Testing Hydrogen admixture for Gas Applications

THYGA
INSTRUCTION FOR THE TEST PROTOCOL for testing in laboratories

WP3

Note that this document is regularely updated with improvements of the test programme in light of the results of the first tests.
The document THY_WP3_019_DataSheet.xls is the datasheet to be used for testing (last version is at the moment *nov 2020a.*
The present ppt document is mainly for communication and explanation and may not be further updated once the labs are using the datasheet document (that will be updated regularely).

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No. 874983. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

Introduction

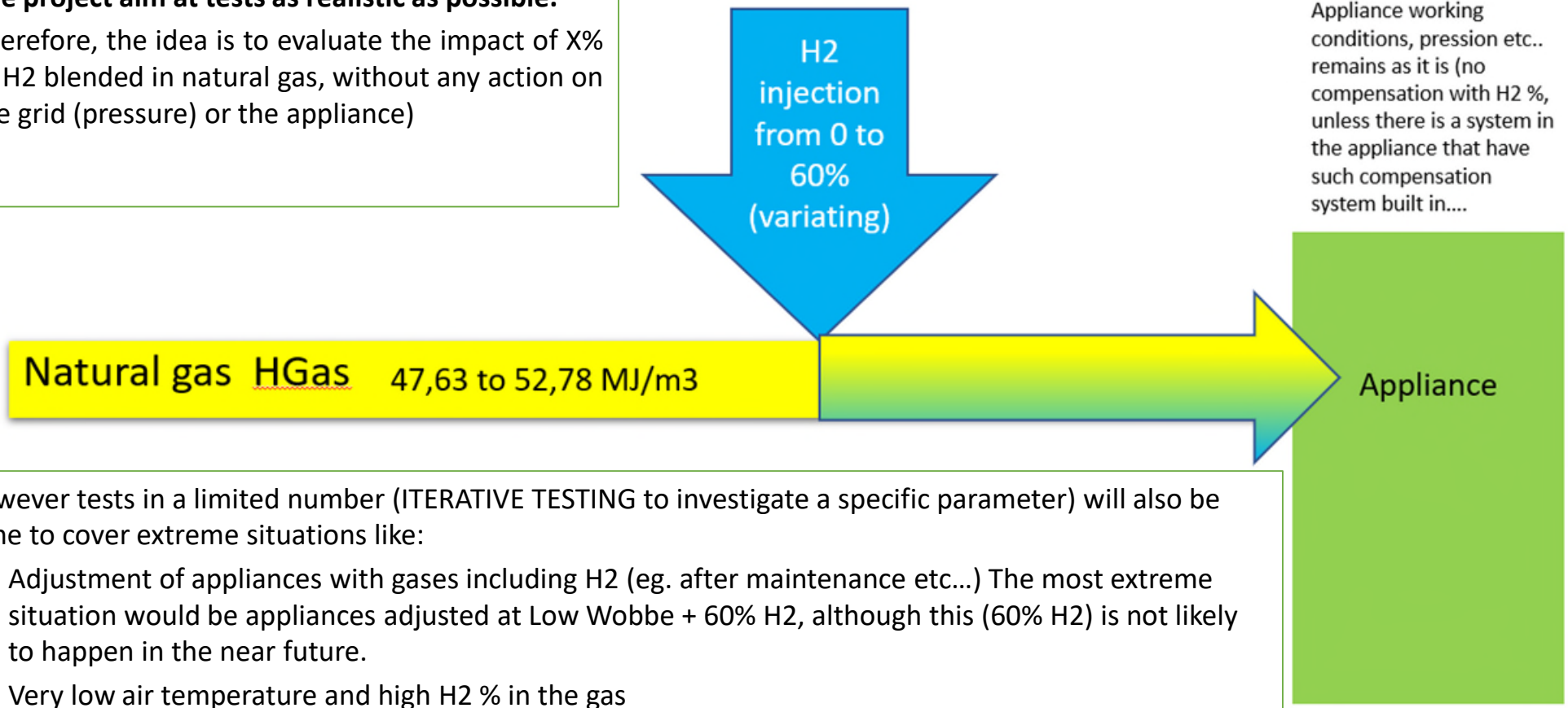
Overall philosophy

of testing in WP3

Overall philosophy of the WP3

The project aim at tests as realistic as possible.

Therefore, the idea is to evaluate the impact of X% of H2 blended in natural gas, without any action on the grid (pressure) or the appliance)



However tests in a limited number (ITERATIVE TESTING to investigate a specific parameter) will also be done to cover extreme situations like:

- Adjustment of appliances with gases including H2 (eg. after maintenance etc…) The most extreme situation would be appliances adjusted at Low Wobbe + 60% H2, although this (60% H2) is not likely to happen in the near future.
- Very low air temperature and high H2 % in the gas
- Etc..

The WP5 (Mitigation) will also look into the impact of specific actions to improve the acceptance rate of H2 (pressure on the grid, control and sensors..)

1. Few abbreviations used
2. Overall chronology. Testing: before, during, after
3. Document DATA Sheet
   - 3.1 Introduction DOCUMENT “DATA SHEET”
   - 3.2 Document DATA SHEET Content
   - 3.3 Overall instructions to fill in sheets
   - 3.4 Nomenclature for saving datasheet files names
   - 3.5 Test programme. Standard Test & additional tests
   - 3.6 Sheet TEST PROGRAMME
   - 3.7 Sheets EU Low and EU high (Gases)
   - 3.8 Gases parameters calculation (for each test)
   - 3.9 Sheet DATA SHEET: Overall colour code
4. Testing
   - 4.1 Overall Test conditions Sheet “STANDARD TEST CONDITIONS”
   - 4.2 Flashback
   - 4.3 Instructions to perform the test following the sheet “DATA SHEET”)
5. Open questions
6. Annexes

1. Few abbreviations used

- ROC: Rate of change (of H2 % increasing or decreasing)
- FB: Flash Back
- SL: Flame speed

2 Overall chronology.
Testing: before, during, after

SEE THE DETAILS IN THE DOCUMENTS

THY_WP3_033_Instructions to labs xx (word)
And
THY_WP3_034_Instructions to labs xx (ppt)

Overall chronology. Testing: before, during, after

CHRONOLOGY:

TO BE DONE BY THE LABS

Decision on what appliance to be tested (WP2)

Purchase of the appliance **Or** Contact Lab- Manufacturer

Agreement Lab- Manufacturer

→ Update the status on **appliance list**

(to be decided how to monitor)

Testing according the protocol & adapted test programme ⇔ Agree with WP3 + ? about **testing programme**

Reporting V01- V02: draft /with internal QA ⇔ Copy to WP3 partner for QA

Reporting V03 /draft with external QA ⇔ Copy to manufacturers for comments (to be decided)

Reporting VF (final) (including man. remarks) → Copy to WP3 leader + manufacturer

Returning the appliance to the manufacturer — Only once the VF is finalised

File List of appliances (example)

THY_WP3_023_appliance list x, is the file that we will use to monitor the testing. It includes the list of appliances for testing with information about testing progress and reporting progress.

Once a laboratory start a test, the list of appliances **on SharePoint** shall be updated:

Check confidentiality. Can we have the list with manufacturers names on Sharepoint?

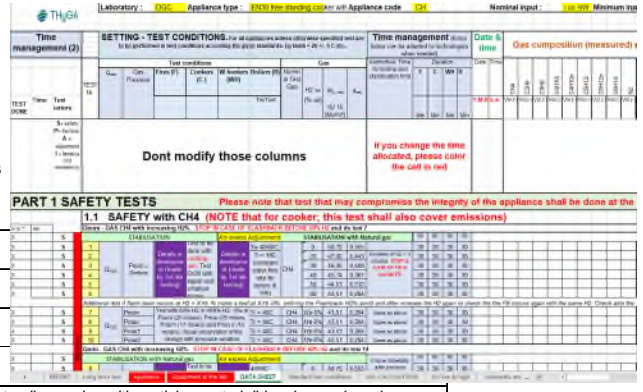
THYGA APPLIANCE TEST LIST

Chronol. Nr.	LAB	Date.		Appliance									Status: date of	
		Appliance reception	Test planed:	Code	Name	Appliance type (*)	Segm.	Purchase situation	Appliance origin	Agreement situation	Appliance condition	Report name	V01: draft	V02: d with int QA
1	DGC	May 2020	may-june 2020	D1	[redacted]	Hob - burner 1		Purchased. In the lab.	Bought in a store	NR	new	THY_Test report_D1	aug-20	
2	DGC	May 2021	may-june 2020	D2	[redacted]	Hob - burner 2		Purchased. In the lab.	Bought in a store	NR	new	THY_Test report_D2	aug-20	
3	DGC	May 2020	may-june 2020	D3	[redacted]	Oven		Purchased. In the lab.	Bought in a store	NR	new	THY_Test report_D3	aug-20	
4	DGC	May 2020	July 2020	D4	[redacted]xxxx	Cond. Boiler		In the lab. Under test	Sent by [redacted]	Not needed	new	THY_Test report_D4	aug-20	
5	DGC	July 2020	aug-20	D5	[redacted] xxx	Hob - burner 1		In the lab.	Sent by [redacted]	Not needed	new	THY_Test report_D5		
6	DGC	May 2020		D6	[redacted]xxx	Hob - burner 2		In the lab.	Sent by [redacted]	Not needed	new	THY_Test report_D6		
7	DGC	May 2020		D7	[redacted]xxx	Oven		In the lab.	Sent by [redacted]	Not needed	new	THY_Test report_D7		
8	DGC	May 2020		D8	tbd	Cond. Boiler		In the lab.	in DGC	Needed?	check	THY_Test report_D8		
9	DGC	May 2020		D9	tbd	Cond. Boiler		In the lab.	in DGC	Needed?	check	THY_Test report_D9		
10	DGC	May 2020		D10	[redacted] xxx	ICE engine		Noy yet in the lab	Will be sent by [redacted]	signed	?	THY_Test report_D10		

