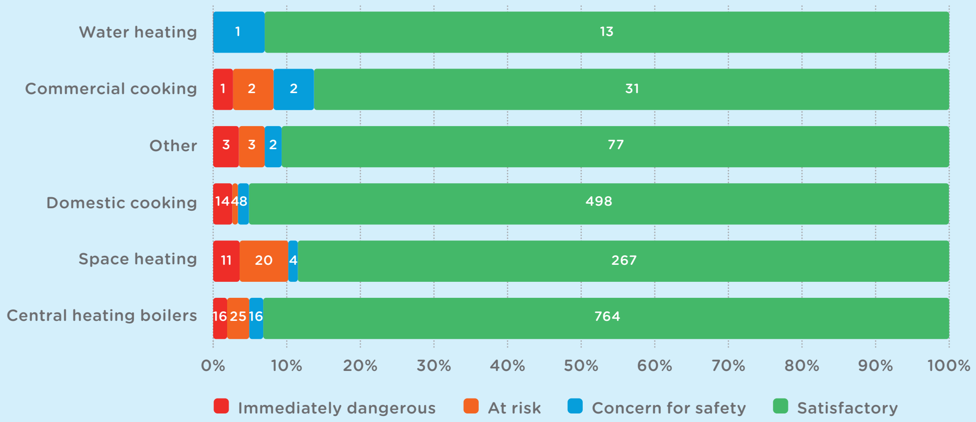
This was due to the pre-existing condition of the appliance and not due to the performance results using the extreme test gas.

Those appliances that were found to be At Risk or Immediately Dangerous when tested on G20 test gas, were rectified or replaced free of charge under the project. The worst case appliances were removed from the customer's property and taken to the laboratory for further testing.

This involved testing faulty appliances and installations across a wide range of WI gases in a variety of fault scenarios such as blocked flue and inadequate ventilation. Examples of two grossly defective appliances removed from properties in Oban are shown opposite.

Examples of faulty appliances found in Oban

Fig. 8 Unsafe situations by appliance category – Oban



In one instance, due to a broken glass panel a local space heater was spilling combustion products into the living room. On another site the customer explained that the CO Alarm had been sounding for a few months but they had chosen to ignore it. This highlights the importance to distinguish between gas quality issues and unrelated appliance condition and/or customer behaviour issues.

Customer participation

In order to provide a robust statistically representative dataset, high levels of customer participation were necessary. Customer and stakeholder engagement was therefore essential to the success of this project.

At a local level in Oban, the customers needed to be engaged and enthused to participate and allow access to their properties in order to test their appliances. This required much emphasis to be placed on communication methods and material. The project team worked alongside the local council, community groups and businesses to help encourage participation and access to customers' properties.

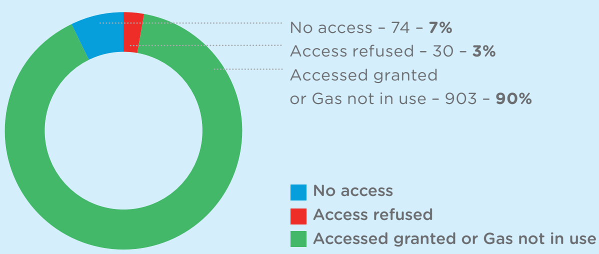
Stakeholder engagement

An example of some of the local stakeholder initiatives undertaken by the project include hosting a 'Cooking with Gas' event whereby a professional chef provided cookery demonstrations on different blends of gas for the local community. Other examples are SGN sponsoring the Oban Winter Festival; drop in sessions in the town hall to provide an opportunity for customers to ask questions; and even showing the project film[7] as a trailer before films in the Oban cinema.

As a further benefit to customers, appliances encountered that were inoperable, dangerous or At Risk were either repaired or replaced and customers were issued with a free CO alarm. The engagement methods were extremely successful, resulting in over 90% of customers in Oban electing to participate in stage 2, providing a very strong, statistically representative dataset.

Cookery demonstrations at the Regent Hotel, Oban

Fig. 9 Property access report



7 Project film can be found at www.sgn.co.uk/oban

Currently only **10%** of the available LNG can be accepted into the GB gas network without processing. Increasing the WI range to 53.25 MJ/m³ would allow **>90%** of the globally available LNG to be injected into the GB gas network without processing.

Stage 3 Field trial

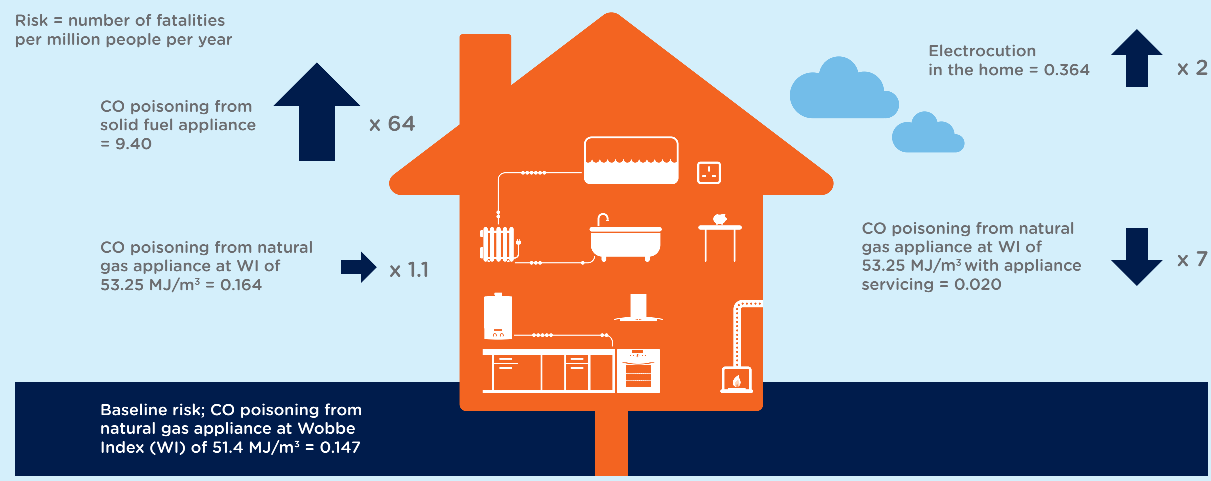
For the final stage, three different sources of gas with a higher WI than permitted in GS(M)R was selected and trialled in the Oban network for one year. In order to carry out the field trial an exemption from the requirements of GS(M)R was sought from the Health and Safety Executive (HSE).

