Testing Hydrogen admixture for Gas Applications

WP3. Intermediate report on the test of technologies by segment - Impact of the different H2 concentrations on safety, efficiency, emissions and correct operation

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Authors	Jean Schweitzer [1]
Affiliation	[1] DGC, Denmark
Corresponding authors	Jean Schweitzer, jsc@dgc.dk
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Partner	**Approval**
P1 – ENGIE	Patrick Milin, patrick.milin@engie.com
P2 – DGC	Jean Schweitzer, jsc@dgc.dk
P3 – GWI	Johannes Schaffert, schaffert@gwi-essen.de ; Hristina Cigarida, hristina.cigarida@gwi-essen.de
P4 – DVGW-EBI	Krishnaveni Krishnaramanujam, krishna@dvgw-ebi.de
P5 – Gas.be	Kris De Wit, kris.dewit@gas.be ; Eric Geerts, eric.geerts@gas.be

Executive summary

The first WP3 reporting period covers M1 to M20 (January 2020 to August 2021), the present report is therefore a first analysis of results that will be consolidated until the end of the project (December 2022). This document has been published for internal review in September 2021 and completed in January 2022, in light of some exchanges during the Workshop held on the 16th of December 2021.

During this reporting period the impact of covid-19 on testing has caused some delays on the planning of tests (4 to 5 months of delay for some labs on the beginning of the testing part).

About 20 appliances have been tested in different segments, defined in the task 2.1. The results so far indicate that observation and analysis from the literature (Tasks 2.2 and 2.3) are confirmed:

- Atmospheric burners are more sensitive to flashback with the addition of H2 in natural gas.
- Premix burners can cope with higher % of H2, but appliances that are “adjustable at constant air-gas ratio” (typically premix) present potentially higher risk (CO emissions).

These results will be used to refine the test programme in order to focus on important or yet unanswered questions.

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List of abbreviations

Non-Technical

AP	Advisory Panel Group
GA	Grant Agreement
GAR	Gas Appliances Regulation
MS	Milestone
TC	Technical Committee (of CEN)
WP	Work Package

Technical

A/F ratio	Air/Fuel ratio, linked to the air excess
CHP	combined heat and power
CH_4	methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
DAF: "dry, air free".	This is used in boilers and other appliances standards to express emission (CO, NOx etc.) values in the combustion products. The concentration of emissions measured is recalculated "dry- air free" which is the same as "dry- 0% O2".
FB	Flashback
FC	Fuel Cell
GHP	Gas Heat Pump
H_2	Hydrogen
H2NG	Hydrogen / Natural Gas blend
HE	Hydrogen Embrittlement
HP	Heat Pump
Hi or Hs	Heating value (Hi: inferior; Hs: superior) (net, gross)
ICE	Internal Combustion Engine
LNG	Liquefied Natural Gas
LPG:	Liquefied Petroleum Gas (usually propane or butane), not considered as a "natural gas"
MN	Methane Number
N_2	Nitrogen
O_2	Oxygen
P.C.B.	Printed Circuit Board
Qmin	Minimum heat input of an appliance (kW)
Qmax	Maximum heat input of an appliance (kW)
ROC	Rate of change (of H2 % increasing or decreasing)
SL	Flame speed or Specific Velocity

UHC	Unburned hydrocarbons
Wi or Ws	Wobbe Index (Wi: inferior; Ws: superior) (net, gross)

Controls

PGS	Pneumatic gas supply
PGAR	Pneumatic gas air ratio
eGAR	Electronic gas air ratio
ACCF	Adaptive combustion control function

1. Introduction

This report is the very first version of the document that will present the THyGA short-term tests' results.

Short-term tests are carried out to observe how appliances react during a small duration (few minutes to few hours) on different H2NG mixtures and long-term test are observing behaviour over several weeks.

The analysis is based on the test of about 20 appliances only and is not yet covering extensively all the segments of the project. However, most of the aspects of the testing are included in the present version that shall be considered as a draft working document to prepare the final report of the end of the project (December 2022). We have tried to incorporate all aspects that are important to us, but there may be more aspects and more analyses that could be added and will be implemented in the light of the comments and corrections we will gather after the dissemination of the document.

Note also that the analysis of the data has disclosed some testing results that need to be discuss more extensively with the laboratories. This may, therefore, lead to changes of some of the data, but we do not expect it should change any of the conclusions made so far.

Deliverable situation for WP3

Table 1 summarizes the public deliverables listed in the Grant Agreement for WP3. The present report is the deliverable D3.5 “Intermediate segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation” within Task 3.2 of the THyGA project. It includes the results from the short-term tests realized on appliances selected by the project during the first steps (activities within WP2)

Deliverable D3.6 will cover the long-term testing and D3.4 will include the “Intermediate testing on components (new and taken from existing installations)”.

Table 1: List of deliverables for the THyGA project (in grey, public deliverable that will be published by December 2022)

Deliverable number	Deliverable title
D3.4	Intermediate testing on components (new and taken from existing installations)
D3.5	Intermediate segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation
D3.6	Intermediate report on the progress of the long-term tests
D3.7	Testing done on components (new and taken from existing installation) from different countries (at least FR, GE, DK and BE) including statistics on results obtained for the leakage testing
D3.8	Segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation
D3.9	Long term effect of H2 on appliances tested
D3.10	Compiling of results from all tasks and development of further statistics at EU and country level

2. Work carried out in WP3 for short term testing. Working method

2.1 WP3 – Experimental Work

The main goals (grant agreement) of WP3 are:

1. To define a **detailed test protocol** based on WP2 input in order to define accurately the details of the testing and to guarantee the best possible reproducibility of testing and making sure that all elements needed for the analysis are included in the reports.
2. To **execute short- and long-term testing** on as many appliances as possible to achieve conclusions on sensitivity to H2 by segments of technologies.
3. To **check the tightness of present indoor installation and appliances components** to H2NG admixture.

The present report covers the short-term testing of point 2, long-term tests are dealt with in D3.6 and leakage tests are in 3.4.

2.2 Elaboration of the protocol

The testing in WP3 is based on a protocol that was developed in the early part of the project, conjointly with WP2 (Task 2.5). The steps of elaboration and interactions with the stakeholders are more precisely described in the public deliverable D2.5 ("Testing programme for hydrogen tolerance tests of domestic and commercial natural gas appliances").

It is important to note that:

- The protocol is as harmonised as possible, so that results of labs are reproducible.
- All aspect related to identified hydrogen impact on appliances are integrated in the protocol so we can be as conclusive as possible at the end of the project.

To reach these two objectives, the project made a lot of efforts to describe as accurately as possible the testing that needs to be executed for internal use. Also, we have involved the test protocol with a wide range of stakeholders, to integrate all existing experience in the project, through several phases.

Phase 1. Preliminary (experimental) protocol (Jan - May 2020)

This phase was based on:

1. Initial analysis of past/previous projects, which have tested gas appliances with H2NG blends.
2. An extended analysis of the effect of H2, based on a simple calculation tool (laminar flame velocity calculation) in order to determine the most crucial situations for H2NG blends.
3. The integration of the conclusion in the test program/test protocol built upon a similar project (GASQUAL, impact on gas quality on domestic appliances).
4. First discussion with all partners (end of January 2020) during the Kick-off meeting.

The preliminary protocol has been subject to several discussions within THyGA and was later sent to the stakeholders (mainly manufacturers and associations in the advisory panel group of the project).

Phase 2. Protocol discussion with the stakeholders (May 2020 and later)

The protocol was presented during a first public event workshop (1st THyGA public Workshop, 6th of May 2020) before being discussed again in further detail in a second workshop including only stakeholders from the advisory panel group (19th of May 2020). The document had previously been sent to this group and also to CEN Technical Committees, to gather as much feedback as possible. Some specific points have also been discussed with stakeholders in bilateral meetings. The protocol was improved and updated following the feedbacks and comments gathered.

Phase 3. Protocol for real use (June 2020 and later)

The testing protocol has been implemented in a practical tool for testing (test sheets & reports) developed in Excel and used as a basis for the testing. The first tests started before the summer 2020 at DGC and GAS.BE and later at GWI for testing/validation of the protocol.

The results have been discussed between the labs, and a number of improvements and corrections were brought to the protocol in order to consider the reality of testing and the first learnings.

During this phase, each new test was analysed, and the new information was used to optimize and improve further the protocol in order to get the best results from the resource allocated. This resulted typically in removing part of some tests that are not contributing very much information and replacing by others that bring more added value to the testing and to the project.

However, the project team stated that the testing structure could only be considered stable by M12; this version was also described and shared with 10 “external labs”[1]. Since then, minor changes and corrections have been added in the light of laboratory regular discussions (every month).

Phase 4. Protocol further improvements (from December 2020)

Each analysis of a new test result is shedding light on how appliances' safety, emissions and performances are impacted by H2 (one of the main goals of WP3). The test results and exchanges with manufacturers on the results also raise new questions.

Therefore, if we want to treat extensively the question of tolerance to H2, we still need to be open to further adaptation of the protocol: we are mainly talking about minor adaptation of the existing protocol and development of operational details on some tests, especially for new appliances not yet tested in the THyGA test program. Most of the changes implemented so far are improvements of the reporting tools (Excel sheets) used for capitalization and comparison of results.

Some complements to the test protocol

- Given the strategy proposed by most DSO/TSOs, the injection to higher level than 30% H2 seems unlikely technically and economically, from a grid perspective. **Thus, in agreement with the FCH JU, THyGA proposes to focus on hydrogen rates below 30%**, while still investigating up to 60% (according to the Grant Agreement).
- The test protocol has been challenged by partners and external stakeholders, it will **cover all points from the Grant Agreement but also include optional tests** that will provide

[1] « External Labs »: independent laboratories interested in putting in practice the THyGA protocol within their facilities; their results could be added to the THyGA’s tests to improve the final analysis of the project.

complementary information and will be performed according to project needs and possibilities (agreement from the manufacturer, availability from the lab, budget, etc.).

Many meetings and communication points both within and outside the project were organised during the covid-19 lockdown period,

- this large number of interactions was very positive for sharing knowledge and dissemination, very useful input was received from the industry (manufacturers and TCs) and implemented in the work programme. The drawback was a need to use quite some time dedicated to meetings for each partner.
- However, a positive consequence was that this methodology favoured communication on the objective of the project and - already - dissemination of THyGA's test protocol. Many manufacturers expressed interest in providing appliances with a consequent potential decrease in cost for the appliances budget.

WP3 has also organised a specific unformal workshop on UHC (Unburned Hydrocarbon) measurements, that are part of the testing programme. This was done in synergy with other projects and has helped laboratories to measure in a harmonised way those emissions.

2.3 Content of the protocol & test program

There are 4 main aspects of H2 impact that THyGA is looking at:

1. Impact on appliance safety
2. Impact on appliance emissions
3. Impact on appliance performances
4. Impact on appliance operation

In practice, we have organised the test in a way to optimise the costs and gathered set points where we could find synergies (for example, some of the safety tests can be combined with performances and emissions tests).

In order to assess these 4 aspects, we have defined the gases that need to be used for the testing, but also all other operation and test conditions that will allow us to make conclusions on the ability of appliances to deal with natural gas/hydrogen blends.

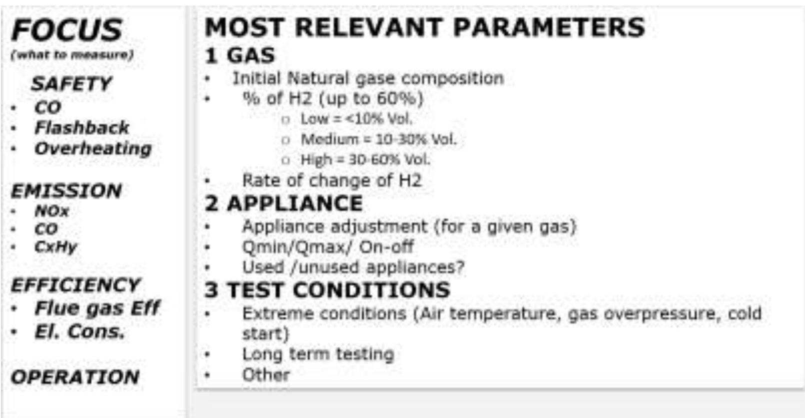


Figure 1: Overall THyGA Test programme

The details of the protocol are given in the document Deliverable D2.5, but for a good understanding of the present report we summarize the main aspects of the testing protocol and test programme in the next section.

2.4 Test programme & protocol for the short-term test

Short-term tests are carried out to observe how appliances react in the short term (few minutes to few hours) on different H2NG mixtures. The evaluation covers safety, energy efficiency, emissions as well as operational aspects (checking that the appliance can give the service it is designed for).

The range of gases chosen for the testing is taken from statistics, from a JRC/ENTSOG Study in 2019. The idea is to test appliances within the extremum of observed range of gases transported in Europe.

- *"The data source for the sensitivity analysis is public, gas quality data for 2015 and 2016 were provided by ENTSOG for the CEN, FGas study on natural gas quality. These data sets correspond to a limited subset of all points. The numbers on the graph are the measured 99th percentile Superior Wobbe Index (15C/15C) of each individual data set. The 1-99th percentile of data was analyzed, as decided upon by SFGas TF1 of the study on gas quality.*
- *The distributed gas quality conformed to national specifications. The size of the markers corresponds to capacity, not actual flow rates.*

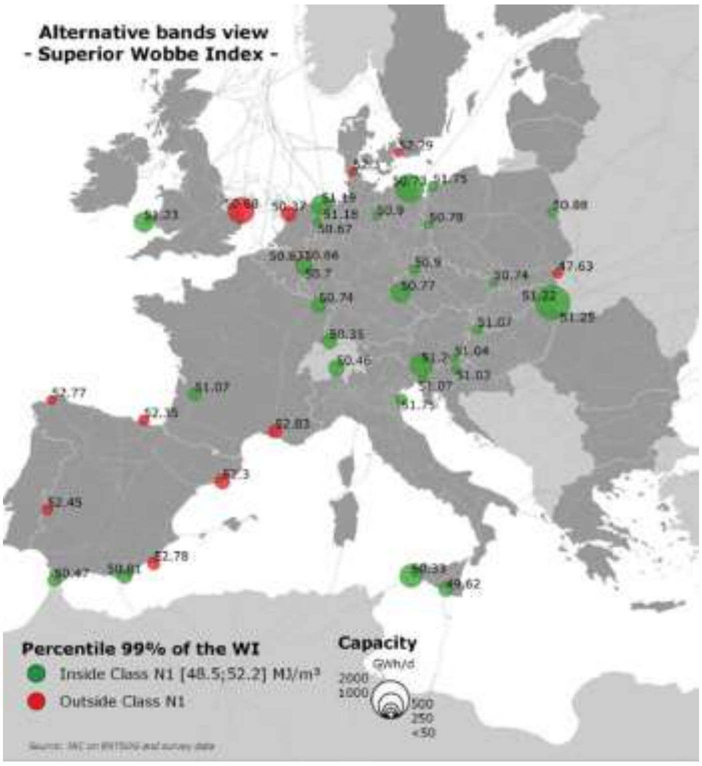


Figure 2: Range of Wobbe Index (superior) transported in Europe from SFGas WG "Pre-normative study of H-gas quality parameters" Survey 2 Information on the currently distributed natural gas quality in different European member states, JRC Zaccarelli, N., Weidner

According to this study,

- the real gas specifications for the Wobbe (Ws) distributed in the EU are between = 47,63 (EU LOW) to 52,78 (EU HIGH) MJ/m3 (15/15) (dWobbe= 5,15 MJ).
- The two limits (EU LOW and EU HIGH) will be used for the project.

In THyGA,

- **EU high is defined as a combination of a binary mix CH_4 + C_3H_8**
- **EU low a binary mix CH_4 + N_2.**

Adding hydrogen to the two gases will bring variation in both Wobbe (Ws) and density as shown on Figure 3.

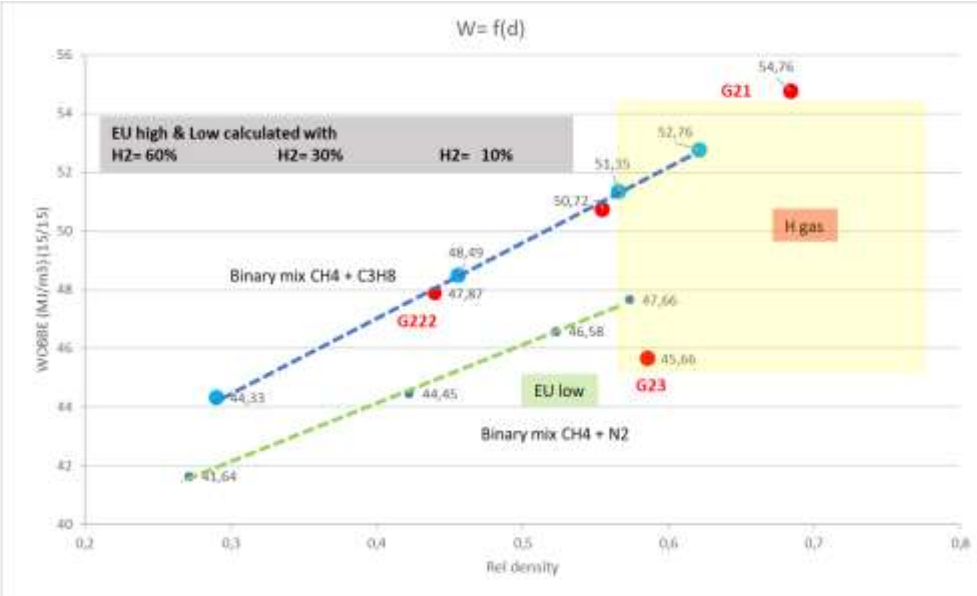


Figure 3: Wobbe (Ws) and Density variations for "EU low" and "EU high" with hydrogen (0, 10, 30, 60%)

Nominal gases chosen for the tests are CH4, EU low, EU high combined with H_2. In addition, tests will comprise various scenarios of adjustment with these gases (with/without H_2) and the use of gases at the other extreme of the range (with and without H_2).

Gas composition (measured) vol (%)												Gas Parameters (Calculated) REF 0/0				
CH4	C2H6	C3H8	C4H10	C4H10	C5H12	C5H12	C6H14	N2	CO2	O2	H2	W_s	d	Hi	Hs	CO2n
Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	Vol (-)	[MJ/m³]	(-)	[MJ/m³]	[MJ/m³]	%
With CH4 as initial gas																
100											0	53,47	0,555	35,818	39,840	11,638
90											10	52,17	0,507	33,314	37,135	11,380
80											20	50,87	0,458	30,810	34,430	11,031
77											23	50,48	0,443	30,059	33,618	10,920
70											30	49,58	0,409	28,306	31,724	10,634
60											40	48,30	0,361	25,802	29,019	10,148
50											50	47,08	0,312	23,298	26,314	9,538
40											60	45,96	0,264	20,793	23,609	8,749
With EU low as initial gas																
95.6								4.4			0	50,30	0,573	34,242	38,087	11,637
86.04								3.96			10	49,17	0,523	31,896	35,557	11,347
76,48								3.52			20	48,04	0,473	29,549	33,027	11,004
73.61								3.388			23	47,71	0,457	28,845	32,268	10,888
66.92								3.08			30	46,94	0,422	27,203	30,497	10,592
57,36								2.64			40	45,87	0,372	24,856	27,967	10,088
47.8								2.2			50	44,87	0,321	22,510	25,438	9,459
38.24								1.76			60	44,00	0,271	20,163	22,908	8,650
With EU high as initial gas																
93		6.6									0	55,51	0,621	39,472	43,759	11,950
84		5.94									10	54,04	0,566	36,602	40,662	11,692
75		5.28									20	52,56	0,511	33,733	37,565	11,384
72		5.082									23	52,10	0,495	32,872	36,636	11,280
65		4.62									30	51,05	0,456	30,863	34,468	11,011
56		3.96									40	49,56	0,401	27,994	31,371	10,551
47		3.3									50	48,10	0,346	25,124	28,274	9,967
37		2.64									60	46,72	0,290	22,255	25,175	9,204

Figure 4: Various gas compositions for the test gases for THyGA project (THY_WP3_019_DataSheet oct 2020c D4) and indicative values for the Wobbe, calorific values and density.

2.5 Reporting methodology

The report is based on a spreadsheet that laboratories are asked to fill in with data and comments about the results obtained.

- The spreadsheet file includes several sheets having each a specific function.
- A data sheet identical for all appliances (and therefore a bit bulky (400 lines X 240 columns)) gives the testing very detail. It includes all test data, text fields, instructions and calculation (gas parameters based on composition, emissions under reference conditions etc.).