3. DOCUMENT “DATA SHEET”

3.1 Introduction DOCUMENT "DATA SHEET"

The document "DATA SHEET" is the **APPLIANCE EXTENDED REPORT** of the appliance. It includes the data sheet with test data and calculation, but also a number of other useful sheets including a sheet for **REPORTING**



THyGA

REPORT V01 **Part 1** **Synthesis**

Appliance identification (info from identification table)

Laboratory	DGC
SEGMENT Nr	19
Report code	D1
Report VERSION (**)	0
Type of appliance	EN30 free standing cooker with partialy aerated ribbon burner (oven) "atmospheric
Appliance THYGA Code (B, CH, CO, F, WH) (*)	CH
Burner type	See above
For cooker hobs: burner tested?	The smallest one

Using the harmonized test sheet is important for we can compare the results and make a proper analyse of the testing.

USE THE LATEST VERSION OF THE TEST SHEET THAT IS AVAILABLE ON SHAREPOINT:
THY_WP3_019_DataSheet *date*

Note that the sheet will change in light of the discussions and results found during the testing.

The data sheet is a help to labs, it is partly automated, but labs shall still read, check , correct and update the pages that are generated for the reporting

Introduction DOCUMENT "DATA SHEET"

The main sheet of the document "DATA SHEET" is the **DATA SHEET** (having given the name to the file…) which contains the rough results of testing and calculations.

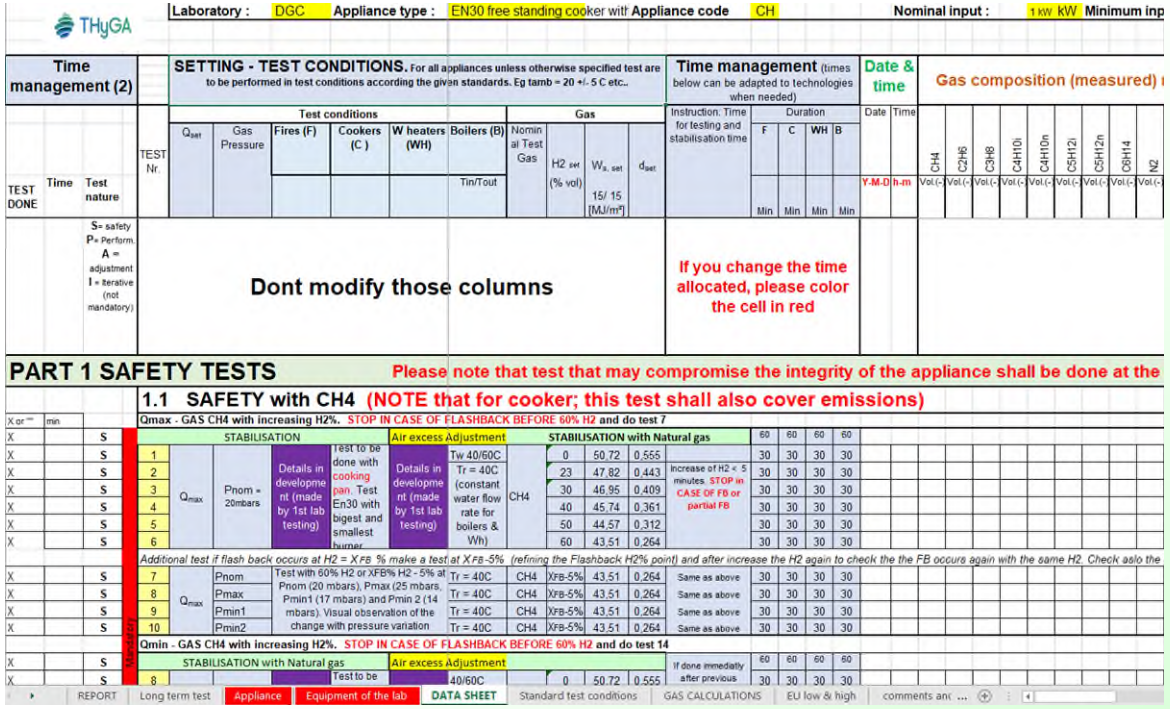
The original idea was to put the testing in this sheet in a **chronological order.**

However this has been very challenging as the initial procedures (including stabilisation time, measurement time, etc.) for testing had to be adapted in light of the first testing (*).

So from the first tests we learned that:

- Safety test from 1.1 are to be as long as performance tests (2.1) and that they shall therefore best be combined
- The highest H2 % shall be tested at the end.
- This needs to rethink (optimize) the number of points with H2%

Therefore we have designed the **data sheet**, or make a new operational instruction sheet with the aim to optimize (= reduce) the testing time & make the use of it easier.



(*) (initially test 1.1 were supposed to be rather short and cover the whole range of H2% to 60%). It appears that this is not adapted to detect flashback (occurring in the first test done after > 50 minutes) and that when happening the burner may be damaged; resulting we had to stop the testing to get a new burner.

3.2 Document DATA SHEET Content

The TEST SHEET file includes several sheets:

1. **Report:** *This will be the **public report** of the appliance testing.*
2. **Appliance:** *Is the description of the appliance tested*
3. **Datasheet:** *Is the sheet with all detailed data measured and calculated*
4. ***Test programme:** is the actual planned testing programme (specific to the appliance tested)*
5. **Pictures:** *Pictures of the appliance on the test rig*
6. ***Remarks:** Remarks on the testing that are not already in the Datasheet*
7. **Equipment of the lab:** *A short description of the laboratory equipment.*
8. **Long term test:** *Test sheet for long term test*
9. **Standard Test conditions:** *Information about overall conditions to be respected*
10. **Gas parameters (= cal. Value, density, etc…)**
11. **EU Low and EU high:** *Information on gases*
12. **Check Internal:** *Internal check of the report before sending to DGC*
13. **Check External:** *Possible question from lab doing the QA*

CAN BE PUBLIC: No confidential information (once the info on appliance model is removed)

NOT PUBLIC: Internal documents shared between labs only

Can be PUBLIC: Informative documents

NOT PUBLIC: Data Check document Internal documents

3.3 Overall instructions to fill in sheets

1- Start with appliance description
2- Data sheet are to be filled in during the testing.
3- Pictures, remarks can be done under way
4- Equipment of the lab can be done one for once

5 - The report is to be done at the end, note that the report is taking some data from the other sheets

1- QA internal is to be done once the report is ready
2- The report is sent to another lab for QA external

Please respect the following nomenclature for the file names:
V01: draft
V02: draft with internal QA
V03: draft with external QA
VF: Final

3.4 Proposal for Nomenclature for saving datasheet - files names

Tests reports and associated files (film, etc…) shall be names according the following nomenclature:

X_SEGM_Y D1_SEGM_301

X is the **appliance identification** made with a **lab code and a chronological Number**.