Quantitative risk assessment

As part of the evidence submitted for the exemption, a Quantitative Risk Assessment (QRA) was carried out by DNV GL. The assessment determined the change in risk associated with transporting gas with WI outside of limits currently allowed by GS(M)R. The results of the Laboratory and field tests fed into the QRA and showed that increasing the WI of the gas up to 53.25 MJ/m³ did not increase the magnitude of risk and appliance servicing/inspection reduces the absolute level of risk 7-fold.

The QRA also benchmarked risks against other common household risks and illustrated that CO risk from natural gas appliances, regardless of WI, is significantly less than that posed by solid fuel appliances.

Fig. 10 Comparison of relative risks at home



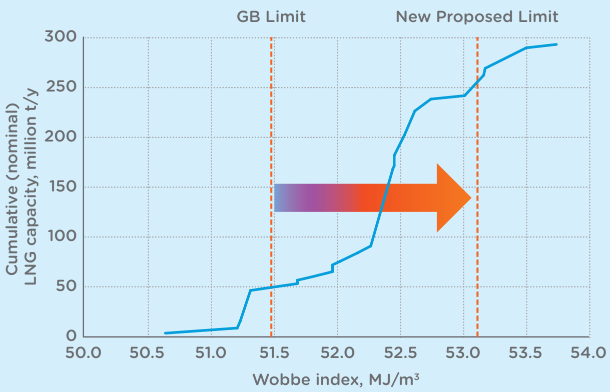
Global LNG availability

A review of globally available LNG carried out by Dave Lander Consulting showed that extending the upper WI limit of GS(M)R to 53.25 MJ/m³ would bring 90% of the globally available LNG into the allowable range without the need for processing. This would be a significant shift from the 10% currently available. The market benefits from this change are unquantifiable at this stage, but expected to surpass the significant savings from avoided processing of gas.

Field trial

On Monday 6th July 2015 at 8.05am, SGN made gas industry history by injecting the first load of liquefied natural gas (LNG), all the way from Zeebrugge, into the Oban network.

Fig. 11 Cumulative LNG production capacity



Three different LNG sources were injected into the Oban network across the 1 year:

- Zeebrugge LNG, WI of 51.8 MJ/m³ (Average across year), trialled for 1 year – 2000t of LNG, 100 x road barrel tankers.
- Isle of Grain LNG, WI of 52.8 MJ/m³ – 20t of LNG, 1 x road barrel tanker.
- Montoir-de-Bretagne LNG, WI of 52.5 MJ/m³ – 15t of LNG, 1 x ISO tanker.

During the trial period, over 300 customers' properties were revisited at regular intervals to test how their appliances were performing on the new gas. All the appliance checks were satisfactory. There were no identifiable or material changes recorded in the burning characteristics and

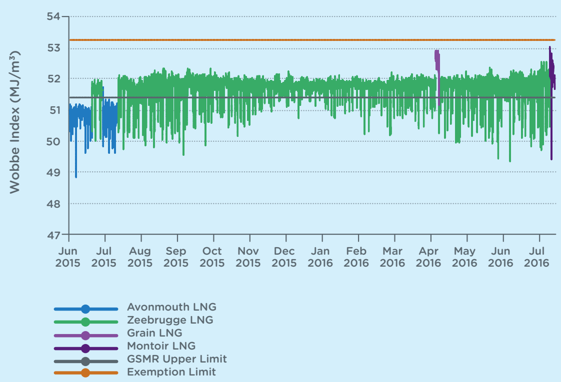
Zeebrugge LNG being offloaded in Oban

performance of appliances on the high WI gases when compared with the results witnessed on the G20 test gas during stage 2.

It was a significant challenge to make this possible involving setting up the first ever contract between a LNG terminal, GB Gas Shipper and Gas Distribution Network (GDN), establishing a complex gas nomination process and overcoming challenging haulage logistics.

Throughout the one year trial, the Oban network operated safely without incident, demonstrating that a higher WI gas can be injected, distributed and utilised safely.

Fig. 12 Daily WI ranges – June 2015 to August 2016



Outcomes against project objectives

Objective	Outcome
1. To demonstrate whether all gas appliances are capable of safely and efficiently burning gas which meets EASEE-gas specifications but sits outside GS(M)R;	Laboratory and field testing demonstrated that appliances (GAD and non-GAD) installed, serviced and operated correctly up to can safely and efficiently burn gas with a WI of up to 54.7 MJ/m³. Applying a headroom factor for appliance age/condition and discussions with manufacturers it was recommended that 53.25 MJ/m³ be the upper WI value.
2. To establish the proportion of older gas appliances that constrict gas quality specification in GB through assessment of a representative appliance sample from Oban network;	Laboratory and field testing results found that all appliances installed, serviced and operated correctly, can safely and efficiently operate with a wider gas quality specification, regardless of age.
3. To demonstrate through the sample population what is required to ensure GB's appliance population is capable of operating safely and efficiently over a wider range of gas quality;	The QRA showed that increasing the WI to 53.25 MJ/m³ has small increase in risk, albeit the risk remains of the same magnitude. The QRA also demonstrated that, if an appliance is maintained and serviced regularly then the increase in risk with WI is negligible. Therefore the small increase in risk for un-maintained appliances could be removed by refocusing CO campaigns on the importance of appliances servicing and maintenance.
4. To identify and record all types/makes of gas appliances, identified through the representative appliance sample from Oban network that are not fit for operation using gas which meets EASEE-gas specifications but sits outside GS(M)R;	No appliances were found to be unfit for EASEE-gas specification. Unsafe appliances were already unsafe on GS(M)R specification gas. A minor reduction from the EASEE-gas specification to 53.25 MJ/m³ provides a headroom factor for appliances in poorer condition.
5. To demonstrate whether gas that meets EASEE-gas specification but sits outside GS(M)R can be conveyed safely and efficiently in the GB gas network;	The field trial demonstrated that there are no network related issues with conveying gas with a WI outside of GS(M)R specification. Three alternative LNG source gases with Wobbe Index > 51.4 MJ/m³ were successfully introduced and used continuously over a 12 month period in the Oban network. During the initial trial period 200 spot checks were carried out on random properties with no issues found.
6. To capture and record all project learning to assist in a full GB roll out in the future;	All learning from the project has been captured and disseminated as appropriate and there is continuing engagement with OFGEM, DECC (now BEIS), HSE, HHIC and other key Stakeholders. The project has led to the formation of the IGEM Gas Quality Working Group, with the objective of moving GS(M)R to an IGEM standard and widening the WI limits within.
7. To compile a project completion report assessing the technical and commercial viability of accepting EASEE compliant gas in GB;	A £325m potential benefit due to less gas processing has been advocated by National Grid (NG). This project has proven that this is technically possible to achieve up to 53.25 MJ/m³ without the need to inspect or replace any appliances.
8. To compile a list of appliances found to be incompatible which will be shared among all relevant stakeholders;	Laboratory and field testing results found that all appliances were compatible. All appliances installed, serviced and operated correctly, can cope with a wider gas quality specification.

