Impact of hydrogen admixture on installed gas appliances

Petra Nitschke-Kowsky

Werner Wessing

E.ON Ruhrgas AG

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1 Background

Against the backdrop of the government's climate protection goals, there are clear political targets for the German heating market going forward. They call for an increase in the rate of modernisation for housing stock (from 1 % to 2 %) and a greater share of renewables in energy consumption (18 % by 2020 and 30 % by 2030). For carbon emissions, the aim is to reduce output by 40 % (2020) and 55 % (2030) compared with 1990 levels. Achieving these targets will pose an enormous challenge to all market partners – manufacturers, installation companies, energy suppliers and not least end users.

Alongside the injection of biogas into natural gas pipeline systems, renewable hydrogen is seen as a way of increasing the level of renewables in natural gas. The growth of wind and solar energy and the wide variations in the volume of power they deliver mean that there will be increasing quantities of surplus electricity available for producing renewable hydrogen from water electrolysis. The technical processes needed for this to happen already exist. The idea is to feed the hydrogen directly into the natural gas transmission pipelines or store it in natural cavern gas storage facilities. Storage and transportation by pipeline thus allow the use of the energy to be deferred while providing an alternative to transmission via electricity grids. Depending on the availability of surplus electricity and the quantity of gas transported by pipeline at any given time, there may be different hydrogen concentrations along the supply chain (**Fig. 1**). To realize these technical prospects, along the chain of natural gas transportation, storage, distribution and use, there are still a large number of technical questions which are being addressed as part of current projects.

2 Objectives

The general aim of the overall project is to establish the limits of blending hydrogen into the natural gas grid while giving due consideration to all aspects of the natural gas chain. The goal of the described project in particular is, to investigate questions concerning the gas distribution grid with its components and the domestic end use appliances. Theoretical and experimental analysis of a broad range of domestic appliances and their combustion behaviour running on natural gas containing increasing levels of hydrogen are conducted. These studies are supplemented by manufacturer surveys and an analysis of the combustion tests on gas appliances conducted in the E.ON Ruhrgas lab over recent years. General conclusions are drawn and recommendations for further action formulated.

3 Methods/Approach

The task of assessing the limits of hydrogen blending is being undertaken in four work packages. In a first theoretical work package, the gas components for mixtures with up to 30% of hydrogen were determined based on a typical European group H gas (North Sea gas). Their effect on flame stability for different types of burner was then evaluated by reference to calculated parameters. For the second work package, using these theoretical considerations and drawing on our extensive experience with burner development and combustion tests on gas appliances (**Fig. 2**), we selected a range of appliances equipped with different premixing atmospheric and fuel-lean burners as well as a micro-CHP system with a Stirling engine for the tests. In the laboratory these appliances were tested for their ignition and combustion behaviour under different operating conditions and with injection rates of up to 30% hydrogen into methane (G20). All results were discussed and analysed in detail with the appliance manufacturers.
The third work package is to verify these results in field tests, and a supply area with a mixed age structure in household appliances plus a number of commercial users will be identified for this purpose. Before hydrogen is added to the gas pipeline network in the selected area,

the appliances will be individually recorded, categorised, and their settings will be checked. Hydrogen will then be added in small increments until the limit of DVGW Guideline G260 is reached. Reported faults will be logged and selected types of appliance will be individually examined.

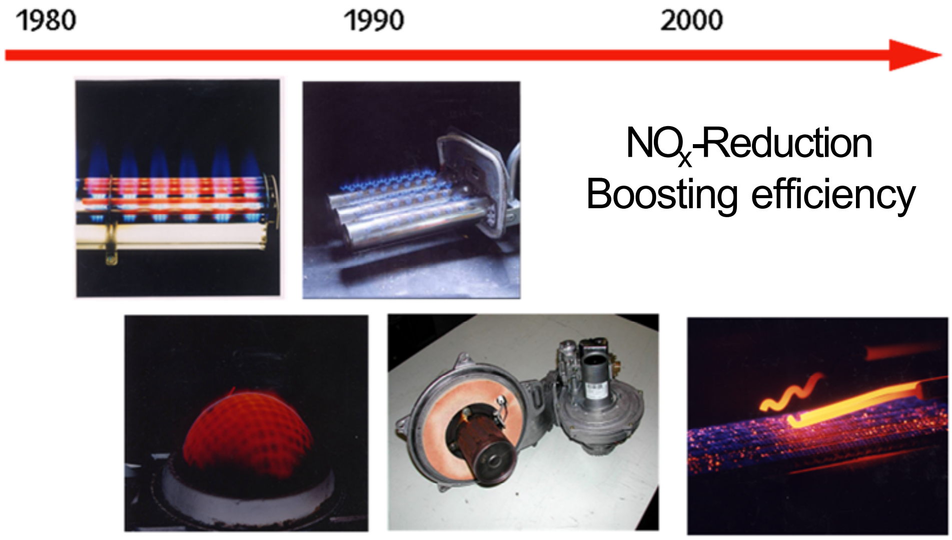


Fig. 2: Development of gas burner technology in domestic gas appliances

In the fourth work package we developed initial assessments of a number of key themes including gas distribution (materials), gas installation (gas flow switches), gas metering (diaphragm meters), gas pressure regulating and flue gas discharge systems, and examined possible interfaces with national codes of practice.

4 Results

4.1 Theoretical Considerations

Characteristics of pure hydrogen

There are a number of factors that are important for combustion where hydrogen differs significantly from typical natural gas, see **Table 1**. Its calorific value and relative density are

Gases (0°C/0°C, 1013 mbar)	Hydrogen H_2	Methane CH_4	Ethane C_3H_6	Natural Gas H (North Sea)
Gross calorific value Hs (MJ/m³)	12.7	39.9	70.3	41.9
Relative Density d	0.07	0.56	1.04	0.63
Wobbe Number Ws MJ/m³	48.3	53.5	68.7	53.0
Air Requirement Lo (m³/m³)	2.4	9.5	16.9	10.1
Maximum Flame Velocity (cm/sec)	346	43	49	43

Table 1: Characteristic values of pure hydrogen, methane and ethane compared with natural gas H from the North Sea

well below those of methane and group H natural gas. The Wobbe number however, which is important for interchangeability is only just below the limit of DVGW Guideline G260 **[1]** and the Common Business Practice (CBP) of EASEE Gas **[2]** which is one objective of European standardisation. The air requirement is only around one quarter of that of methane. At 8 times higher than that of methane, the maximum laminar flame velocity of pure hydrogen is often the subject of intense debate because it is so important for flame stabilisation. By way of comparison, the third column in Table 1 lists the parameters for ethane which can be present with levels of 10% and over in LNG in particular.

Characteristics of natural gas/hydrogen mixtures

The characteristics of natural gas/hydrogen mixtures and the composition of their flue gases were calculated using the GasCal **[3]** programme for blending rates of up to 30%; they are presented in **Table 2**. The results are discussed below.

Wobbe number and relative density

The Wobbe number, an important characteristic which can be used to calculate a load variation for example, falls slightly as blending increases but does not drop below 48.2 MJ/m³ (0°C/0°C/1013mbar) and so is only just below the limits in [1] and [2]. Relative density which is basically a characteristic of gas composition can quickly fall below the lower limit of 0.5 or 0.55 **[1;2]** however, depending on the starting gas. In **Figure 3** the characteristic values of typical group H gases as distributed through German and European gas grids in recent years are plotted against the prescribed limit s [1;2].

Mixtures of Russian natural gas, a typical LNG or a German hybrid gas with an increase level of hydrogen were calculated and are also presented. Blending rates of 5% (Russian natural gas) up to more than 15% (heavy LNG) can be achieved within these limits.