- **Lab codes are D**: DGC**; EN**: ENGIE/CRIGEN, **EB**: EBI; **GA**: GAS.BE; **GW**: GWI
- **Number** is a chronological number decided by the lab starting with 1 (one)

Agree on a code for the new labs

SEGM is the SEGMENT nr of THYGA

Y is the **status** of the report

- V01: draft
- V02: draft after internal QA
- V03: draft after external QA (can be sent to the manufacturer for comments)
- VF: Final

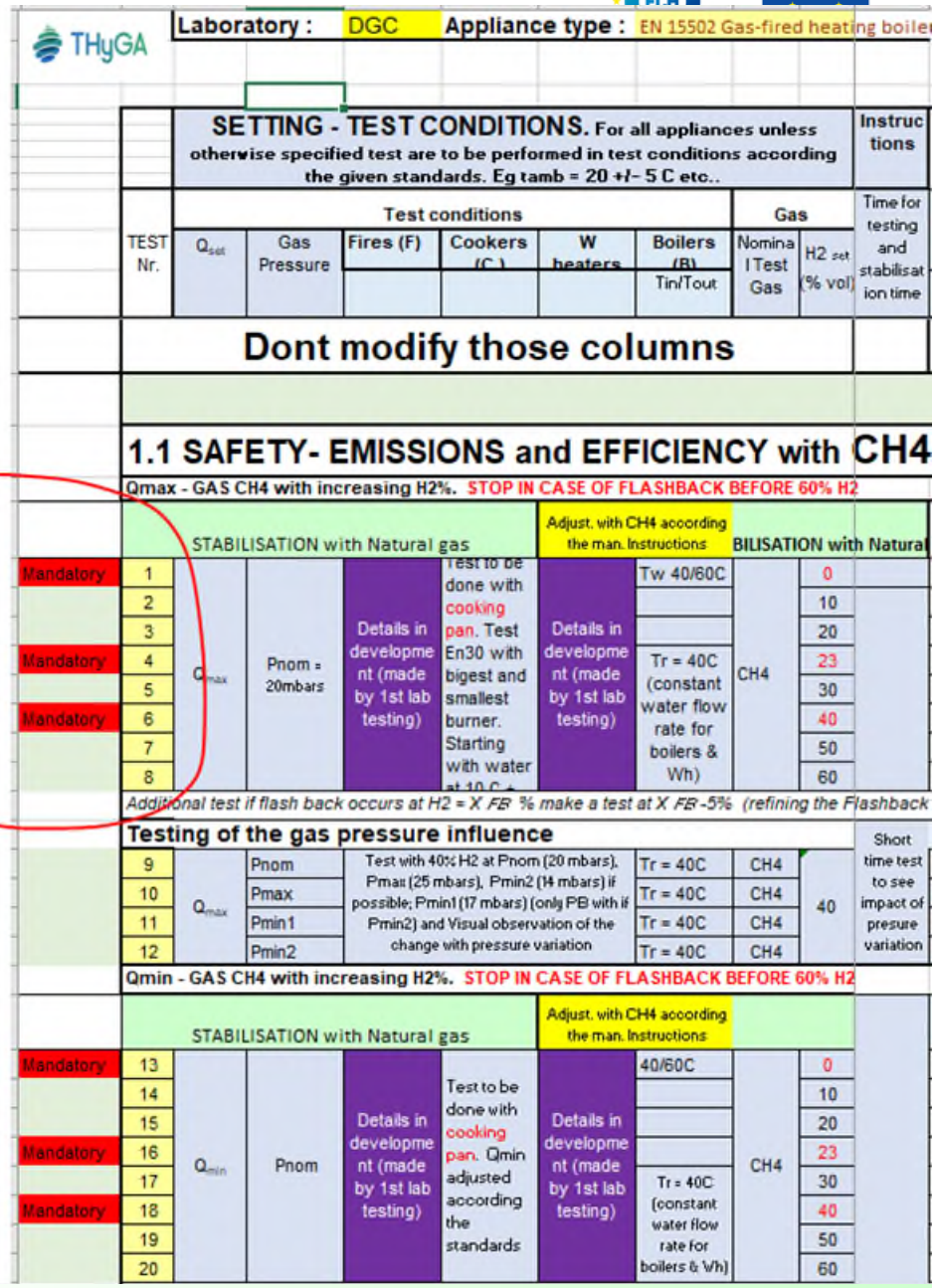
Example of file name: **D1_SEGM_301_V02** is the first report by DGC (appliance segment 301) in the version after internal QA

3.5 Test programme. Standard Test & additional

1) A **standard test protocol with MANDATORY TESTS** that apply to all appliances and covers the majority of cases (systematical testing)
2) A **specific additional testing (also called "iterative testing"**, on some parameters or some aspects and for some segments when this is relevant). Those should bring information on aspects that are not treated in 1) and that cannot be treated extensively or systematically for cost reasons

To start with labs have been asked to perform as much as additional testing ("iterative testing") as possible with the limit of the capacity. We have; in view of the first results already adapted the test programme few times

The column "D" in the **data sheet** indicates if the test is standard (mandatory) or "iterative"



THyGA — Laboratory : DGC — Appliance type : EN 15502 Gas-fired heating boiler

	TEST Nr.	Q_{set}	Gas Pressure	Fires (F)	Cookers (C)	W heaters	Boilers (B) Tin/Tout	Gas: Nominal Test Gas	Gas: H2 set (% vol)	Time for testing and stabilisation time
		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
		Dont modify those columns								
		1.1 SAFETY- EMISSIONS and EFFICIENCY with CH4								
		Qmax - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2								
		STABILISATION with Natural gas				Adjust. with CH4 according the man. Instructions		BILISATION with Natural		
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 at 10 C +	Details in development (made by 1st lab testing)	Tw 40/60C	CH4	0	
	2								10	
	3								20	
Mandatory	4						Tr = 40C (constant water flow rate for boilers & Wh)		23	
	5								30	
Mandatory	6								40	
	7								50	
	8								60	
		Additional test if flash back occurs at H2 = X FR % make a test at X FR -5% (refining the Flashback								
		Testing of the gas pressure influence								Short time test to see impact of presure variation
	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	
	10		Pmax				Tr = 40C	CH4		
	11		Pmin1				Tr = 40C	CH4		
	12		Pmin2				Tr = 40C	CH4		
		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				
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	
	14								10	
	15								20	
Mandatory	16								23	
	17						Tr = 40C (constant water flow rate for boilers & Wh)		30	
Mandatory	18								40	
	19								50	
	20								60	

3.6 Sheet TEST PROGRAMME.

TEST PROGRAMME

LABORATORY		DGC
Appliance		D1
Segment		19
Cross here		
X	M	1.1 SAFETY with CH4 (NOTE that for cooker; this test shall also cover emissions)
X	A	1.2 SAFETY with EU low and G23.
		1.3 SAFETY & EMISSIONS COOKERS without Cooking pan. This test was deleted following the first test carried out
X	A	1.4 Extreme conditions. Cold start.
X	A	1.5 Hot start. (possibly connected to a previous test)
	A	1.6 Extreme conditions. Low air temperature (- 10 C) (only GWI)
NR	A	1.7 Extreme conditions. Flue gas pipe length
X	A	1.8 ROC (PLUGG FLOW)
NR	A	1.9 Impact of H2 on flame detection. Measurement of the signal? Ionisation
X	A	1.10 Flash back analyse. In case there has been flash back, this part is dedicated to make the analyse.
X	M	2.1 PERFORMANCES with CH4
X	A	2.2 PERFORMANCES with CH4 (extented range for H2)
X	A	2.3 PERFORMANCES with EU low. This test can be simplified or even removed after the experimental test
	A	2.4 UHC and H2 emission at start stop
NR	M	3.1 ADJUSTMENT A (mostly to see FB & CO). ONLY FOR APPLIANCES THAT CAN BE ADJUSTED
NR	M	3.2 ADJUSTMENT B (mostly to see FB & CO)
NR	M	3.3 ADJUSTMENT H (mostly to see FB & CO)
NR	M	3.4 ADJUSTMENT G (mostly to see FB & CO)
	A	4.1 Delayed ignition test.
	A	4.2 Soundness
X	A	4.3 Quick variation Qmin-Qmax Shut-off condition (cookers and fires only). Qualitative test (observation)
	A	4.4 Overheat. Measurement of the temperature
	A	4.x Other test to check more parameters. Used / unused appliances. or any other test not yet planned
	Mandatory	(M)
	Additional	(A) (also called Iterative)

The sheet "TEST PROGRAMME) indicates the list of the testing. **Labs are requested to cross the test that will be executed.**

The list shall be sent to WP3 leader for information/ validation (This for coordination sake: we need to make sure that additional tests are done – so that at the end we have for all segments all aspects tested)

Other input sheets

Appliance | DATA SHEET | Test programme | PICTURES | Pictures before-after | Equipment of the lab

Appliance identification (info from identification table)

SEGMENT Nr	*108*
Report test lab code	*D4*
Appliance type	*EN 15502 Gas-fired heating boiler*
Burner type	*Premix*
For cooker hobs: burner tested?	*na*
Modulating burner (Y/N)	*Y*
Pressure regulator (Y/N)	*na*
Can the appliance be adjusted (Y/N)	*Y*
If the appliance can be adjusted. Instructions:	*CO2 shall be adjusted to 9%*
Is the appliance equiped with a combustion control (Y/N	*Y*
If Yes what technology is used?	
Max. power input (net) [kW]	*20,0*
Min. power input (net) [kW]	*4,8*
Flue type	*na*
Flue lenght	*na*
Applicable standard(s)	*EN 15502*
Gas category	*II 2H3B/P*
Origin of the appliance	*Sent by the manufacturer*
Manufacture year	*Not known*

Information that will not be public:

Manufacturer name	
Appliance model name	
Burner manufacturer	

"Appliance" is a description of the appliance tested.

