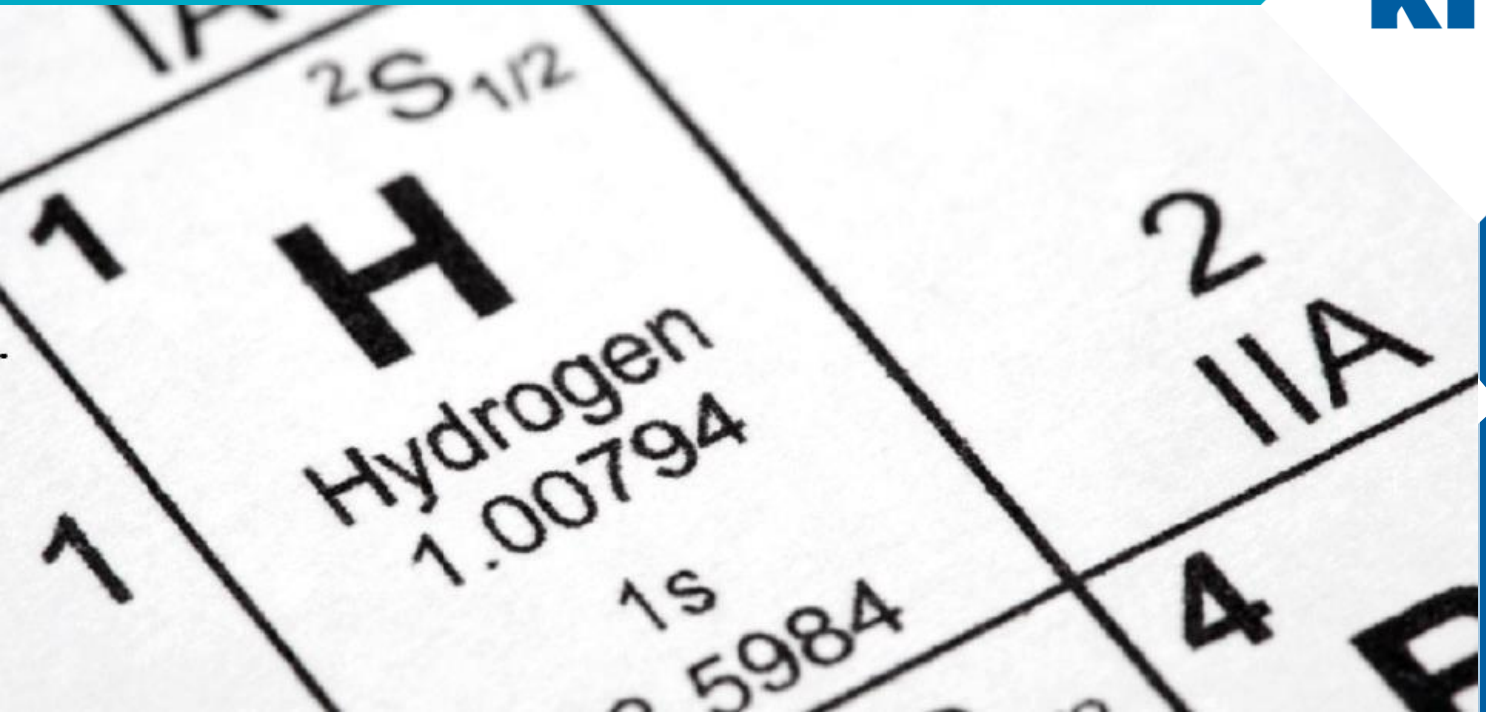
HyDeploy- 20% v/v H2 Appliance performance

Mark Crowther



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This presentation is based upon the following paper

Operation of UK Gas Appliances with Hydrogen Blended Natural Gas

Pursell, M.R.1, Hooker, P.2, Hawksworth, S. J. 3, McLaughlin,P.4, Wilcox, S.5, McCluskey, I.6,