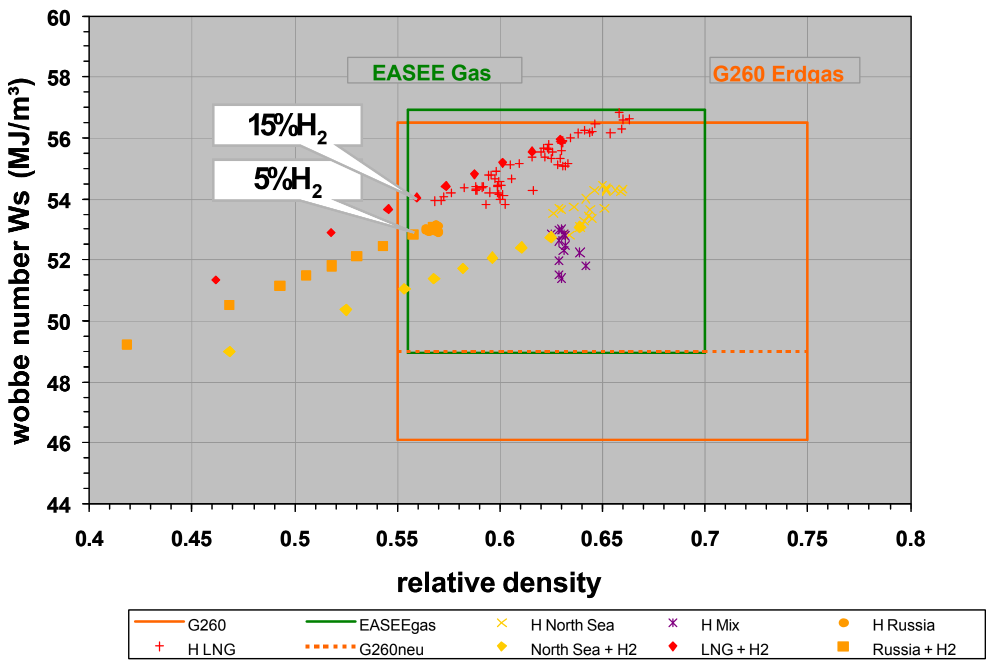


Fig. 3: Wobbe number and relative density of distributed and future natural gases in Europa without and with hydrogene injection

Natural Gas H, North Sea		100,0 %	97,5%	95,0%	92,5%	90,0%	87,5%	85,0%	82,5%	80,0%	77,5%	75,0%	72,5%	70,0%
hydrogen		0,0%	2,5%	5,0%	7,5%	10,0%	12,5%	15,0%	17,5%	20,0%	22,5%	25,0%	27,5%	30,0%
gas components	Mol.-%													
methane		89,2	87,0	84,7	82,5	80,3	78,0	75,8	73,6	71,4	69,1	66,9	64,7	62,4
nitrogene		0,8	0,8	0,8	0,7	0,7	0,7	0,7	0,7	0,6	0,6	0,6	0,6	0,6
carbon dioxide		1,8	1,8	1,7	1,7	1,6	1,6	1,5	1,5	1,4	1,4	1,4	1,3	1,3
ethane		6,5	6,3	6,2	6,0	5,9	5,7	5,5	5,4	5,2	5,0	4,9	4,7	4,6
propane		1,3	1,3	1,2	1,2	1,2	1,1	1,1	1,1	1,0	1,0	1,0	0,9	0,9
n-butane		0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,2	0,2	0,2	0,2	0,2
n-pentane		0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0
n-hexane		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
hydrogene		0,0	2,5	5,0	7,5	10,0	12,5	15,0	17,5	20,0	22,5	25,0	27,5	30,0
C/H		0,26	0,26	0,26	0,25	0,25	0,25	0,24	0,24	0,23	0,23	0,23	0,22	0,22
gross calorific value	kWh/m³	11,65	11,44	11,24	11,04	10,83	10,63	10,43	10,22	10,02	9,82	9,61	9,41	9,21
calorific value	kWh/m³	10,53	10,34	10,15	9,96	9,77	9,58	9,39	9,20	9,01	8,82	8,63	8,45	8,26
Wobbe number	kWh/m³	14,71	14,62	14,53	14,43	14,34	14,25	14,15	14,06	13,96	13,87	13,78	13,68	13,59
relative density	-	0,627	0,613	0,599	0,585	0,571	0,557	0,543	0,529	0,515	0,501	0,487	0,473	0,459
min. air requirement	m³/m³	10,07	9,88	9,68	9,49	9,30	9,11	8,91	8,72	8,53	8,33	8,14	7,95	7,76
min. flue gas volume dry	m³/m³	9,07	8,89	8,71	8,52	8,34	8,16	7,98	7,80	7,62	7,44	7,26	7,08	6,90
CO_2 factor	g/kWh	205	204	202	201	199	197	195	193	191	189	187	185	183
CO_{2max} dry	Vol-%	12,1	12,0	12,0	11,9	11,8	11,7	11,7	11,6	11,5	11,4	11,3	11,2	11,1
H_2O content dry	g/m³	182	184	185	187	188	190	191	193	195	196	198	200	202
water dew point (GERG 2004)	°C	58,6	58,7	58,9	59,0	59,1	59,3	59,4	59,6	59,7	59,9	60,1	60,2	60,4
lower ignition limit	Vol%	4,12	4,12	4,12	4,11	4,10	4,11	4,10	4,09	4,10	4,10	4,09	4,09	4,08
higher ignition limit	Vol%	17,7	18,0	18,4	18,8	19,2	19,6	10,1	20,6	21,1	21,6	22,1	22,7	23,3

Table 2: Characteristic values of natural gas H from the North Sea with increasing admixture of hydrogen.

Flame velocity

Figure 4 plots the laminar flame velocity of hydrogen, pure methane and 2 mixtures against the air ratio **[4]**. The maximum laminar flame velocity of hydrogen is around 8 times that of natural gases or pure methane.
However mixing with methane greatly reduces the flame velocity which for mixtures with 30% hydrogen in methane is only about 30% above that of pure methane. The maximum velocity has shifted towards the stoichiometric point.

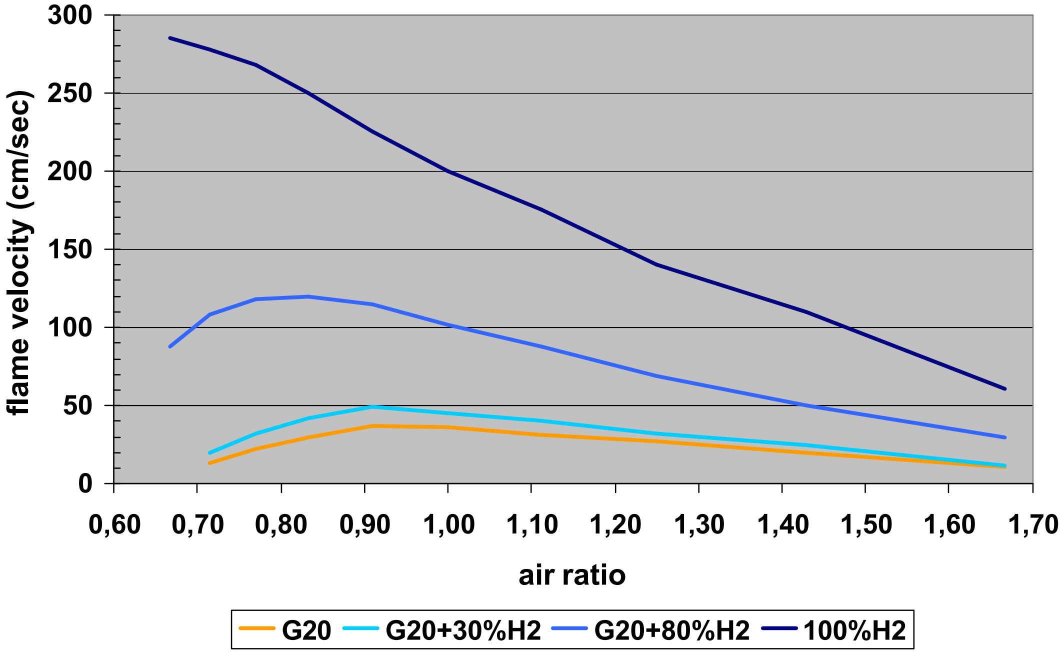


Fig. 4: Flame velocity of hydrogen, methane and mixtures of both [4]

Impact on flame stability and load

Within a supply area for group H natural gas, the gas appliances are usually set to G20 (100% methane) with a Wobbe number of 53.5 MJ/m³. If hydrogen is now added to this supply of natural gas H, the load and the air ratio or primary air ratio at the burner will change while the burner setting remains constant. Both variables can be calculated from the key data of the gases:

$$Q_{new} = Q_{G20} \times \frac{W_{new}}{W_{G20}}; \ (1) \qquad \lambda_{new} = \lambda_{G20} \times \frac{l_{G20}}{l_{new}} \times \sqrt{\frac{d_{new}}{d_{G20}}}; \ (2)$$