For the point "combustion control" we suggest to use the definition presently in discussion in TC 109:

- *Either a pneumatic gas supply (PGS) ,using a partially or fully premixed burner*
- *Or Pneumatic gas air ratio (PGAR) controller using a fully premixed burner ,*
- *Or electronic gas air ratio (eGAR) controller using a fully premixed burner,*
- *Or an electronic gas air ratio (eGAR) controller with an Adaptive combustion control function (ACCF) using a fully premixed burner.*

So only the last one is an **adaptive combustion control**

Pneumatic gas supply (PGS) control

A device determining the gas supply volume rate … ply pressure or an internal appliance pressure regulator.
Note 1 to entry: pneumatically driven me… rtional to the pressure difference.
Note 2 to entry: the most commo…

Pneumatic gas/air ratio (PGAR) co…

A device where the…
Note 1to ent… to the product of the density and the square of the volume rate of the air.
Note 2 to entry… ver this nozzle is driven by a pressure difference resulting from a restriction in the…

Electronic gas/air ratio (eG…

Still discussion on t… s the content of the Notes.
Option 1
A device where the g…
Option 2
A device where the gas … ed range of the air to gas ratio respectively ⍰, with no adaption to the Wobbe i…
Note 1 to entry: driven us… ds on the design of the EGAR) control.
Note 2 to the entry: The pr… mains the same, regardless of the density, composition, calorific value, specific heat, … ne.

Electronic gas air ratio control with ar…

A device where the gas supply … ded range of the air to gas ratio respectively ⍰, with adaption to the Wobbe index, see prEN 12067-2…

Note 1 to the entry: the relation b… the influence of the other signals is not pre defined.
Note 2 to the entry: The Ideally pre… pply rate of the air, is that the air factor λ remains the same, regardless of the density, composition, calorific value, specific heat, viscosity … Wobbe index of the gas at reference conditions.
Note3: Combustion behavior does not … gas composition.

Adaptive Combustion Control Function

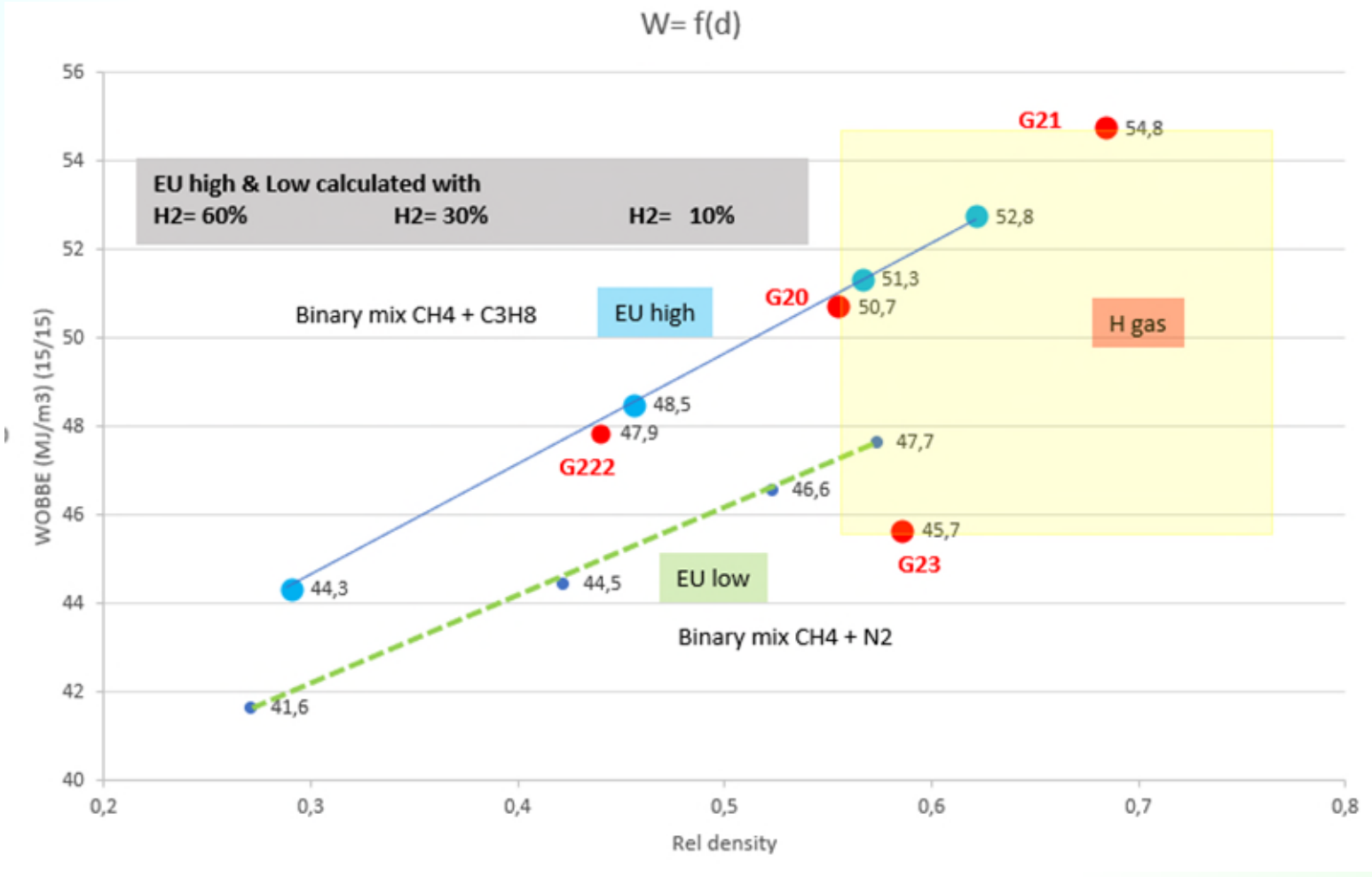
No definition for the moment !

EXPLANATION TEXT FROM TC109, WE SHALL WAIT FOR A FINAL VERSION (meeting 17/11)

3.7 Sheets EU Low and EU high (Gases)

Check the corresponding sheet to get the gas composition for test gases

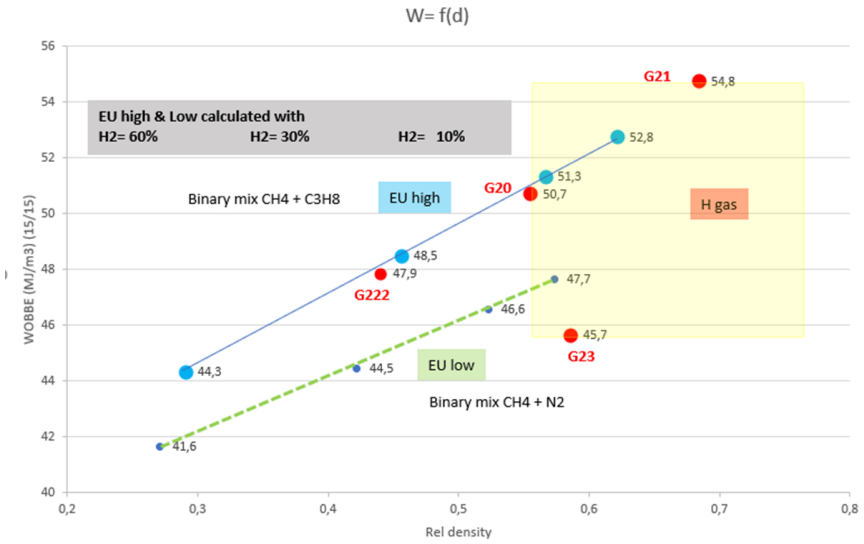
Gases for testing WP3 “STANDARD TESTS”



Gases for testing WP3 "STANDARD TESTS"

		TEST GASES								Other limit gases (info)		
		EU low	EU low	EU low	EU low	EU high	EU high	EU high	EU high	G20	G21	G23	G222
			10% H2	30% H2	60% H2		10% H2	30% H2	60% H2				
H2	%vol.		10,0	30,0	60,0		10,0	30,0	60,0				
CH4	%vol.	95,6	86,0	66,9	38,2	93,4	84,1	65,4	37,4	100,0	87,0	92,5	77,0
C3H8	%vol.					6,6	5,9	4,6	2,6		13,0		
N2	%vol.	4,4	4,0	3,1	1,8							7,5	
Hs	MJ/m3 (*)	36,1	33,7	28,9	21,7	41,6	38,6	32,7	23,9	37,4	45,3	35,0	31,9
Ws	MJ/m3 (*)	**47,7**	46,6	44,5	41,6	**52,8**	51,3	48,5	44,3	50,7	54,8	45,7	47,9
d	(-)	0,6	0,5	0,4	0,3	0,6	0,6	0,5	0,3	0,6	0,7	0,6	0,4

(*) 15/15



- Green line = EU low + x% H2
- Blue line = EU high + x% H2
- For both: Binary compositions + x% H2

Few additional tests will be done **with below "EU low"** eg Flash back with G23 (proposal is to stay with H gas range in any case) to check if the sensitivity of FB to the initial gas composition Outside the EU range.