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Test Gas		Composition (% mol/mol)				Wobbe Number (MJ/m^3)
		CH_4	C_3H_8	H_2	N_2	
G21	Upper Wobbe Limit	87	13	0	0	54.6
G21 + 10%	Hydrogen enriched upper Wobbe Limit	78.3	11.7	10	0	53.0
G24	Over-heating limit gas	68	12	20	0	51.9
G20	Reference gas	100	0	0	0	50.7
G20 + 10%	Hydrogen enriched reference gas	90	0	10	0	49.4
G20 + 15%	Hydrogen enriched reference gas	85	0	15	0	48.8
G20 + 20%	Hydrogen enriched reference gas	80	0	20	0	48.2
G222	Light back limit gas	77	0	23	0	47.8
G20 + 28.4%	Hydrogen enriched reference gas at lower GSMR limit	71.6	0	28.4	0	47.2
G23	Lower Wobbe Limit	92.5	0	0	7.5	45.6
G23 + 10%	Hydrogen enriched lower Wobbe Limit	83.25	0	10	6.75	44.6

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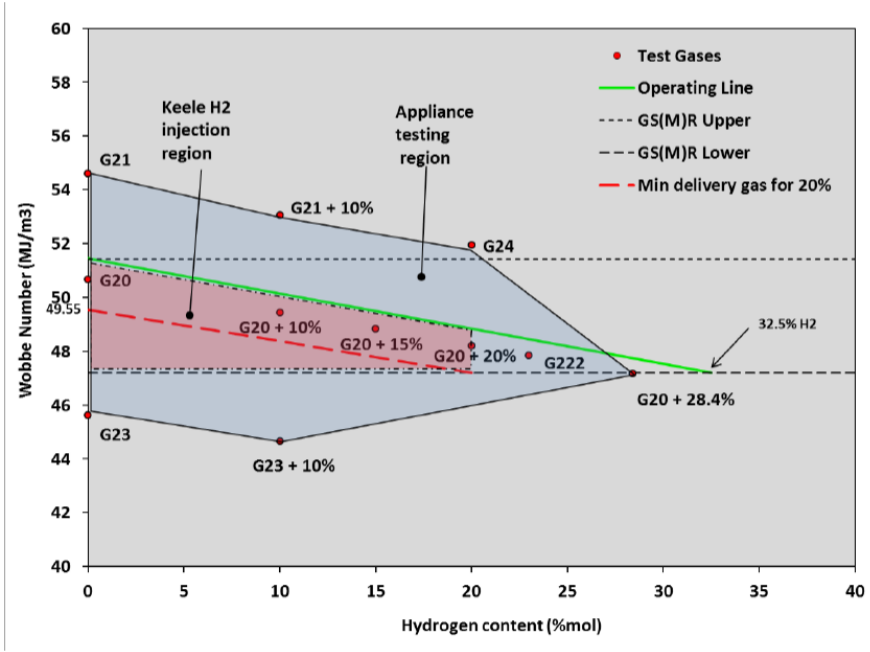

Figure 1 **Test Gases Used to Assess Appliance Operation**

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Table 4 **Gas Appliance Type and Manufacturer Used in the Laboratory Test Program.**

	Make	Model	Rating (kW)	Flue Type	Appliance Category	Appliance Type	Combustion Premix	Test Standard
1	Zanussi	ZCG664GNCHob Burner	2.9	Flueless	Gas Cooker	Oven / Hob / Grill	Partial	BS EN 30-1-1
2	Trimford			Flueless	Gas Catering	Fryer	Partial	BS EN 203-1
3	Legend	Evora BF	4.5	Balanced Flue	Gas Fire	With delayed ignition relief panel	Partial	BS EN 613
4	Paragon	Focus HE S/C	5.5	Conventional	Gas Fire	Inset	Partial	BS 7977-1
5	Baxi	Bermuda 552	16 (Max)	Conventional	Gas Boiler	System (Back) Boiler	Partial	BS 7977-2
6	Myson	Marathon 500B	19.6 (Max)	Conventional	Gas Boiler	System Boiler	Partial	BS EN 15502-1
7	Worcester Bosch	Greenstar 30i ErP	30	Balanced Flue	Gas Boiler	Combi Boiler	Fully	BS EN 15502-1
8	Sime	Format 30 HE	30	Balanced Flue	Gas Boiler	Combi Boiler	Fully	BS EN 15502-1

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Table 6 Laboratory Test Results