		SETTING - TEST CONDITIONS. For all appliances unless otherwise specified test are to be performed in test conditions according the given standards. Eg tamb = 20 +/- 5 C etc..								Instructions	Date & time		Gas composition (measured) vol (%)												Gas Parameters (Calculated)					Gas (Measured)			Gas (Calculated)
	TEST Nr.	Q_{set}	Gas Pressure	Test conditions: Fires (F)	Cookers (C)	W heaters (WH)	Boilers (B) Tin/Tout	Gas: Nominal Test Gas	H_2 set (% vol)	Time for testing and stabilisation time	Date Y-M-D	Time h-m	CH4 Vol.(-)	C2H6 Vol.(-)	C3H8 Vol.(-)	C4H10i Vol.(-)	C4H10n Vol.(-)	C5H12i Vol.(-)	C5H12n Vol.(-)	C6H14 Vol.(-)	N2 Vol.(-)	CO2 Vol.(-)	O2 Vol.(-)	H2 Vol.(-)	W_s (15/15) [MJ/m³]	d (-)	Hi [MJ/m³]	Hs [MJ/m³]	CO2n %	p_{gas} [mbar]	T_{gas} [°C]	Qgas gas flow [m³/h] (at 0,1013)	Q_{test} meas. + corr. [kW]
	Dont modify those columns																																
	1.1 SAFETY- EMISSIONS and EFFICIENCY with CH4 (NOTE that for cooker; Efficiency is treated apart due to the test procedure- see below)																																
	Qmax - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2												QUANTITATIVE TEST: REPORT SHALL BE BASED ON AVG (DATA FILE) AND NOT INSTANTANEOUS DATA NOTED MANUAL																				
	STABILISATION with Natural gas					Adjust. with CH4 according the man. Instructions		BILISATION with Natura																	Don't change the yellow cells (calculations)								
Mandatory	1	Q_{max}	Pnom = 20mbars	Details in development (made by 1st lab testing)	Test to be done with cooking pan. Test En30 with bigest and smallest burner. Starting with water	Details in development (made by 1st lab testing)	Tw 40/60C	CH4	0		27-07-2020	15:45	99.8	0	0	0	0	0	0	0	0.18	0	0	0	50.54	0.556	35.819	39.748	11.638	20.281	19.835	2.0166	20.06
	2								10		28-07-2020	10:31	90.6	0	0	0	0	0	0	0	0.16	0	0	9.28	49.40	0.511	33.497	37.243	11.381	20.432	19.439	2.0857	19.41
	3								20		28-07-2020	10:41	81.1	0	0	0	0	0	0	0	0.15	0	0	18.7	48.23	0.465	31.133	34.693	11.075	20.42	19.326	2.182	18.87
Mandatory	4						Tr = 40C (constant water flow rate for boilers & Wh)		23		27-07-2020	16:08	78.4	0	0	0	0	0	0	0	0.14	0	0	21.5	47.89	0.452	30.443	33.950	10.976	20.211	19.482	2.2373	18.92
	5								30		28-07-2020	08:50	71.6	0	0	0	0	0	0	0	0.13	0	0	28.3	47.06	0.418	28.739	32.111	10.707	20.346	19.954	2.2963	18.33
Mandatory	6								40		28-07-2020	10:59	61.5	0	0	0	0	0	0	0	0.11	0	0	38.4	45.84	0.369	26.211	29.385	10.233	20.379	19.335	2.4347	17.73
	7								50		28-07-2020	09:37	51.2	0	0	0	0	0	0	0	0.1	0	0	48.7	44.62	0.319	23.618	26.589	9.621	20.422	19.814	2.5997	17.06
	8								60		14-08-2020	15:21	39.7	0	0	0	0	0	0	0	0.01	0	0	60.3	43.47	0.262	20.743	23.489	8.720	20.361	19.693	2.8543	16.45
	Additional test if flash back occurs at H2 = X FB % make a test at X FB -5% (refining the Flashback H2% point) and after increase the H2 again to check the the FB occurs again with the same H2. Check aslo the gas pressure influence																																
	Testing of the gas pressure influence									Short time test to see impact of presure variation			QUALITATIVE TEST: YOU MAY NOTING MANUALLY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE INCREAS																				
	9	Q_{max}	Pnom	Test with 40% H2 at Pnom (20 mbars), Pmax (25 mbars), Pmin2 (14 mbars) if possible; Pmin1 (17 mbars) (only PB with if Pmin2) and Visual observation of the change with pressure variation			Tr = 40C	CH4	40%		14-08-2020	15:21	39.7	0	0	0	0	0	0	0	0	0	0	60.3	43.47	0.262	20.737	23.481	8.718	0	0	0	0.00
	10		Pmax				Tr = 40C	CH4			14-08-2020	16:18	39.6	0	0	0	0	0	0	0	0	0	0	60.4	43.46	0.262	20.714	23.457	8.709	0	0	0	0.00
	11		Pmin1				Tr = 40C	CH4			14-08-2020	16:31	39.6	0	0	0	0	0	0	0	0.01	0	0	60.4	43.47	0.262	20.733	23.478	8.717	0	0	0	0.00
	12		Pmin2				Tr = 40C	CH4			14-08-2020	16:50	39.7	0	0	0	0	0	0	0	0	0	0	60.2	43.48	0.263	20.759	23.506	8.726	0	0	0	0.00
	Qmin - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2																																
	STABILISATION with Natural gas					Adjust. with CH4 according the man. Instructions							QUANTITATIVE TEST: REPORT SHALL BE BASED ON AVG (DATA FILE) AND NOT INSTANTANEOUS DATA NOTED MANUAL																				
Mandatory	13	Q_{min}	Pnom	Details in development (made by 1st lab testing)	Test to be done with cooking pan. Qmin adjusted according the standards	Details in development (made by 1st lab testing)	40/60C	CH4	0		29-07-2020	11:27	99.8	0	0	0	0	0	0	0	0.18	0	0	0	50.54	0.556	35.820	39.749	11.638	19.878	19.417	0.4372	4.35
	14								10		29-07-2020	15:34	89.8	0	0	0	0	0	0	0	0.16	0	0	10	49.31	0.507	33.312	37.044	11.359	19.803	19.493	0.4588	4.25
	15								20		29-07-2020	16:04	80.3	0	0	0	0	0	0	0	0.14	0	0	19.5	48.14	0.461	30.932	34.477	11.047	19.783	20.031	0.4769	4.10
Mandatory	16								23		29-07-2020	12:29	77.4	0	0	0	0	0	0	0	0.14	0	0	22.5	47.77	0.447	30.192	33.679	10.938	19.831	19.785	0.4861	4.08
	17						Tr = 40C (constant water flow rate for boilers & Wh)		30		29-07-2020	13:30	70.5	0	0	0	0	0	0	0	0.13	0	0	29.4	46.92	0.413	28.459	31.810	10.659	19.774	19.654	0.5018	3.97
Mandatory	18								40		29-07-2020	16:42	62.2	0	0	0	0	0	0	0	0.12	0	0	37.7	45.91	0.372	26.371	29.558	10.266	19.845	19.772	0.5261	3.85
	19								50		29-07-2020	14:31	52.1	0	0	0	0	0	0	0	0.1	0	0	47.8	44.73	0.323	23.842	26.830	9.680	19.738	19.888	0.5632	3.73
	20								60		14-08-2020	12:06	40.7	0	0	0	0	0	0	0	0	0	0	59.3	43.57	0.267	20.988	23.752	8.808	19.894	20.003	0.6177	3.60

Figure 5: Extract from the “test sheet”

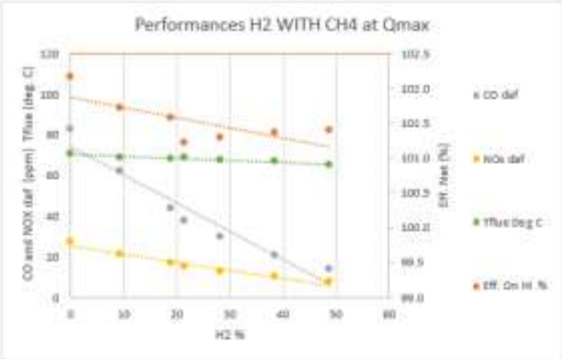
Partners have been asked not to modify the data sheet so as to make the further work with the data and results easier.

The sheet has been improved in light of the first testing and is regularly corrected and improved when new questions and observation are made by partners. So, it is expected that the document will continue to evolve, to get the highest benefit from the test carried out.

The data sheet also includes a report sheet that is partly automated with the data extracted from the data. The main information is included in those “report” sheets with a sufficient level of detail for the analysis of the results. When there is a need to discuss more about the testing results, we can investigate the very detail in the data sheet or in the original data files for each test that are kept by the laboratories. This report allows the labs to see the results in a glance and possibly resolve visible issues. **So far (M20), the project has gathered about 20 test files**.

2.1 & 2.2 PERFORMANCES with CH4 (Qmax) test at 60/40 C (for the first test)

	H2	Wobbe (Ws)	Eff	CO daf	NOX daf	Qtest (input)	Tfluegas	CO2	O2
	%	[MJ/m³]	% on Hi	ppm	ppm	kW	[°C]	[%]	[%]
1	0.0	50.54	102.2	83	28	20.06	70	9.1	4.8
2	9.3	49.40	101.7	62	21	19.41	69	8.3	5.4
3	18.7	48.23	101.6	44	17	18.87	68	7.8	6.0
4	21.5	47.89	101.2	37	15	18.92	69	7.7	6.2
5	28.3	47.06	101.3	30	13	18.33	68	7.3	6.6
6	38.4	45.84	101.4	21	10	17.73	67	6.7	7.3
7	48.7	44.62	101.4	14	8	17.06	65	6.0	8.0
8	60.3	43.47		11	8	16.45	0	5.3	8.4



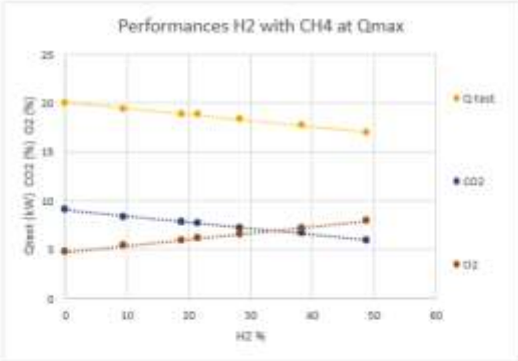


Figure 6: Example of data table and figures extracted from the rest report.

2.6 Control of the report quality

Before finalisation, the report is **controlled by a third party** (another THyGA laboratory). The objective is double:

1. Control & discuss the test results and check that no important point was missed and that there are no mistakes.
2. Having the third party learn how the other labs are performing the test. This should result in a better harmonisation of practice and reproducibility of the test between the labs.

2.7 Present state of reporting. THyGA appliance ID

We have so far gathered about 20 reports, note that not all of them have been through the control and there are still possible changes and corrections on some aspects. However, the project included the existing data and results for this preliminary intermediate view in the following analysis. Table 2 lists the appliances that were tested (anonymized), it shows that there is already a wide variety of appliances of different types and different burners.

Table 2: Appliances tested so far (at M20)

Report	SEGMENT Nr		Appliance category	Appliance type (2)	Burner type	For cooker hobs: burner tested?	Modulating burner (Y/N)	Pressure regulator (Y/N)	Can the appliance be adjusted (Y/N)	Combustion control (Y/N)	Max. power input (net) [kW]	Min. power input (net) [kW]
GA1_SEGM_	101		Boiler		Atmospheric		Y	Y	N	N	25.8	11.0
GW2_SEGM	102		Boiler		Low Nox		Y	Y	Y	N	22.2	8.9
GW03_SEGI	103		Boiler		Atmospheric		N	Y	Y	N	17.0	
BA01_SEGM	107		Boiler		Low NOx		Y	Y	Y	Y	24.8	10.6
D4_SEGM_1	108		Boiler		Premix		Y	Y	Y	Y	20.0	4.8
GW1_SEGM	108		Boiler		Premix		Y	Y	N	Y	24.0	6.9
GA5_SEGM_	201		Water heater		Atmosperhic		N	N	N	N	10.5	5.3
GA5_SEGM_	201		Water heater		Atmosperhic		N	N	N	N	10.5	5.3
D1_SEGM_3	301		Cooking Hob		Atmospheric (*)	Large	N	N	N	N	3.0	0.8
D2_SEGM_3	301		Cooking Hob		Atmospheric (*)	Small	N	N	N	N	1.0	0.5
D3_SEGM_3	301		Oven			Oven	N	N	N	N	2.5	1.0
D7_SEGM_3	301		Cooking Hob		Atmospheric	Large	N	N	N	N	2.7	0.7
D8_SEGM_3	301		Cooking Hob		Atmospheric	Small	N	N	N	N	0.9	0.3
D9_SEGM_3	311		Oven		Cavity burner	Oven	N	N	N	N	2.4	0.8
D10_SEGM_	311		Oven	Grill	Cavity burner	Oven	N	N	N	N	1.7	
GA4_SEGM_	406		Catering	Fryer	Premix		Y	Y	Y	Y	31.0	16.0
GA3_SEGM_	407		Catering (O)	Gas grill	Atmospheric		N	N	N	N	5.9	
GA2_SEGM_	503		Fire - Convection heater		Atmospheric		Y	Y	N	N	5.8	3.1
				(*) Atmospheric Partially Aerated Single Ring burner” (hob)								

Some explanation for the understanding of the table:

- The “Report” column discloses the code name of the report with the nomenclature agreed upon (Lab_chrono number_segment).
- The “Segment” column gives the type of appliance tested as defined in the segmentation from WP2 (Task 2.1, see list in ANNEX).

In order to make it easy to visualize the tolerance to H2NG admixture, the project a “THyGA appliance ID card” (Figure 7), where the main results can be seen at a glance, without reading a long report.

The concept of the ID card is quite new and has not yet been discussed extensively withing THyGA, and therefore it may evolve in the near future in view of new results and partners' suggestions.

THyGA Appliance ID card for D4_SEGM_108

Appliance	B
Burner	Premix
Origin	Sent by the manufacturer
Segment	108
Max. power input (net) [kW]	20
Min. power input (net) [kW]	5

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	x	x	x	x	x	x	X
1.2 SAFETY- with EULOW	X				X			
1.3 SAFETY- with G23								
1.4 Cold start.	X							X
1.5 Hot start.								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X							X
1.9 Impact of H2 on flame detection.	X							X
1.10 Flash back analyse.	X							
3.1 ADJUSTMENT A	X	X			X			X
3.2 ADJUSTMENT B	X	X			X			X
3.3 ADJUSTMENT H	X	X			X			X
3.4 ADJUSTMENT G	X		X					
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	NA	NA	NA	NA	NA	NA	NA	NA
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X					X		
4.x Other test								

OVERALL

The appliance was tested for short term test with up to 60% H2. Within the test programme executed there has not been any safety issue apart the case of the appliance is adjusted with EU low including 20% H2 and is operated with EUhigh. Efficiency and emissions are impacted by H2.

Figure 7: Example of THyGA ID card (NA = not applicable)

Safety characterization

The card is presently designed in a way to represent **mostly safety aspects** and gathers the information about what level of H2 was tested and what are the results obtained.

- The colour green indicates that we have not detected a safety risk during the testing according to the protocol adopted.

- The colour red indicates that we have detected a safety risk during the testing according to the protocol adopted.
- The colour orange indicates that we have detected a potential safety risk during the testing according to the protocol adopted.
- The colour yellow indicates that we have open questions.

The nuance between risk and potential risk can be difficult to define, but **generally a safety risk will be declared when appliances are no longer behaving as we expect them to when performing a certification test**. This means, for example, that flashback or partial flashback will be considered a safety risk, the same with CO emissions above 1000 ppm (dry - air free).

A potential safety risk signifies that we assume that a situation can develop into a safety risk in the long run. For example, this can be an unstable low flame that may in the long run deteriorate a burner due to the increase of temperature. It is of course a more subjective assessment.

Other reading information

Testing points are indicated with “X” so everybody can see what was tested and what was not (not all % of H2 are compulsory within the THyGA protocol, for example).

The cell colour is interpolated between two points of the same colour, but not in case the colour is different. In this case, the colour is left blank, which means that we cannot conclude (= interpolate between cells of different colours).

Note also that there is a large variety of tests that can be done, but not all of them can be performed due to the budget and capacity of the labs (for example, the delayed ignition can only be performed by one lab).

The advantage of using such cards is to have an easy way to compare results and see in a glance where are the issues with H2 for different or similar appliances.

	GA04	GA03
Appliance	Catering	Catering (O)
Burner	Premix	Atmospheric
Origin	New device, but already used for another project (3 test days).	New appliance, it was a back-up appliance for another project.
Segment	406	407
Max. power input (net) [kW]	31	6
Min. power input (net) [kW]	16	Not specified

SAFETY H2 tested	GA04 0	GA04 10	GA04 20	GA04 23	GA04 30	GA04 40	GA04 50	GA04 60	GA03 0	GA03 10	GA03 20	GA03 23	GA03 30	GA03 40	GA03 50	GA03 60
1.1 SAFETY- with CH4	X			X		X			X			X		X		
1.2 SAFETY- with EULOW		X			X								X			
1.3 SAFETY- with G23																
1.4 Cold start.						X								X		
1.5 Hot start.						X								X		
1.6 Low air temperature (- 10 C)																
1.7 Flue gas pipe length																
1.8 ROC (PLUGG FLOW)						X			X			X		X		
1.9 Impact of H2 on flame detection.						X			X			X		X		
1.10 Flash back analyse.						X			X			X		X		
3.1 ADJUSTMENT A				X					NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B				X					NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H									NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G			X	X	**Not extensive test done**				NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.																
4.2 Soundness																
4.3 Quick variation Qmin-Qmax Shut-off						X								X		
4.4 Overheat. Meas. of temp.																
4.5 Cooker hob test with 4 burn	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind														X		
4.7 Long tem (limited time)																
4.8 Fluctuation of the aux. energy																
4.9 Fluctuation of pressure						X								X		
4.x Other test																

	GA04	GA03
OVERALL	The appliance was tested for the short term test up to 40% H2. The CO value was too high (>5000ppm) when the appliance was adjusted with EULOW30 and tested with EUHIGH. There were no safety issues at Qmax and Qmin when the appliance was adjusted with CH4. According to the manufacturers manuel the appliance may be adjusted between G20 and G25. Other adjustements must be carried out by the manufacturer.	The correct and safe functioning of the appliance is guaranteed up to a mixture of 40%H2. Only the minimum load should be set slightly higher in order to eliminate the occurring noise.

Figure 8: Comparison of results from 2 different THyGA ID card (NA = not applicable)

The cards of the appliances tested so far are given in Annex 1.

3. Test results and analysis. Overall lessons

The results from the first tests are showing that **the most important impact that may hinder the easy development of hydrogen is on safety**. This is especially true for atmospheric appliances that are most sensitive to H_2, but this is also valid for premix appliances that can be severely impacted as well even at low levels of H2 when they are adjusted on site.

Another aspect is linked to the operation, the "**fit for purpose**". Hydrogen may impact the operation of appliances, so they become unsuitable for the purpose they were intended for. For example, decorative heaters may not give the same flame aspect that the customer used to have with natural gas. We do not have enough results to conclude yet on this aspect.

The **impact on appliance emissions is generally positive** (decrease of measured emissions).

The **impact on appliance performances is generally very modest** and can be either positive or negative.

4. Results and analysis for safety

4.1 Introduction

The safety assessment is made through several tests where we evaluate if hydrogen is going to bring appliances in an increased safety risk compared to use with natural gas.

The following risk are considered:

1. The **flame stability and especially the flashback** (or light back) which is often considered as one of the main risks because hydrogen generally increase the flame speed and therefore the probability of flashback appearance.
2. The emissions of CO.
3. The increasing risk of explosion, detonation, fire etc. because of a failure of flame detection, late ignition, leakage etc.
4. The risk of deterioration of components leading to the risk above.

The safety assessment is done through the following testing programme:

1.1 SAFETY- with CH4
1.2 SAFETY- with EULOW
1.3 SAFETY- with G23
1.4 Cold start.
1.5 Hot start.
1.6 Low air temperature (- 10 C)
1.7 Flue gas pipe length
1.8 ROC (PLUGG FLOW)
1.9 Impact of H2 on flame detection.
1.10 Flashback analysis.
3.1 ADJUSTMENT A
3.2 ADJUSTMENT B
3.3 ADJUSTMENT H
3.4 ADJUSTMENT G
4.1 Delayed ignition test.
4.2 Soundness
4.3 Quick variation Qmin-Qmax Shut-off
4.4 Overheat. Meas. of temp.
4.5 Cooker hob test with 4 burners on
4.6 Influence of wind
4.7 Long term (limited time)
4.8 Fluctuation of the aux. energy
4.9 Fluctuation of pressure
4.x Other test

Not all the tests are relevant to all appliances and some new test may need to be added on the way for appliances not yet tested.

4.2 Table with overview of the results (safety)

Table 3 summarizes the results obtained so far; we have separated the premix appliances from the atmospheric ones.

Table 3: Overview of the results from file THY_WP3_045_TTHYGA OVERVIEW v07 (august 2020)

APPLIANCE						H2 % Tested								ELEMENTS TESTED																									
						At what level the problem may occur								Reason for the problem																									
Code	Appliance	Burner	Origin	Segment	Qmax	0	10	20	23	30	40	50	60	CH4	EU LOW	G23	CS	HS	LT	FGP	ROC	FD	FBA	AD_A	AD_B	AD_H	AD_G	DI	S	QV	OH	4B	W	LT	AUX	P	O
PREMIX BURNERS						PREMIX BURNERS																																	
GA04	C	Premix	New de	406	31	X			X		X			X	X		X	X			X	X	X	X	X		X			X		NA				X	
GW02	B	Low NO	old/ use	102	22.2	X	X	X	X	X	X			X		X	X	X			X	X		In discussion								NA					
GW01	B	full prem	old use	108	24	X	X		X	X	X			X	X		X		X	X	X	X		NT	NT	NT	NT					NA					
BA01	B	Low NO	New ap	107	24.8	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	NA	NA	X				NA			X	X	
D4	B	Premix	Sent by	108	20	X		x	x	x	x	x	X	X	X		X				X	X	X	X	X	X	X			NA		NA				X	
D5	B	Premix	Sent by	108	20.8	X		X	X	X	X	X	X	X			X	X			X	X	X	X	X	X	X					NA				x	
ATM BURNERS						ATM BURNERS																																	
D3	CO	atmosp	Bought	301	2.5	X				X	X		X	X	X	x	X	x		NA	tbd	tbd	X	NA	NA	NA	NA	NA		tbd		tbd				X	
D2c	CH	atmosp	Bought	301	1	X							X	X	X	X	X			NA	tbd	X	X	NA	NA	NA	NA	NA		tbd		tbd					
D1	CH	atmosp	Bought	301	3	X						X		X	X		X				tbd	X	X							tbd		tbd					
D7	CH	Surf.at	sent by	301	2.703	X	x		x		x			X	X			X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				X	
D8	CH	Surf.at	sent by	301	0.901	X			x		x			X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X						x	
D9	CO	Cavity	sent by	311	2.432	X			x		x			X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				x	
D10	CO	Cavity	sent by	311	1.712	X					x			X				X	NA	NA				NA	NA	NA	NA	NA				NA					
GA03	C	Atmos	New ap	407	5.9	X					X			X	X		X	X			X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA05	WH	Atmos	Already	201	10.5	X			X		X			X	X		X				X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA02	F	Atmos	Already	503	5.8	X			X		X	X	X	X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	X
GA01	B	Atmos	Already	101	25.8	X			X		X	X		X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	
GW03	B	atmosp	old/use	103	17	X	X	X	X	X	X	X	X	X	X		X	X			X	X	X	X	X		X					NA				X	

In the above table, the following code is used for the appliances: B= Boiler; CH = Cooker Hob; CO = Cooker Oven; WH = Water Heater; C = Catering equipment; F = Fire; FC = Fuel Cell; ICE = Internal combustion Engine; GHP = Gas Heat Pump.

Addition following dialog with labs: for GWI02 the adjustment test was not done: the appliance was wrongly categorised as premix (but it is an atmospheric burner). This will be corrected in the final report end of 2022.

There are three sections in the table

- The section “APPLIANCE” gives brief elements about the appliance tested.
- The section “H2 % Tested” shows at what level of H2 % we have detected safety issues.
- The section “ELEMENTS TESTED” shows what is tested (and not) and reveals what was the reason of the issue identified.

For simplification, we have used the following acronyms to identify the risk (test) assessed:

- CH4 1.1 SAFETY- with CH4
- EULOW 1.2 SAFETY- with EULOW
- G23 1.3 SAFETY- with G23
- CS 1.4 Cold start.
- HS 1.5 Hot start.
- LT 1.6 Low air temperature (- 10 C)
- FGP 1.7 Flue gas pipe length
- ROC 1.8 ROC (PLUGG FLOW)
- FD 1.9 Impact of H2 on flame detection.
- FBA 1.10 Flashback analysis.
- AD_A 3.1 ADJUSTMENT A
- AD_B 3.2 ADJUSTMENT B
- AD_H 3.3 ADJUSTMENT H
- AD_G 3.4 ADJUSTMENT G
- DI 4.1 Delayed ignition test.
- S 4.2 Soundness
- QV 4.3 Quick variation Qmin-Qmax Shut-off
- OH 4.4 Overheat. Meas. of temp.
- 4B 4.5 Cooker hob test with 4 burners on
- W 4.6 Influence of wind
- LT 4.7 Long term (limited time)
- AUX 4.8 Fluctuation of the aux. energy
- P 4.9 Fluctuation of pressure
- Other

4.3 Overall comments on safety results

APPLIANCE						H2 % Tested							
						At what level the problem may occur							
Code	Appliance	Burner	Origin	Segment	Qmax	0	10	20	23	30	40	50	60
PREMIX BURNERS													
GA04	Catering	Premix	New de	406	31	X			X		X		
GW02	B	Low NC	old/ use	102	22.2	X	X	X	X	X	X		
GW01	B	full pren	old use	108	24	X	X		X	X	X		
BA01	B	Low NC	New ap	107	24.8	X	X	X	X	X	X	X	X
D4	B	Premix	Sent by	108	20	X		x	x	x	x	x	X
D5	Boiler	Premix	Sent by	108	20.8	X		X	X	X	X	X	X
ATM BURNERS													
D3	EN30 free	atmosp	Bought	301	2.5	X				X	X		X
D2c	EN30 free	atmosp	Bought	301	1	X							X
D1	EN30 free	atmosp	Bought	301	3	X						X	
D7	CH	Surf. at	sent by	301	2.703	X	x		x		x		
D8	CH	Surf. at	sent by	301	0.901	X			x		x		
D9	C Oven	Cavity b	sent by	311	2.432	X			x		x		
D10	C Oven	Cavity b	sent by	311	1712	X					x		
GA03	Catering (	Atmos	New ap	407	5.9	X					X		
GA05	WH	Atmos	Already	201	10.5	X			X		X		
GA02	EN613 Co	Atmos	Already	503	5.8	X			X		X	X	X
GA01	B	Atmos	Already	101	25.8	X			X		X	X	
GW03	B	atmosp	old/use	103	17	X	X	X	X	X	X	X	X

Figure 9: Overall table showing the present tolerance of appliances tested. For GW01 and GW02 the adjustment test was not done therefore there is an uncertainty on the impact of hydrogen due to adjustment.