As is generally known, the formula for calculating the load variation (1) is based on the Bernoulli equation applied to the gas flow through the nozzle, and is used for comparison at constant nozzle pressures and hence for all burner types, such as atmospheric burners, premixing burners, jet burners etc. to which the gas is fed via a nozzle. The formula for calculating the air ratio variation (2) is based on the assumed constant volumetric flow rate of the combustion air. This assumption is quite reliable for premixing, jet burners and similar burners to which the gas is fed with the help of a fan. As gas composition changes however, pressure conditions at the burner or in the combustion chamber can also change, e.g. as the burner surface gets hotter from flames sitting closer to it. In this case the flow rate of the combustion air may be influenced and the formula ceases to apply exactly.
With atmospheric burners and injector burners, the volume of aspirated air is determined by the mass flow of the open gas jet. Calculations based on the physical laws of the free gas jet

indicate that for highly premixing atmospheric injector burners, assuming a constant combustion air flow is equally justified.
These types of burner are used in all more recent low-NO_x atmospheric domestic appliances. If we apply both formulae to typical premixing burners with a basic setting of G20 and an air ratio of 1.2, we can calculate the variations in load and air ratio when using different standard test and pipeline gases from Germany, see **Figure 5.**

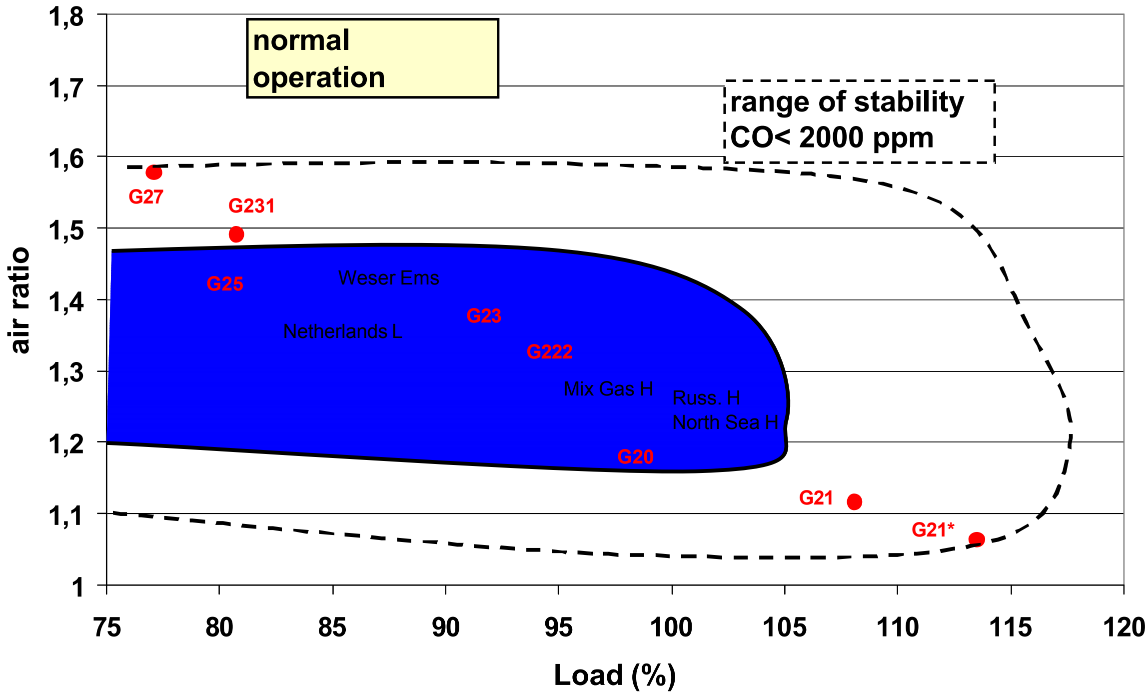


Fig. 5: Diagram of relative load and air ratio for a burner adjusted to G20 at 100% load and air factor of 1.2 and operated with different gases

Each burner has a certain range of stability in terms of load and air ratio within which it burns stably and with low emissions. Depending on the basic setting, we can now apply a certain bandwidth to the Wobbe number without the burner suffering major operational limitations or even faults. Figure 5 also shows the standard test gases used for burners. Test gas G222 with 23% hydrogen is used as standard in Europe as a test gas against flash-back. The variations in air ratio and load have also been calculated for hydrogen blending into natural gas H from the North Sea, and are shown in **Table 3**.

Admixture of Hydrogen to Natural Gas (North Sea) Calculated Load and Air Ratio for a Burner adjusted to G20			
Hydrogen (%)	Load (%)	adjusted to λ=1,25	adjusted to λ_p=0,8
0.0%	99.0%	1.31	0.80
2.5%	98.4%	1.32	0.81
5.0%	97.8%	1.33	0.82
7.5%	97.1%	1.34	0.82
10.0%	96.5%	1.35	0.83
12.5%	95.9%	1.36	0.84
15.0%	95.2%	1.37	0.85
20.0%	94.0%	1.40	0.86
25.0%	92.7%	1.42	0.88
30.0%	91.4%	1.45	0.89

Table 3: Variation of load and air ratio λ for a burner adjusted with G20 to λ = 1.3 or λ = 0.8 respectively and operated with natural gas H from the North Sea with increasing levels of hydrogen. For changes in temperature of the air, λ may increase by another 0.05.

Under otherwise constant boundary conditions therefore, injecting 30% hydrogen results in a reduction in load of 8.6 %.

The air ratio is very important for flame stability, as flame velocity changes significantly with changes in air ratio. As is generally known, the stability of the flame is based on the local equilibrium between the flame velocity and the velocity of the inflowing uncombusted mixture. When hydrogen is added, the flame velocity will change because of the changing air ratio and because of the different composition of the mixture. In the case of a fuel-lean premixing burner (e.g. a premixing burner for a gas condensing boiler), these two effects work in the opposite direction, see **Figure 6**, so that it should be possible to stabilise the flame up to higher air ratios than is the case with pure natural gas operation.

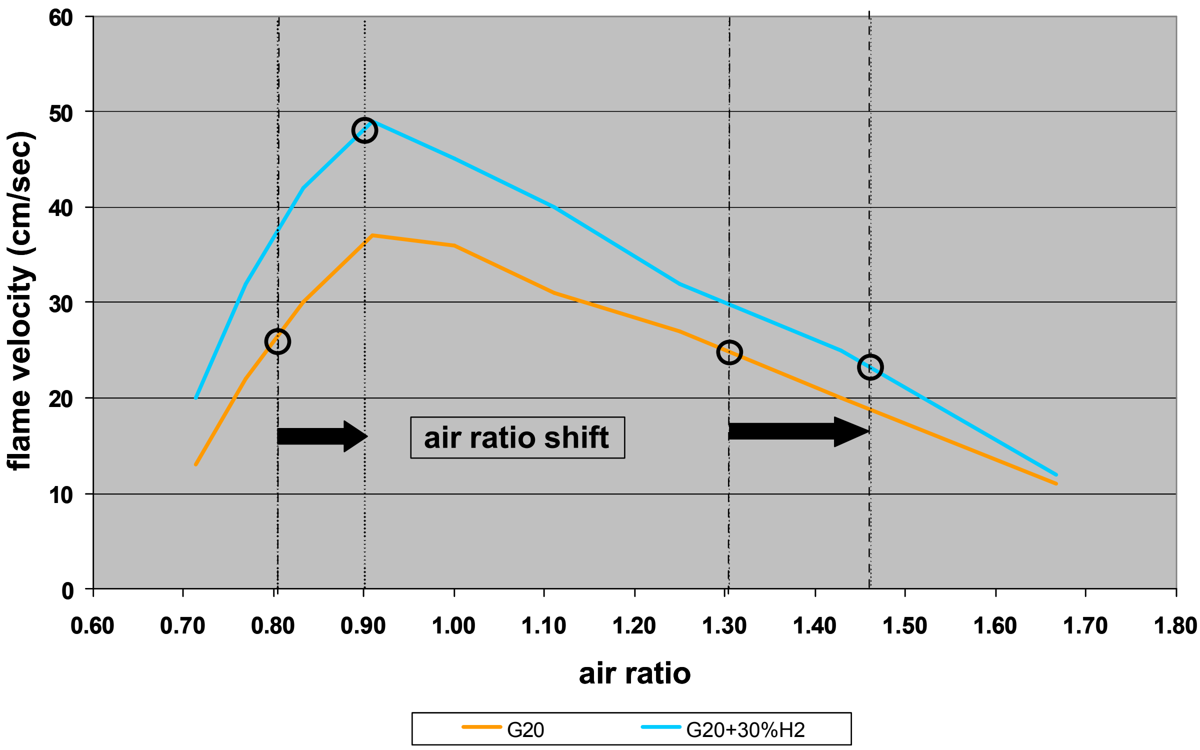


Fig. 6: Shift in (primary) air ratio for two different premix burners and the change of flame velocity, when switching the gas from methane to 70/30 methane/hydrogen mixture, flame velocity data from **[4]**