Test Assessment	General Test Result	Variation Within Test Result	Comments
CO Production	No change or a reduction in CO production with increasing hydrogen concentration compared to that of natural gas: compliance demonstrated against BS 7967:2015	Appliances displayed similar behaviour albeit at different absolute levels due to predicted differences in combustion style [2]	Deviation from specification is not significant except in extreme conditions.
Combustion Behaviour including ignition efficiency, cross lighting and assessment of light back.	No evidence of deterioration in combustion performance, no ignition failings and no occurrence of light back [2]	None	No significant change in appliance performance.
Combustion behaviour (100% Hydrogen)	Light back at concentrations greater than 80 % mol/mol hydrogen. Below 80 % mol/mol, no ignition issues or occurrences of flame failure [2]	At > 80% mol/mol hydrogen ignition issues observed	Suggests an upper functional limit of 80% mol / mol hydrogen is present.
Function of Oxygen Depletion Sensor (ODS)	One of four live flame effect fires showed a compliance against ODS specification with G20 but failed the safety criteria when hydrogen was added.	The fire with oxy pilot ODS trialled against the various test gases failed to provide ODS function with sufficient safety factor to be acceptable. Further studies into ODS design and function is recommended.	Inset live flame effect fires contain an oxygen depletion sensor (ODS) to guard against flue blockage. BS EN 7977-1 requires that the ODS shuts off the gas supply before the CO concentration reaches 200 ppm in the test chamber
Flame Failure Devices (Ionisation Probe)	Up to 90 % mol/mol hydrogen the measured ionisation current in the Worcester Bosch boiler showed a reduction in ionisation current with increasing hydrogen concentration. No false flame out events occurred.	Ionisation current is used as a control mechanism by a number of boiler manufactures. None of these appliance types are present on the G3 network at Keele University and therefore this aspect has not been considered as part of the HyDeploy test programme.	It is a well-established consensus that there is limited ionisation current in hydrogen flames: the trials reaffirmed this consensus.
Energy Efficiency	Minimal effect of hydrogen on the efficiency of the appliances. [2]		The Wobbe Number of the delivered gas was kept within GSMR limit.

More recent work indicates that the issue with the ODS, whilst real, is statistically extremely unlikely to occur. Most CO events historically occurred with soot falls, birds and mal-functioning boilers. Lined flues, terminals and condensing boilers have effectively addressed this.

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Table 2 Appliance Population on the G3 Network

Appliance Category	Subcategory	Flat	Semi-detached	Detached	Student halls	Non-residential	Total
Gas fire / space heater	Decorative fuel effect fire		2	1			3
	Inset live fuel effect fire		2				2
	Radiant heaters					4	4
Central heating boilers	Combination	13	15	12		5	45
	Regular / system - condensing	16	14	6	12	26	74
	Regular / system - non-condensing	4	3	8	2	6	23
Domestic cooking	Built-in hob		4	5			9
	Built-in oven			1			1
	Cooker / range		9	13			22
Water heaters	Storage water heater				7		7
Commercial cooking	Hob					2	2
	Oven					3	3
	Salamander					1	1
	Fryer					2	2
	Brat pan					1	1
Total		**33**	**49**	**46**	**21**	**50**	**199**

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Table 8 Gas Mixtures for Onsite Testing at Keele University

Onsite Test Gas	Wobbe Number (MJ/m^3)	Hydrogen Concentration (% mol/mol)	Comments
Line Gas	47.20 – 50.85	0	The normal distributed gas on the Composition variable within GSMR limits
Reference Gas	50.7	0	G20 (100% methane)
			Standard gas mixture that is used by manufacturers to set appliance operating conditions.
Hydrogen Test Gas 1	51.9	20	G24 Examines the upper limit on the hydrogen injection High WI gas enriched with hydrogen
Hydrogen Test Gas 2	47.2	28.4	G20 + 28.4% H_2 Low WI Hydrogen Gas Hydrogen enriched reference gas at lower GSMR limit. Hydrogen content beyond 20% H_2 range