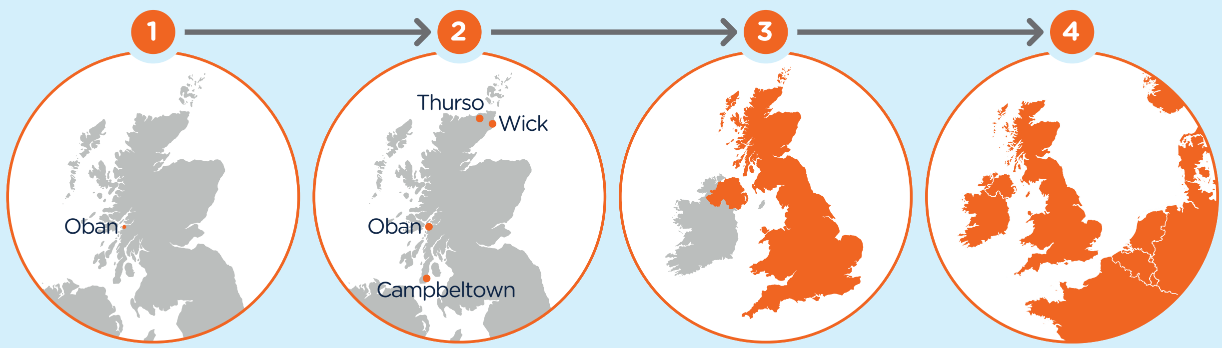
Key conclusions

Based on the findings from the three stages of the project a number of conclusions were able to be drawn. The main conclusions are summarised below.

1. There is a significant incentive to change the allowable gas quality in GB, specifically the WI, circa £325m per annum for avoided Nitrogen ballasting.	8. Appliance maintenance, servicing and replacement when required produces a 7-fold reduction in the absolute risk.
2. Currently only 10% of the available LNG can be accepted into the gas network without processing. Increasing the WI range to 53.25 MJ/m³ would allow >90% of the globally available LNG to be accepted.	9. Both the Sooting Index and the Incomplete Combustion Factor as stated in GS(M)R are no longer valid.
3. Domestic and small commercial appliances correctly installed, serviced and operated can safely burn gas with WI of up to 54.76 MJ/m³.	10. CO campaigns that focus solely on CO alarms are not the most effective means of reducing CO risk.
4. An upper WI limit of 53.25 MJ/m³ allows sufficient headroom for any deleterious unknowns in the field condition of the appliance.	11. Increasing the WI to 53.25 MJ/m³ has negligible impact on the efficiency, performance and life of a domestic or small commercial appliances.
5. The cost of maintaining the current GS(M)R limits is grossly disproportionate to the risk involved in widening the WI limits to 53.25 MJ/m³.	12. The interchangeability diagram can be simplified and updated to reflect current requirements.
6. Using Oban as a statistical representation of GB, it is estimated that 4% of the GB appliance population would be classified as 'at risk' against the Unsafe Situations Procedure currently.	13. The Oban Network safely stored, injected, distributed and utilised gas with WI ranging from 49 MJ/m³ to 53.2 MJ/m³ during the one-year trial period.
7. Using Oban as a statistical representation of GB, it is estimated that 2% of the GB appliance population would be classified as 'immediately dangerous' against the Unsafe Situations Procedure currently.	14. No evidence of deterioration in appliance performance was found after one full year operation on gas outside of GS(M)R limits.

Road map to GB roll-out

Fig. 13 Road map for roll-out



Recommendations

In review of the findings of this project, the following recommendations are made as part of the road map for GB roll-out:

1. The upper WI limit to be increased to 53.25 MJ/m³
2. No changes to the lower WI limit at current time
3. The interchangeability diagram to be updated
4. Transfer GS(M)R to IGEM Standard
5. Review CO guidance message
6. Permanent GS(M)R exemptions for the SIUs

1. The upper WI limit to be increased to 53.25 MJ/m³

Based on the results of the project it is recommended the upper WI limit in GB is increased from 51.40 MJ/m³ to 53.25 MJ/m³. Although the extensive appliance testing results demonstrated that all domestic and small commercial appliances correctly installed, serviced and operated can safely burn gas with WI of up to 54.76 MJ/m³, a reduced upper WI limit of 53.25 MJ/m³ is proposed to allow sufficient headroom for any deleterious unknowns in the field condition of appliances. This provides a safety margin (approximately 1.5 units) for factors such as:

- Appliance safety device performance.
- Ambient temperature effects.
- Start of exponential increase of CO around 53.50 MJ/m³ (for some appliances).
- Sub-optimal adjustment of air/gas ratio controlled fully premix boilers.
- Other deleterious unknowns and poor condition of appliances.

Furthermore, it was noted that this upper limit is only marginally above the current GS(M)R emergency limit (52.85 MJ/m³).

Using Oban as a statistical representation of GB, it is estimated that 4% of the GB appliance population would be classified as ‘at risk’ and 2% ‘immediately dangerous’ against the Unsafe Situations Procedure currently. The QRA determined that increasing 53.25 MJ/m³ does not materially affect CO risk. Appliance installation condition is the most significant contributor to risk.

There is a significant incentive in terms of LNG availability at this level. Currently only 10% of the available LNG can be accepted into the GB gas network without processing. Increasing the WI range to 53.25 MJ/m³ would allow >90% of the globally available LNG to be accepted.

2. No changes to the lower WI at current time

Although this project did not find any safety issue testing on gases as low as 45.66 MJ/m³ WI, it is suggested that more work is required in this area to investigate mal-adjustment of boilers with gas/air ratio controls. Extending the upper WI limit to 53.25 MJ/m³ and retaining 47.20 MJ/m³ at the lower end, would effectively widen the WI range beyond the 5-6 MJ/m³ safe operational range identified by the project. Thus an upper limit of 53.25 MJ/m³ leaves less scope to extend the lower limit below 47.20 MJ/m³ without potentially having to re-adjust boilers from their G20 factory set point, which the majority are set.