3.8 Gases parameters (for info)

DGC sheets workplace -> | Gas parameters | Adjustnent figure

All values ref 0/0C (combustion/metering) Slight difference with ISO 6976

	Metan	Etan	Propan	iso-Butan	n-Butan	iso-Pentan	n-Pentan	C6+	Nitrogen	Carbon dioxyde	Oxygen	Brint	Propen	Etylen	Buten	Carbon monoxyde
	CH4	C2H6	C3H8	C4H10	C4H10	C5H12	C5H12	C6H14	N2	CO2	O2	H2	C3H6	C2H4	C4H8	CO
Lower Calorific value of components (kJ/nm3)	35883	64345	93215	122910	123810	154990	156560	193380			0	10783	87575	59457	117710	12633
Higher Calorific value of components (kJ/nm3)	39819	70293	101242	133119	134061	167530	169190	208700				12745	93576	63414	125863	12633
density (kg/nm3)	0,7174	1,356	2,015	2,706	2,714	3,427	3,454	4,32	1,25	1,977	1,429	0,09	1,913	1,261	2,599	1,251
Lower Calorific value of components (kJ/m3) Calculated	35883	64345	93215	122910	123810	154990	156560	193380			0	10783	87575	59457	117710	12633
Higher Calorific value of components (kJ/nm3)	39819	70293	101242	133119	134061	167530	169190	208700				12745	93576	63414	125863	12633
O2 need m3n/m3n	2,003	3,533	5,115	6,776	6,797	8,508	8,576	10,664			-1	0,499	4,581	3,02	6,248	0,5
CO2 produced m3n/m3n	0,996	2,007	3,051	4,146	4,158	5,287	5,329	6,696		1		0	3,036	2,002	4,141	0,994
H20 produced m3n/m3n	1,94	2,934	3,965	5,05	5,066	6,182	6,232	7,613				0,967	2,959	1,951	4,035	0
density (kg/nm3)	0,7174	1,356	2,015	2,706	2,714	3,427	3,454	4,32	1,25	1,977	1,429	0,09	1,913	1,261	2,599	1,251

Ref T	Air d.	Cor 0 / 15 C
273,15	1,225	1,054915

3.9 Sheet DATA SHEET: Overall colour code

DATA SHEET

NR =	Not relevant	NM =	Not measured
	Calculated	empty cell =	Not measured

Flue Gas (Measured)													Flue Gas Paramet			
NO_x	NO_2	C_xH_y (over the period)	C_xH_y	C_xH_y per cycle	n cycles (for UHC)	H2 (over the period)	H2	H2	H2 (on)	$T_{fluegas}$	soot index	Condensate	CO ref	NOx ref	CO ref	NOx ref
[ppm]	[ppm]	[ppm]	mg/kWh	mg/cycle	(-)	[ppm]	mg/kWh	mg/cycle	[ppm]	[°C]	[Bacchara]	ml/min	[ppm]	[ppm]	mg/kWh	mg/kWh
		AVG Emissi	AVG Emissi								Radiant	Condensin			Note that value in	
		PROTOCOL & CALCULATIONS ON THE WAY for UHC														
21,5	8,95	NM								0	NR		83	28	88	49
15,6	7,15	NM								70,4	NR		62	21	66	38
11,8	6,29	NM								69	NR		44	17	47	30
10,8	5,94	NM								68,4	NR		37	15	40	27
8,58	5,18	NM								68,6	NR		30	13	32	22
6,69	4,67	NM								67,7	NR		21	10	22	18
4,79	3,77	NM								66,8	NR		14	8	15	14
4,66	3,9	NM								65,2	NR		11	8	12	13
stion impact, etc.																
0	0	NR	NR	NR	NR	NR	NR	NR			NR		NM	NM	NM	NM
0	0	NR	NR	NR	NR	NR	NR	NR			NR		NM	NM	NM	NM
0	0	NR	NR	NR	NR	NR	NR	NR			NR		NM	NM	NM	NM
0	0	NR	NR	NR	NR	NR	NR	NR			NR		NM	NM	NM	NM

NR = Not relevant
Yellow cell = calculated -> Don't modify!
NM or empty cell = Not measured

The other cells are for measured data.

We haven't indicated what is mandatory to measure and what is not as the sheet is "universal" for all appliances → labs shall measure what is needed for the given test and what is normally required by standards.
Eg for efficiency of boiler, water flow and temp, etc…

3.9 Sheet DATA SHEET: what is calculated

DATA SHEET

Gas composition (measured) vol (%)												Gas Parameters (Calculated)					Gas (Measured)			Gas (Calculated) (Hi)
CH4	C2H6	C3H8	C4H10i	C4H10n	C5H12i	C5H12n	C6H14	N2	CO2	O2	H2	W_s (15C)	d	Hi (15C)	Hs (15C)	CO2n	p_{gas}	T_{gas}	Qgas gas flow rate (at	Q_{test} meas. • corr.
Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	Vol.(-)	[MJ/m³]	(-)	[MJ/m³]	[MJ/m³]	%	[mbar]	[°C]	[m³/h]	[kW]

for cooker; Efficiency is treated apart due to t Don't change the yellow cells (calculations)

QUANTITATIVE TEST: REPORT SHALL BE BASED ON AVG (DATA FILE) AND NOT INSTANTANEOUS DATA NOTED MANUALLY

99,8	0	0	0	0	0	0	0	0,2	0	0	0	50,54	0,556	33,954	37,679	11,638	20,28	19,84	2,097	**19,37**
90,6	0	0	0	0	0	0	0	0,2	0	0	9,28	49,40	0,511	33,497	37,243	11,381	20,43	19,44	2,192	**19,75**
81,1	0	0	0	0	0	0	0	0,1	0	0	18,7	48,23	0,465	31,133	34,693	11,075	20,42	19,33	2,292	**19,21**
78,4	0	0	0	0	0	0	0	0,1	0	0	21,5	47,89	0,452	30,443	33,950	10,976	20,21	19,48	2,325	**19,26**
71,6	0	0	0	0	0	0	0	0,1	0	0	28,3	47,06	0,418	28,739	32,111	10,707	20,35	19,95	2,418	**18,66**
61,5	0	0	0	0	0	0	0	0,1	0	0	38,4	45,84	0,369	26,211	29,385	10,233	20,38	19,34	2,557	**18,04**
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	20,42	19,81	2,736	**17,36**
39,7	0	0	0	0	0	0	0	0	0	0	60,3	43,47	0,262	20,743	23,489	8,720	20,35	19,65	2,972	**16,75**

2 Gas heat input is calculated from **gas parameters and Gas measured P,T Q.** Give the **gas pressure** in mbars rel. to air

Ref is 15/15

Q given on Hi

1 Gas parameters are calculated from **gas composition.** Give the **gas composition of component** in number from 0 to 100

3.9 Sheet DATA SHEET: what is calculated

DATA SHEET

Calculated | empty cell = | Not measured

Flue Gas (Measured)