In the above table, the following code is used for the appliances: B= Boiler; CH = Cooker Hob; CO = Cooker Oven; WH = Water Heater; C = Catering equipment; F = Fire; FC = Fuel Cell; ICE = Internal combustion Engine; GHP = Gas Heat Pump.

The results from the table may appear slightly unexpected considering what we know from the literature that most issues are expected with flame stability and flashback with hydrogen, therefore especially for atmospheric appliances supposed to be more impacted by the increase of flame speed[2]. **The results show a good behaviour regarding the flashback aspect for atmospheric boiler**.

The main problem identified with premix boilers, identified through the tests, is not flashback but rather the **increase of CO when appliances are adjusted in a situation where in the grid, we have a gas of low Wobbe index with H2**. This situation could become rather common is many places if

[2] See deliverables D2.2 (combustion theory) and D2.3 (past practice and literature analysis) for more details

hydrogen is injected in the grid. In such situations when gas is switching to a gas with higher Wobbe and without H2 (for example in case of interruption of H2 injection), the appliance's air/gas ratio will come closer to stoichiometry and high CO emissions will occur. The only appliances having not faced the issue with adjustments is the BA01 in the table and it was because the test protocol was not respected fully. This is opening a discussion (to be done) about how to treat (within THyGA), appliances that are adjustable (in principle) but when manufacturer instructs the installers NOT to adjust the appliances. We are discussing the adjustment more in detail in a later section.

The threshold we have used for the CO evaluation is 1000 ppm (Dry, air-free) which is one of the limits given for the present appliance certification in the EU.

In conclusion, regarding the safety aspects,

- **the atmospheric technologies tested so far have been able to cope with 30% of H2.**
- As highlighted on Figure 10, **the principal reason for issues for the premix appliances is the adjustment** (code "AD_G"). If we consider this can be solved (blocking the hardware on appliances so that making adjustment by third party is impossible), most appliances will have no problem anymore and can burn up gas with at least 40% H_2.

APPLIANCE						H2 % Tested							
						At what level the problem may occur							
Code	Appliance	Burner	Origin	Segment	Qmax	0	10	20	23	30	40	50	60
PREMIX BURNERS													
GA04	C	Premi	New de	406	31	X			X		X		
GW02	B	LowN	old' us	102	22.2	X	X	X	X	X	X		
GW01	B	full pre	old us	108	24	X	X		X	X	X		
BA01	B	LowN	New ap	107	24.8	X	X	X	X	X	X	X	X
D4	B	Premi	Sent by	108	20	X		X	X	X	X	X	X
D5	B	Premi	Sent by	108	20.8	X		X	X	X	X	X	X
ATM BURNERS													
D3	CO	atmos	Bought	301	2.5	X				X	X		X
D2c	CH	atmos	Bought	301	1	X							X
D1	CH	atmos	Bought	301	3	X						X	
D7	CH	Surf. a	sent by	301	2.703	X	x		x		x		
D8	CH	Surf. a	sent by	301	0.901	X			x		x		
D9	CO	Cavity	sent by	311	2.402	X			x		x		
D10	CO	Cavity	sent by	311	17.2	X					x		
GA03	C	Atmos	New ap	407	5.9	X					X		
GA05	WH	Atmos	Already	201	10.5	X			X		X		
GA02	F	Atmos	Already	503	5.8	X			X		X	X	X
GA01	B	Atmos	Already	101	25.8	X			X		X	X	
GW03	B	atmos	old us	103	9	X	X	X	X	X	X	X	X

Code	ELEMENTS TESTED																							
	Reason for the problem																							
	CHI	EU LOW	G20	CS	HS	LT	FGP	RDC	FD	FBA	AD_A	AD_B	AD_H	AD_G	DI	I	QV	OH	4B	W	LT	AUX	F	O
PREMIX BURNERS																								
GA04	X	X		X	X			X	X	X	X	X		X			X		NA				X	
GW02	X		X	X	X			X	X		In discussion								NA					
GW01	X	X		X		X	X	X	X		NT	NT	NT	NT					NA					
BA01	X	X		X	X		X	X	X	X	X	X	NA	NA	X				NA			X	X	
D4	X	X		X				X	X	X	X	X	X	X			NA		NA				X	
D5	X			X	X			X	X	X	X	X	X	X					NA				x	
ATM BURNERS																								
D3	X	X	x	X	x		NA	tbd	tbd	X	NA	NA	NA	NA	NA		tbd		tbd				X	
D2c	X	X	X	X			NA	tbd	X	X	NA	NA	NA	NA	NA		tbd		tbd					
D1	X	X		X				tbd	X	X							tbd		tbd					
D7	X	X			X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				X	
D8	X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X						x	
D9	X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				x	
D10	X				X	NA	NA				NA	NA	NA	NA	NA				NA					
GA03	X	X		X	X			X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA05	X	X		X				X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA02	X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	X
GA01	X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	
GW03	X	X		X	X			X	X	X	X	X		X					NA				X	

Figure 10: (same as fig 10) Overall table showing the origin of the issues observed. Applies for H2 up to 60%.

In the above table, the following code is used for the appliances: B= Boiler; CH = Cooker Hob; CO = Cooker Oven; WH = Water Heater; C = Catering equipment; F = Fire; FC = Fuel Cell; ICE = Internal combustion Engine; GHP = Gas Heat Pump.

4.4 Flame stability - flashback

Flashback was observed for several appliances

Table 4: Table with result of FB (the table is the same as shown previously (the column under "H2 tested" covers all tests, not only FB test)

APPLIANCE						H2 % Tested								Test
						At what level the problem may occur								
Code	**Appliance**	**Burner**	**Origin**	**Segment**	**Qmax**	0	10	20	23	30	40	50	60	**Flash Back**
PREMIX BURNERS														
GA04	C	Premix	New de	406	31	X		X			X			X
GW02	B	Low NO	old/ use	102	22.2	X	X	X	X	X	X			
GW01	B	full prem	old use	108	24	X	X		X	X	X			
BA01	B	Low NO	New ap	107	24.8	X	X	X	X	X	X	X	X	X
D4	B	Premix	Sent by	108	20	X		x	x	x	x	x	X	X
D5	B	Premix	Sent by	108	20.8	X		X	X	X	X	X	X	X
ATM BURNERS														
D3	CO	atmosp	Bought	301	2.5	X				X	X		X	X
D2c	CH	atmosp	Bought	301	1	X							X	X
D1	CH	atmosp	Bought	301	3	X						X		
D7	CH	Surf. at	sent by	301	2.703	X	x		x		x			X
D8	CH	Surf. at	sent by	301	0.901	X			x		x			X
D9	CO	Cavity b	sent by	311	2.432	X			x		x			X
D10	CO	Cavity b	sent by	311	1712	X					x			
GA03	C	Atmos	New ap	407	5.9	X					X			X
GA05	WH	Atmos	Already	201	10.5	X			X		X			X
GA02	F	Atmos	Already	503	5.8	X			X		X	X	X	X
GA01	B	Atmos	Already	101	25.8	X			X		X	X		X
GW03	B	atmosp	old/use	103	17	X	X	X	X	X	X	X	X	X

Flashback or partial flashback was observed on 5 appliances, 4 of them being atmospheric appliances.

- Partial flashback for a full premix boiler (BA01) was observed only at 60% H2, but not at 50%.
- For the atmospheric appliances, flashback was generally observed at 60% H2 as well, but signs of partial flashback (e.g., increasing of combustion noise) was observed already at 40 % for some (GW03).

The flashback occurrence may sometimes be difficult to identify for appliances where the burner is not visible (typically for premix appliances), consequently there may be some partial flashback in some case that we are not aware of. Moreover, even if labs have been working with H2 handling in the past, FB is occurring for level of H2 that are above 40% and there is not much experience with it.

Test D2 showed that the testing time is critical to identify the risk of flashback

- Tests on cooking hobs with 10 min steps up to 60% H2 showed no flashback. Repeating the test with 60 min steps shows another picture: flashback happens after some time event at H_2% below 60%.
- The picture from the test D2 (right side of Figure 11) shows the appearance of the burner after FB compared (being darker) to a burner where no FB was observed.

A first learning for the future is that the procedure to assess FB shall be carefully chosen (input to WP4 on standardization/certification).

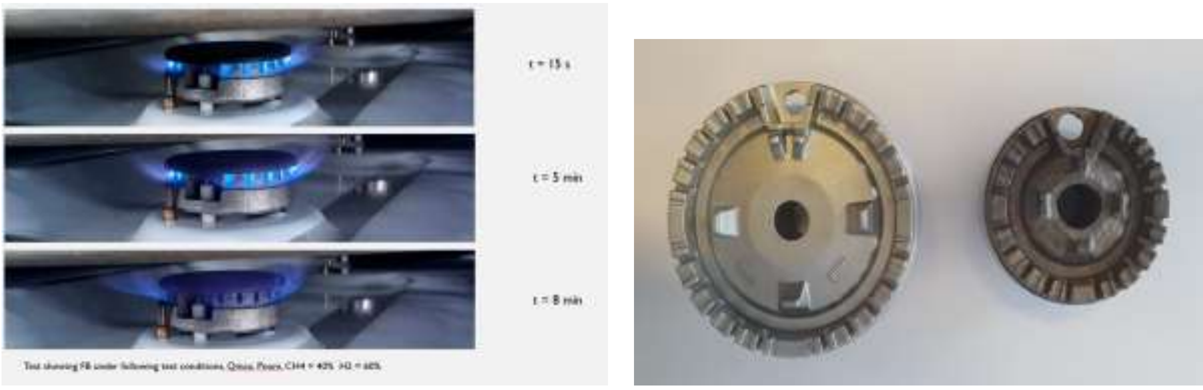


Figure 11: Impact of time on the flame (left picture) and impact of flashback on gas burners (right picture)

4.5 Flame detection

Most of the appliances tested have flame supervision systems based on ionization. For most of them, the ionization signal remains quite high and above the threshold (below which the safety system closes the gas inlet).

The ionization works surprisingly well with the level of H_2 tested (60% in many cases) while we expected problems since the hydrogen flame is invisible and literature feedbacks (see D2.3) highlighted problems with H_2NG admixture. This is a positive result.

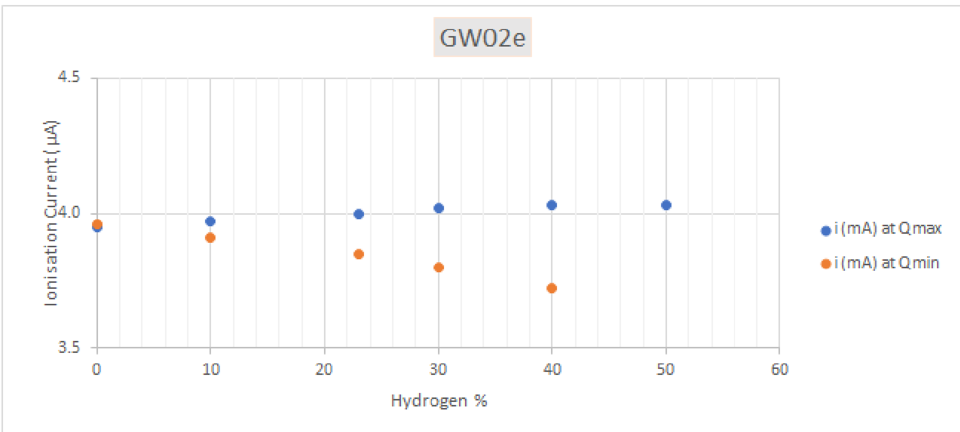


Figure 12: example of ionization signal for GW02

In order to compare the signal measured on different appliances, we have gathered in a single table the result obtained considering a linear evolution. The linear evolution is a biased hypothesis as the signal is generally stable up to 20% and is evolving after, but it has the merit to allow for an easy comparison of trends.

Table 5: Comparison of ionization signal evolution for the appliances tested (at maximum (Qmax) and minimum (Qmin) power)

	D4	BA01	GW01c	GW03	GW02	GA01	GA02	GA03	GA04
Qmax									
Initial value Qmax (µA)	4.9	5.4	16.7	6.2	4.0	12.9	5.9	7.9	102.0
Slope Qmax (µA **for 10 %H2**)	0.2	0.2	0.0	0.8	0.0	-0.5	-1.0	-0.2	0.3
Qmin									
Initial value Qmin (µA)	5.1	6.0	13.7		4.0	7.5	5.4	4.7	103.0
Slope Qmax (µA **for 10 %H2**)	-0.2	-0.1	0.0		-0.1	-0.6	-0.2	0.1	0.3

The model was based on an interpolation between the gas without hydrogen and the maximum percentage of H_2 tested (from 30 to 60%). There is an obvious limit to this calculation, however it allows the following observations

1) For one appliance the signal is much higher than the other ones (GA04). The origin of the signal is not clearly identified, but it is not ionisation
2) For the other appliances, the signal is between 4 and 17 µA for 10% H2.
3) The signal is rather constant apart from one appliance (variation for GA02 is 1 µA for 10% H2 at Qmax).
4) The signal can increase or decrease.
5) The signal at Qmin can be higher or lower compared to the signal at Qmax.

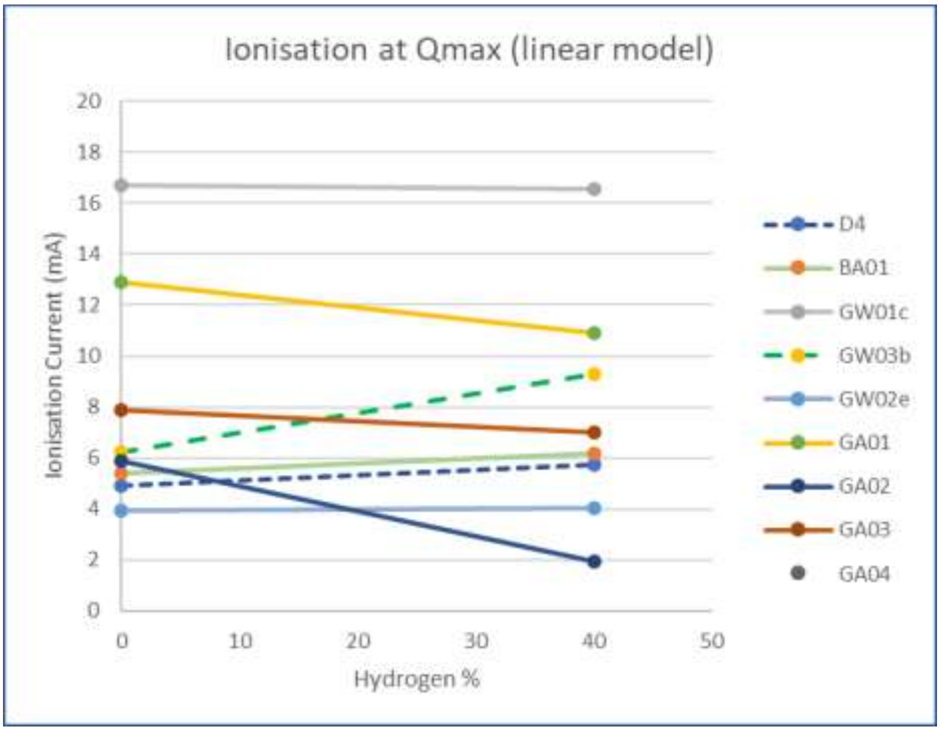


Figure 13: Ionization signal evolution (in µA) for the appliances tested (at maximum power) without the outlying GA04

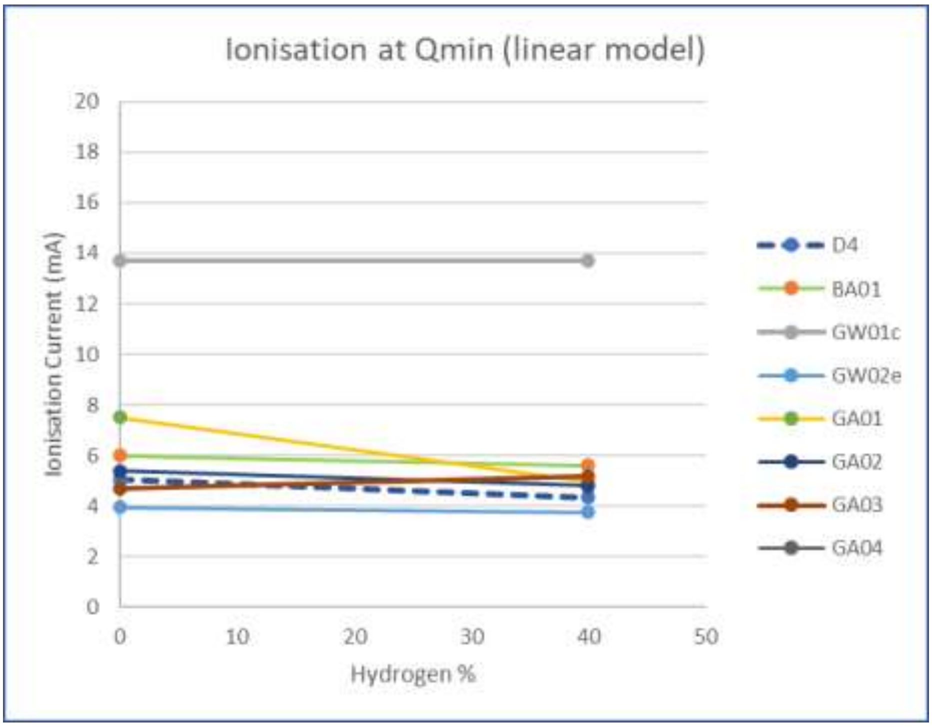


Figure 14: Ionization signal evolution (in µA for the appliances tested (at minimum power)

4.6 Adjustment

4.6.1 Introduction

In practice, some appliances run with the specified settings for the adjustment and are adjusted according to manufacturer instructions.

- Previous investigations about gas quality impact on appliances have in the past already concluded that the adjustment of gas appliances is critical for the safety of appliances. The main issue identified was CO emissions due to air excess changes with changes of gas quality. Adding fluctuating % of hydrogen to a fluctuating (in composition) natural gas makes things even worse.
- Today, some appliances like premix condensing boilers are set manually by an installer at a given gas quality (Wobbe index) and may be used later on a very different gas quality (different Wobbe index).
- Tomorrow, when injecting hydrogen in the gas grid, the adjustment may occur at a time there is (or not) hydrogen (depending on the supply situation), and later on the appliance may (or not) be used with gas with hydrogen as well.

The adjustment of appliances with gas containing hydrogen can in principle lead to:

- high CO emissions mainly due to variations of the air excess.
- Increased flashback risk in some circumstances.

4.6.1.1 Reminders on adjustment

Field adjustment of appliances is **routinely carried out in a number of European countries** on condensing boilers with fanned premix burners. The procedure seems not to be allowed in all countries, however, as far as the manufacturers' instructions mention an adjustment procedure of the air/gas ratio when commissioning or maintaining the appliances, it is possible that even if it is not done on a general basis some installers do adjust the appliances.

The reasons for appliance field adjustment are that commissioning, routine maintenance and replacement of gas train components require **air/gas ratio tuning** to meet combustion performance criteria (such as O_2 or CO_2) as stated in manufacturers' installation and maintenance procedures.

The appliance field adjustment of air/gas ratio is carried out according to possible national regulations and to manufacturers' instructions. It typically consists of adjusting the air/gas ratio to reach the CO_2 or O_2 concentration in the combustion products specified by the manufacturer. Thus, the final air/gas ratio adjustment will depend on the gas quality distributed on the day of the adjustment. Furthermore, as there is no product standard regarding the minimum metrological requirements of the instruments used by installers to control the CO_2 or O_2 concentrations, this may also influence the final adjustment.

The appliances adjusted for air/gas ratio are typically modern, condensing boilers with premix burners. In general, these appliances have fully modulating controls on both air and gas to enable part-load efficiency and emission targets to be met[3]. The market trend for this type of appliance is increasing across Europe and other boiler technologies are more or less banned today. Other appliances identified as requiring field adjustment of their air/gas ratio are appliances with forced draught, jet burners, but also GHP and even catering.

Other boilers, water heaters, cookers and space heaters, mostly with partially aerated burners, do not generally have requirements for field adjustment. If adjustments are needed, it concerns only the burner pressure that does not depend on the gas quality distributed.

4.6.1.2 Expected impact of the change of Wobbe index

As demonstrated in the project GASQUAL, those scenarios are not H_2 specific and may happen without injection of H_2, but H_2 increases the potential amplitude of Wobbe variation (Figure 3), which we know may bring issues on some appliances when adjusted.

This is especially true when an appliance is adjusted with a lean gas with H2 (low Wobbe index) and then used with a rich gas (high Wobbe index). In this case the main issue observed is CO due to the decrease of air excess, similarly to GASQUAL observations.

- Therefore, the main concern with the adjustments including gases with H_2 is not the flashback, but CO emissions due to changes in air excess.
- In general, premix burners have a CO=f(air excess) curve having a "U" shape, the bottom of the curve being for air excess for which the burners are offering a best compromise between efficiency and emissions (e.g., λ =1.3).
    - CO emissions are typically low (around 10 ppm to 50 pm DAF).
    - Coming closer to stoichiometry (air excess = 1), CO emission increase strongly up to several 1000 of ppm.
- The same happens also for the other side of the U with very high air excess (e.g., λ =1.8) also resulting in high CO values.

[3] Ecodesign directive requirements

The Figure 15 (from GASQUAL) illustrates the above explained concept, but the air excess is here replaced by O2%[4].

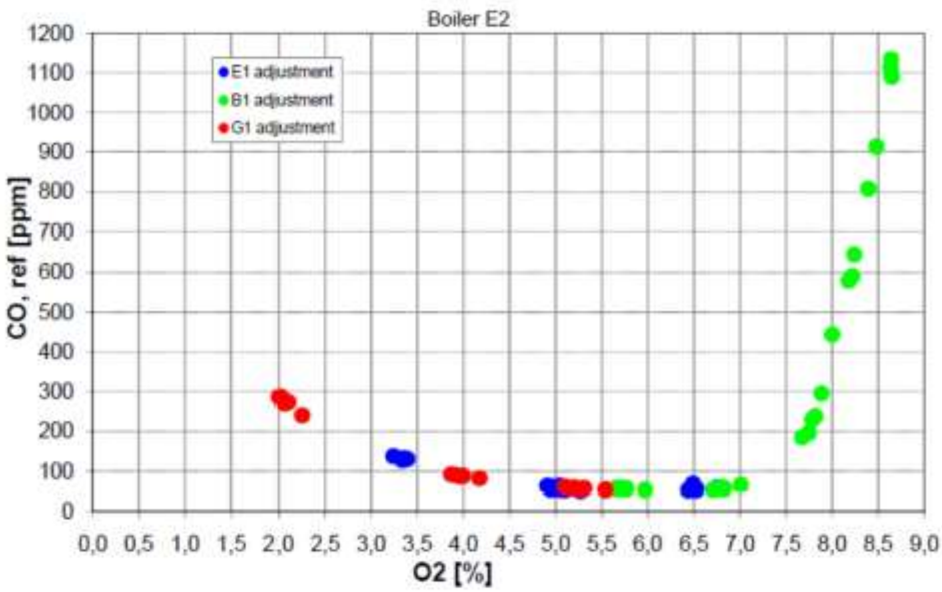


Figure 15: GASQUAL test results showing the variation of CO emissions with O2. Variations are created by testing appliances with gases of different Wobbe and for 3 different initial adjustments (high range, CH4, low range)

4.6.1.3 Objectives of the ThyGA tests

This part of testing aims at studying what happens when appliances are adjusted to a given gas and used afterwards with different gases. This test is only feasible for the appliances that can be adjusted with CO_2 or O_2 values given by the manufacturers (e.g., premix condensing boilers), it is not applicable for:

- Appliances with automatic combustion controls that are designed to be automatically adjusted.
- Most of appliances with atmospheric burners.