There have been concerns raised about re-commissioning 'repaired' gas appliances when the gas service operative does not know the quality of the gas being supplied to the property at that moment. This is a recognised problem in Germany[8] and other countries developing an alternative gas strategy. Therefore additional laboratory test work to determine materiality of this was carried out under the project. The laboratory test work demonstrated that it would be possible to adjust and operate the boilers tested on a gas supply network within a WI range between 48.00-53.00 MJ/m³ with only modest effects on CO production. (i.e. ±2.50 MJ/m³ from a central point of 50.50 MJ/m³).

A boiler could be factory set at either 48.00 or 53.00 MJ/m³ and still meet the safety action level on a gas network that has a WI that varies between these two extremes. For example, if the boiler was adjusted at 48.00 MJ/m³, the gas WI could increase by 5.00 MJ/m³ and the combustion would still be acceptable, and vice versa. In theory, if the boiler was adjusted at 48.00 MJ/m³ and the gas WI decreased by 5.00 MJ/m³, to 43.00 MJ/m³, the combustion would be still be satisfactory (48.00 MJ/m³ becomes the new upper point of adjustment). The same applies at 53.00 MJ/m³.

Theoretically, outside this range, extreme adjustment (either low or high) fed with extreme opposite WI gas (either high or low) could lead to substantial increases of CO in the flue products. In future this would essentially only be an issue in areas where Biomethane is injected into the distribution system unconstrained by thermal energy compliance. Currently, in order to comply with the Thermal Energy Regulations, biogas plants enrich the gas by adding propane in order to meet the Flow Weighted Average Calorific Value (FWACV) of the network. This compensates for the dilution effect the Biomethane would have on the FWACV. Therefore the WI of the Biomethane is likely to fall within the safe appliance adjustment zone.

The 'Oban limits' identified allow for WI headroom allocated to on-site appliance issues. Indeed notwithstanding this, many appliances (such as flued and room sealed) pose no potential for CO spillage to room. This is however an issue that should be considered in any unconstrained development, such as that being considered under the Real-time networks project[9]. Whilst the CO concentrations may not be harmful the appliance may be operating outside the manufacturer's recommended CO/CO_2 envelope, which could give future complications.

This is an example of where both the appliance industry and gas supply chain must continue to closely co-operate to understand future widening of sources in terms of thermal energy and gas quality management.

The driver for extending the lower WI limit may become more prevalent in the future as new renewable and unconventional gas sources with lower WIs become available. Therefore no changes to the lower WI limit of 47.20 MJ/m³ are recommended at this time.

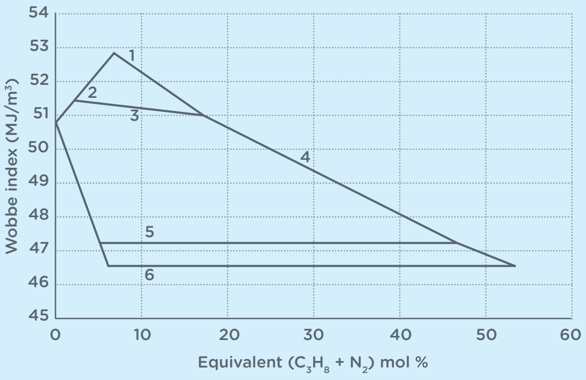
3. The interchangeability diagram to be updated
The interchangeability diagram, published in the HSE's Guide to the GS(M)R[10], is a visual representation of the WI, ICF and SI limits embodied in Schedule 3 of the GS(M)R. These limits and the Interchangeability Diagram are a simplification of the limits introduced and operated by the British Gas Corporation prior to 1996 and the Dutton Diagram, published[11] following a series of work carried out by B.C.Dutton in the 1970-1980s. The interchangeability diagram has served GB well and was certainly fit for purpose based on the gases available and type of appliances in use at that time. In light of the work conducted under this project it is considered that it can be simplified and updated to reflect current requirements.

Figure 14 shows the existing interchangeability diagram and various limits as defined within GS(M)R.

8 Joint declaration by European transmission and distribution system operators to Pilot Study 2.0 Contribution to the pre-normative study of H-gas quality parameters (2016).
9 https://www.sgn.co.uk/real-time-networks/
10 Health and Safety Executive. 'A Guide to the Gas Safety (Management Regulations'. HSE Books ISBN 978 0 7176 1159 1.
11 B.C.Dutton. 'A new dimension to gas interchangeability'. IGEM Communication 1246, 50th Autumn Meeting. 1984.

There is a **significant incentive** to change the allowable gas quality in GB, specifically the WI, circa £325m per annum for avoided Nitrogen ballasting.

Fig. 14 Existing interchangeability diagram



The abscissa in the current Interchangeability Diagram is based on the propane and nitrogen content of the equivalent mixture[12]. However, an alternative approach adopted within Europe is to plot WI against RD. This offers has a number of advantages:

- Simplification – reduction of composition to an equivalent mixture is not required.
- Harmonisation with European practice.

The EASEE-gas specification sets interchangeability limits solely in terms of WI and RD, so limits can be compared directly.

Replotting the Interchangeability Diagram in terms of WI and RD has only a minor impact on the diagram because RD is a good proxy for equivalent Nitrogen (N_2) and Propane (C_3H_8) – this can be seen by a plot of the two terms for a series of hypothetical gas compositions selected by Monte-Carlo methods – see Figure 15. The hypothetical compositions were selected to reflect GB natural gases that were both compliant and non-compliant with the requirements of the GS(M)R.

Fig. 15 Demonstration that RD is a good proxy for equivalent (N_2 + C_3H_8)

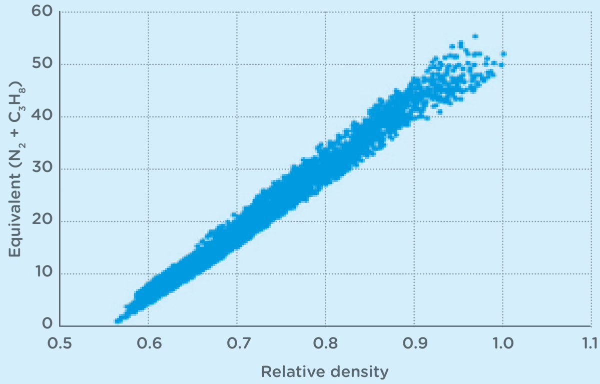


Figure 16 shows the modified Interchangeability diagram resulting from employing RD as the abscissa. Superimposed on the diagram are the EASEE-gas interchangeability limits in WI and RD. The diagram also shows the location of the stage 1 and 2 test gases and the stage 3 trial gases within the various boundaries. Note these gases are above GS(M)R normal upper limit and sit within the emergency envelope of GS(M)R.