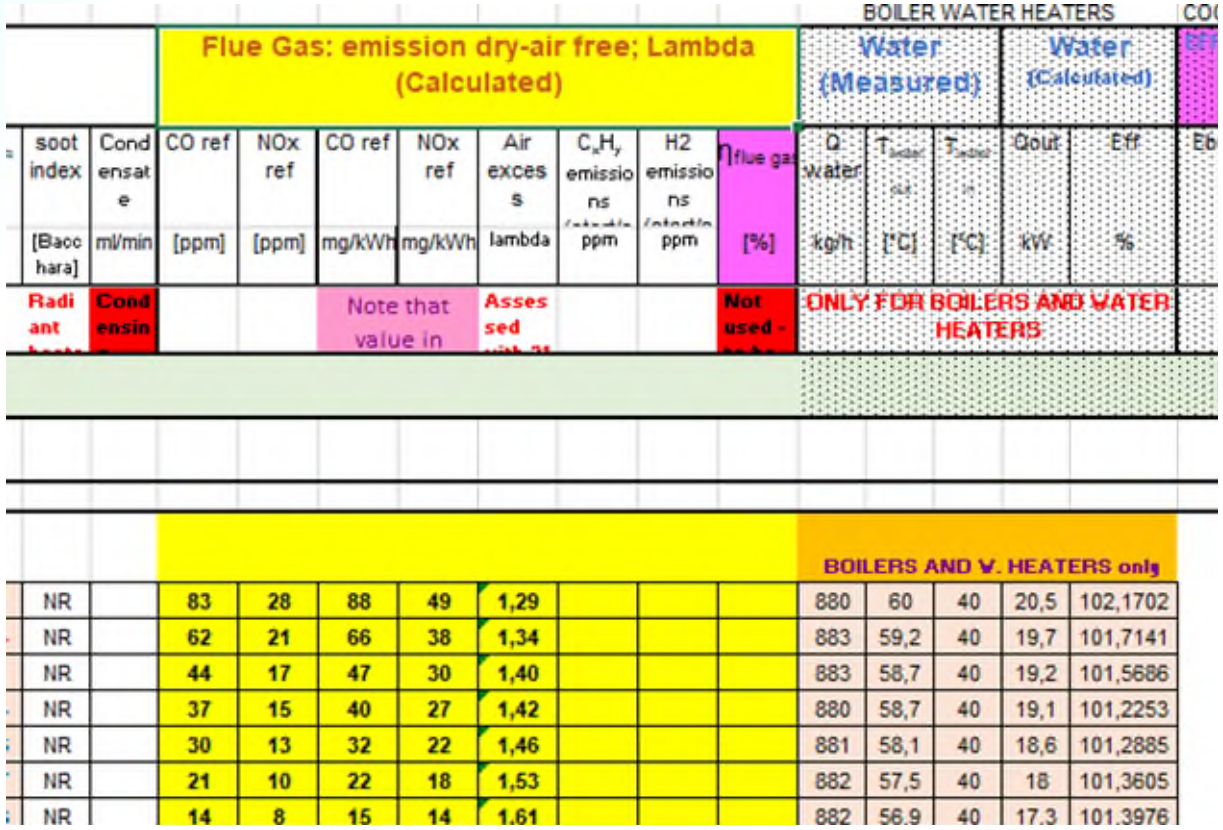
CO_2	O_2	CO	NO_x	NO_2	C_xH_y (over the period)	C_xH_y	C_xH_y per cycle	n cycles (for UHC)	H2 (over the period)	H2	H2	H2 (on)	$T_{fluegas}$	soot index	Condensate
[%]	[%]	[ppm]	[ppm]	[ppm]	[ppm]	mg/kWh	mg/cycle	(-)	[ppm]	mg/kWh	mg/cycle	[ppm]	[°C]	[Bacchara]	ml/min
										CHECK THIS					
3,4	15,1	5	5	2	370,6	702,5	497,2	4,0		0,0	0,0				
1,9	16,7	6	0	0	139,0			5,0	158,0						
2,1		*9*			*116*				*158*						
						nm	nm			nm	nm				
						nm	nm			nm	nm				
						nm	nm			nm	nm				
						nm	nm			nm	nm				

3 UHC
are calculated from **value in ppm.**
The calculation is presently under validation and will be implemented asap

A specific test protocol for UHC is on the way

3.9 Sheet DATA SHEET: what is calculated

DATA SHEET



			Flue Gas: emission dry-air free; Lambda (Calculated)								BOILER WATER HEATERS Water (Measured)			Water (Calculated)		
	soot index [Bacchara]	Condensate ml/min	CO ref [ppm]	NOx ref [ppm]	CO ref mg/kWh	NOx ref mg/kWh	Air excess lambda	C_nH_y emissions ppm	H2 emissions ppm	η flue gas [%]	Q water kg/h	$T_{water\ out}$ [°C]	$T_{water\ in}$ [°C]	Qout kW	Eff %	Eb
	Radiant	Condensing			Note that value in		Assessed			Not used -	ONLY FOR BOILERS AND WATER HEATERS					
											BOILERS AND V. HEATERS only					
	NR		83	28	88	49	1,29				880	60	40	20,5	102,1702	
	NR		62	21	66	38	1,34				883	59,2	40	19,7	101,7141	
	NR		44	17	47	30	1,40				883	58,7	40	19,2	101,5686	
	NR		37	15	40	27	1,42				880	58,7	40	19,1	101,2253	
	NR		30	13	32	22	1,46				881	58,1	40	18,6	101,2885	
	NR		21	10	22	18	1,53				882	57,5	40	18	101,3605	
	NR		14	8	15	14	1,61				882	56,9	40	17,3	101,3976	

4 Flue gas
Emissions are calculated dry-air feee and in mg/kWh from **value in ppm.**
The calculation is presently under validation and will be implemented asap

A specific test protocol for UHC is on the way

Note that for the moment we use the same formula as CH4 for all gas mixes → not correct but small error in absolute emission values

NOx correct calculation mg/kWh	NOx simple calculation mg/kWh	Mistake due to simplification: mg/kWh
48,6	48,6	0,0
37,3	37,6	0,3
29,1	29,6	0,5
26,4	27,0	0,6
21,7	22,4	0,6
17,4	18,1	0,8
12,8	13,6	0,8
12,3	13,5	1,1

Ex. From test D4
THY_WP3_019_DataSheet nov 2020a

4. TESTING

4.1 Overall Test conditions. Sheet "STANDARD TEST CONDITIONS"

- Tamb = 20 C+/- 5C
- Air humidity (no requirement but shall be measured)
- Appliance shall be stabilized at steady temperature conditions (time depending on appliance) Indicated in the data sheet. For cold start appliances shall be at ambient conditions
- Take care of open doors & windows for the FB test of atm appliances (no air draught of the test labs in this project in order to have repeatable results).

- Tolerance on H2 to be achieved (for efficiency & emission test) = 2%? (to be discussed)

SEE MORE INFO IN TEST SHEET (SHEET "Standard Test Conditions")

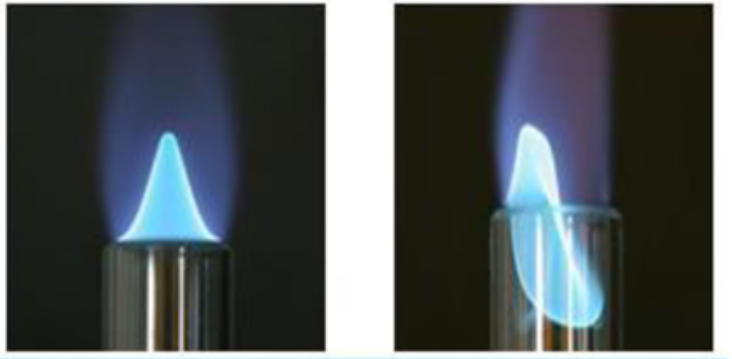
4.2 Flashback (NOTE THAT THIS MAY BE REVISED IN LIGHT OF TEST RESULTS)

Flashback (FB) is one of the main parameters: we need to be certain to reproduce as best as possible during the testing.

This is more likely to happen with atm. appliances
We will use basically two methods:

1) **Detection with TC at top & below burner when possible. FB will typically result in a strong increase of temperature**
2) **Visual: Labs are requested to film open flames.**

There will be limitations to the methods above and we will not be able to instrument appliances with closed combustion chambers and on those we will not see the flame either. We will have to rely on noise or increase or variation of another measured parameters in the flue gas



Picture THyGA application 2019

Flashback analyze If flashback is occurring during testing, laboratories shall as far as possible check the possible consequences on the appliances. Pictures of damaged component shall be taken a discussion with manufacturers shall be established. The result of the discussion shall be reported

For cookers/hobs the is done with the pot as this is the real situation and this is also a more severe condition.

We can distinguish between **partial flashback** (example on the flame on the right side) and **complete flashback** (this is where the flames is entirely below the surface of the burner.

4.2 Flashback and other safety test that may damage the appliance

Flashback (FB), overheating, delayed ignition, etc. may damage the appliance, therefore before the testing:

- Labs shall agree with the manufacturer what is the maximum % of H2 the appliance shall be used for the testing. Appliances may be returned damaged to the manufacturer and we have no possibility to compensate for the damages occuring.

- Testing with high level of H2 (50 to 60%) and other test that may damage appliances shall preferably be done at the end of the testing programme!