If appliances can be adjusted over the whole range of H gas AND with H_2 up to 60% and after that be used with any H gas AND any % of H2 up to 60%, we already know that there will be no appliance that will be safe! However, such a situation is not realistic (too far from realistic gas quality characteristics) and testing this would have a limited added value. Consequently, the assumption taken is that there will not be more than 20% H2 in the grid when appliances are adjusted.

The first tests results showed that one of **the most critical situations is an adjustment with a low Wobbe index gas with some hydrogen and a switch later on to a high Wobbe index gas without or with a low hydrogen level** (adjustment G in the test protocol), the main consequence is a very strong increase of CO emissions levels.

[4] GASQUAL D6.1

4.6.2 Adjustment tested

We have selected 4 adjustment scenarios based on the analysis of the impact of each of them on the flame speed and air/gas ratio.

- Adjustment A: appliances are adjusted with EU high and tested with EU low, and EU low + H_2 (10%, 30%, 60%)
- Adjustment B: appliances are adjusted with EU low and tested with EU high, and EU high+ H_2 (10%, 30%, 60%)
- Adjustment G: appliances are adjusted with EU low + 20% H_2 and tested with EU high, and EU high + H_2 (10%, 30%, 60%)
- Adjustment H: appliances are adjusted with EU high + 20% H_2 and tested with EU low, and EU low + H_2 (10%, 30%, 60%)

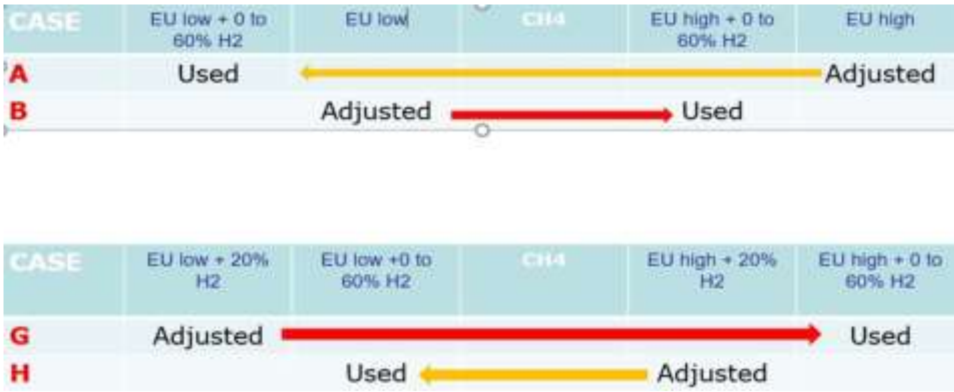


Figure 16: Adjustments within THyGA test programme

The 4 adjustments were studied in detail in the preparation phase (see D2.5). The evolution of the flame speed was calculated for the 4 different scenarios.

The theory and the first tests have shown that test G with 20% H_2 in "EU Low" was the most challenging and therefore, the test was extended to 2 new test gases 10 and 30 % H_2 to check what would be the influence of other H_2 concentrations in the gas used for adjustment.

As seen on Figure 17, this situation will also result in the increase of flame speed, for the testing point with high Wobbe index.

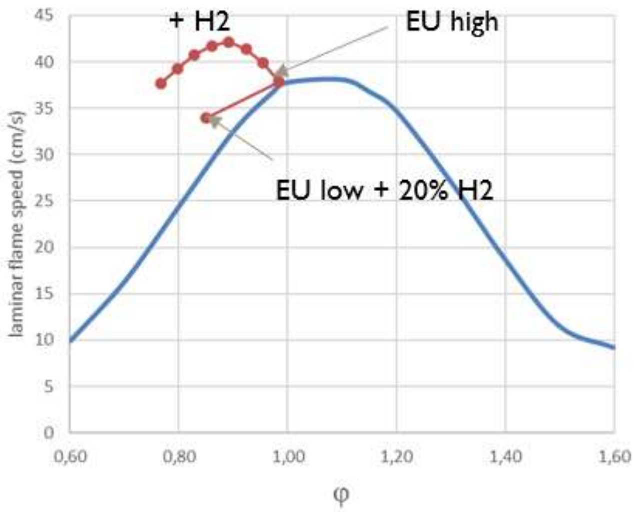


Figure 17: Variation of the flame speed with equivalence ratio (inverse of air gas ratio)

4.6.3 Results

Table 6: Results of adjustment test

APPLIANCE						H2 % Tested											
						At what level the problem may occur											
Code	Appliance	Burner	Origin	Segment	Qmax	0	10	20	23	30	40	50	60	AD_A	AD_B	AD_H	AD_G
PREMIX BURNERS																	
GA04	C	Premix	New de	406	31	X			X		X			X	X		X
GW02	B	Low NO	old/ use	102	22.2	X	X	X	X	X	X			test not done			
GW01	B	full pre	old use	108	24	X	X		X	X	X			test not done			
BA01	B	Low NO	New ap	107	24.8	X	X	X	X	X	X	X	X	X	X	NA	NA
D4	B	Premix	Sent by	108	20	X		x	x	x	x	x	X	X	X	X	X
D5	B	Premix	Sent by	108	20.8	X		X	X	X	X	X	X	X	X	X	X
ATM BURNERS																	
D3	CO	atmosp	Bought	301	2.5	X				X	X		X	NA	NA	NA	NA
D2c	CH	atmosp	Bought	301	1	X							X	NA	NA	NA	NA
D1	CH	atmosp	Bought	301	3	X						X					
D7	CH	Surf. at	sent by	301	2.703	X	x		x		x			NA	NA	NA	NA
D8	CH	Surf. at	sent by	301	0.901	X			x		x			NA	NA	NA	NA
D9	CO	Cavity b	sent by	311	2.432	X			x		x			NA	NA	NA	NA
D10	CO	Cavity b	sent by	311	17.12	X					x			NA	NA	NA	NA
GA03	C	Atmos	New ap	407	5.9	X					X			NA	NA	NA	NA
GA05	WH	Atmos	Already	201	10.5	X			X		X			NA	NA	NA	NA
GA02	F	Atmos	Already	503	5.8	X			X		X	X	X	NA	NA	NA	NA
GA01	B	Atmos	Already	101	25.8	X			X		X	X		NA	NA	NA	NA
GW03	B	atmosp	old/use	103	17	X	X	X	X	X	X	X	X	X	X		X

Among the 6 premix appliances tested so far:

- One was not tested for adjustment
- One other was not necessarily tested according to the protocol (early test)
- The 4 others have issues with adjustment" G" but not any other adjustment.

The issue observed was high CO, so far, we have not yet been confronted with flashback during experimental testing phase of adjustments.

Figure 18: Results for adjustment boiler D4.

Figure 18 shows the results obtained with the boiler D4: adjustment G is leading to a very high increase of CO (> 1000 ppm DAF) at the maximum power of the boiler. At minimum, this is not the case at all, and the appliance is safe for all points measured.

The adjustment B shows the same situation but starting from a gas without hydrogen. As expected, there is still an increase of CO, but much lower (we have here about 300 ppm DAF).

4.6.4 Consequences of the findings

The above may have an important consequence on the field:

- the installers would need to be able to know the percentage of H_2 in the grid during installation and maintenance to determine the correct settings (how will they get the information? Which frequency?).
- According to the theory, and practice, the adjustment should preferably be done with O_2% rather than CO_2% (doing this will make the appliance less depending on the gas quality used for adjustment & use), but this alone will not guarantee the safety of appliances, if adjusted when H2 was present in the grid.

In general, this raises a new question about the policy for adjustment of such appliances with the possible presence of H2 and what would be the best way to proceed in practice. Installers of appliances may need to know the gas quality during the settings and therefore have H_2 meters for installing gas boilers (or other new sensors); or adjustment shall be strictly prohibited in areas where H_2 can be injected

4.7 Other safety issues observed

Table 7: Overview of the safety test results

APPLIANCE						ELEMENTS TESTED																							
																Reason for the problem													
Code	Appliance	Burner	Origin	Segment	Qmax	CH4	EU LOW	G23	CS	HS	LT	FGP	ROC	FD	FBA	AD_A	AD_B	AD_H	AD_G	DI	S	QV	OH	4B	W	LT	AUX	P	O
PREMIX BURNERS						PREMIX BURNERS																							
GA04	C	Premi	New de	406	31	X	X		X	X			X	X	X	X	X		X			X		NA				X	
GW02	B	Low NC	old/ us	102	22.2	X		X	X	X			X	X		In discussion								NA					
GW01	B	full pre	old use	108	24	X	X		X		X	X	X	X		NT	NT	NT	NT					NA					
BA01	B	Low NC	New ap	107	24.8	X	X		X	X		X	X	X	X	X	X	NA	NA	X				NA			X	X	
D4	B	Premi	Sent by	108	20	X	X		X				X	X	X	X	X	X	X			NA		NA				X	
D5	B	Premi	Sent by	108	20.8	X			X	X			X	X	X	X	X	X	X					NA				X	
ATM BURNERS						BURNERS																							
D3	CO	atmos	Bought	301	2.5	X	X	X	X	X		NA	tbd	tbd	X	NA	NA	NA	NA	NA		tbd		tbd				X	
D2c	CH	atmos	Bought	301	1	X	X	X	X			NA	tbd	X	X	NA	NA	NA	NA	NA		tbd		tbd					
D1	CH	atmos	Bought	301	3	X	X		X				tbd	X	X							tbd		tbd					
D7	CH	Sut. at	sent by	301	2.703	X	X			X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				X	
D8	CH	Sut. at	sent by	310	0.981	X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X						X	
D9	CO	Cavity	sent by	311	2.432	X			X	X	NA	NA	X	X	X	NA	NA	NA	NA	NA		X		NA				X	
D10	CO	Cavity	sent by	311	1.712	X				X	NA	NA				NA	NA	NA	NA	NA				NA					
GA03	C	Atmos	New ap	407	5.5	X	X		X	X			X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA05	VH	Atmos	Alread	201	10.5	X	X		X				X	X	X	NA	NA	NA	NA			X		NA	X			X	
GA02	F	Atmos	Alread	503	5.8	X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	X
GA01	B	Atmos	Alread	101	25.8	X	X		X	X			X	X	X	NA	NA	NA	NA					NA				X	
GW03	B	atmos	old/use	103	17	X	X		X	X			X	X	X	X	X		X					NA				X	

From the overall table of results, we can make the following comments:

1. The issues indicated with CH4 test (GW02, BA01, GA02, GW03) are typically the FB issues already discussed (see column « FB »). The fact that the issue is not mentioned for EU low and G23 is that the two are less extensive and not go up to 60% H_2 as for CH_4.
2. Cold start (« CS ») is an issue with BA01, but it has occurred at 60% H_2. The test is not systematically done, and we will require it to be done in the next protocol version at least for the highest achievable H_2%. The same has happened for GW02 appliance that is not working for H2 above 40% at minimum load (the appliance simply doesn't start).

3. Hot start was also an issue for two appliances (GA02, GW03). It has occurred at 60% H_2 for both. GW03 has passed at 40% (50% not tested) and GA02 passed at 50% H_2.
4. At the moment, quick variation between Qmin and Qmax, does not seem to be a problem, (but there is an open discussion on D9).
5. Several appliances have shown that the variation of gas pressure with high % of H_2 is bringing some instability of the flame. However, not in a way that safety was considered as not guaranteed.

Note that we do not necessarily have the test done with CH_4, so we are not certain that H_2 is the worsening factor. Therefore, for further test, we may decrease the number of tests, but perform one reference test with CH_4. Appliances equipped with pressure regulators are not having issues.

4.8 Safety aspect not being an issue (so far)

Both impacts of "**low air temperature (- 10 °C)**" and "**Flue gas pipe length**" have been tested on 1 and 2 appliances (boilers) respectively, and the results from the test done show no impact of hydrogen.

ROC (PLUG FLOW) was executed on 13 appliances without showing any issue (generally variation from 0 to 40% H_2 and the other way round).

The test is not always possible. A recent test on a Fuel cell (not yet reported) shows that the appliance control is stopping the appliances (security mode) and force the appliance to remained stopped for 10 minutes before changing gas. This will be an operational issue in the field, we will report more on that when needed when getting the full report of the FC appliance.

The **delayed ignition** test was made on 1 appliance with 30% H_2. There was no safety issue, but we need to have a few more of those tests.

The **soundness** was newly tested on 1 appliance that is not yet part of this report (GA07 and there was no issue observed). The requirements from standards are not very severe, we do not expect issues there, but there is no specific test protocol for hydrogen natural gas blends. We may contact TC 109 to ask if there is a test procedure on the way that we could incorporate in our programme.

Fluctuation of the auxiliary energy was tested on 1 appliance, without impact on safety.

For **overheating due to hydrogen**, the temperature was measured on a gas cooker hob.

The **influence of wind** on exhaust ducts was tested on 2 appliances (no impact).

Long-term (limited time)[5] consisted in testing appliances for few hours when possible. Some tests were done (GA tests) and have not shown issues so far.

4.9 Safety aspect not covered yet

The assessment of the operation of a cooking hob with 4 burners on shall be done to check possible interferences.

[5] Note that realistic long-term tests are done and reported in deliverable D3.6

4.10 Impact of initial gas composition on safety

One of the questions we have to answer is if the initial composition of the gas has an influence on the results of impact of hydrogen.

The problem was thoroughly discussed in relation to the adjustment and in this case, there is an obvious and strong influence of the initial gas quality / composition on the result obtained. As explained, the change in gas quality impacts the air/gas ratio of appliances and combined with hydrogen, may have negative impact on safety in potential increase of CO emissions.

The other possible problem is the flame speed as it depends on the gas composition as well. However, the impact can be considered as marginal with the gas composition of natural gases L distributed in Europe (see Figure 19). Therefore, making the test with CH_4 or with another gas in the range EU low – EU high will not make a significant difference for the flame speed.

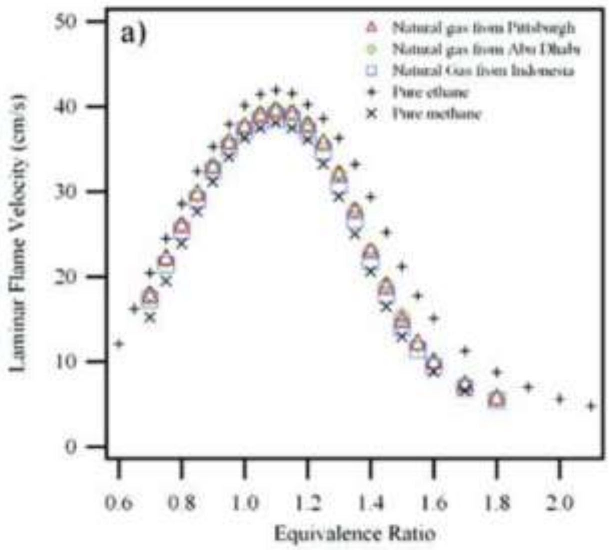


Figure 19: Flame speed for different natural gas qualities[6]

5. Test results and analysis. Efficiency

5.1 Boiler efficiency short analysis

In this section, we discuss the impact on efficiency when adding hydrogen to natural gas, this analysis has been done in synergy with the GERG project WP8[7].

The potential changes in efficiency for a boiler are due to the following factors and could counteract each other:

---

[6] Ref: Measurements of Laminar Flame Velocity for Components of Natural Gas. Patricia Dirrenberger, Hervé Le Gall, Roda Bounaceur, Olivier Herbinet, Pierre-Alexandre Glaude, et al. Measurements of Laminar Flame Velocity for Components of Natural Gas. Energy and Fuels, American Chemical Society, 2011, 25 (9), pp.3875-3884. ff10.1021/ef200707hff. ffhal-00776646f

[7] CEN Hydrogen -H2NG Initiative – WP8: End use appliances. GERG 2021

1. The ratio Hs/Hi is higher for blends of hydrogen with methane compared to methane alone.
    a. When expressed on Hi the efficiency for condensing appliances will increase due to a higher volume of water in the flue gas and so condensates (in case the boiler is condensing).
    b. As the dew point with H2 will increase there will be condensation also at higher water temperature as for example with test at 60/80°C (return/forward) where there is normally not much condensation with NG.
    c. With the addition of H_2 the dew point increases and there will be condensation and consequently a gain in efficiency.
    d. This will not be the case at low water temperature at a level where condensation is already complete or near complete with natural gas; this effect is therefore marginal (effect only due to the "additional" water condensate).
2. The impact will also be different comparing a traditional boiler to a condensing one.
3. The injection of hydrogen in case the air excess is not controlled, will result in higher air excess and as a result higher flue gas losses and so a decrease in efficiency.
4. If not changing any operation parameters when injecting hydrogen, the return temperature of heating appliances will decrease (because of the lower heat input), and this will result in an increase of the efficiency.

These elements explain why there are different conclusions on the topics in literature about the impact of hydrogen on efficiency: boilers tested at high water temperature will have a large positive impact due to the condensate impact as explained above, this resulting in a situation where some references say there is an increase of efficiency, and some say there is a decrease[8].

In addition, **the effect is generally small and so difficult to measure. It is generally not larger than 1%** which is below the uncertainty of measurement of laboratories. The tests shall be done under repeatable conditions, as the repeatability of labs should be better than the uncertainty, and repeatability of 0,5 % is not unusual when the tests with and without H2 are immediately performed after each other, if possible, the same day.

The project will consider here that differences below 0.5% (net efficiency) are not significant when tests are carried out the same day. If carried out different days, the differences below 1% are not significant either. **This means in such situation when the differences are below the proposed thresholds, we will not be able to conclude about the hydrogen having an impact on efficiency**.

[8] More details in THyGA deliverable D2.3

5.2 Results and comments for boilers

5.2.1 Ga01

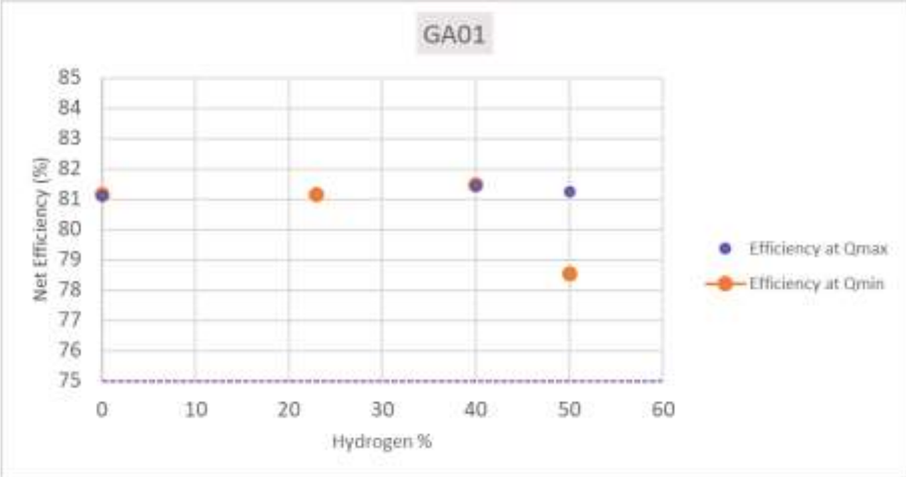


Figure 20

No impact of hydrogen, the point at Qmin with 50% looks more like a measurement outlier. It was investigated, but there is no reason found explaining the difference.

5.2.2 D4

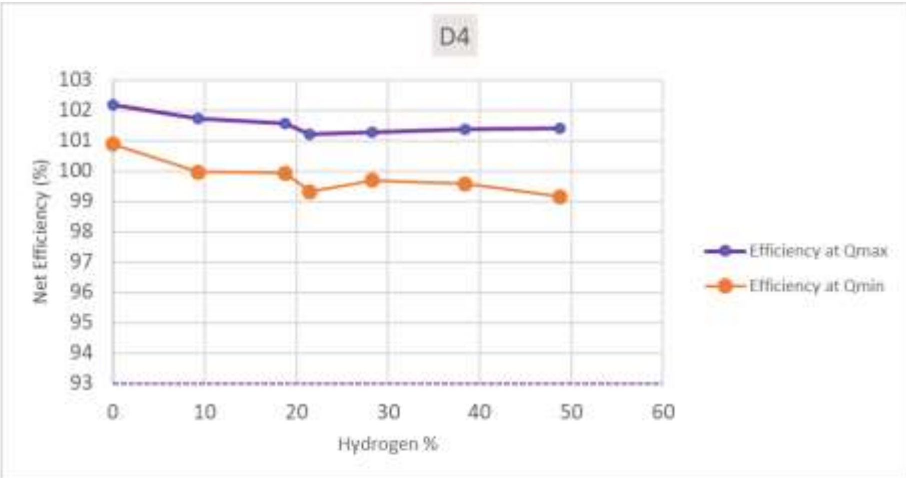


Figure 21

Slight decrease in efficiency both at Qmin and Qmax.

5.2.3 BA01

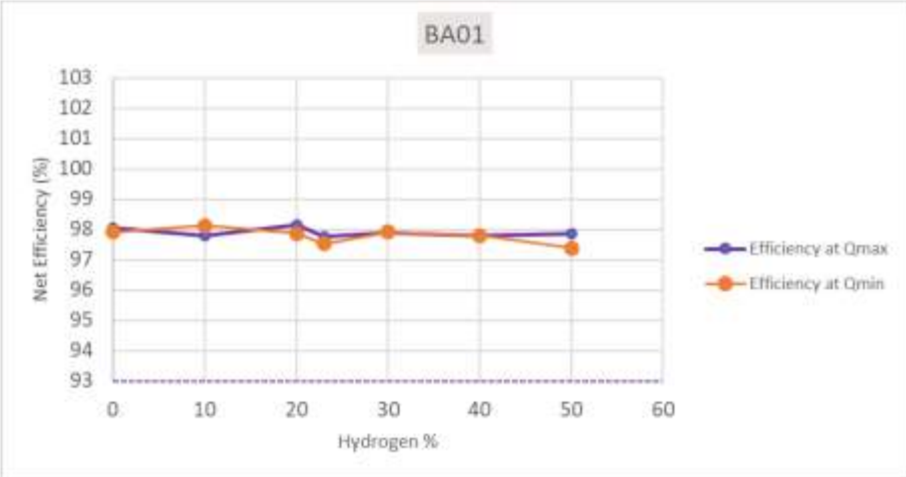


Figure 22

No impact of hydrogen.