Fig. 16 Modified natural gas interchangeability diagram showing stage 3 gas positions

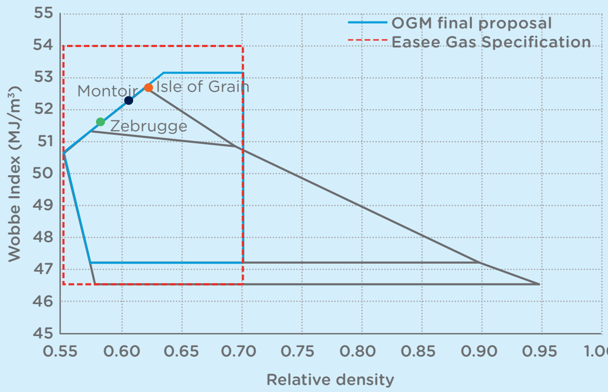
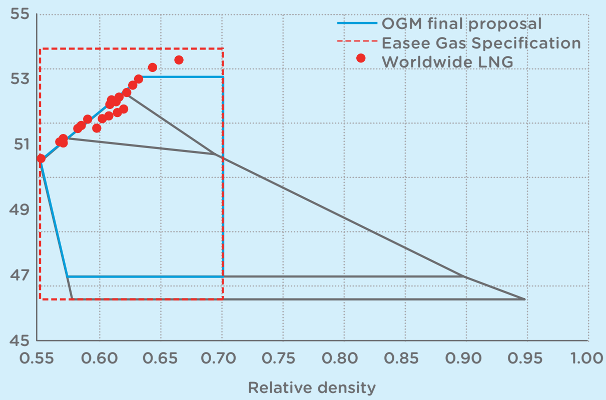


Figure 17 again depicts the GS(M)R, EASEE-gas and proposed Oban limits, but this contains the location of the globally available LNG within the various boundary limits. It illustrates the headroom below the EASEE-gas limits and how extending the upper WI limit to 53.25 MJ/m³ would accommodate most of globally available LNG without the requirement for processing, whilst satisfying appliance performance and safety considerations.

12 The equivalent mixture is a hypothetical mixture of methane, propane, nitrogen and hydrogen that has the same Wobbe index as that of the gas under consideration.

Fig. 17 Modified interchangeability diagram showing position of globally available LNG



The following proposals are therefore made to the interchangeability requirements of the GS(M)R:

Incomplete combustion factor (ICF) is removed as a requirement

The ICF parameter was introduced by Dutton because test results indicated a small dependence of flue gas CO/CO_2 ratio upon equivalent ($N_2 + C_3H_8$). In practice, this dependency is quite small over the range of interest (around 0 – 18%, corresponding to a relative density range of 0.55 – 0.70). Subsequent testing by the GASQUAL consortium and by KIWA in this project have confirmed that for today's appliances, WI as a sole parameter is appropriate provided RD is limited to no more than around 0.70.

ICF was derived by Dutton from the performance of instantaneous water heaters; these appliances (together with the radiant gas fire) were commonly found in most homes in the 1970s and generally generated flue gas CO/CO_2 ratios that doubled when WI was increased by approximately 1.5 MJ/m³. Such appliances are now rare and today's 'equivalent' appliance is the central heating/hot water boiler. Such appliances do not show such severe sensitivity to WI: KIWA testing of a combi boiler with partially premixed burner suggests doubling of flue gas CO/CO_2 ratios only occurs when WI is increased by 3.0 MJ/m³. As a result, Dutton's relationship for calculating ICF from composition over-predicts true ICF for today's appliances.

ICF is simply a measure of how flue gas CO/CO_2 ratio increases as WI increases and takes no account of flue gas CO content. Today's appliances tend to operate with much lower flue gas CO content and the GASQUAL consortium, for instance, characterised appliance performance by a combination of flue gas CO content and increase as WI increased.

The upper WI limit is increased from 51.41 MJ/m³ to 53.25 MJ/m³

This is the key finding from the project and is based on the findings of the laboratory, in-premises and field testing of a wide range of appliances.

The WI limit of 51.41 MJ/m³ arose from the selection of ICF limit of 0.48 by Dutton because this value corresponds approximately to the WI limit of 51.2 MJ/m³ that was in use by the British Gas Corporation following a survey of GB appliances carried out in 1978.

Sooting Index is replaced by relative density

Dutton's basis for limiting equivalent ($N_2 + C_3H_8$) was based on limiting sooting associated with higher density gases and the Sooting Index limit value of 0.60 is based on visual assessment of the discolouration of ceramic radiants of gas fires commonly in use at the time. Sooting at this level is not a safety consideration and becomes a concern only when considering excessive deposition – in the flues of flame-effect fires, for instance. Testing in this project and by the GASQUAL consortium shows that limiting relative density to 0.70 limits propensity for significant sooting.

It is worth pointing out that the relative density limit of 0.70 generally represents a stricter limitation compared with the SI limitation of the GS(M)R. Most natural gases have relative density lower than 0.70 and only some associated natural gases or heavily-enriched gases would be affected.

No change to the lower WI limit

The lower WI value of 47.20 MJ/m³ was originally proposed by Dutton on the basis heat service considerations, i.e. heat output from instantaneous water heaters (and to a lesser extent gas fires and cookers) led to consumer complaints if WI falls by more than 5% of the reference gas[13].

13 Note that reduction of WI to 95% of the reference gas corresponds to 48.18 and not 47.2 MJ/m³. Dutton's discussion of heat service limitation in the IGEM communication contains a number of discrepancies that are not readily interpreted.

The low emergency limit of the GS(M)R permits WI as low as 46.50 MJ/m³ to be conveyed in order to prevent a gas supply emergency and this limit value corresponds to the limit value for lift index of 1.16, which was established by visual assessment of flame detachment from the burners of cooker hobs.