With fuel-rich premixing burners, especially with high primary air ratios such as low-NO_x atmospheric burners, both effects work in the same direction however, so the local flame velocity can almost double. The flame will therefore sit much closer to the burner and could cause problems of overheating in practice.
If we allow for additional influences due to inexact burner adjustment, the temperature of the combustion air, pressure from flue updraught, manufacturing variations and similar factors, it will be difficult in practice to achieve adequate 'fitness for purpose' in all applications with such high blending rates.

Impact on flue gas composition
The change in the combustion gas mixture will naturally affect the composition of the flue gas, **see Figure 7**. With increasing level of hydrogen the C/H ratio decrease and with it the maximum CO_{2max} value. The local concentration of ions in the flame is changing. The level of

water vapour and hence the dew point increase. All three effects can also gain significance in practice.

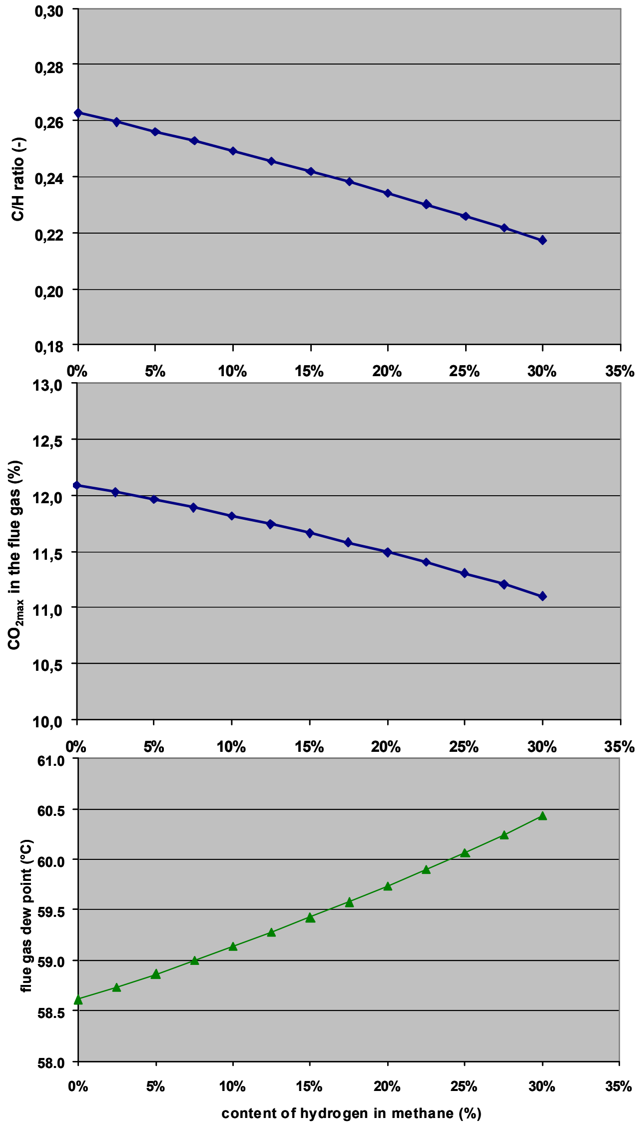


Fig. 7: Characteristic values for the flue gases of methane/hydrogen mixtures: The C/H-ratio, the maximum CO_2-content and the water dew point.

When it comes to burner settings, manufacturers with the installing instructions of the manufacturers quote the measured CO_2 level as a measure for the air ratio that must be obtained. However since with

$$\lambda = 1 + \frac{v_{\min}}{l_{\min}} \times \left(\frac{CO_{2\max}}{CO_2} - 1\right) \quad (3) \qquad \text{or simplified} \quad \lambda \sim \frac{CO_{2\max}}{CO_2} \quad (4)$$

the air ratio depends not only on the measured CO_2 but on the CO_{2max} value of the current gas mixture as well, the setting of the burner becomes increasingly inexact. The air ratio actually present at the burner was calculated for a typical setting instruction to 9.5% CO_2 in the flue gas for blending rates of up to 30%, and is shown in **Figure 8**. For the highest blending rate therefore the air ratio is set around one tenth lower than directed: NO_x emissions will be higher and the bandwidth of the burner to higher Wobbe numbers will be restricted. The long-term objective therefore should be to make burner settings and burner checks by reference to O_2 figures. Most modern portable instruments already measure O_2. For convenience internally a CO_2-value is calculated from this measured O_2–value with a

formula containing an average CO_{2max}-value for natural gases. This causes further deviations.
Figure 7 shows that even with 30% hydrogen, condensation only sets in about 2 K earlier, i.e. at 60.5°C instead of at 58.5%°C. This is positive, as condensation occurs earlier, but will not have a significant effect in practice.

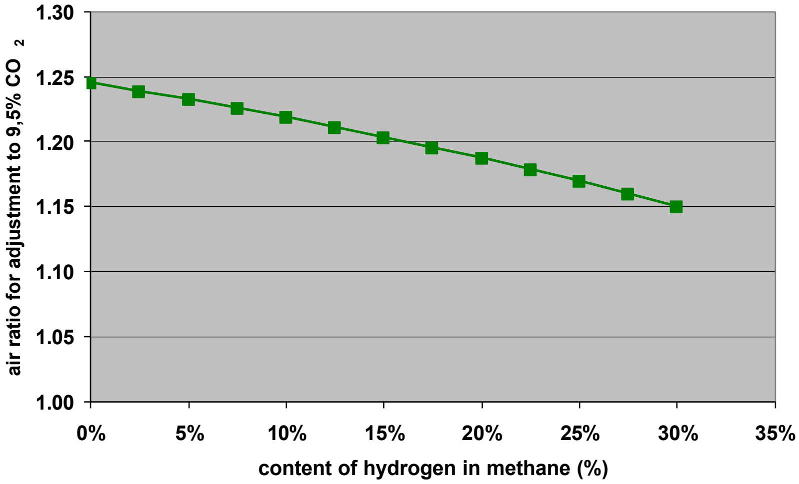


Fig. 8: Resulting air factor when a burner is adjusted to 9.5% CO_2 in the flue gases and operated with methane/hydrogen mixtures.

The concentration of ions in the flame is important for flame safety device. The ionisation signal is also used for SCOT® combustion control systems. Both of these influences were investigated in the laboratory using measurement techniques.