- For long term test it may be advisable to request from manufacturers additional components that may need to be replaced (especialy those that may be damaged by mounting dismounting for the photography sessions before after use)

4.3 Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.1 SAFETY- EMISSIONS and EFFICIENCY with CH4 (NOTE that for cooker; Efficiency is treated apart due to the test procedure)

Short Description	The test is aiming at detecting FB. Or safety issues + checking impact of H2 on efficiency and emissions. For cookers efficiency is treated apart due to the test procedure
More detailed description	The test is first carried for Qmax at Pnom and with an increasing % of H2. The same tests are repeated for Qmin (see H2 % at next slide)
Gas to be used	CH4 (NG OK for getting stabilization)
Execution	CH4 with increasing H2%. STOP IN CASE OF FLASHBACK. The test shall be FILMED for open flames and high H2 where FB can occur.
Appliance set up	If adjustable, appliances are set up according manufacturer instructions
Other test conditions	See TEST SHEET
Time	Test shall be carried out with a period of stabilization long enough to guarantee repeatability of efficiency test. The duration of each of the tests shall be registered in the datasheet as time is an important factor for FB.

4.3 Instructions to perform the test following the sheet "DATA SHEET)

TESTING

PART 1 SAFETY TESTS

1.1 SAFETY- EMISSIONS and EFFICIENCY with CH4

Qmax - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2

		STABILISATION with Natural gas				Adjust. with CH4 according the man. Instructions		BILISATION with Natural		
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 at 10 C +	Details in development (made by 1st lab testing)	Tw 40/60C	CH4	0	
	2								10	
	3								20	
Mandatory	4						Tr = 40C (constant water flow rate for boilers & Wh)		23	
	5								30	
Mandatory	6								40	
	7								50	
	8								60	
		Additional test if flash back occurs at H2 = X FB % make a test at X FB -5% (refining the Flashback								
		Testing of the gas pressure influence								Short time test to see impact of presure variation
	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	
	10		Pmax				Tr = 40C	CH4		
	11		Pmin1				Tr = 40C	CH4		
	12		Pmin2				Tr = 40C	CH4		

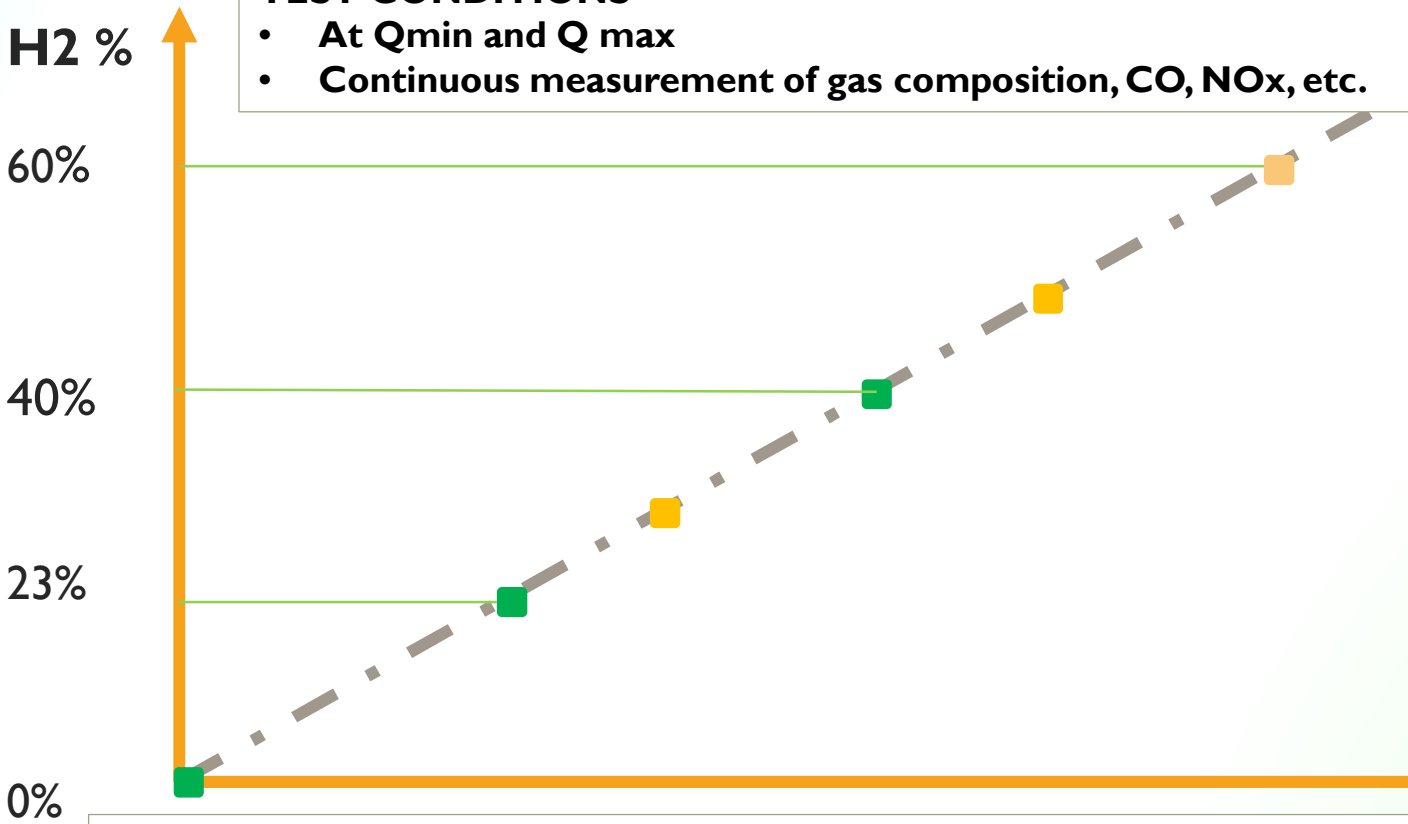
Tests at 0%, 23% and 40 % og H2 are mandatory. Test are done under stable conditions. We recommend that for boilers and water heater the test is carried out for a period of 30 minutes at least for each testing point.

The impact of Pressure change is done just after test 8. This is a short test (few minutes for each pressure)

Pnom (20 mbars), Pmax (25 mbars, Pmin1 (17 mbars) and Pmin 2 (14 mbars). Visual observation of the change with pressure variation

Testing 1.1 SAFETY. Increasing H2 until Flashback

TEST CONDITIONS
- **At Qmin and Q max**
- **Continuous measurement of gas composition, CO, NOx, etc.**



Continuous measurement:

Flue gas:
- Temperature
- CO, NOX, O2, CO2

Input:
- Pg, Tg, Vg, Qin,
- Gas analyse

Test conditions
- Tamb, Tair, Patm

Safety & operation
- Flashback
- Overheating (T burner surface) (*)
- Ionisation (*)

(*) For some appliances

PROCEDURE
- Run the appliance for 60 minutes with **NG**
- Increasing H2 by steps(0, 23,40 % mandatory – more point optional) with **qualitative observation (flashback) and accurate measurement of efficiency and emissions. Film open flames for high % of H2**
- **Measuring for 30 minutes at each point**
- **Stop at if flashback or partial flashback**

Testing 1.1 SAFETY. Increasing H2 until Flashback

LESSONS FROM THE FIRST TESTS:

OBSERVATION 01 FB doesn't necessarily happens within short term, for the cooker nr one FB was observed after 50 min DURING EFFICIENCY TEST!
Therefore SAFETY is now combined with EMISSIONS and PERFORMANCES

LESSONS FROM THE FIRST TESTS:

OBSERVATION 02 FB may damage the burner (as for the cooking hob testing at DGC) and this makes cause logistic issues (replacement of the burner, waiting time, etc…)
→ Verifying repeatability of FB is impossible if the burner is damaged, the damage can make the burner more sensitive to FB

→ The protocol was revised knowing that FB cannot be "repeated"
→ Keep high H2 % testing for the very end.
→ Try to avoid FB situation in testing in general?
→ Having if possible spare parts to replace damaged components

Combine SAFETY with EMISSIONS and PERFORMANCES (when possible)

1.1 SAFETY- EMISSIONS and EFFICIENCY with CH4

Qmax - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2

		STABILISATION with Natural gas				Adjust. with CH4 according the man. Instructions		BILISATION with Natural		
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 at 10 C +	Details in development (made by 1st lab testing)	Tw 40/60C	CH4	0	
	2								10	
	3								20	
Mandatory	4						Tr = 40C (constant water flow rate for boilers & Wh)		23	
	5								30	
Mandatory	6								40	
	7								50	
	8								60	
Additional test if flash back occurs at H2 = X FR % make a test at X FR -5% (refining the Flashback										
Testing of the gas pressure influence										Short time test to see impact of presure variation
	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	
	10		Pmax				Tr = 40C	CH4		
	11		Pmin1				Tr = 40C	CH4		
	12		Pmin2				Tr = 40C	CH4		

1. Heating of the appliance
2. Test with pure CH4
4. Test with a intermediate H2 %
3. Test with a reasonably high H2 %
5. Test with maximum H2 % (end)

For cookers efficiency shall be tested apart due to the test method

Proposal

Review again (later on) the procedure in light results of testing especially efficiency evolution with H2

Combine SAFETY with EMISSIONS and PERFORMANCES (when possible) Conclusion:

1. Heating up – stabilization
2. Test with pure CH4 (0% H2)
3. Test with intermediate H2 (23%).
4. Test with reasonably high H2 (40%) (H2 high)
5. IN OPTION. Test with high H2 % (60% or lower level agreed with manufacturer(H2 very high)) wait the very end of the testing as it can be destructive

If variation of efficiency for tests is not significant we will in the future suggest to test only emissions (shorter) with all points and efficiency with reduced amount of points.