No change in the lower WI limit is proposed at the current time, although there is scope for revision should assessment of future gas quality scenarios incorporating unconventional and renewable gases require this.

No change to the hydrogen limit
Prior to 1996 the British Gas Corporation employed a normal limit for hydrogen content of 10% (mol/mol), based on the consideration by Dutton of earlier work carried out in the 1970s. The limit was proposed by Dutton in anticipation of an imminent arrival of Substitute Natural Gases (SNGs) manufactured from petroleum feedstocks. In practice SNGs have not figured in GB energy mix to date and for the coming into force of the GS(M)R in 1996, hydrogen was set at an arbitrarily low value of 0.1 mol%. This removed the influence of hydrogen on calculation of WI, ICF and SI, effectively converting Dutton's three-dimensional 'interchangeability volume' into the current two-dimensional interchangeability diagram.

No change in the hydrogen limit is proposed at the current time, although there is scope for revision should assessment of future gas quality scenarios incorporating unconventional and renewable gases, together with hydrogen injection into natural gas grid, require this.

Figure 18 shows therefore the Modified Interchangeability Diagram resulting from the proposed changes discussed in the previous section. The majority of gases of Group H of the Second Gas Family sit within the boundary designated by the blue line. The arrows illustrate deviation from limits as follows:

A: High WI/low RD gases. Generally, these are not feasible, unless blending with low-density hydrogen is carried out (or significant helium is present, in which case its economic value would suggest extraction of helium prior to combustion).

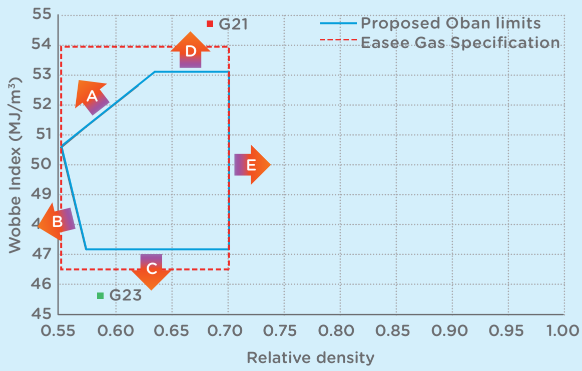
B: Low WI/low RD gases. Generally, these are not feasible, unless addition of low-density gases such as hydrogen is carried out (or significant helium is present).

C: Low WI gases. Generally, these are gases containing significant inerts (e.g. nitrogen, carbon dioxide) and little higher hydrocarbons. Some natural gases such as those from Morecambe bay and some biomethanes and coal bed methanes would fall into this category. Some shale gases may contain significant inerts and may also fit in this category.

D: High WI gases. Typically, these are likely to be a limited number LNG supplies, although some pipeline gases from Norwegian North Sea fields might fall into this category. Some ballasting with nitrogen would be required.

E: High density gases. Typically, this would be limited to: associated natural gases containing significant C2+ content; heavily enriched biogases (i.e. containing significant carbon dioxide – not biomethanes) and LPG-air mixtures (not employed in GB).

Fig. 18 Modified natural gas interchangeability diagram



4. Transfer GS(M)R to IGEM Standard
An IGEM Gas Quality Standard working group should be established, based on representation from the whole GB Industry to consider evidence and determine the appropriateness of a new upper Wobbe Index Limit of 53.25 MJ/m³. If the Gas Quality Working Group supports a change to the gas quality requirements specified in GS(M)R Schedule 3, this should take the form of an IGEM Standard, simplifying the process for further changes to be accommodated within this area of the industry.

Following a number of meetings with IGEM, DECC, OFGEM and the HSE a structure has been agreed in principle, by the industry, that will oversee the transfer of schedule 3 of GS(M)R to an industry produced standard. This will support the rollout of the Oban findings and other work into GB. Simultaneously a wider review of the GS(M)R will be undertaken to ensure much needed changes are incorporated into the revised legislation at the same time.

Why an IGEM standard
An IGEM standard is regularly reviewed and amended and has the confidence of industry and government agencies. Incorporating Schedule 3 into an IGEM standard provides a robust approach with the flexibility of allowing the specification to be appropriately developed as and when new evidence emerges. The review of IGEM standards follows a peer review process which involves wide industry consultation. This flexibility will benefit the consumer and the industry as the nature of the composition of the gas being consumed by GB customers' changes. As innovation and diversity of supply continues this would present GB with a robust, flexible, appropriate and future proofed mechanism.

IGEM Gas Quality standard working group
This group and associated sub groups should compose subject matter experts from across the gas industry and other key stakeholders. The group should be an umbrella gas quality working group that initially considers the gas quality changes proposed in the Oban (Opening up the Gas Market) project, and then subsequently evaluates, identifies and facilitates projects toward gas quality changes. It will create a database of evidence in support of changes. It will potentially identify a number of offshoot projects, subject to a materiality and Cost benefit assessment.

The objectives of the working group are:

- Set up of a core group to drive the production of the standard and ensure appropriate representation from across the industry and supply chain.
- Identify and map relevant industry groups and bodies.
- Identify links and necessary representation for these both in GB and in the EU.
- Set up of sub groups (where required) which will examine the specific potential effects of a change in GS(M)R on the supply chain, industry, customers and asset owners.
- Develop database of current and previous studies into gas quality.
- Production of an IGEM standard covering GB gas quality specification in order to facilitate a change from GS(M)R.
- Evaluate, identify and facilitate projects toward future gas quality changes.
- Successful completion of the review process of the IGEM standard covering GB gas quality specification in order to facilitate a change from GS(M)R.
- Agreement and approval of the IGEM standard covering GB gas quality specification in order to facilitate a change from GS(M)R.

IGEM role
IGEM should take the lead in establishing and facilitating the core working group developing the standard for gas quality. This will involve engagement and consultation with industry, mapping of industry groups and identifying links and necessary representation both in GB and in the EU. The core group will comprise key stakeholders and subject matter experts on matters relating to schedule 3 of GS(M)R. IGEM will develop and maintain an evidence database of all relevant studies and projects, both previous and current.

5. Review CO guidance message
A key learning from the project is that around 6% of GB appliances are likely at risk or immediately dangerous currently. Gas Quality in the range proposed presents a very small component of CO risk from appliances.

The project has shown that the importance of CO safety lies predominantly with the effective maintenance of appliances, with the correct installation of a CO alarm being treated as a secondary safeguard, rather than as the sole preventative measure.