4.2 Experimental laboratory investigations

For the laboratory investigations we selected 6 different appliances – an atmospheric gas boiler, two gas condensing boilers, two gas condensing boilers with SCOT combustion control and a Stirling Micro CHP appliance, see **Table 4.**

	Appliance	**Load**	**Burner Type**
1	Atmospheric boiler	8 – 20 kW	Atmospheric flat, fully premixed, water cooled burner,
1	Condensing boiler	3 – 15 kW	Fully premixed modulating premix burner flat perforated ceramic burner plate SCOT combustion control
1	Condensing boiler	7 – 22 kW	Fully premixed modulating premix burner Perforate, cylindrical metal burner
1	Condensing boiler	4 – 12 kW	Fully premixed modulating premix burner Half spherical metal mesh burner surface SCOT combustion control
1	Condensing boiler	5 – 15 kW	Fully premixed modulating premix burner flat perforated metal burner plate SCOT combustion control
1	Stirling Micro CHP	5 – 24 kW 5 kW Stirling	One burner for the stirling engine Second burner for the add on heater

Table 4: Appliances investigated on the test stand in the labs of E.ON Ruhrgas

The appliances were installed one after the other on the E.ON Ruhrgas test stand at Altenessen, see **Figure 9.**

Each appliance was operated with natural gas H, methane (G20) and mixtures of G20 and up to 30% hydrogen at full load and partial load and at two different water flow return temperatures. At each test point the measured variables in **Table 5** were recorded, digitised and stored. From these measured variables we determined the load and efficiency as well as the air ratios from O_2 and calculated the air-free, dry pollutant levels (NO_x and CO). Finally a cold
start was excecuted. The greatest possible emphasis was placed on high measuring accuracy, especially of the flow rate for the gas. An energy balance for each appliance was prepared at the start of the tests for control purposes, see **[5].**

Fig. 9: Condensing boiler installed on the test stand in the lab at E.ON Ruhrgas in Altenessen

Measured variable	**Unit**
Temperatures	
water flow in, out	°C
flue gas	°C
room temperature	°C
Flow	
mass flow gas	kg/h
Volume flow water	m³/h
Flue Gas	
O_2	ppm
CO_2	ppm
NOx	ppm
CO	ppm
CxHy	ppm

Table 5: Measured variables

Combustion quality and flame stability

Air ratio and CO emissions as well as cold-start attempts are good indicators against which to judge flame stability and combustion quality. **Figures 10 to 13** plot the measured air ratios, thermal efficiency and CO and NO_x emissions from the four gas appliance types against the blending rate.

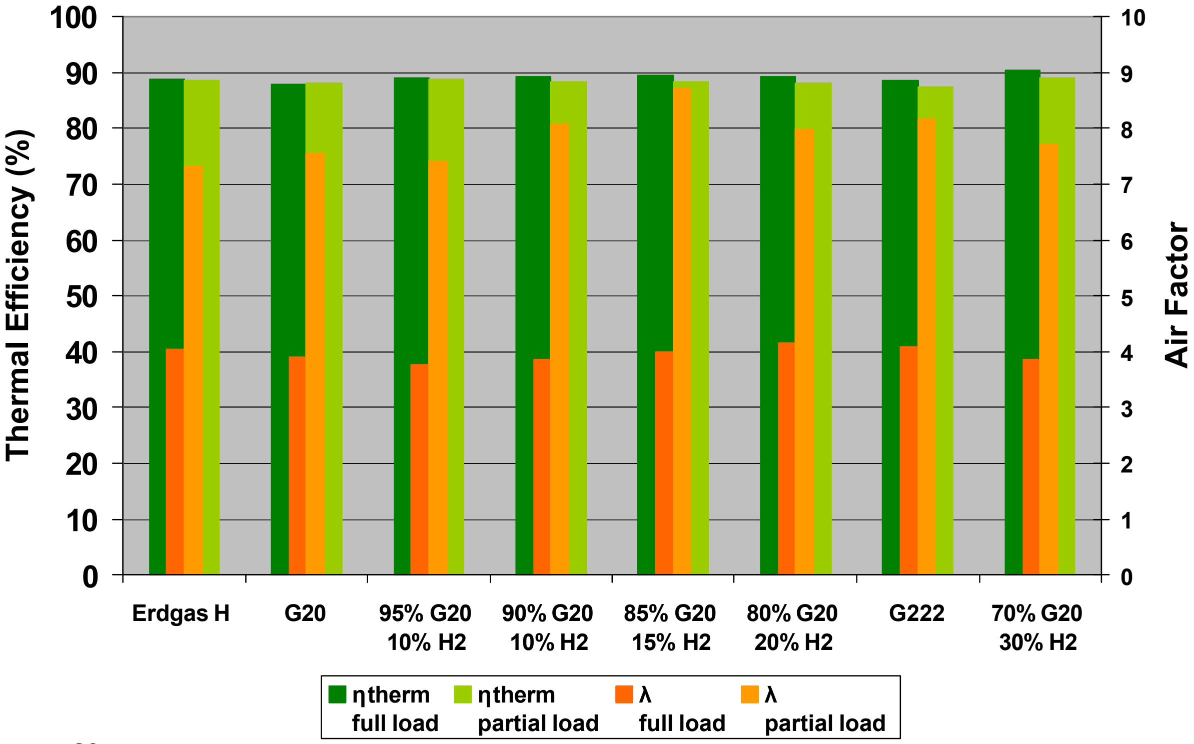
The total air ratio measured for the atmospheric boiler downstream of the flow trip (Figure 10) shows only minimal dependence on the blending rate. The CO and NO_x emissions in full load fall as blending increases. The CO emissions rise again in partial load from 15% H2, indicating that the flame is becoming increasingly unstable, however a cold start was achieved at all test points.

In the appliances without combustion control – the condensing boiler (Figure 11) and the Micro CHP (Figure 13) – the air ratios increase significantly from approx 1.3 to approx. 1.5 as the rate of blending rises. The measured values closely match those calculated by formular (2), see the black curves in the figures 11 and 13. The CO emissions remain low, i.e. the flame stable, in all cases. Again, a cold start was achieved in all cases.

Surprisingly the SCOT combustion control was unable to correct the air ratio as the rate of blending increased (see Figure 12) even though this was kept constant when the appliances were operated with the test gases and usual pipeline gases in the Wobbe range of 33.9 MJ/m³ (G231) to 47.8 MJ/m³ (G21) and even beyond [6]. Appliances with combustion control are therefore subject to the same increase in air ratio as appliances without a control system. However because they are sometimes operated with a higher air ratio at the design point in order to achieve low NO_x emissions, they could react even more sensitively to hydrogen blending.
The reason for the limited effect of the control system is to be found in a very different chemical reaction in the combustion zone with a changed ion concentration. Further investigations into this are needed, particularly since initial results suggest that the control system still exerts some influence at partial load.
A cold start was successfully achieved for all rates of blending even with the combustion controlled appliances.
In contrast to the investigations in the lab, in practice gas condensing boilers are fed with air from outside, which leads to very strongly varying temperatures in summer and winter. An appliances witch was adjusted in summer with an air temperature of 20°C to an air factor of 1.3, will reach an air factor of nearly 1.5 in winter with air temperatures of -15°C. With 10% hydrogen injected in the Natural Gas the air factor will increase another 0.05, so that the appliances will run with 1.55. A lot of premix burners show a strong tendency to flame lift, cause noise or may fail completely.
For all of the test appliances it was found that as the level of hydrogen rises the NO_x emissions decrease owing to the lower temperatures in the combustion zone.

Efficiency
Generally speaking the addition of hydrogen reduced efficiency only minimally (less than 1%). Individual tests with high blending rates indicated a reduction of barely 2%. With the Stirling Micro CHP appliance the electrical efficiency falls increasingly starting from a rate of around 10% and reaches a reduction of up to 2% at 30% hydrogen. This has high practical significance for the electric energy output and hence for the financial return for the end user. Also the overall CO_2 reduction is decreasing, as less electric grid energy with a higher CO_2-factor is replaced by local production.

Load
As hydrogen is added, the Wobbe number falls. The load reduces arithmetically according to (1) by up to 7.3% at 30% hydrogen. (This is a bit less than the reduction with natural gas H as, the Wobbe number of mixtures of methane and hydrogen is slightly higher than that of mixtures with natural gas H, see table 3). Experimental results obtained on three typical appliances – the atmospheric boiler, a condensing boiler and a SCOT-controlled boiler in **Figure 14** – show that in practice the load decreases rather more significantly by approx. 8% to as much as nearly 12%. This is also the case with the combustion controlled appliance because – as was stated above – the control system does not work as expected.
With most domestic boilers, a drop in performance can be tolerated in practice. With large boilers, water heaters, commercial appliances or industrial applications however, customers will often notice a 10% drop in output immediately and complain.