5.2.4 GW01

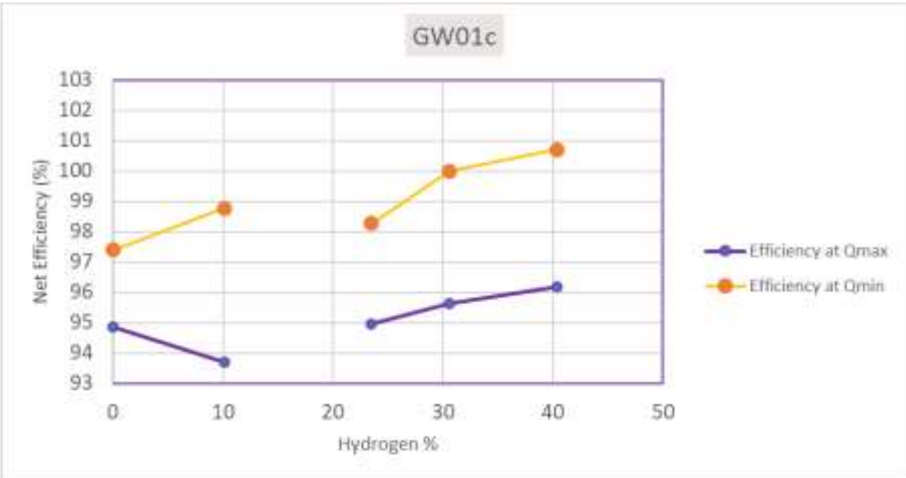


Figure 23

Increase of efficiency.

5.2.5 GW03

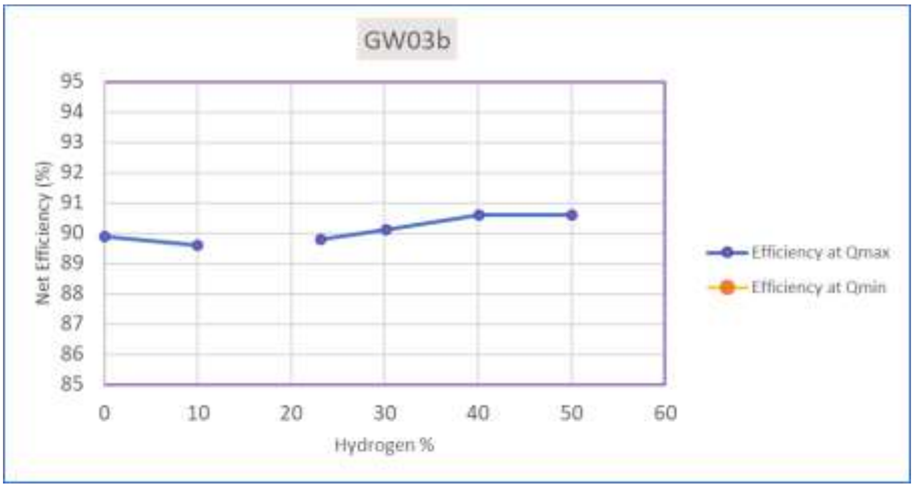


Figure 24

No impact of hydrogen.

5.2.6 GW02

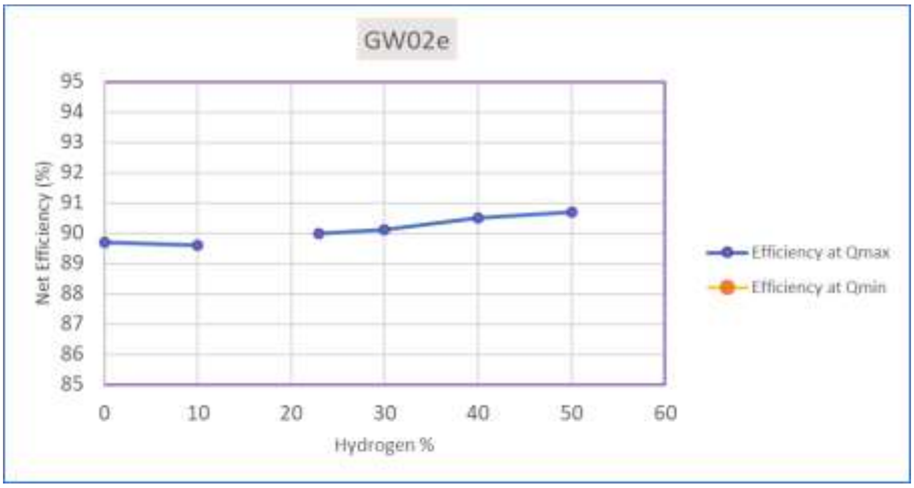


Figure 25

No impact of Hydrogen.

5.2.7 Conclusion for boilers

There is no general trend, in most of the case the efficiency is stable, it may, however, increase or decrease slightly.

5.3 Water heaters - short analysis

More or less the same applies for water heaters, with the difference that most water heaters are operated at higher temperature compared to boilers. As a result, there may be a higher impact and increase in efficiency levels can be expected.

The project will consider here that differences below 0.5% (net efficiency) are not significant when tests are carried out the same day. If carried out different days, the differences below 1% are not significant either. **This means in such situation when the differences are below the proposed thresholds, we will not be able to conclude about the hydrogen having an impact on efficiency**.

5.4 Results and comments for water heaters

5.4.1 Ga05

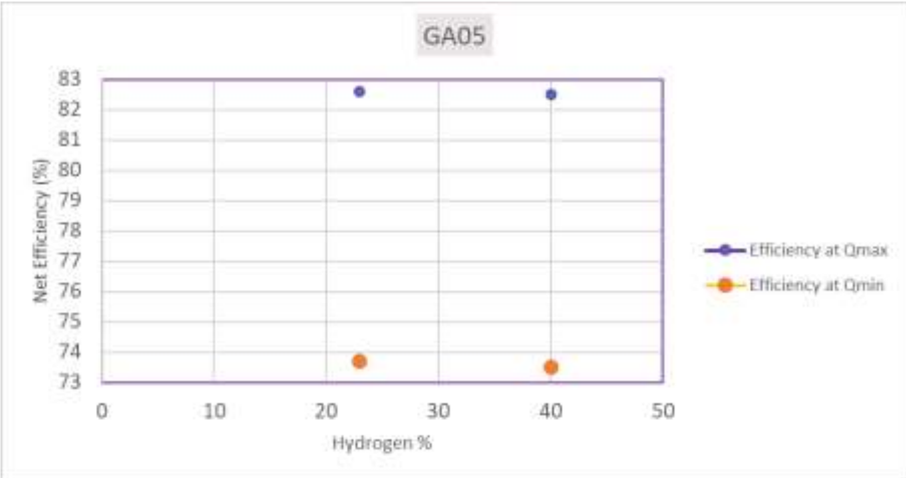


Figure 26

No impact of hydrogen.

5.4.2 Conclusion for water heaters

This will need to be revised with more results.

5.5 Results and comments for cooking hobs, ovens and catering (test at Qmax only)

For cookers, the condensation should not play a role in the efficiency. As the flue gas loss will still increase with the injection of H_2 we can presume a slight decrease of the efficiency.

For cookers, the project will consider here that differences below 1.5% (net efficiency) are not significant when tests are carried out the same day as the reproducibility of the test is not as good as for boilers. **This means in such situation when the differences are below the proposed thresholds, we will not be able to conclude about the hydrogen having an impact on efficiency**.

5.5.1 D1 (Hob)

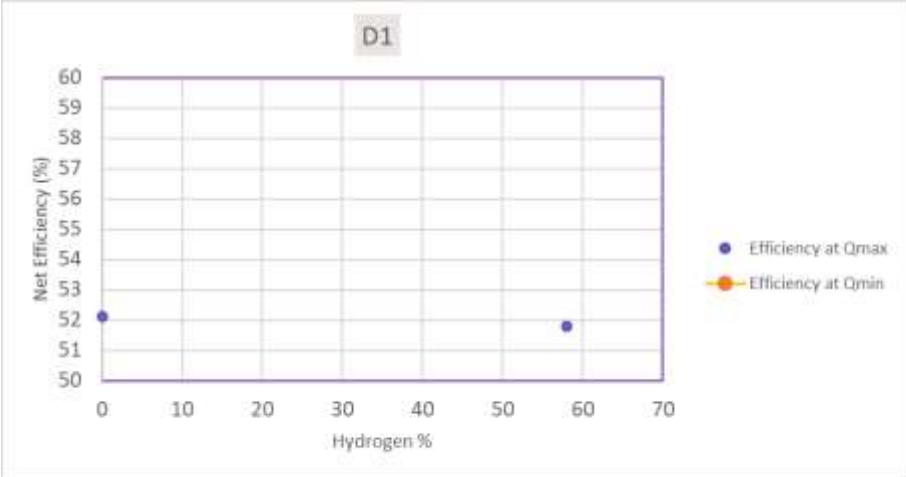


Figure 27

No impact of Hydrogen.

5.5.2 D7 (Hob)

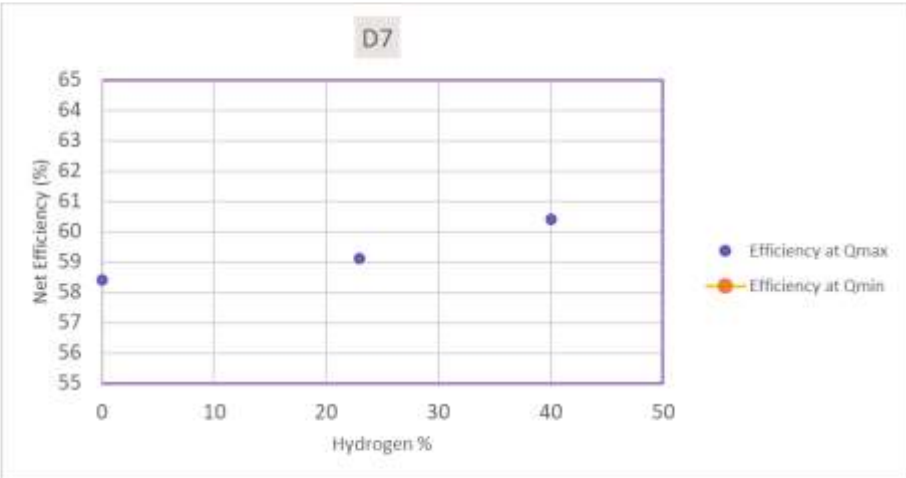


Figure 28

The efficiency increases by 2% from 0% to 50% H_2.

5.5.3 D8 (Oven)

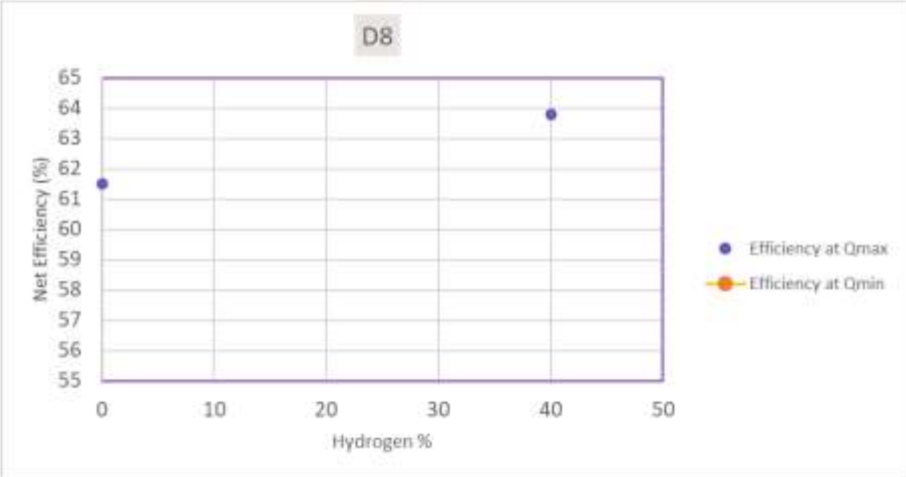


Figure 29

Here also we see a slight increase of efficiency.

5.5.4 Conclusion for cooking hobs and ovens

This will need to be revised in light of more results.

5.5.5 Conclusion for catering

No efficiency test was performed yet.

5.6 Results and comments for fires (test at Qmax only)

For fires, the condensation should not play a role in the efficiency (same as cookers). As the flue gas loss will still increase with the injection of H_2 we can presume a slight decrease of the efficiency.

For fires, the project will consider here that differences below 1.5% (net efficiency) are not significant when tests are carried out the same day as the reproducibility of the test is not as good as for boilers. **This means in such situation when the differences are below the proposed thresholds, we will not be able to conclude about the hydrogen having an impact on efficiency**.

5.6.1 GA02

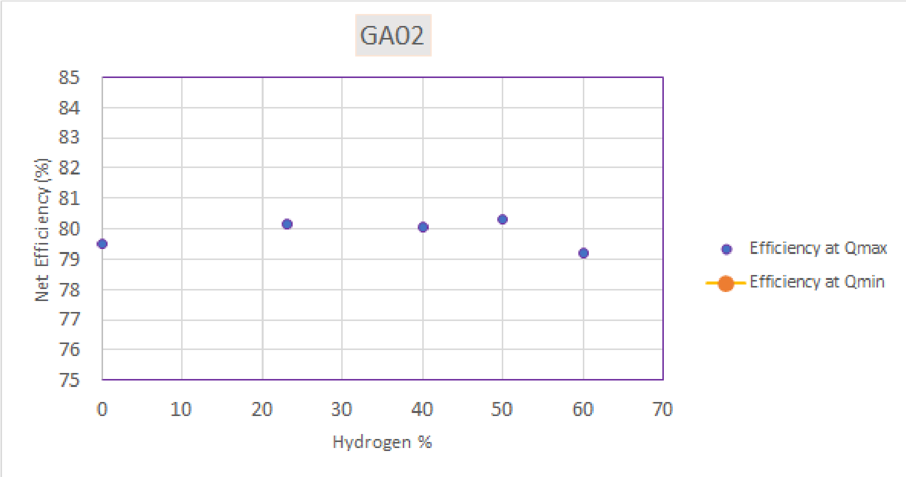


Figure 30

Here also we see a very constant efficiency

5.6.2 Conclusion for fires

This will need to be revised in light of more results.

5.7 Overall conclusion for efficiency at M20

Efficiency is not very much impacted by H_2. It is mostly stable, but it may also slightly decrease or increase.

This can be confirmed by further testing; however, we suggest not to use too many resources to get a more accurate picture as in any case the impact will be small. For cooker hobs, one result is showing an increase of efficiency with H_2.

6. Test results and analysis. Emissions

6.1 Short analysis

In principle, H_2 injection will result in higher air excess and lower flame temperature resulting in lower NOx.

For CO, things are slightly more complicated as CO is following a “U curve” and slight changes on air excess will not impact CO emissions until a certain point where CO can increase dramatically as seen in the analysis for the adjustment discussion.