While CO alarms, when installed correctly, are effective at raising the alarm in the event of a CO leak, they are reactionary rather than preventative. Whereas effective maintenance means that an appliance limits CO exposure, by taking effective measures where required during an inspection, the CO alarm could only highlight that a leak has already occurred.

In order to address this finding, it is recommended a review of CO awareness campaigns to ensure focus is targeted in areas that offer the most cost effective and real risk reductions i.e. appliance maintenance, servicing and replacement.

Furthermore, the optimum frequency and nature of appliance servicing should be reviewed and discussed between the gas distribution, appliance industries and IGEM gas quality standard working group in order to inform CO campaigns. Opportunities to effectively reduce pre-existing CO risk and improve appliance performance should also be explored with the relevant governmental and regulatory bodies.

Although not exhaustive, a number of options range from a focused CO campaign, targeted appliance inspection and replacement via scrappage schemes, to mandated periodic appliance servicing. These measures would have to be proportionate to the reduction in risk they could achieve.

6. Permanent GS(M)R Exemptions for the SIUs
SGN own and operate four mainland SIUs (Scottish Independent Undertakings) in Oban, Wick, Thurso and Campbeltown. These are discrete networks that are not connected to the main gas grid, rather supplied by regasified LNG. Historically, LNG for the four mainland SIU's has been obtained from any one of four LNG liquefaction facilities across GB, namely Glenmavis, Partington, Denyvor Arms and Avonmouth. In recent years, Partington and Denyvor Arms have closed and in July 2010 National Grid LNG advised SGN of their doubt regarding the long-term viability of the LNG plant at Glenmavis due to the age and condition of critical equipment.

Fig. 19 SGN's Mainland Scottish Independent Undertakings

In December 2010 SGN was notified that the liquefier had failed, causing LNG production to cease and that liquefaction facilities at Avonmouth would be the single source of compliant LNG supply for the SIU's. The originally selected Compressed Natural Gas (CNG) solution in 2011 was not viable and contingency LNG storage facilities were installed in Provan. In early 2013, National Grid announced that its Avonmouth LNG facility would be closing in 2018, therefore leaving SGN with no GS(M)R compliant supply option for the SIU's post 2018. Following an exhaustive review of multiple options, originally initiated when Glenmavis was due to close, it was determined that the most viable (in the time permitted) was to install nitrogen ballasting facilities at the four mainland SIU sites. Thus providing flexibility to procure LNG from any of the European truck loading LNG terminals and ballast the LNG to GS(M)R specification.

In parallel with this, in 2013 SGN received funding for this ambitious project (OGM) to assess the potential to widen the permissible Wobbe range under GS(M)R.

In December 2013 National Grid LNG announced they were going to expedite the closure of the Avonmouth facility to April 2016. The ballasting could not be ready on all sites until 2018. At this point in time, the OGM project was progressing well and the likelihood of its success significantly increased.

Following the comprehensive appliance testing and inspection programme in Oban, an exemption was granted by the HSE to allow SGN to supply rich WI gas in Oban in 2014. In parallel to the development of the ballasting solution, the learning from the OGM project, in terms of appliance inspection, was applied to the remaining mainland SIU's. Exemptions for all SIU's has now been granted until April 2018. It is recommended that from 2018 onwards the exemptions are made permanent based upon the learning of this project.

Further works

The following recommendations for further work are made as part of the Road Map for GB roll out.

1. Study on the impact of gas quality changes on industry and large commercial gas fired equipment.
2. Study on the impact of gas quality changes on the National Transmission System.
3. Report on findings from wider SIU appliance inspections.

1. Impact on industrial and large commercial gas fired equipment

Large commercial and industrial appliances were out with the scope of this project as there are no such appliances located within the Oban network. Whilst it is broadly accepted that industrial and commercial gas fired equipment is more tolerant due to investment in more sophisticated process control, certain production processes could be affected by gas quality changes.

Appropriate evidentiary requirements should be identified and projects scoped by the IGEM Gas Quality Standard working group. This should include a commercial impact analysis both of the change and the cost of delay.

Industrial and commercial gas-fired equipment are designed to tolerate to a wider range of WI and calorific value. In general, installed equipment for industrial use has more sophisticated burner types and process controls. Burner types may include:

- Air blast burners.
- Diffusion flame or post aerated burners with no premixing of gas and air.
- Nozzle mix burners.
- Pulse combustors.
- Catalytic burners.

It is acknowledged, there are a number of industrial processes that could be sensitive to a change towards gas with a higher WI such as:

- Furnaces with controlled atmospheres.
- Ceramics and glazing processes.
- Gas engines.
- Direct fired textile processes.

From a safe operation perspective, there are few concerns amongst manufacturers and industrial users alike, however it is recognised that the consequences in lost production or heating services could be significant to individual customers who may be affected by gas quality changes.

The impacts of a change in WI on gas fired Combined Cycle Power Plants is variable and very much depends on the quality and hydrocarbon contents of the gas used. Use of higher WI gases that are outside the acceptable gas quality band for a particular turbine could lead to operational issues such as, but not limited to, combustion dynamics, increased emissions including NOx, decreased component life and the change in fuel characteristics could potentially lead to substantial load swings.

Experience has shown that the combustion system of gas turbines is impacted by variations in fuel quality. A number of research studies to identify robust combustion system configurations that are capable of reliable operation with variable gas quality have been undertaken over the years.

Gas turbines are usually designed to operate without significant impact on performance with WI gases that are typically +/- 10% of their optimum design criterion.

The current WI band for GB specification gas is 47.20 > 51.41 MJ/m^3, so turbines designed to work with natural gas in GB would have a WI design criterion of 49.30 MJ/m^3 (+/- 10%) which gives an allowable swing of 4.9 MJ/m^3. This is comfortably within the current GB gas specification but although they are capable of accepting quite wide variations in gas quality most generating companies would require either automation via control instrumentation or prior notice and manual intervention to allow optimisation of the machines.

If not already fitted there are various instrumentation packages available that allow gas turbines to operate on a wider range of gas quality whilst maintaining optimum performance and exhaust emission levels, these systems allow greater flexibility in fuel specification and hence would enable power generators to leverage cost reduction due to reduced processing costs at the Gas/LNG reception terminals.

Most manufacturers offer upgrades for their generator packages that have the ability to automatically accept a wide and rapid variation in WI whilst protecting the operational boundaries of the gas turbine and optimising its performance. These systems require no manual intervention and achieve fuel flexibility throughout the operating envelope of the machine. They would typically allow systems to accommodate a 20% swing in WI and a rate of change in excess of 18% per minute.