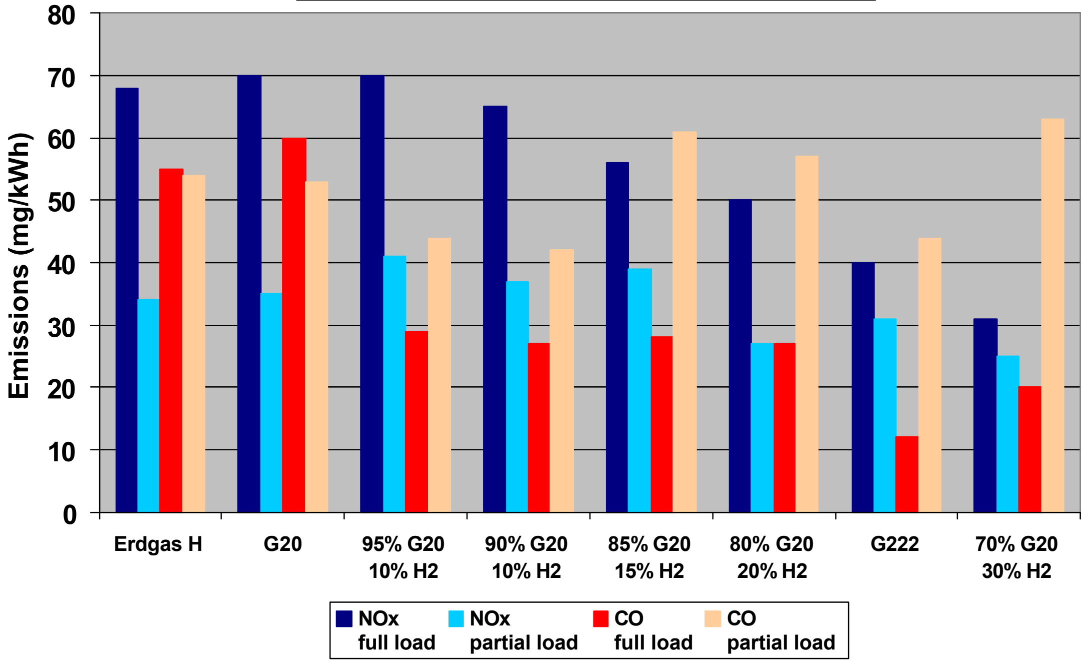
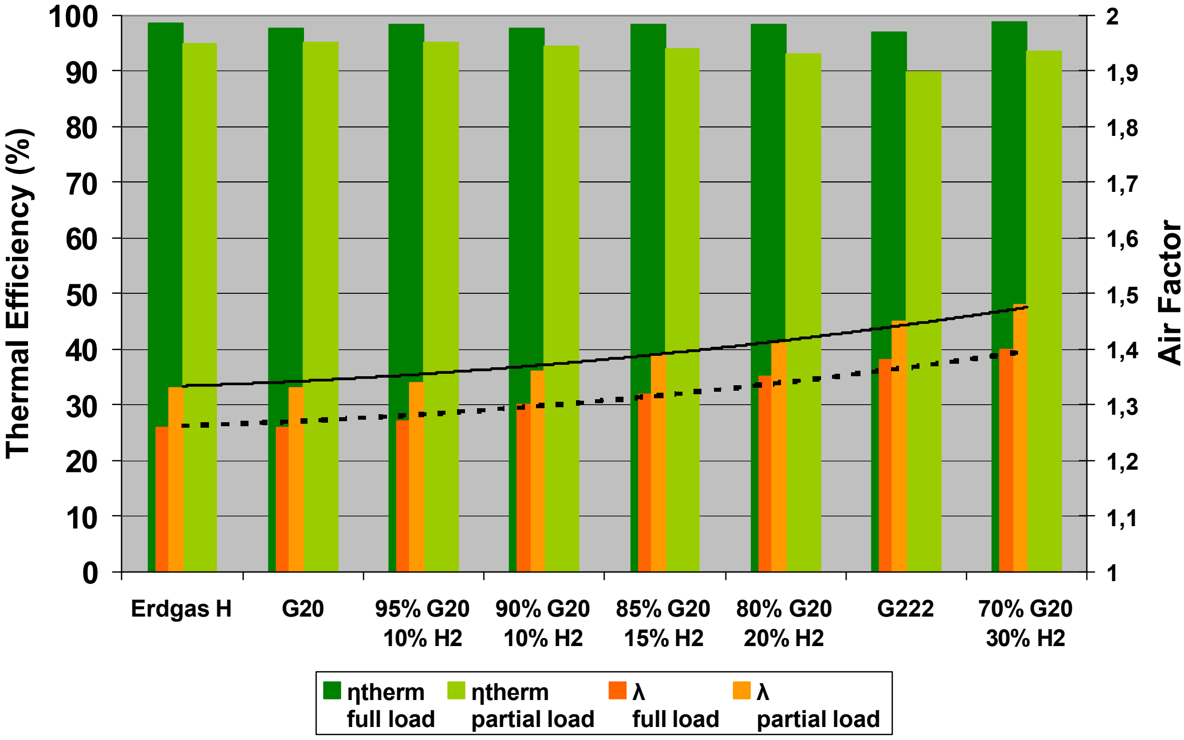


Fig. 10: Measuring results of the atmospheric boiler in full load and partial load; Thermal efficiency and total air factor (above), emissions of CO and NO_x, dry air free (below). Stable combustion in full load, varying CO Emission in partial load show a tendency to flame instability.



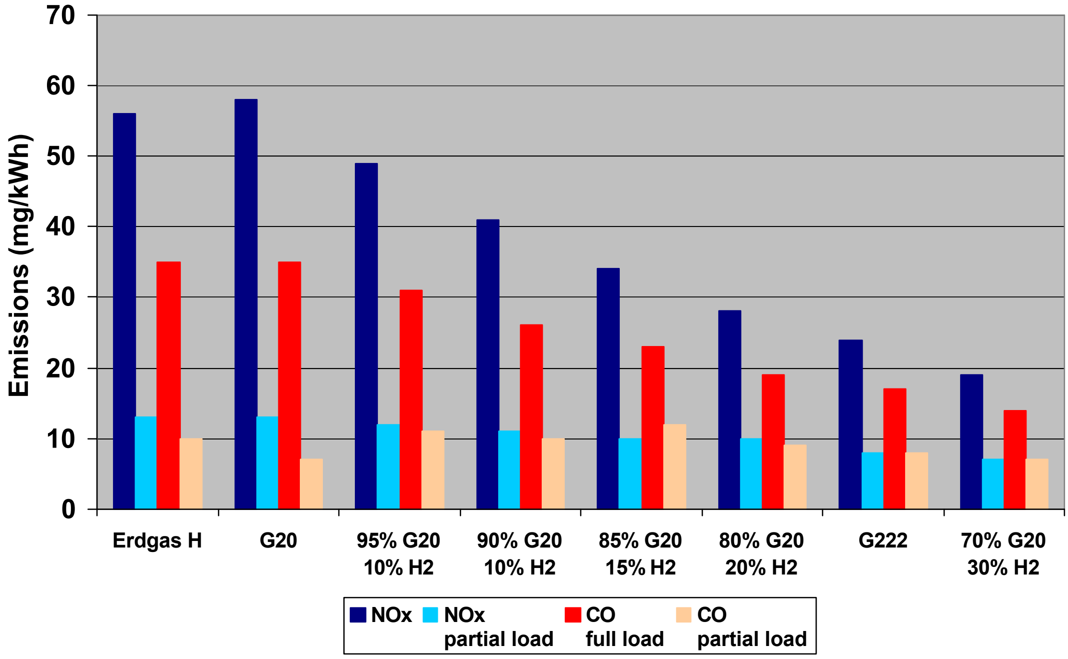


Fig.11: Measuring results of the condensing boiler in full load and partial load; thermal efficiency and air factor with the two prediction curves calculated by (2) (above) and emissions of CO and NO_x, dry air free (below). Air factors are very well predicted, stable combustion and low CO in all measuring points.