6.2 Results and comments for all appliances (test at Qmax only)

6.2.1 Boiler D4

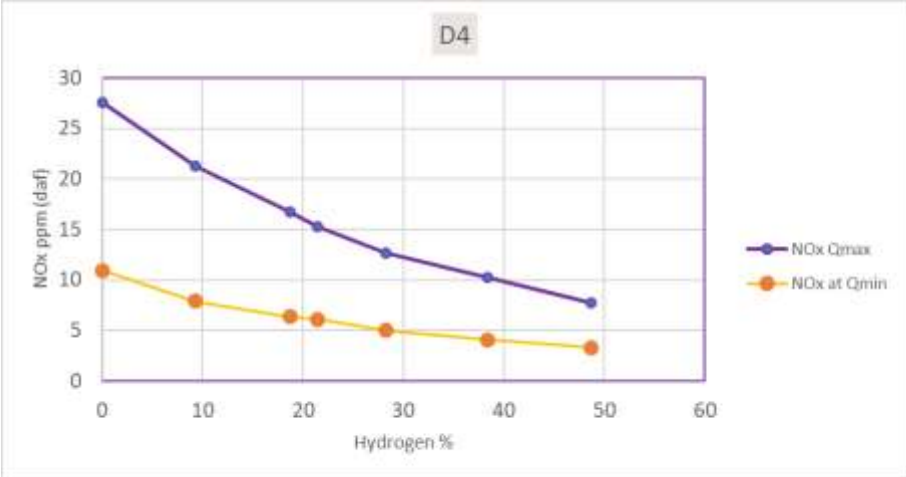


Figure 31

6.2.2 Boiler BA01

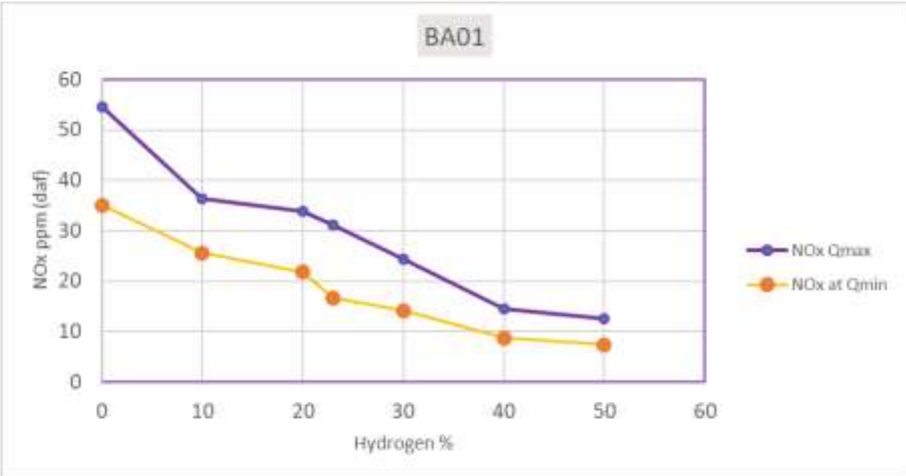


Figure 32

6.2.3 Boiler GW01

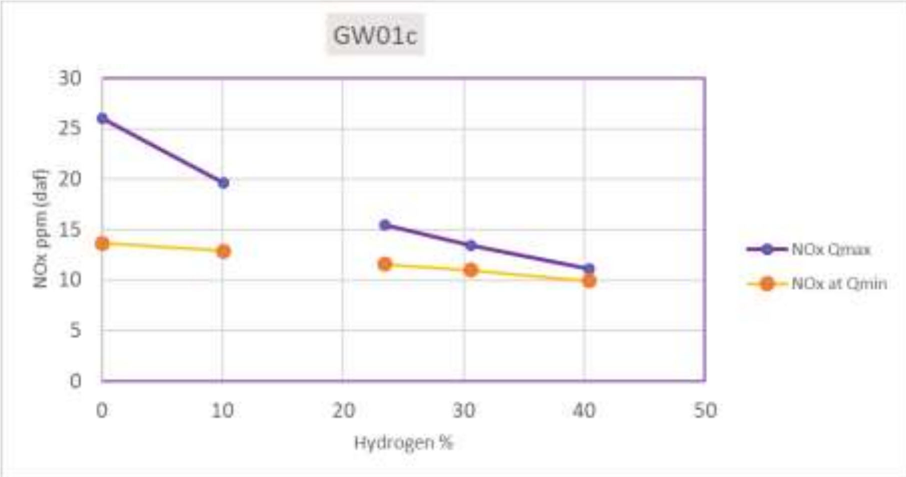


Figure 33

6.2.4 Boiler GW02

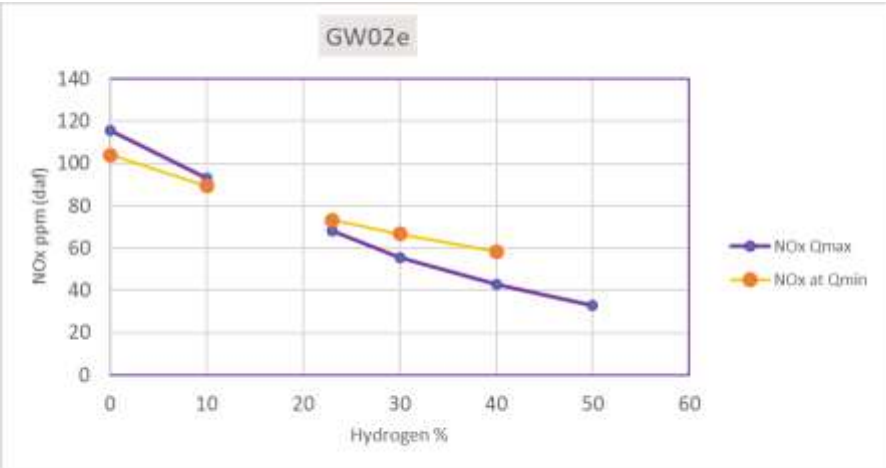


Figure 34

6.2.5 Boiler GW03

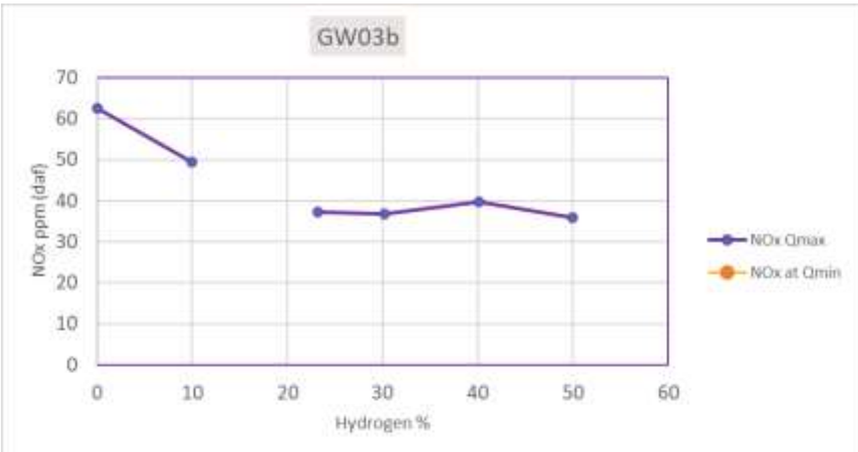


Figure 35

6.2.6 Boiler GA01

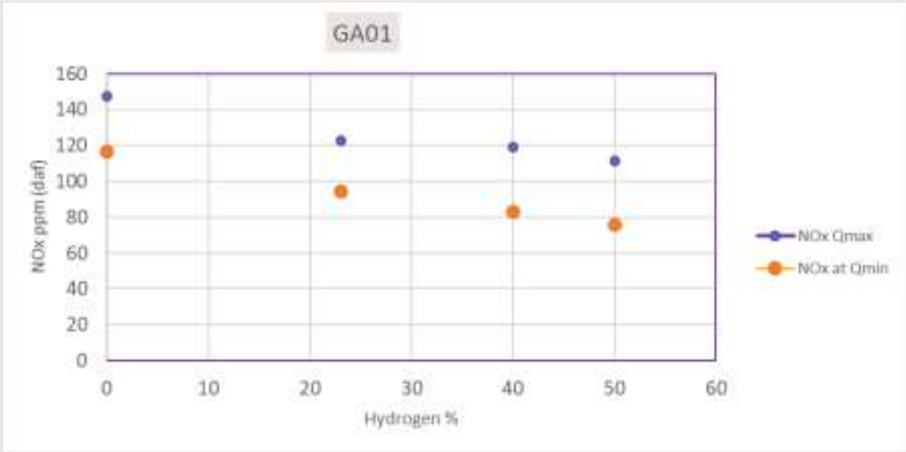


Figure 36

6.2.7 Water heater GA05

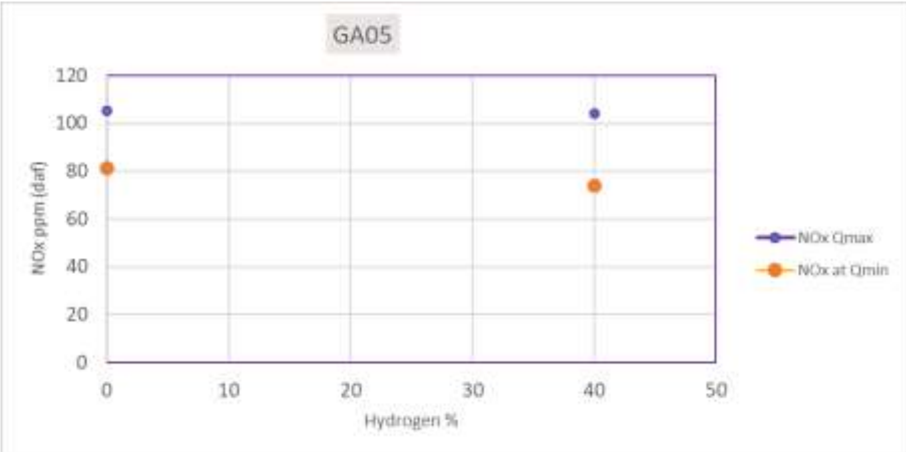


Figure 37

6.2.8 Cooking hob D1

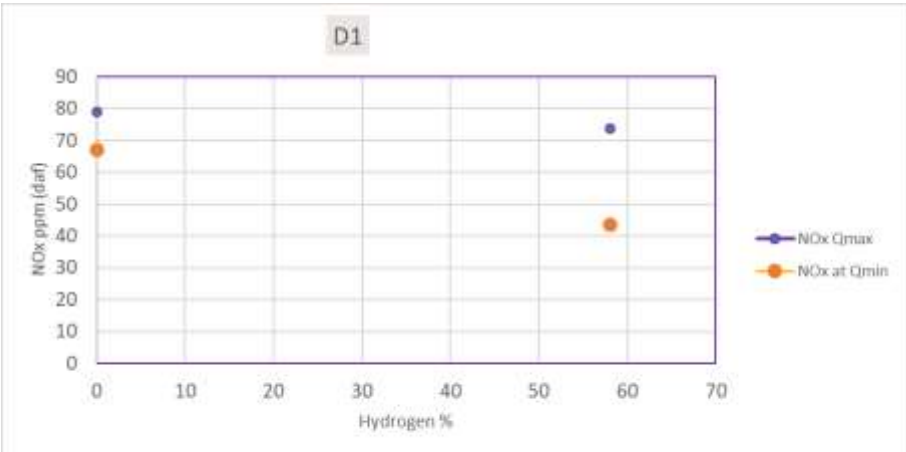


Figure 38

6.2.9 Cooking hob D2

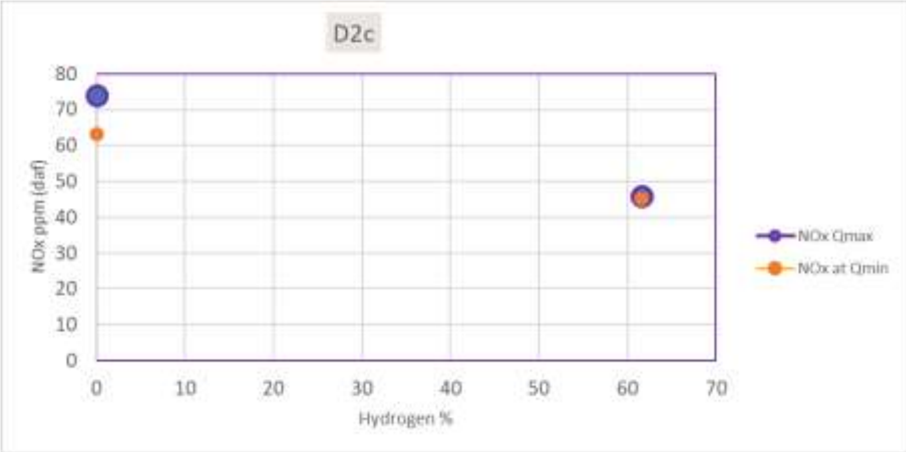


Figure 39

6.2.10 Oven D3

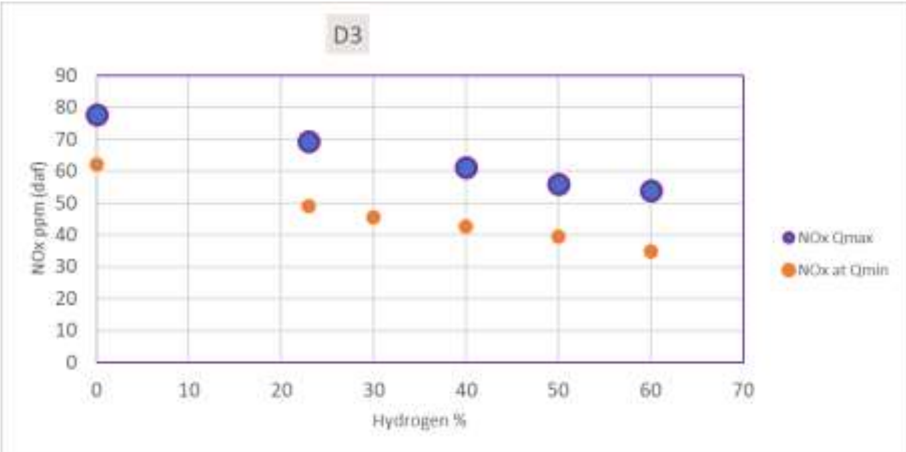


Figure 40

6.2.11 Cooking Hob D7

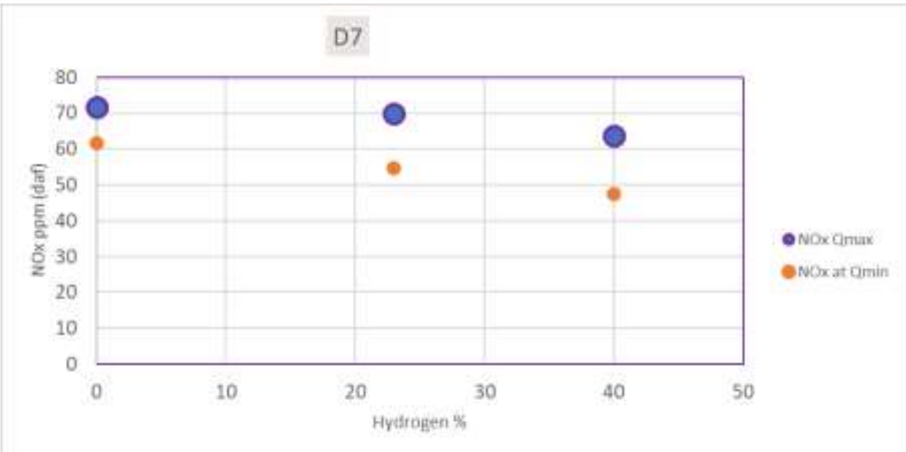


Figure 41

6.2.12 Cooking Hob D8

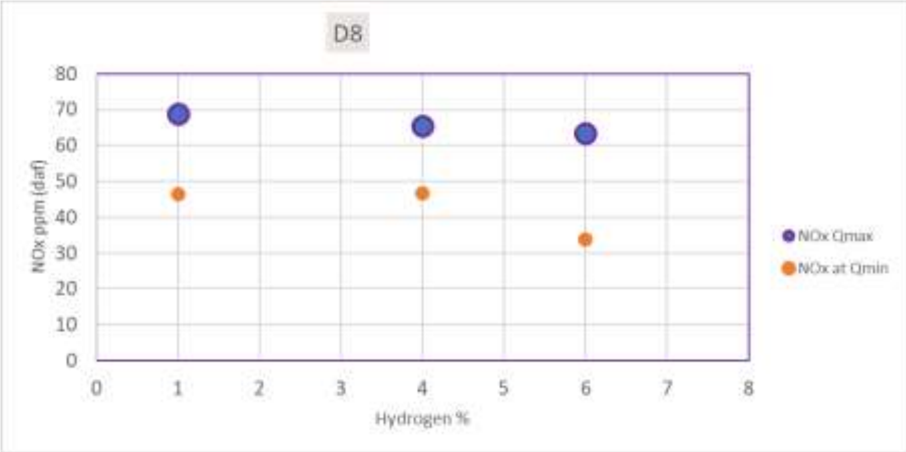


Figure 42

6.2.13 Oven D9

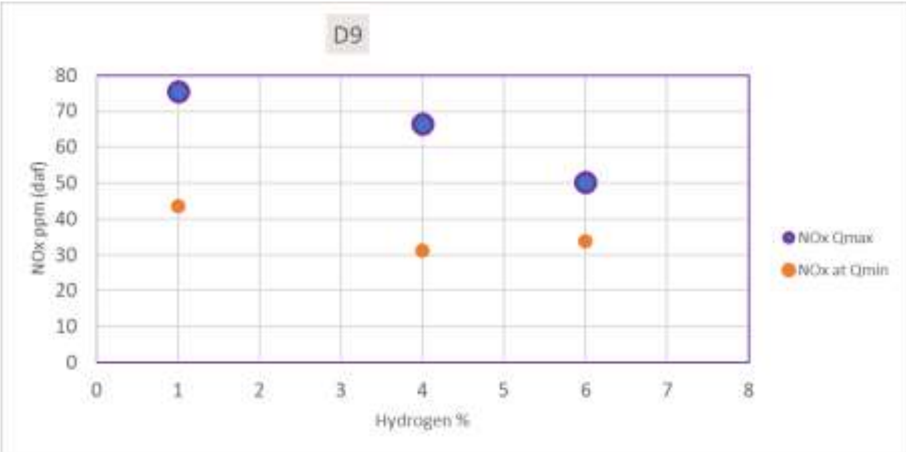


Figure 43

6.2.14 Oven D10

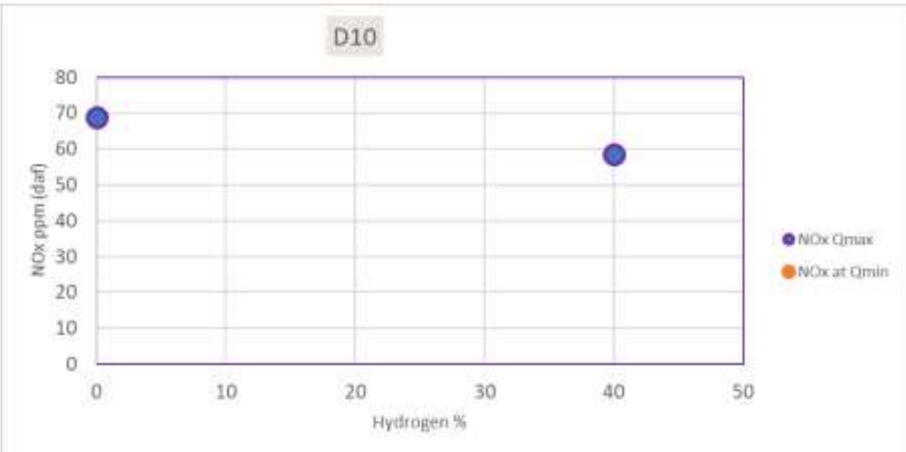


Figure 44

6.2.15 Catering GA03

Not measured.

6.2.16 Catering GA04

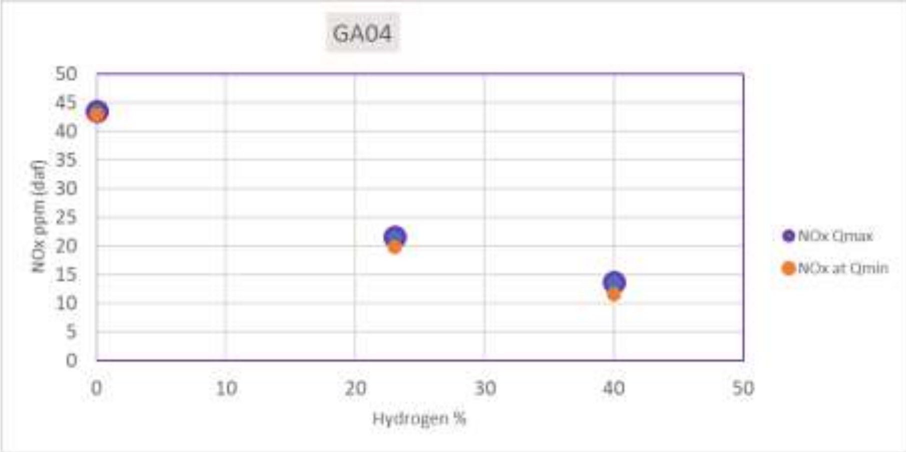


Figure 45

6.2.17 Fire Ga02

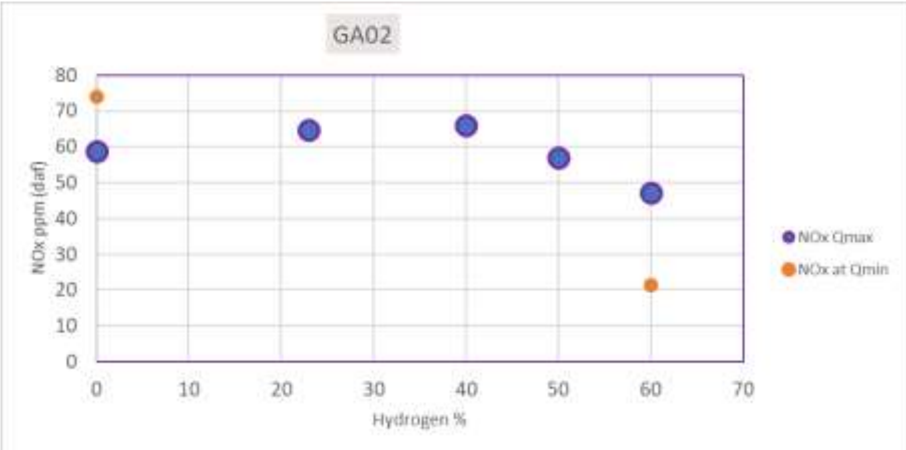


Figure 46

The evolution of NOx for this fire is different compared to all other appliances tested. We will conclude on this in light of more test results.

6.3 Conclusion for NOx

As expected, the tests are showing a decrease of NOX emissions in the vast majority of cases. The actual decrease is different by technology and from appliance to appliance.

Table 8: Initial value of NOx (ppm daf) at Qmax H2 = 0% and average slope of decrease (ppm for 10% H2

Appliance	D1	D2c	D3	D4	BA01	GW01c	GW03b	GW02e	
Initial value at Qmax (ppm)	78.88	74.08	77.91	27.56	54.66	26.01	62.43	115.7	
Slope Qmax (ppm for 10 %H_2)	-0.89	-4.58	-5.45	-6.11	-13.4	-4.88	-7.49	-24.3	

Appliance	D7	D8	D9	D10	GA01	GA02	GA03	GA04	GA05
Initial value at Qmax (ppm)	71.81	68.77	75.64	68.77	147.6	58.74	NM	43.48	105.1
Slope Qmax (ppm for 10 %H_2)	-2	-1.34	-6.08	-2.55	-7.06	-0.34	NM	-9.5	-0.67

6.4 Other emissions

Other emissions are measured,

- CO is mostly considered as a safety issue, and we are therefore not treating CO emissions extensively here as with NOX (to be discussed).
- Unburned hydrocarbons are also measured, but the reporting is incomplete at M20, and we will treat this extensively in the next version of the report.

7. Test results and analysis. Operational

7.1 Operational aspect with appliances with combustion controls (report D5)

We encountered the case of a boiler with a combustion control (D5) where the boiler may be adjusted with CO2 as reference, but this is not part of the standard commissioning procedure. According to the manual, adjustment is only required when converting to another fuel gas or when extraordinary maintenance is performed involving the replacement of a component, such as the P.C.B. or components in the air, gas and flame control circuits. In that case the boiler will need to be calibrated (means “adjusted” here).

When performing this test with 20% H_2 in EUlow, we could observe some instability in the “auto adjust” function of the boiler, with frequent auto adjust attempts accompanied of CO peaks.

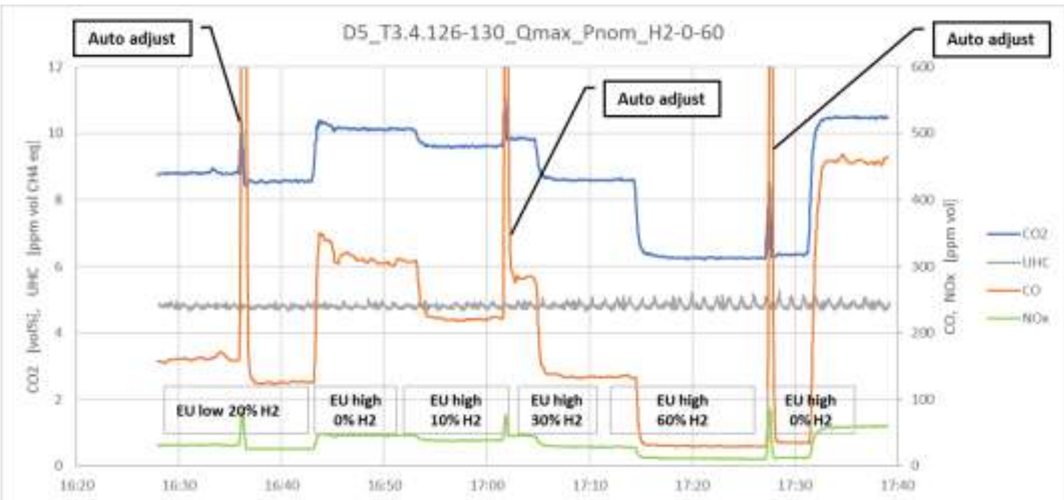


Figure 47: Boiler D5 ADJUSTMENT G2 (Qmax - GAS set to EU low + 20% H2 and used with EU high with increasing H2%)

7.2 Impact of hydrogen on the heat input

7.2.1 Introduction, qualitative analysis

Obviously, H2 impacts the Wobbe and calorific value of the gas and this will result in a decrease of the heat input. However, in practice the flow of gas may just increase and will so be compensating some of the decrease in energy brought to the appliance.

The heat input reduction may be a sensitive parameter for some utilization, and ultimately some of the end users may complain about the appliances no longer providing the service he bought it for. The main consequences:

- For cooking, it will increase the heating time.
- For hot water, production it will reduce the amount of produced hot water, potentially bringing discomfort.
- For heating appliances like boilers, it should not be a problem as those are in general oversized. However, it can be an issue for appliances chosen to just cover the maximum heat demand without oversizing. In this case, the appliances may not be able to cover the heat need in the coldest winter days.

7.2.2 Impact of H2 on Hi, density and Wobbe (theoretical)

The following impact is calculated with the THyGA datasheet:

Table 9: Absolute impact of H2 on Hi, density and Wobbe (15C/15C)

CH4	H2	Ws	d	Hi	Hs
Vol.(-)	Vol.(-)	[MJ/m³]	(-)	[MJ/m³]	[MJ/m³]
100	0	53.47	0.56	35.82	39.84
90	10	52.17	0.51	33.31	37.13
80	20	50.87	0.46	30.81	34.43
70	30	49.58	0.41	28.31	31.72
60	40	48.30	0.36	25.80	29.02
50	50	47.08	0.31	23.30	26.31
40	60	45.96	0.26	20.79	23.61
0	100	48.46	0.07	10.78	12.79

Table 10: Relative impact of H2 on Hi, density and Wobbe

CH4	H2	Ws	d	Hi	Hs
Vol.(-)	Vol.(-)	%	%	%	%
100	0	100%	100%	100%	100%
90	10	98%	91%	93%	93%
80	20	95%	83%	86%	86%
70	30	93%	74%	79%	80%

60	40	90%	65%	72%	73%
50	50	88%	56%	65%	66%
40	60	86%	48%	58%	59%
0	100	91%	13%	30%	32%

As seen on Figure 48 and Figure 49, the relative variation of Wobbe and Hi is very much different: the Hi is decreasing faster than the Wobbe (linear) while the Wobbe (not linear) shows "only" a reduction by 16% at 60% H2 (compared to 42% for the Hi).

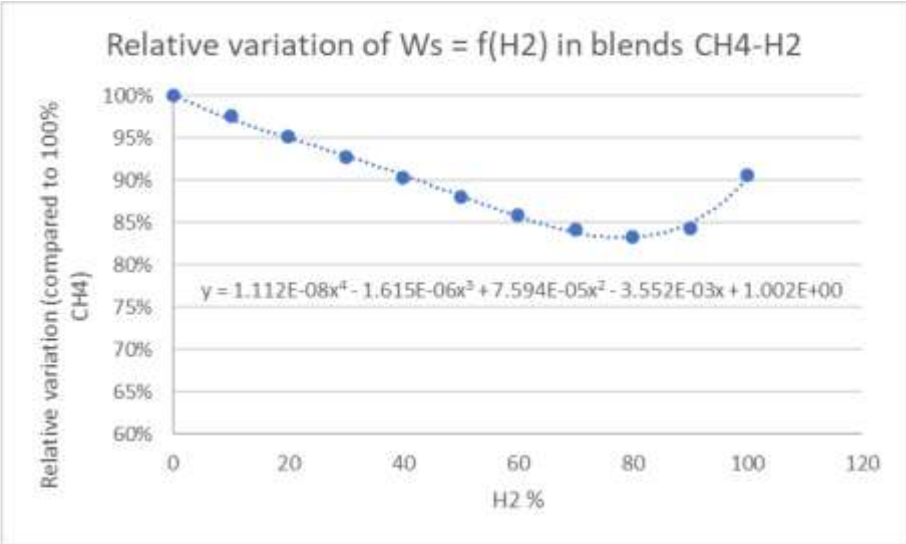


Figure 48: Relative variation of Ws = f(H2) in blends CH4-H2.

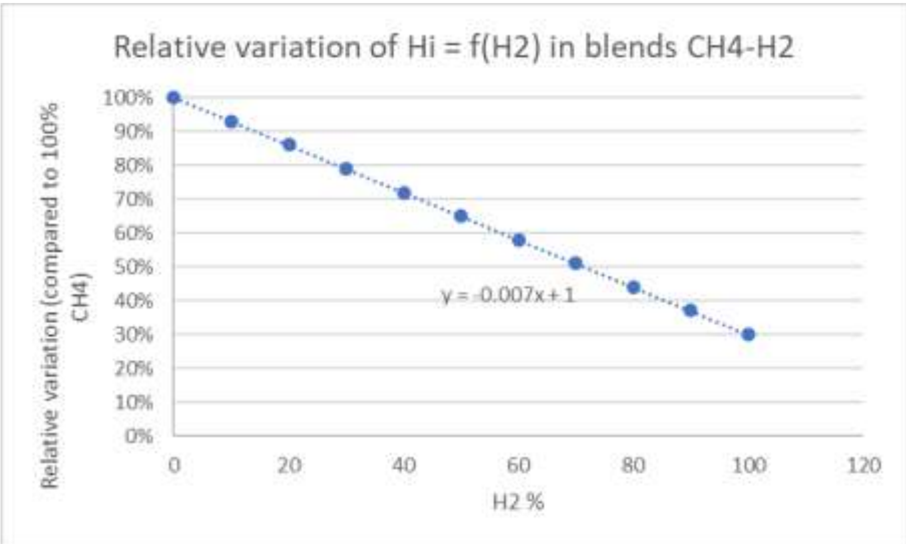


Figure 49: Relative variation of Hi = f(H2) in blends CH4-H2.

7.2.3 Quantitative analysis

When plotting the heat input (Qtest) against the Wobbe index for the appliances tested, we see a rather linear evolution.