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Table 9 Onsite Test Results

Test Assessment	General Test Result	Comments
Presence of correctly fitted CO Alarm with suitable placement	58 out of 91 properties (64% compliance)	Correct placement was within same room as gas appliance.
Presence of correctly fitted smoke alarm with suitable placement	52 out of 91 properties (57% compliance)	.
Presence of Detectors in non-domestic locations	Safety devices (eg fusible links) present in boiler locations.	
Ventilation sufficient for removal of flue gases and ensure efficient combustion	Adequate ventilation was provided at all properties	
Flueing	Adequate flueing present in all properties	Two premises had the flue outlet terminals closer to the ground than regulation (150 mm rather than 300 mm). One premises had the flue outlet installed upside down, allowing potential rain ingress. A chimney blocked by birds nest was also identified. In both of these scenarios the flueing was modified to ensure adequate flueing was present in all properties.
Combustion Behaviour: Gas Composition	Increases in CO production occurred when using hydrogen test gas 1 (higher Wobbe Number gas with added propane). Test gas 2, (low Wobbe Number gas), resulted in a reduction in CO. Both these observations were in line with laboratory results, the carbon content of the fuel and the stoichiometric oxygen requirement.	Flue gas analysis was undertaken on all appliances.
Combustion Behaviour : Heat Output	The addition of hydrogen to natural gas led to a reduction in CO due to a decrease in oxygen demand and move away from incomplete combustion at the burner surface; furthermore the lower carbon content	In accordance with the calorific content of the gases, higher energy input occurred with the higher Wobbe Number gases and the hydrogen test gas 2 had a lower rate of heat input.
	of the fuel gas led to a reduction in CO.	
Maloperation	See Discussion Below	
Gas Tightness	See Discussion Below	

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Maloperation

Maloperation of an appliance was not an aspect specifically tested during the trial but data was taken from observations by the test engineer and/or combustion measurement from house-to-house enquiries. Two instances of maloperation were found at the test site.

1) A grill in the Chancellors refectory had a build-up of grease close to the burner ports. This was thought to potentially reduce the flow of air into the burner resulting in poor combustion and increased CO production. In this commercial kitchen environment however there was sufficient forced ventilation to mitigate this effect.

2) A boiler in a residential property had ad hoc repairs by a non-competent person. The boiler itself was poorly maintained and was emitting combustion products into the room. The boiler was deemed immediately dangerous, capped off and replaced with a new boiler.

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Tightness Testing – Meters and Connections

As part of the gas safe checks routine assessment of the functionality of the installation of meters and fittings was undertaken. Deviation from standard requirements for four meters were found as detailed in Table 10. All other meters on the network where determined to be leak tight

Table 10 Installation remedial works for gas tight testing of meters with Natural Gas

Fitting type	Issue and remedial work
Meter	Old meter (1960s, imperial type) with lead pipes. Meter replaced.
Meter	Gas outlet rotated when an attempt to disconnect was made with the nut rotating rather than unscrewing. Meter replaced.
Meter	Leaking regulator found – regulator replaced.
Emergency control valve	False positive report of being unable to close fully. Further assessment found to be a very tight valve that could be closed.

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Tightness Testing – Installations with Natural Gas

Of the 133 installations tested, three were found to fail the maximum permitted leak rate (MPLR) criteria defined in IGEM UP/1B [3]; this is detailed in Table 11.

Table 11 Installation Remedial Works Following Tightness Testing

Location	Issue and remedial work
Domestic Property	Gas leakage observed from the hob. This was replaced along with the gas fire and various other maintenance works
Science and Learning Centre	Failed due to a leak on the gas governor. Components replaced.
Sports Hall	The installation passed the initial two minute test but failed over the longer test duration conducted. A subsequent retest of the installation confirmed these findings. Onsite inspection identified the source to be a hot water heater in the plant room.

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CONCLUSION

A detailed laboratory-based programme of work has been undertaken to investigate the effect of hydrogen injection into a natural gas-based distribution network up to a hydrogen concentration of 20% mol/mol in preparation for live trials on a closed network at the Keele site. Some minor concerns have been identified specifically for the Keele network relating to the use of ODS and ionisation detectors. Difficulties were encountered relating to broken appliances, blocked flues, poor repairs, incorrect siting of detectors and failed leak tests. However, the majority of test data indicates no deterioration in public safety when using a hydrogen blended natural gas mixture.

Discussion

Thank you.

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