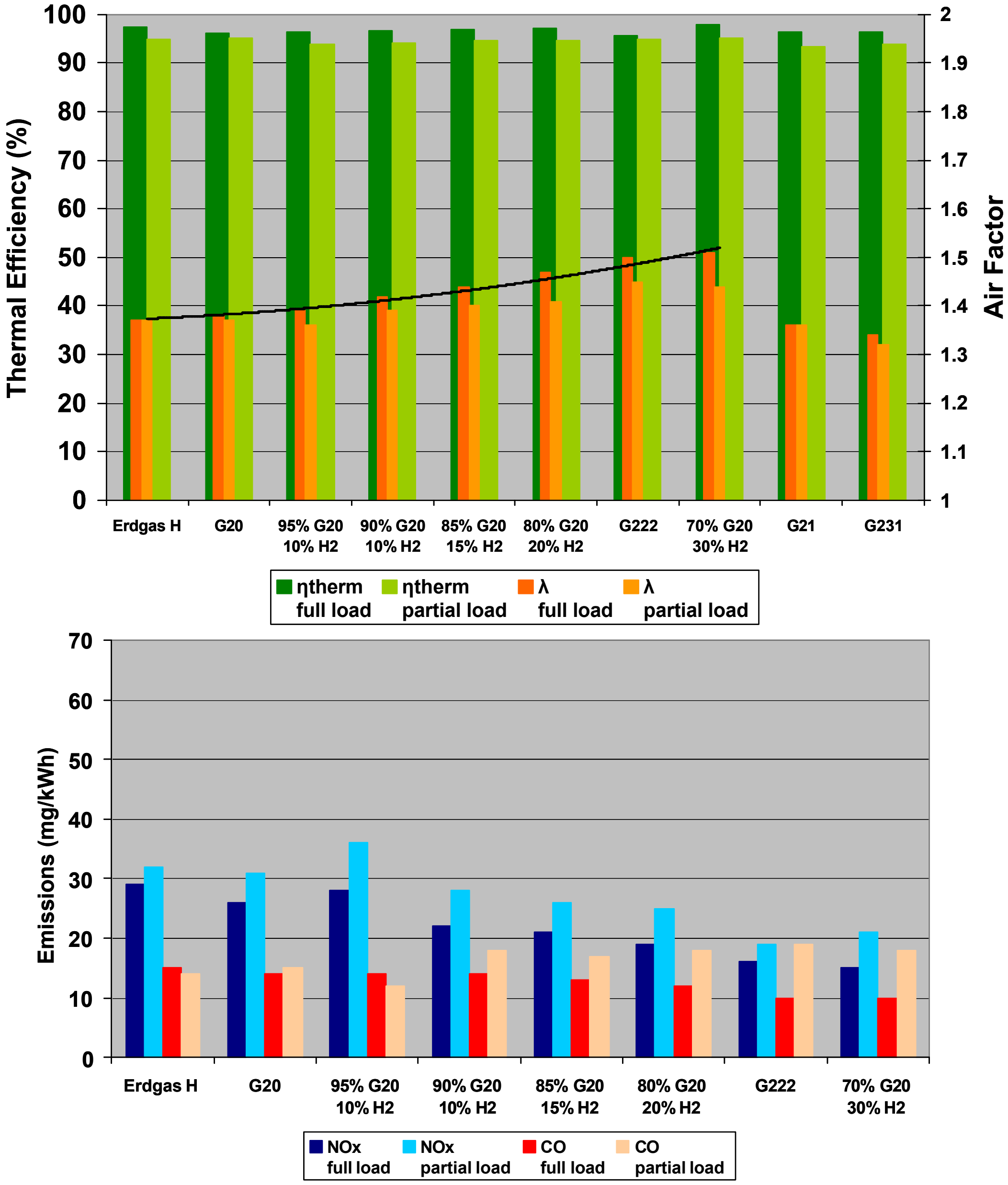


Fig. 12: Measuring results of the condensing boiler with SCOT Combustion control in full load and partial load, thermal efficiency and air factor (above) and emissions of CO and NO_x, dry air free (below). The combustion control does not correct the air factor for gases with hydrogen, but measured values comply with calculated values (black curve) for non controlled burners (2). For standard test gases without hydrogen (right side) the control is working properly. Stable combustion and low CO in all measuring points.

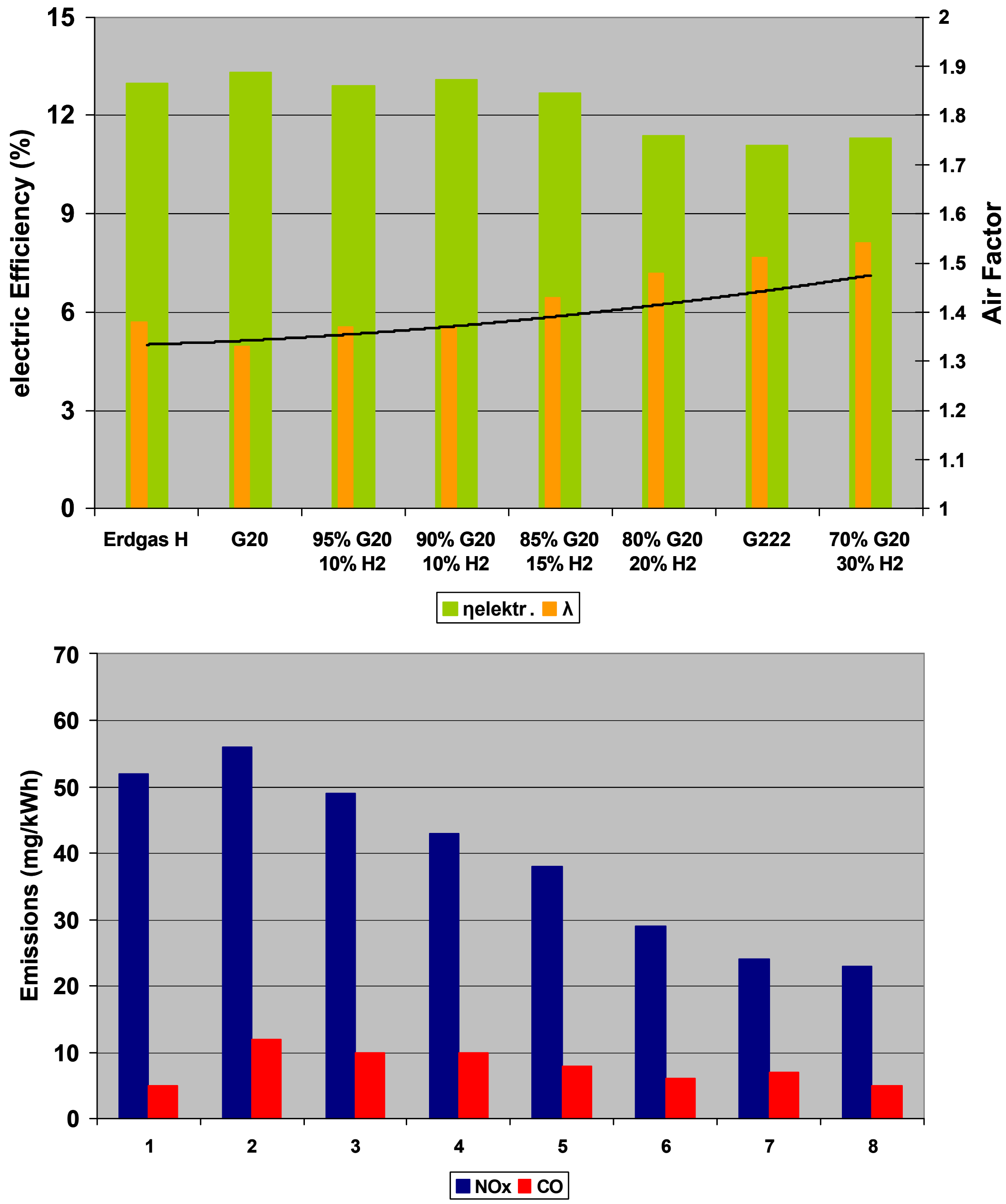


Fig. 13: Measuring results of the Stirling MikroCHP in full load and partial load; thermal efficiency and air factor with the prediction curve calculated by (2) (above) and emissions of CO and NO_x, dry air free (below). Stable combustion and low CO in all measuring points.