7.2.3.1 Boilers

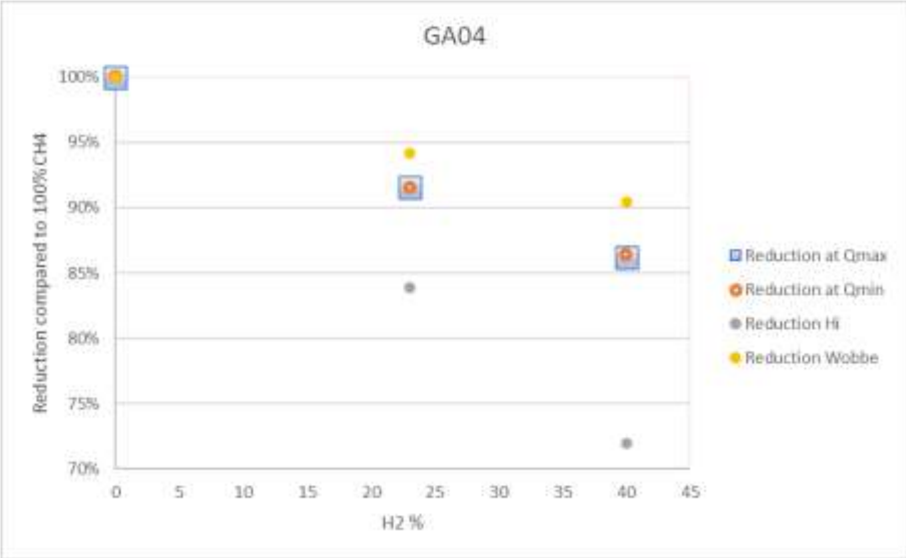


Figure 50

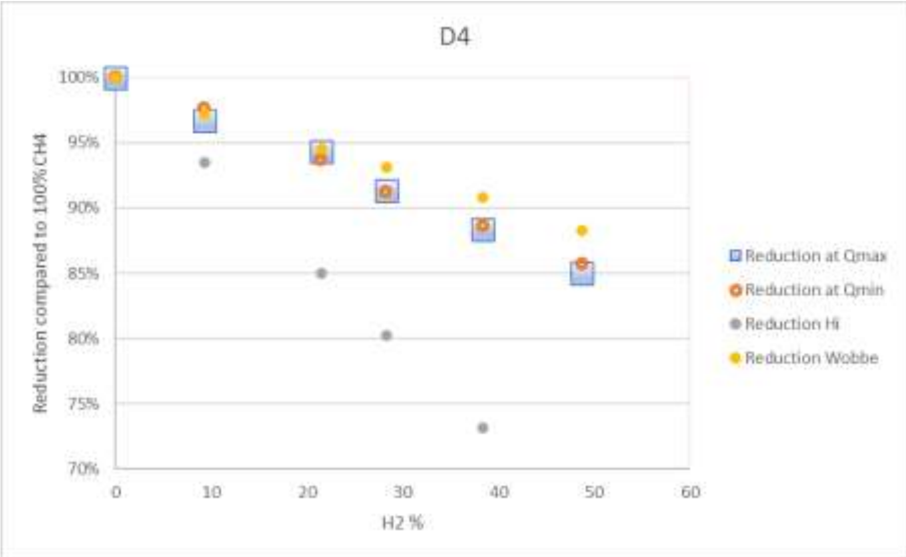


Figure 51

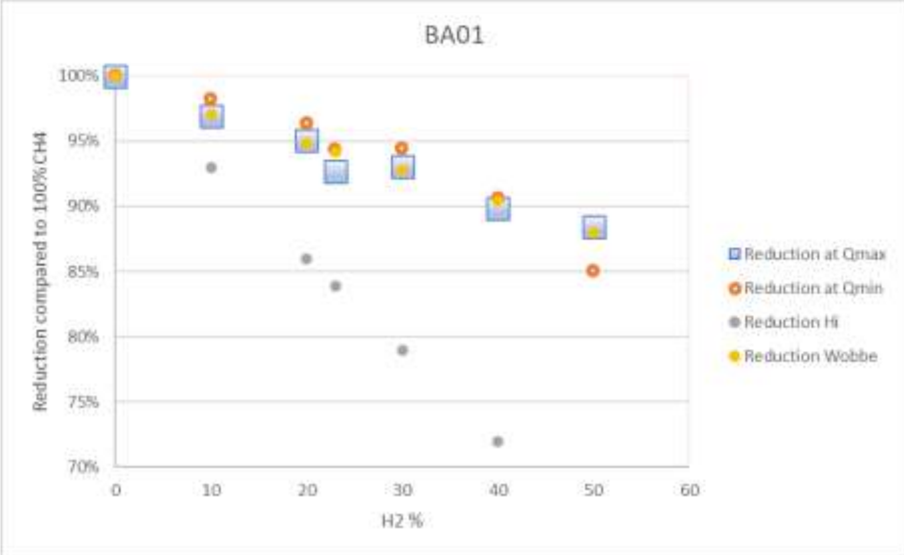


Figure 52

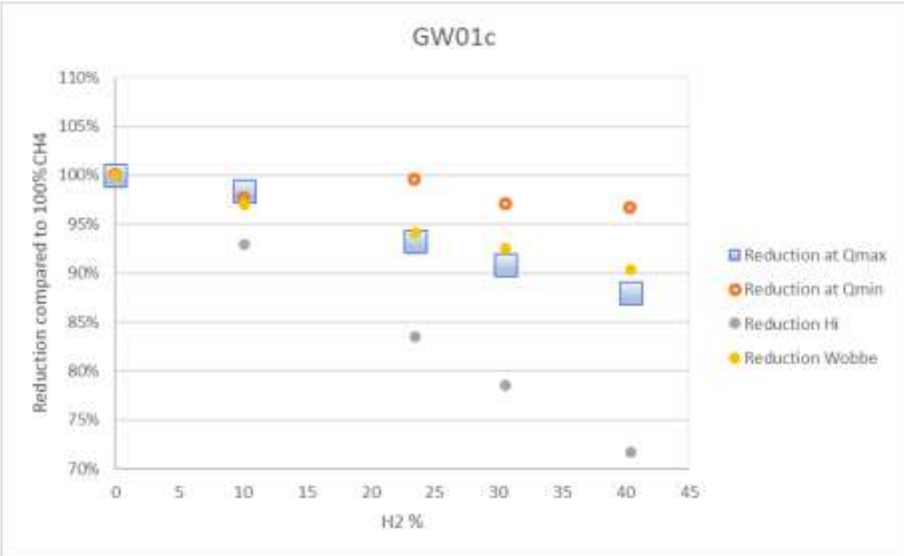


Figure 53

The result above is rather strange at **Qmin**, the laboratory has indicated that the result observed could be due to the uncertainty of measurement.

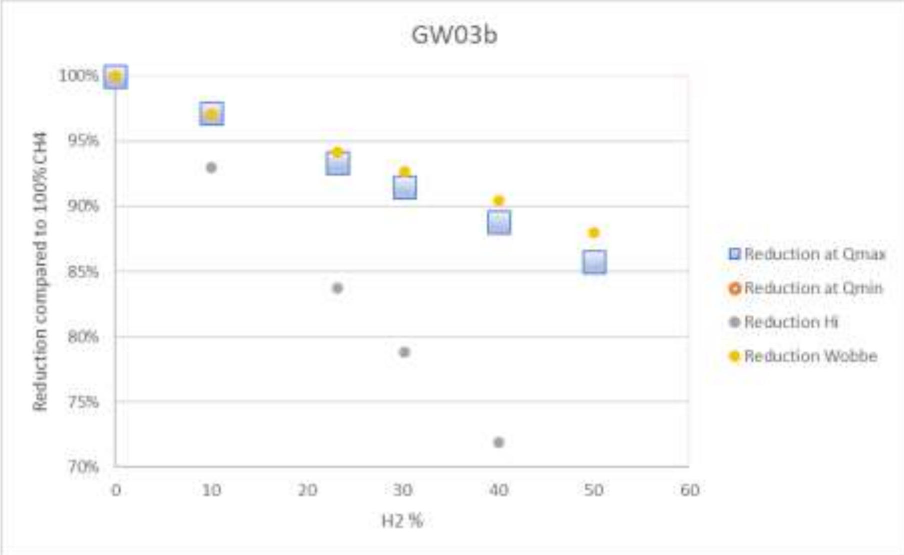


Figure 54

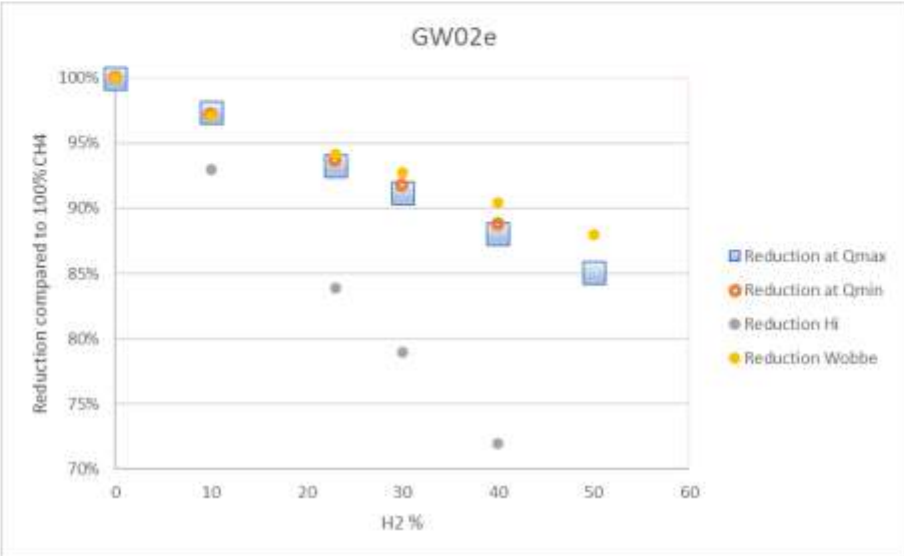


Figure 55

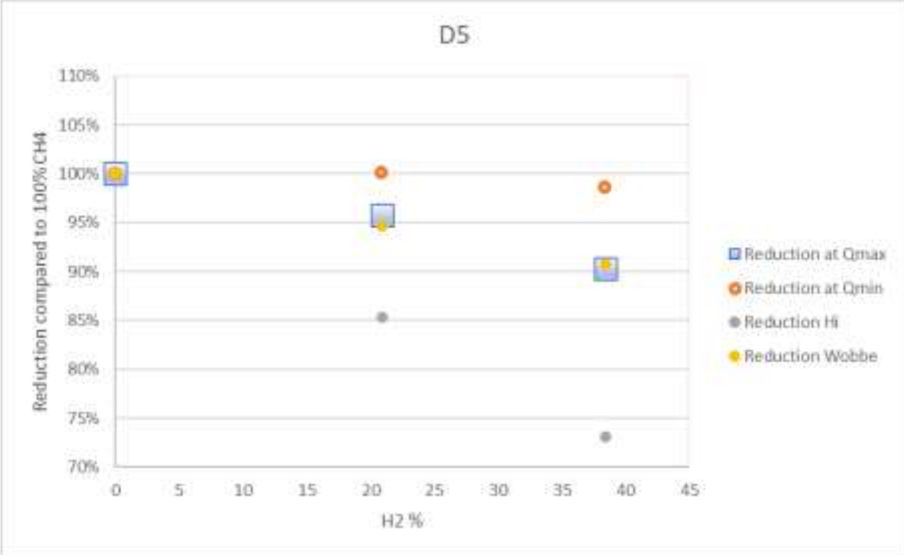


Figure 56

There is almost no reduction of heat input for the minimum of the modulation range.

7.2.3.2 Water heater

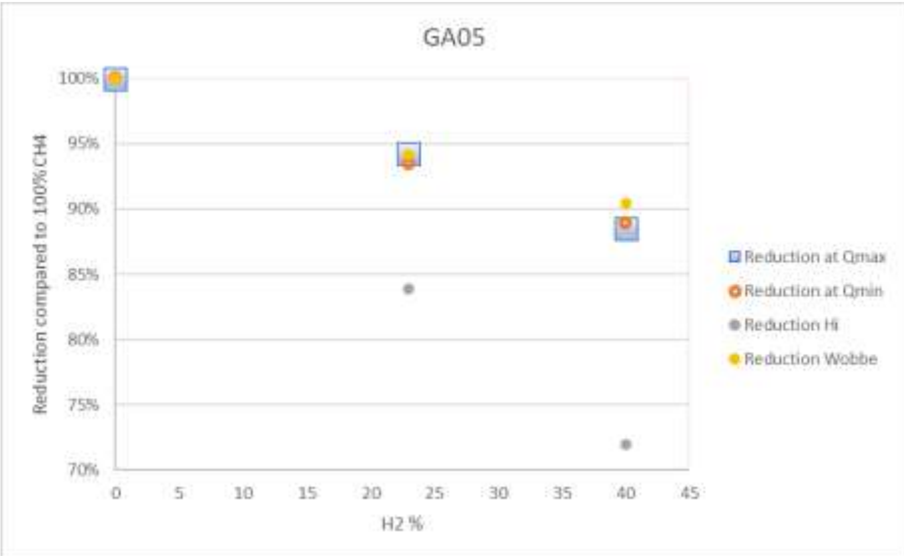


Figure 57

7.2.3.3 Cooker hob

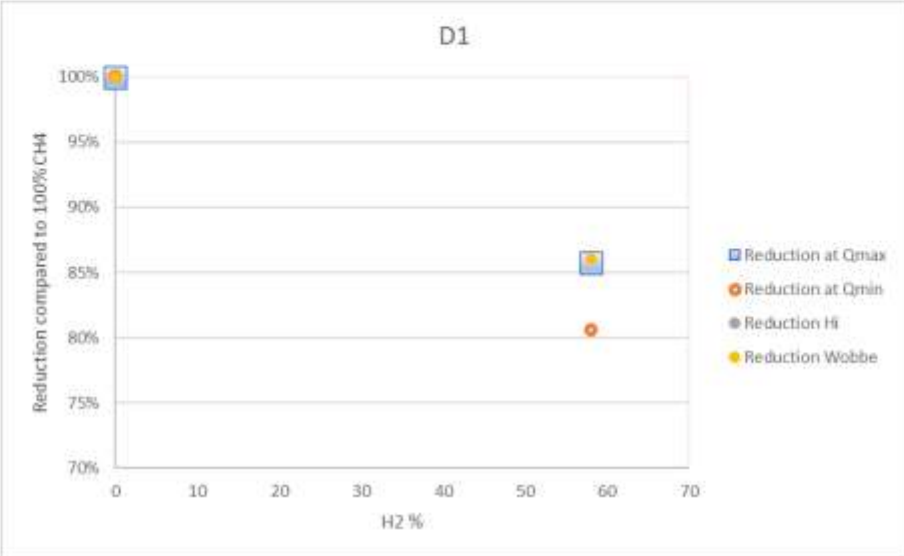


Figure 58

For the cooker D2 we have quite small value for the flow measured, and a large uncertainty on flow.

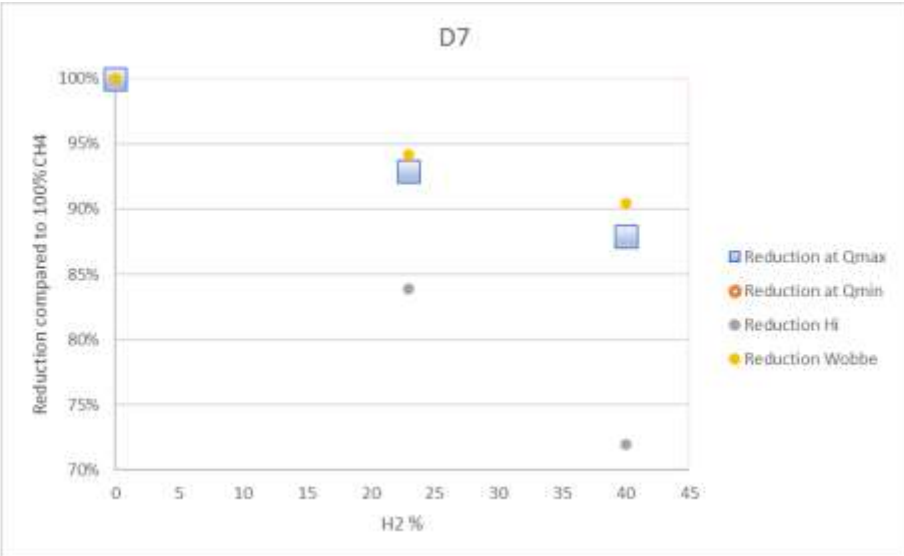


Figure 59

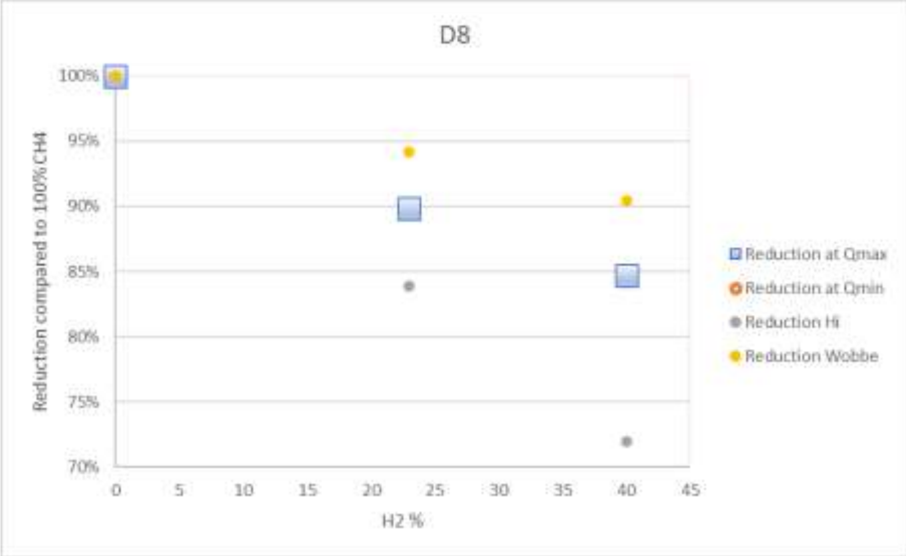


Figure 60

7.2.3.4 Oven

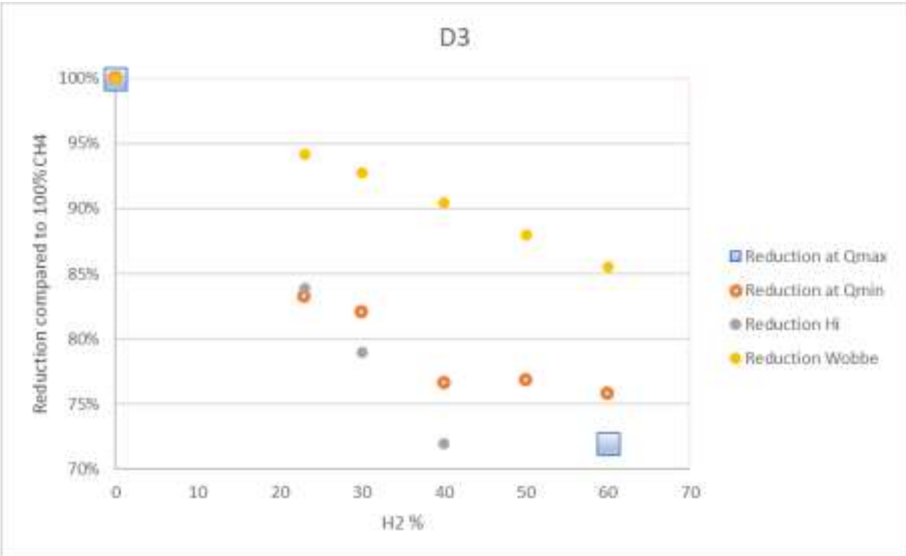


Figure 61

The results seem to follow more the variation of the calorific value in this case. The duration of the test may have an influence on the results

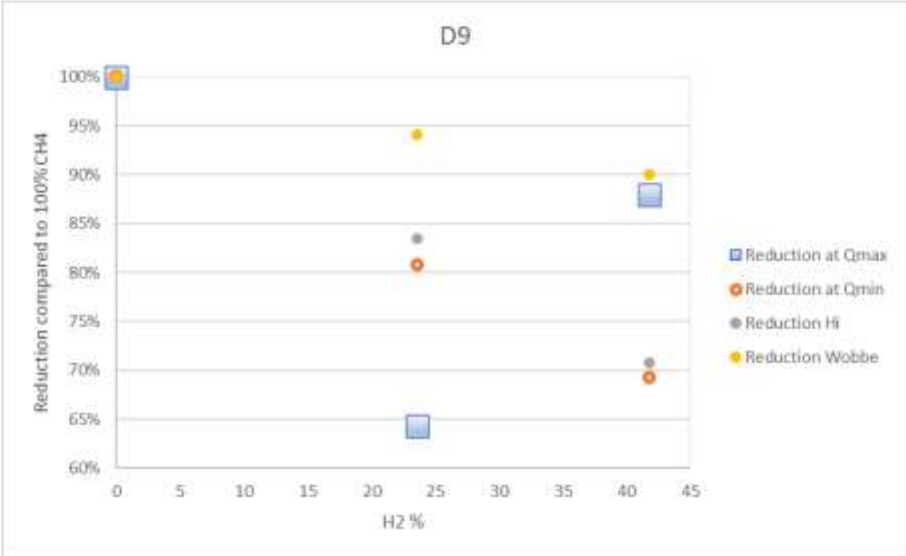


Figure 62

For this appliance, the Qmax point at 23% Shall be considered as an outlier (after checking with the laboratory we couldn't find the reason of the results shown.)

7.3 Impact of hydrogen on parameters that are depending on the heat input

The heat input will directly impact some performances like energy delivered or heating time. This is especially important for cooking. The measurement of cooking time to heat the same quantity of water was measured for the cooking hob D7

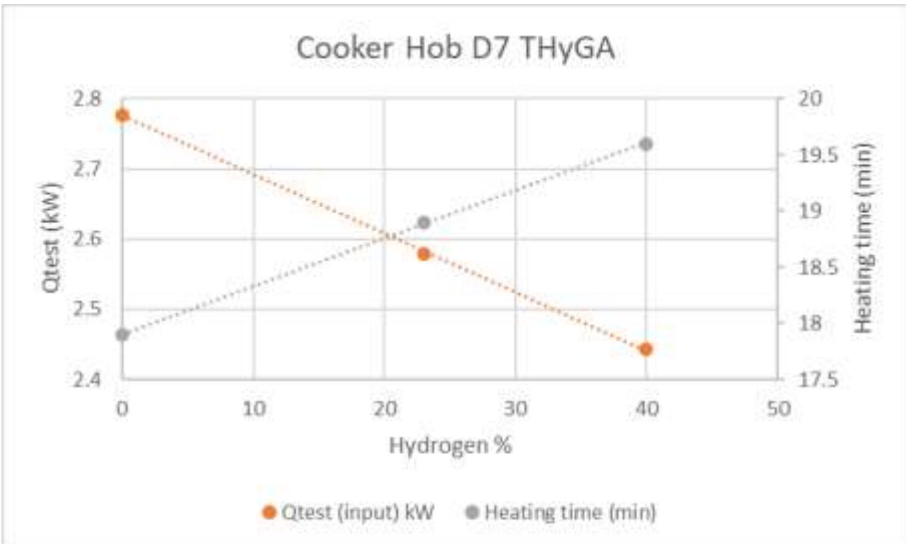


Figure 63

The heating time is a linear function of the % of H2, the heating time of a standard pan with water (time to boil) is increased here from about 18 minutes (at 0% H2) to 19.5 minutes with 40% H2.

7.4 Impact of hydrogen on flame aspect for decorative heaters.

For the time, we do not have visuals showing the aspect (colour) of the flame and variations of it with H2 % for decorative heaters (see also movies or other visuals taken for the test). It is observed that with white stones, the flame is blue and lower. This could be acceptable for people not used to it. After some time, it become also yellow (like wood appliances) A lot of parameters are having an influence on this aspect of hydrogen impact. From the test done until now, 20% seems to be acceptable at the moment.

8. Next steps: improvement of the test protocol

Part of the work was presented in this report was recently presented at a workshop to discuss the adjustment procedure. The discussion has confirmed that the procedure used in THyGA was conforming to real situation of adjustment on the field. Also, the project results were presented at a GERG project on Hydrogen with CEN, and we have not got observations on the testing methods & protocols used.