With dynamic control systems it is possible to effectively change Gas Turbine control settings to adequately compensate for measured changes in fuel composition, two examples are given below.

Where WI is the critical feature controlled fuel heating and variable Vane technology can be used to effectively modify the WI in response to a change in gas composition, for example there is a system available called Opflex Balance auto tune which utilises a high speed Wobbe meter and fuel heating in conjunction with variable vane technology to effectively and continuously optimise system behaviour.

On the same lines one manufacturer has a system called Integrated Fuel Characterisation which as above incorporates a high speed Wobbe meter, fuel heating and variable vane technology to modify the combustion characteristics of its Gas Turbines.

Both systems can be fitted from new with retrofit solutions available for most turbines currently in service. These systems help mitigate the risk associated with gas composition variations but as always operators need to be aware of these developments to ensure that potential variations in fuel gas composition are properly considered.

A number of manufacturers supply instruments and telemetry such with various instruments that could be used in power generation control systems.

In understanding potential issues with power generation and industrial uses, SGN carried out engagement with a number of organisations. For the purposes of this report, specific details of site operation efficiency and capacity are considered commercially sensitive therefore we have not referenced or included the detail discussed.

Thus anecdotally, a substantial widening of WI allowed under GS(M)R should not be an issue for power generators in the UK using gas turbines to generate electricity. Most sites would require some upgrade work, mostly software with some older sites requiring upgrades to telemetry and instrumentation, especially if within day changes to gas quality were likely to be experienced.

This should initially take the form of a detailed review of prior studies worldwide, some of which have been identified through Marcogaz Gas Quality Working group. Any gaps in understanding the effect should be identified with the relevant representations, such as ICOM and Energy UK, and subsequently a programme of in-situ testing should be carried out.
A number of older designs of industrial gas appliances incorporate partially premixed burners, where the natural gas is mixed with a sub-stoichiometric quantity of air at the injector and then additional combustion air diffused into the flame after its emergence from the burner ports. These burners tend to show a relatively flat response of CO emissions with WI variations i.e. CO emissions do not increase quickly as WI increases or decreases.

Fully pre-mixed burners using gas/air ratio controls effectively 'meter' precise quantities of natural gas and air into the appliance (at a fixed gas/air ratio) and no additional excess air permitted. Previous studies and the OGM project have shown that, depending on the Wobbe Index of initial adjustment, fully pre-mixed appliance performance can be sensitive to WI variations and CO emissions can rise as the WI of the gas supplied changes.

The OGM project has demonstrated that fully pre-mixed burners, which have been initially adjusted at a WI of 50.72 MJ/m³ (G20), are shown to operate satisfactorily at the gas 'Oban limit' WI range i.e. 47.20-53.25 MJ/m³.

However, it has not yet been confirmed that this also applies for large-scale Industrial and Commercial gas equipment.

It is recommended that further analysis is required to understand the impact of the change to Wobbe limits proposed. This should be co-ordinated through the proposed Gas Quality standard working group umbrella project.

2. Impact on National Transmission System
National Grid Gas Transmission (NGGT) is conducting a project[14] to understand the likely impact of different gas specifications on existing and future National Transmission System (NTS) assets and operations. The risks and impacts to the NTS asset capability due to a change in WI need to be identified, qualified and quantified. Of particular consideration is the % ethane content, as anecdotally it can behave differently above 12% in terms of hazardous areas and pipeline/storage failure characteristics.

The initial phase of the project will concentrate on the identification of assets, processes and operations that may be impacted by a change in the specification of GB gas quality in respect to all NTS assets.

An assessment will be carried out to qualify and quantify the risk and impact on specific performance of key NTS asset types that will be impacted by a change in specification. Where an adverse impact is identified, the risk will be quantified and where remedial action is possible, an estimation of outline cost will be provided. For emissions, the cost of remedial action will focus on those assets selected on highest risk and priority as advised by NGGT.

The results of the project should be reviewed by the IGEM Gas Quality Standard working group.

3. Report on findings from wider SIU appliance inspections
In December 2015 National Grid LNG announced that Avonmouth liquefaction facility was closing in April 2016. Avonmouth was the only facility left in GB that can supply GS(M)R compliant LNG to the SIUs.

SGN was planning to construct Nitrogen ballasting facilities in the SIUs, however these could not be commissioned in all four SIU sites until 2018 and hence SGN would not able to supply GS(M)R compliant gas to these sites until 2018.

A project was therefore undertaken by SGN to seek an exemption to GS(M)R by the HSE in order to supply high Wobbe Index LNG from Europe or Isle of Grain until such time that the ballasting facilities were installed.

The exemption application used the work already carried out in Oban under the 'Opening up the Gas Market' project as a blueprint for obtaining an exemption. Results from the OGM in Oban demonstrated that gas appliances correctly installed, serviced and operated can safely burn gas with WI up to 53.25 MJ/m³.

14 http://www.smarternetworks.org/NIA_PEA_PDF/NIA_NGGT0094_4114.pdf

With this in mind and given the tight timescale until April 2016, it has was agreed with industry experts (Dave Lander Consulting and Kiwa) that the best approach to obtaining an exemption was to inspect all 5,981 appliance installations in the remaining SIUs to confirm that they are installed, serviced and operated correctly, and rectify where necessary. The work was also necessary to generate the required evidence base to support formal application to the HSE for GS(M)R exemption from gas quality limits in the SIUs until 2018.

An exemption level of 53.25 MJ/m^3 for each mainland SIU was subsequently approved by the HSE in April 2016. The exemptions are due to expire in 2018.

It is suggested that a full report detailing the findings of the appliance inspections is produced. This will add to the evidence produced from Oban to support the insight in to GB appliance health.

Data pertaining to CO alarms was captured that included a check for the existence of alarms in rooms with gas appliances and also whether or not the alarm was fully functional and correctly installed.

This additional data should form part of this report to give an insight into the effectiveness of CO alarms installed in customers properties. This will support the data provided by 'The Carbon Monoxide – Be Alarmed!' campaign run by Energy UK on behalf of British Gas, EDF Energy, E.ON, npower, Scottish Power and SSE, in partnership with the Dominic Rodgers Trust[15].

15 http://www.co-bealarmed.co.uk/about/

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Carbon Monoxide (CO) can kill.
For more information:
www.co-bealarmed.co.uk

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