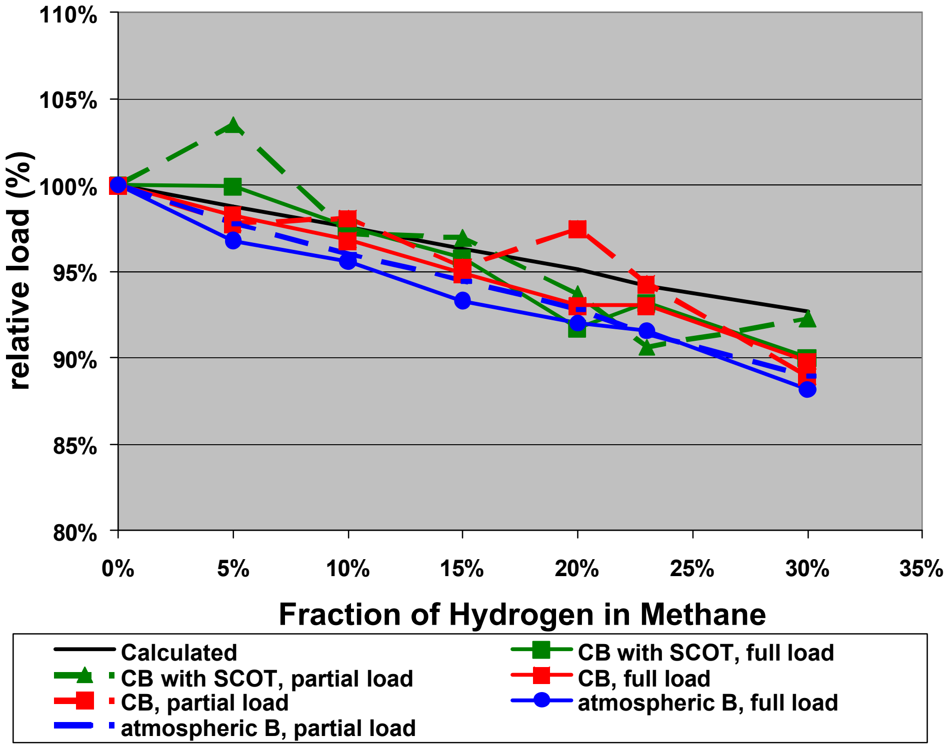


Figure 14: Relative load for the tested boilers with varying content of Hydrogen in Methane.

Summary of experimental investigation
No major problems with combustion stability, efficiency or drop in load were found in the appliances investigated so far with hydrogen blending of up to around 10%. Initial limitations were observed above 10% blending:

- the atmospheric appliance shows an initial rise of CO in partial load,
- the electrical efficiency of the Micro CHP appliance falls by up to 2%,
- the load falls by more than 5% with all appliances
- the rise in air ratio accelerates.

The predicted values of load and air factor fit quite well with the measured values in the lab. Under field conditions of course there are a number of other major factors such as temperature variations in the combustion air, 'drag' in the supply air and flue gas streams, the age of the appliance, the usual variations in gas quality etc., with the result that the blending limit for these appliances should not exceed 10% in practice.

4.3 Preparations for field trials

In order to reach a decision on blending limits that is technically sound and reliable, the laboratory investigations must be broadened out with further appliance tests and practical field trials. Initial field trials were carried out by KIWA Gastec on new, selected gas fires and gas boilers. The appliances were installed in 14 occupied dwellings on the Dutch island of Ameland and operated with up to 20% hydrogen **[8]**. The feedback has been generally positive.
In the trials that are proposed for Germany, a supply area with around 100 to 300 domestic and commercial gas customers will be identified and a good age mix of buildings will be selected. The project will therefore examine a typical fleet of used gas appliances that work on different operating systems and with different years of registration. Before hydrogen

blending into the grid of this supply area commences, the appliances will be individually logged, their settings will be checked and they will be categorised using the system developed in the GasQual project **[9]**. Hydrogen will then be added in small increments until the limit of DVGW Guideline G260 is reached. Appliances from each category will undergo repeat measurements over the entire period of the trials, and any faults, breakdowns or error messages will be logged.

4.4 Impact on gas distribution components

Gas is distributed using methods, pipelines made from different materials and a huge number of components whose ability to function on hydrogen has been tested.

PE Pipes

The use of PE pipes in gas distribution is on the rise as these materials are easy to work and corrosion resistant. Unlike metal pipes however, plastic pipes display a slight permeation rate. Permeation rates for methane and hydrogen have been measured by KIWA Gastec in a project and published **[10]**, see table 6. The permeation rate of pure hydrogen is some 4.6 times higher than that of pure methane. The measured permeation coefficients were used to calculate the values for mixtures with an increasing level of hydrogen. With 10% hydrogen level released gas volume increases from 4,6 m³/km a to about 6,2 m³/km a which is still acceptable. With higher rates of blending up to 30%, the released amount of gas doubles (9.5 m³/km a). Detailed assessment for a range of field scenarios, e.g. pipeline under an asphalt deck, is still required.

Pipe nr.	Resin type	PC (ml.mm/m²/bara/day) CH_4	H_2	Factor H_2/CH_4
A	PA12	1.64	84.2	51
B	PA12	1.81	79.1	44
C	PA6.12	0.38	-	-
E	“long-chain PA” pipe	5.76	-	-
F	PA12	2.37	95.8	40
	PE100 pipe	35.7 [2]	166 (a)	4.6
	HDPE film	-	156 (b)	-

a: measured at the author’s lab in another project. b: at 25 °C [13]

Table 6: Permeability coefficient (PC) at 21°C for methane and hydrogen of PA pipes and their ratio and comparison to PE100 pipe and HPDE film **[10]**

The effect of temperature on permeation also requires further study, as initial findings indicate that a clear reduction with temperature can be expected. By this the operation of gas distribution pipelines made from PE would be rather possible under special scenarios.

Odorisation

The necessary addition of odorant has to be calculated by reference to the lower ignition limit of the distributed gas. Because the ignition limit varies only slightly, as shown in Table 2, the addition of odorants also remains virtually constant. Additional investigations will be done in the field at the point of longest distances to the odorant injection.

Components in the distribution system

There have been extensive talks with manufacturers on components used in Germany such as diaphragm gas meters, gas pressure regulators and flow monitors.
It is diaphragm meters that are normally used in Germany for volume metering. Identical appliances were already in use at the time of town gas distribution with a level of 40% to 65% H_2. The Elster company also holds town gas licences for its meters. Apart from some slightly higher internal leak rates, no other effects are expected from blending hydrogen with natural gas.
Similarly, gas pressure regulators can be used even with pure hydrogen without affecting operation, i.e. the use of natural gas/hydrogen mixtures requires neither technical modifications nor changes to licensing regulations.
In Germany, gas flow switches which shut off the pipeline above a predetermined flow rate are used as standard to protect gas pipelines from excavator impact for instance. This flow rate depends on the density of the flowing gas and can be calculated with formula (5):

$$V_{mixture} = V_{EG} \times \sqrt{\frac{d_{EG}}{d_{mixture}}} \qquad (5)$$

In the case under review – a maximum of 30% hydrogen blending – the shutoff flow rate increases by approx. 17% and the length of pipeline that can be protected also increases. Safety objectives are fulfilled.

5 Conclusions

There is a growing debate about the blending of renewably produced hydrogen into the natural gas network. There are many technical questions along the entire chain from gas transmission and storage, distribution and ultimately customer gas usage to which answers are needed. The aim of the project was to answer the questions about final distribution and domestic usage.
Theoretical considerations, laboratory tests on selected appliances and a review of methods, pipeline materials and components would indicate that concentrations of hydrogen up to approx. 10% in the distribution system and domestic appliances are unlikely to cause serious problems in practice.
Above 10% however a number of issues must be resolved, including:

- Safety in distribution (permeation through PE pipes),
- Function (ignition and hygienic combustion under all climatic conditions),
- fitness for purpose (reduction in load)

These results represent initial steps on the road to using renewably produced hydrogen from surplus electricity.
Field trials on a fleet of appliances with a broad age mix and length of service will provide additional intelligence with which to further improve final distribution and domestic usage.
Further in-depth work is needed in the areas of commercial and industrial gas usage, as gas turbines, large gas jet burners, etc. and the automotive sector and in gas storage.
Here the gas industry will progressively create opportunities to assume the key role of storing surplus electricity from wind and solar power while boosting its share of renewable energy in the heating market, meeting key political demands in the process.

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