For the tests to come we have suggested in the report some conclusions that can be used to slightly adjust the focus for testing for the next test to come, **the most important points to consider in the test protocol are listed below**:

1. Adjustment of premix appliances with gas that can contain hydrogen is one of the major issues. It is important that the test is done systematically on such appliances, and it shall be done according to the protocol. There will be an urgent need to have a specific meeting between the labs to recap the details of the testing.

2. Flashback is generally only an issue for H2% above 30 or 40% of hydrogen even for atmospheric burners. However, long-term testing of appliances may change this positive conclusion as we have already observed issues appearing with longer testing times.

3. Efficiency variations are small. Testing the variations for more than 2 hydrogen concentrations is unnecessary and not cost effective as the test requires long stabilisation time (at least for a number of appliances). We suggest measuring at 0% and 30 or 40%.

4. NOx emissions could also be treated with two points (same as above).

5. Tests like Delayed ignition shall be measured on a few more appliances when possible.

For the testing programme the following points shall be noted:

- The delayed ignition test was made on one appliance with 30% H2. There was no safety issue, but we need to have a few more of those tests.
- The soundness was not tested so far for any appliance. The requirements from standards are not very severe, we do not expect issues there, but there is no specific test protocol for such test in case of hydrogen natural gas blends. We may contact e.g., TC 109 to ask if there is a test procedure on the way that we could incorporate in our programme.
- At the moment, we do not have visuals showing the aspect of the flame and variations of it with H2 % for decorative heaters

9. ANNEX 1 APPLIANCES ThyGA ID cards

In this section we are publishing the details of the safety test executed by the different laboratories.

The results are given by laboratory using a chronological number per appliance tested.

9.1 BA

THyGA Appliance ID card for BA01_SEGM_107

Appliance	B
Burner	Low NOx technology burners
Origin	New appliance (2021)
Segment	107
Max. power input (net) [kW]	25
Min. power input (net) [kW]	11

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X	X	X	X	X	X	X
1.2 SAFETY- with EULOW	X	X	X	X	X	X		
1.3 SAFETY- with G23								
1.4 Cold start.						X		X
1.5 Hot start.								X
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length					X			
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.	X	X	X	X	X	X	X	X
3.1 ADJUSTMENT A	X	X			X	X		
3.2 ADJUSTMENT B	X	X			X	X		
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.					X			
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy			X					
4.9 Fluctuation of pressure						X		
4.x Other test								

OVERALL

The boiler works correctly up to 40% of H2 in the blend. Using G20, EU_low or EU_high in the mixture does not compromise the correct operation of the boiler. The differences between the three type of gases can be seen on slightly different emissions and heat inputs due to the different compositions and Wobbe indexes. Adding H2 to the blend make the flame to be closer to

9.2 GW

THyGA Appliance ID card for GW1_SEGM_108

Appliance	B
Burner	full premixed
Origin	old used by GWI many times
Segment	108
Max. power input (net) [kW]	24
Min. power input (net) [kW]	7

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X		X	X	X		
1.2 SAFETY- with EULOW	X					X		
1.3 SAFETY- with G23								
1.4 Cold start.						X		
1.5 Hot start.								
1.6 Low air temperature (- 10 C)						X		
1.7 Flue gas pipe length						X		
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.								
3.1 ADJUSTMENT A								
3.2 ADJUSTMENT B			NOT TESTED					
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G								
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								
4.x Other test								
OVERALL	The boiler work well for the test performed (up to 40% H2). The boiler was not tested for adjustment (please confirm it cannot be adjusted despite it is a premix?)							

THyGA Appliance ID card for GW2_SEGM_102

Appliance	B
Burner	Low NOx technology burners
Origin	old/ used by GWI many times
Segment	102
Max. power input (net) [kW]	22
Min. power input (net) [kW]	9

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X	X	X	X	X	X	
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23					X			
1.4 Cold start.						X		
1.5 Hot start.						X		
1.6 Low air temperature (- 10 C)						X		
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.								
3.1 ADJUSTMENT A								
3.2 ADJUSTMENT B			To be discussed /clarified					
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G								
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure		Test To be discussed /clarified (as there is a PR it is not critical)						
4.x Other test								
OVERALL	No safety issues noticed by normal operation. High CO levels noticed with the adjustment tests, specifically the adjustment test with Eulow and then using EU high. The boiler doesn't run with 50% H2 at Qmin (can you possibly add details)							

THyGA Appliance ID card for GW2_SEGM_102

Appliance	B
Burner	Low NOx technology burners
Origin	old/ used by GWI many times
Segment	102
Max. power input (net) [kW]	22
Min. power input (net) [kW]	9

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X	X	X	X	X	X	
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23					X			
1.4 Cold start.						X		
1.5 Hot start.						X		
1.6 Low air temperature (- 10 C)						X		
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.								
3.1 ADJUSTMENT A								
3.2 ADJUSTMENT B			To be discussed /clarified					
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G								
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure		Test To be discussed /clarified (as there is a PR it is not critical)						
4.x Other test								
OVERALL	No safety issues noticed by normal operation. High CO levels noticed with the adjustment tests, specifically the adjustment test with Eulow and then using EU high. The boiler doesn't run with 50% H2 at Qmin (can you possibly add details)							

THyGA Appliance ID card for GW03_SEGM_103

Appliance	B
Burner	atmospheric
Origin	old/used by GWI
Segment	103
Max. power input (net) [kW]	17
Min. power input (net) [kW]	NA

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X	X	X	X	X	X	X
1.2 SAFETY- with EULOW	X				X			
1.3 SAFETY- with G23								
1.4 Cold start.	X					X		
1.5 Hot start.	X					X		X
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.	X	X	X	X	X	X	X	X
3.1 ADJUSTMENT A	X				X			
3.2 ADJUSTMENT B	X				X			
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G	X				X			
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure						X		
4.x Other test								

OVERALL

The system works well up till 40% H2. After 40% it gets louder. Flashback happens at 60% H2 and the system doesn't start again after that.

9.3 GA

THyGA Appliance ID card for GA1_SEGM_101

Appliance	B
Burner	Atmospheric
Origin	Already used for other project . Received september 2016 .
Segment	101
Max. power input (net) [kW]	26
Min. power input (net) [kW]	11

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			X		X	X	
1.2 SAFETY- with EULOW	X				X			
1.3 SAFETY- with G23	performed without H2							
1.4 Cold start.							X	
1.5 Hot start.								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X						X	
1.9 Impact of H2 on flame detection.	X							
1.10 Flash back analyse.	X						X	
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off							X	
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure							X	
4.x Other test								
OVERALL	No safety issues observed							

THyGA Appliance ID card for GA2_SEGM_503

Appliance	EN613 Convection heater
Burner	Atmospheric
Origin	Already used for other project . Received september 2016 .
Segment	503
Max. power input (net) [kW]	6
Min. power input (net) [kW]	3

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			X		X	X	X (FB)
1.2 SAFETY- with EULOW	X				X			
1.3 SAFETY- with G23								
1.4 Cold start.								X
1.5 Hot start.							X	X (FB)
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X							X
1.9 Impact of H2 on flame detection.	X							X
1.10 Flash back analyse.	X						X	X (FB)
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								X
4.x Other test (flame aspect)	X							X

OVERALL

Flashback occurred during the ignition test in warm condition with a mixture of 60% hydrogen. The device is equipped with an explosion hatch that catches this small explosion. No further damage to the device has been established. The correct functioning of the device is guaranteed with a lower hydrogen mixture.

THyGA Appliance ID card for GA3_SEGM_407

Appliance	Catering (O)
Burner	Atmospheric
Origin	New appliance, it was a back-up appliance for another project.
Segment	407
Max. power input (net) [kW]	6
Min. power input (net) [kW]	Not specified

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			X		X		
1.2 SAFETY- with EULOW					X	table missing in the report		
1.3 SAFETY- with G23								
1.4 Cold start.						X		
1.5 Hot start.						X		
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X			X		X		
1.9 Impact of H2 on flame detection.	X			X		X	works despite flamme brignteness change	
1.10 Flash back analyse.	X			X		X		
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off						X		
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind						X		
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure						X	thudding sound can be heard @14mbar and a whistling sound at the injector	
4.x Other test								

OVERALL

The correct and safe functioning of the appliance is guaranteed up to a mixture of 40%H2. Only the minimum load should be set slightly higher in order to eliminate the occurring noise.

THyGA Appliance ID card for GA4_SEGM_406

Appliance	Catering
Burner	Premix
Origin	New device, but already used for another project (3 test days).
Segment	406
Max. power input (net) [kW]	31
Min. power input (net) [kW]	16

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			X		X		
1.2 SAFETY- with EULOW		X			X			
1.3 SAFETY- with G23								
1.4 Cold start.						X		
1.5 Hot start.						X		
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.						X		
3.1 ADJUSTMENT A				X				
3.2 ADJUSTMENT B				X				
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G			X	X	**Not extensive test done**			
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off						X		
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure						X		
4.x Other test								

OVERALL	The appliance was tested for the short term test up to 40% H2. The CO value was too high (>5000ppm) when the appliance was adjusted with EULOW30 and tested with EUHIGH. There were no safety issues at Qmax and Qmin when the appliance was adjusted with CH4. According to the manufacturers manuel the appliance may be adjusted between G20 and G25. Other adjustements must be carried out by the manufacturer.

THyGA Appliance ID card for GA5_SEGM_201

Appliance	WH
Burner	Atmosperhic
Origin	Already used for other project
Segment	201
Max. power input (net) [kW]	11
Min. power input (net) [kW]	5

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			X		X		
1.2 SAFETY- with EULOW		X			X			
1.3 SAFETY- with G23								
1.4 Cold start.						X		
1.5 Hot start.								
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back analyse.						X		
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off						X		
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind	X	Issue with CH4 test and H2 test				X		
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure						X		
4.x Other test								
OVERALL	No issue wuth H2 for the test performed, but the wind test performed with CH4 shows that the applinace is not conform. Tafter addition of H2 it is still not conform (is the situation worthened with H2?)							

9.4 D

THyGA Appliance ID card for D1_SEGM_301

Appliance EN30 free standing cooker with partialy aerated ribbon burner (oven) ”atmospheric Partia

Burner atmospheric Partially Aerated

Origin Bought new in a shop 2020

Segment 301

Max. power input (net) [kW] 3

Min. power input (net) [kW] 1

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X							X
1.2 SAFETY- with EULOW	X							X
1.3 SAFETY- with G23								
1.4 Cold start.							X	
1.5 Hot start.								
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	**Planned to be done long before long term**							
1.9 Impact of H2 on flame detection.	X							X
1.10 Flash back analyse.	X							X
3.1 ADJUSTMENT A	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
3.2 ADJUSTMENT B	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
3.3 ADJUSTMENT H	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
3.4 ADJUSTMENT G	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	**Planned to be done long before long term**							
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	**Planned to be done long before long term**							
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								
4.x Other test								
OVERALL	No safety issues observed							

THyGA Appliance ID card for D2_SEGM_301

Appliance	EN30 free standing cooker with partialy aerated ribbon burner (oven) ”atmospheri
Burner	atmospheric Partially Aerated
Origin	Bought new in a shop 2020
Segment	301
Max. power input (net) [kW]	1
Min. power input (net) [kW]	0

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	No FB for short tests (< 10 min) but FB over longer period						X
1.2 SAFETY- with EULOW	X							X
1.3 SAFETY- with G23	X							X
1.4 Cold start.	X							X
1.5 Hot start.								
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length	NR	NR	NR	NR	NR	NR	NR	NR
1.8 ROC (PLUGG FLOW)	Planned to be done long before long term							
1.9 Impact of H2 on flame detection.	X							X
1.10 Flash back analyse.	X	No FB for short tests (< 10 min) but FB over longer period						X
3.1 ADJUSTMENT A	NR	NR	NR	NR	NR	NR	NR	NR
3.2 ADJUSTMENT B	NR	NR	NR	NR	NR	NR	NR	NR
3.3 ADJUSTMENT H	NR	NR	NR	NR	NR	NR	NR	NR
3.4 ADJUSTMENT G	NR	NR	NR	NR	NR	NR	NR	NR
4.1 Delayed ignition test.	Delayed ignition for cookers NR							
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	Planned to be done long before long term							
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	Not tested?							
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								
4.x Other test								
OVERALL	While short test test with up to 60% H2 have not shown any issue, flashback was observed during efficiency test with 60% H2 after long running time of the cooker (50 minutes or so). This has resulted in damages making the rest of the test impossible							

THyGA Appliance ID card for D3_SEGM_301

Appliance	EN30 free standing cooker with partialy aerated ribbon burner (oven) ”atmospheri
Burner	atmospheric Partially Aerated
Origin	Bought new in a shop 2020
Segment	301
Max. power input (net) [kW]	3
Min. power input (net) [kW]	1

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X				X	X		X
1.2 SAFETY- with EULOW	X							X
1.3 SAFETY- with G23	X							X
1.4 Cold start.	X			X		X		
1.5 Hot start.	X					X		X
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length	NA	NA	NA	NA	NA	NA	NA	NA
1.8 ROC (PLUGG FLOW)	Make a fast test before long term							
1.9 Impact of H2 on flame detection.								
1.10 Flash back analyse.	X							X
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.	Delayed ignition for cookers NR							
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	Planned to be done long before long term							
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	Not tested?							
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								X
4.x Other test								
OVERALL	No Flash back Observed, but clear changes in flamme at 60% that may translate in higher burner surface temperature and possibly issues at later stage (FB, component aging, etc..)							

THyGA Appliance ID card for D4_SEGM_108

Appliance	B
Burner	Premix
Origin	Sent by the manufacturer
Segment	108
Max. power input (net) [kW]	20
Min. power input (net) [kW]	5

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	x	x	x	x	x	x	X
1.2 SAFETY- with EULOW	X				X			
1.3 SAFETY- with G23								
1.4 Cold start.	X							X
1.5 Hot start.								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X							X
1.9 Impact of H2 on flame detection.	X							X
1.10 Flash back analyse.	X							
3.1 ADJUSTMENT A	X	X			X			X
3.2 ADJUSTMENT B	X	X			X			X
3.3 ADJUSTMENT H	X	X			X			X
3.4 ADJUSTMENT G	X		X					
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	NA	NA	NA	NA	NA	NA	NA	NA
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X					X		
4.x Other test								

OVERALL

The appliance was tested for short term test with up to 60% H2. Within the test programme executed there has not been any safety issue apart the case of the appliance is adjusted with EU low including 20% H2 and is operated with EUhigh. Efficiency and emissions are impacted by H2.

THyGA Appliance ID card ID5_SEGM_108

Appliance	Boiler
Burner	Premix
Origin	Sent by the manufacturer
Segment	108
Max. power input (net) [kW]	21
Min. power input (net) [kW]	4

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X				X	X		
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23								
1.4 Cold start.	X					X		
1.5 Hot start.	X					X		
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length								
1.8 ROC (PLUGG FLOW)	X					x	X	X
1.9 Impact of H2 on flame detection.	X					x		
1.10 Flash back analyse.	X					x		
3.1 ADJUSTMENT A								
3.2 ADJUSTMENT B								
3.3 ADJUSTMENT H								
3.4 ADJUSTMENT G	X		X	X	X	X	X	X
4.1 Delayed ignition test.								
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	NA	NA	NA	NA	NA	NA	NA	NA
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X							x
4.x Other test								

OVERALL

The appliance was tested for short term test with up to 40-60% H2 depending on test purpose. Within the test programme executed there has been safety issues when the appliance is adjusted* with EU low including 20% H2 and is operated with EUhigh. Safety issues were apparent as detonation/flashback and high CO concentrations larger than 6000 ppm during auto adjustment performed by the boiler electronics.

No safety issues at Qmax when the appliance were adjusted with CH4. CO peaks larger than 300 ppm during auto adjust at Qmin.

Efficiency and emissions are impacted by H2.

THyGA Appliance ID card 1D7_SEGM_301

Appliance	CH
Burner	Surf. atmospheric burner (large)
Origin	sent by manufacturer
Segment	301
Max. power input (net) [kW]	3
Min. power input (net) [kW]	1

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	x		x		x		
1.2 SAFETY- with EULOW	X	x		x		x		
1.3 SAFETY- with G23								
1.4 Cold start.								
1.5 Hot start.	X	x		x		x		
1.6 Low air temperature (- 10 C)	NA	NA	NA	NA	NA	NA	NA	NA
1.7 Flue gas pipe length	NA	NA	NA	NA	NA	NA	NA	NA
1.8 ROC (PLUGG FLOW)	X					x		
1.9 Impact of H2 on flame detection.	X					x		
1.10 Flash back analyse.	X					x		
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.	NA	NA	NA	NA	NA	NA	NA	NA
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	X					x		
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X					X		
4.x Other test								

OVERALL

The appliance was tested for short term test with up to 40% H2. Within the test programme executed there has not been any safety issue. General remarks: It was observed high CO emissions when the burner operated at CH4. Please note, that tests at Qmin (minimum heat input) were performed at initial settings e.g. without any ajustments.

THyGA Appliance ID card D8_SEGM_301

Appliance	CH
Burner	Surf. atmospheric burner (small)
Origin	sent by manufacturer
Segment	301
Max. power input (net) [kW]	1
Min. power input (net) [kW]	0

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			x		x		
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23								
1.4 Cold start.	X					x		
1.5 Hot start.	X					x		
1.6 Low air temperature (- 10 C)	NA	NA	NA	NA	NA	NA		
1.7 Flue gas pipe length	NA	NA	NA	NA	NA	NA		
1.8 ROC (PLUGG FLOW)	X					x		
1.9 Impact of H2 on flame detection.	X					x		
1.10 Flash back analyse.	X					x		
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA		
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA		
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA		
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA		
4.1 Delayed ignition test.	NA	NA	NA	NA	NA	NA		
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	X					x		
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on								
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X					x		
4.x Other test								

OVERALL

The appliance was tested for short term test with up to 40% H2. Within the test programme executed there has not been any safety issue. General remarks: It was observed high CO emissions when the burner operated with CH4. Please note, that tests at Qmin (minimum heat input) were performed at initial settings e.g. without any ajustments.

THyGA Appliance ID card for D9_SEGM_3

Appliance	C Oven
Burner	Cavity burner "metal sheet"
Origin	sent by manufacturer
Segment	311
Max. power input (net) [kW]	2
Min. power input (net) [kW]	1

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X			x		x		
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23								
1.4 Cold start.	X					x		
1.5 Hot start.	X					x		
1.6 Low air temperature (- 10 C)	NA	NA	NA	NA	NA	NA		
1.7 Flue gas pipe length	NA	NA	NA	NA	NA	NA		
1.8 ROC (PLUGG FLOW)	X					x		
1.9 Impact of H2 on flame detection.	X					x		
1.10 Flash back analyse.	X					x		
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA		
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA		
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA		
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA		
4.1 Delayed ignition test.	NA	NA	NA	NA	NA	NA		
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off	Check the results				x			
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA		
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure	X					x		
4.x Other test								
OVERALL	conclusion in development							

THyGA Appliance ID car D10_SEGM_311

Appliance	C Oven
Burner	Cavity burner "metal sheet" with deflector
Origin	sent by manufacturer
Segment	311
Max. power input (net) [kW]	2
Min. power input (net) [kW]	not relevant

H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X					x		
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23								
1.4 Cold start.								
1.5 Hot start.	X					x		
1.6 Low air temperature (- 10 C)	NA	NA	NA	NA	NA	NA		
1.7 Flue gas pipe length	NA	NA	NA	NA	NA	NA		
1.8 ROC (PLUGG FLOW)								
1.9 Impact of H2 on flame detection.								
1.10 Flash back analyse.								
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA		
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA		
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA		
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA		
4.1 Delayed ignition test.	NA	NA	NA	NA	NA	NA		
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA		
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy								
4.9 Fluctuation of pressure								
4.x Other test								
OVERALL	conclusion in development							

10. Annex 2 Segment list from WP2 (from D1.2)

THyGA Segment	Type of appliance	Category	Burner type	Standard	Estimation of Total EU Appliance Population 2020 (x 1,000)
101	BOILERS	open flued (former EN 297)	partial pre-mix/conv. (atmos. & fan-assisted)	EN 15502	13,588
102			low NO_x		2,012
103			full pre-mix		152
104		room-sealed (former EN 483)	partial pre-mix/conv. (atmos. & fanned)		25,333
105			low NO_x		1,972
106			full pre-mix		1,781
107		condensing boiler (former EN 677)	partial pre-mix fan-assisted		2,920
108			full pre-mix (including CCB)		56,492
109		Forced-draught burners / jet burners (former EN 303-3)	Forced-draught / jet		1,129
201	WATER HEATERS	instantaneous open flued	partial pre-mix/atmos.	EN 26	14,945
202		instantaneous room sealed	partial pre-mix/fanned		
203		storage, open flued	partial pre-mix/atmos.	EN 89	3,121
204		storage, room-sealed	partial pre-mix/fan-assisted		
301	COOKERS	surface burner (cooktops) with atmospheric burner or "Venturi" burner (vertical venturi burner)	single ring	EN 30-x	32,574
302			single crown		
303			multi ring (mainly double or triple ring)		
304			single ring		1,352

305		surface burner (cooktops) with partially pre-mix burner (long horizontal venturi)	single crown		
306			multi ring (mainly double or triple ring)		
307		cavity burner "tubular" (ovens, freestanding ranges)	atmospheric burner		3,853
308			"venturi" burner		
309			partially pre-mix		27,712
310		cavity burner "metal sheet" (ovens, freestanding ranges)	atmospheric burner		13,056
311			"venturi" burner		
312			partially pre-mix		14,658
401	CATERING	open burners and wok burners	circular burner with vertical slots	EN 203-2-1	unknown
402			circular burner with holes		
403		mixed ovens	draught burners	EN 203-2-2	unknown
404		ovens	tubular or circular burners		
405		boiling pans / pasta cookers	micro-perforated burner	EN 203-2-3 EN 203-2-11	unknown
406		fryers	pre-mix burner	EN 203-2-4	unknown
407		salamanders / rotisseries	ceramic or blue flame burners	EN 203-2-7	unknown
408		brat pans	multi-ramp tubular slot burners	EN 203-2-8	unknown
409		covered burners (griddles, solid tops, pancake cookers)	tubular burner or multi-ramp tubular burner	EN 203-2-9	unknown
410		barbecues	chargrill with burner tubes w/ holes on top	EN 203-2-10	unknown
501	SPACE HEATERS	Independent gas-fired convection heaters type B	heating & decoration	EN 613	4,678
502		Independent gas-fired convection heaters type C	heating & decoration, balanced	EN 613	1,839
503		Decorative fuel-effect gas appliance/burner	heating & decoration	EN 13278 + EN 509	2,529

504		Independent gas-fired flueless space heaters	heating & decoration	EN 14829	98
601	CHP	Stirling engines	heating & electricity production	EN 50465	14.8
602		Internal combustion engine			40.8
603		Micro gas turbine			0.5
604		PEM Fuel Cell			5
605		SO Fuel Cell			2.7
701	GHP	engine HP	Heating	EN 16905	60
702		adsorption		EN 12309	
703		absorption			
801	OTHER	commercial dryers		EN 12752-1 and -2	unknown
802		infrared radiant heaters (former EN 416-1)	non-domestic, tube radiant heaters	EN 416	1,000
803		infrared radiant heaters (former EN 419-1)	non-domestic, luminous radiant heaters	EN 419	
804		infrared radiant heaters (former EN 777-1)	non-domestic, tube radiant heaters	EN 416	
805		air heaters (former EN 1020)	non-domestic, forced convection, fan, <300kW	EN 17082	1,000
806		air heaters (former EN 525)	non-domestic, forced convection, <300kW	EN 17082	
807		air heaters <70kW (former EN778)	Ducted warm air; forced convection air heaters	EN 17082	
808		domestic washing machines		EN 1518	< 10
809		domestic dryers		EN 1518	< 10
				sum	**approx. 228,000**