Combine SAFETY with EMISSIONS and PERFORMANCES (when possible) with EU low and G23

1.2 SAFETY- EMISSIONS and EFFICIENCY with EULOW (NOTE that for cooker

GAS EU LOW

STABILISATION					the man. Instructions		STABILISATION with Natural gas					60	60	60	60
21	Q_{min}	Pnom	Details in development (made by 1st	Test to be done with cooking pan	Details in development (made by 1st	Tr = 40C (constant water flow	EULow	0				50	50	50	50
22	Q_{max}						EULow					50	50	50	50
23	Q_{min}	Pnom	Details in development (made by 1st	Test to be done with cooking pan	Details in development (made by 1st	Tr = 40C (constant water flow	EULow	(XFB-5% or High)				50	50	50	50
24	Q_{max}						EULow					50	50	50	50

1.3 SAFETY- EMISSIONS with G23

GAS EU LOW

Iterative

23	Q_{min}	Pnom	Details in development (made by 1st	Test to be done with cooking pan	Details in development (made by 1st	Tr = 40C (constant water flow	G23	(XFB-5% or High)				50	50	50	50
24	Q_{max}						G23					50	50	50	50

Tests with EU low and G23 shall be done immediately after each other

The testing is mainly **to check** if there is a difference with other gas compositions compared to the test with CH4

What can we expect to see:

Safety: the FB point may be different, FB may happen when no FB was observed with CH4

Efficiency: we don't expect the initial gas quality to play a role **(verified so far on D1 cooker hob and boiler)**

Emissions: will depend on initial gas composition, but we just want to check if the trends are the same

So far test for there is no trend visible for emission or emissions:

TO BE DISCUSSSED IN LIGHT OF MORE RESULTS

Specific Instructions to perform the test for Hobs

For cooker hobs **emissions (1.1)** the following or similar sampling system shall be used.

Efficiency tests (2.1) are done with pots according EN 30-2-1 2015

Other **safety tests** (1.4, 1.5, 1.8, 1.9) are done with pots on burner.

ROC test (1.8) and **flame detection test (1.9)** is to be filmed as well as other test if there is a change visible in flame.

UHC test (2.4) are done both for start stop and on time of the burner.

4 burners test (4.5) is done with 40% H2.

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.2 SAFETY with EU low and G23. This TEST is TO CHECK THERE TH… e same (= check that the gas quality influence)

Short Description	The test is aiming primaril… g if the FB may occurs with other gases under the same … as 1.1
More detailed description	The test is carried … th 60% H2 or at the FB point- 5%
Gas to be used	EU low and G… for getting stabilization)
Execution	Only … as indicated here above and test at Qmax and Qmin
Appliance set up	…, appliances are set up to CH4 according manufacturer instructions (no …cation of the appliance setting compared to 1.1)
Other test conditions	See columns G to L
Time	See columns Q to T. Note that in light of the first tests the testing times may be changed

NOW MERGED WITH SAFETY -EFFICIENCY -EMISSIONS (see previous slides)

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.3	SAFETY & EMISSIONS COOKERS without Cooki	s TEST was deleted following the first test carried out

Test without cooking pots are not having an added value and are therefore not part of the present prpgramme (tests with pots are more severe)

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.4 Extreme conditions. Cold start.

Short Description	The test is aiming at checking the behavior of appliances at cold start.
More detailed description	The test is carried out with at least H2 = 40%
Gas to be used	CH4 + 40% H2
Execution	Three levels of % of H2 test at the more sensitive load (Qmax or Qmin) or for boiler in letting the appliance make the normal start procedure decided by own control
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	See the test sheet
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.5 Hot start. (possibly connected to a previous test)

Short Description	The test is aiming at checking the behavior of appliances at hot start.
More detailed description	The test is carried out with 23 % of H2 and 40% of H2
Gas to be used	CH4 (NG OK for getting stabilization)
Execution	Three levels of % of H2 test at the more sensitive load (Qmax or Qmin) or for boiler in letting the appliance make the normal start procedure decided by own control
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	See the test sheet
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.6 Extreme conditions. Low air temperature (- 10 C) (only GWI)

Short Description	The test is aiming at checking the behavior of appliances with very cold air inlet
More detailed description	The test is carried out with increasing % of H2 (3 points) ALTERNATIVELY IF STARTING WITH HIGH H2 and passing the test, lower % of H2 are not needed. Note that the test is only relevant for appliances that are taking air directly form outdoor (Water heaters, Boilers, etc)
Gas to be used	CH4 (NG OK for getting stabilization)
Execution	Three levels of % of H2 test at Qmin or for boiler in letting the appliance make the normal start procedure decided by own control. **DETAILS TO BE DISCUSSED WITH GWI**
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	See next slide
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING

PART 1 SAFETY TESTS

1.6 Extreme conditions. Low air temperature (- 10 C) (only GWI)

Cold combustion air

Cold start
T_L=-10°C
P_{min} (EN437),
$p_{min,Abgas}$

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.7 Extreme conditions. Flue gas pipe length

Short Description	The test is aiming at checking the possible influence of the exhaust gas pipe
More detailed description	The test is carried out with 30% of H2 at Qmin with an increasing length of flue gas pipe
Gas to be used	CH4 (NG OK for getting stabilization)
Execution	The exact length of the pipe will depend on the lab. possibilities
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions
Other test conditions	
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.8 ROC (PLUGG FLOW) THIS TEST SHALL BE FILMED

Short Description	The test is aiming at checking the behavior of appliances when gas composition is changing very rapidly
More detailed description	The test is carried out H2= 40%
Gas to be used	CH4 + 40% H2
Execution	Test at Qmax and Qmin. The test configuration shall make the "Plugg flow" possible. This mean that the switch of gas shall be done as close as possible to the appliance (< 1 meter?) to avoid mixing phenomena on longer gas supply lines. The test is done from 40% to pure CH4 and the other way round. If the appliance pass, the test can be stopped, if not the test is repeated by decreasing the H2 % by 10%
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.9 Impact of H2 on flame detection. Measurement of the signal? Ionisation

Short Description	The test is aiming at checking the if H2 can impact the flame detection. - The work consist in assessing if H2 may impact the detection of the flame (change of shape or change in the ionization signal, etc…) in a way that can compromise the safety of the appliances
More detailed description	The test is carried out during the previous tests (safety, efficiency, emissions)
Gas to be used	See specifications of the safety, efficiency, emissions test
Execution	Information from the manufacturer of appliances (about flame detection system used and how to measure ionization signal when relevant) will be required to define the execution of this test more accurately. Ionization current will be measured for some appliances if there is a way to acceded to the information from the control panel OR if the manufacturer has prepared the appliance with a measurement point for the lab to measure without interfering with the appliance operation.
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 1 SAFETY TESTS

1.10 Flash back analyse. In case there has been flash back, this part is dedicated to make the analyse.

Short Description	The test is aiming at evaluating the possible FB conscequences
More detailed description	This is not a test as such, but an analyse of the FB if such has occurred during the testing
Gas to be used	NR
Execution	This will consist in making pictures /films etc.. to document the FB and describing the observations. If possible taking contact with manufacturers to discuss the conscequences.
Appliance set up	NR
Other test conditions	NR
Time	NR

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 2 PERFORMANCE TESTS

2.1 PERFORMANCES with CH4

Short Description	The test is aiming at check… …2 can impact efficiency & emissions
More detailed description	PERFORMANCES = Po… … + Efficiency + and Emissions (note that for cookers emissions … … in test 1.1) .The first test is done with pure CH4 is the reference
Gas to be used	CH4 (N… …etting stabilization)
Execution	T… …x and Qmin with up to 30% H2. The test is done with 10,20 and 30% H2. … consider to simplify after the first appliances are tested (in view of the results)
Appliance set up	…adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditi…	See columns G to L
Time	See columns Q to T. Note that in light of the first tests the testing times may be changed

NOW MERGED WITH SAFETY -EFFICIENCY -EMISSIONS (see previous slides)

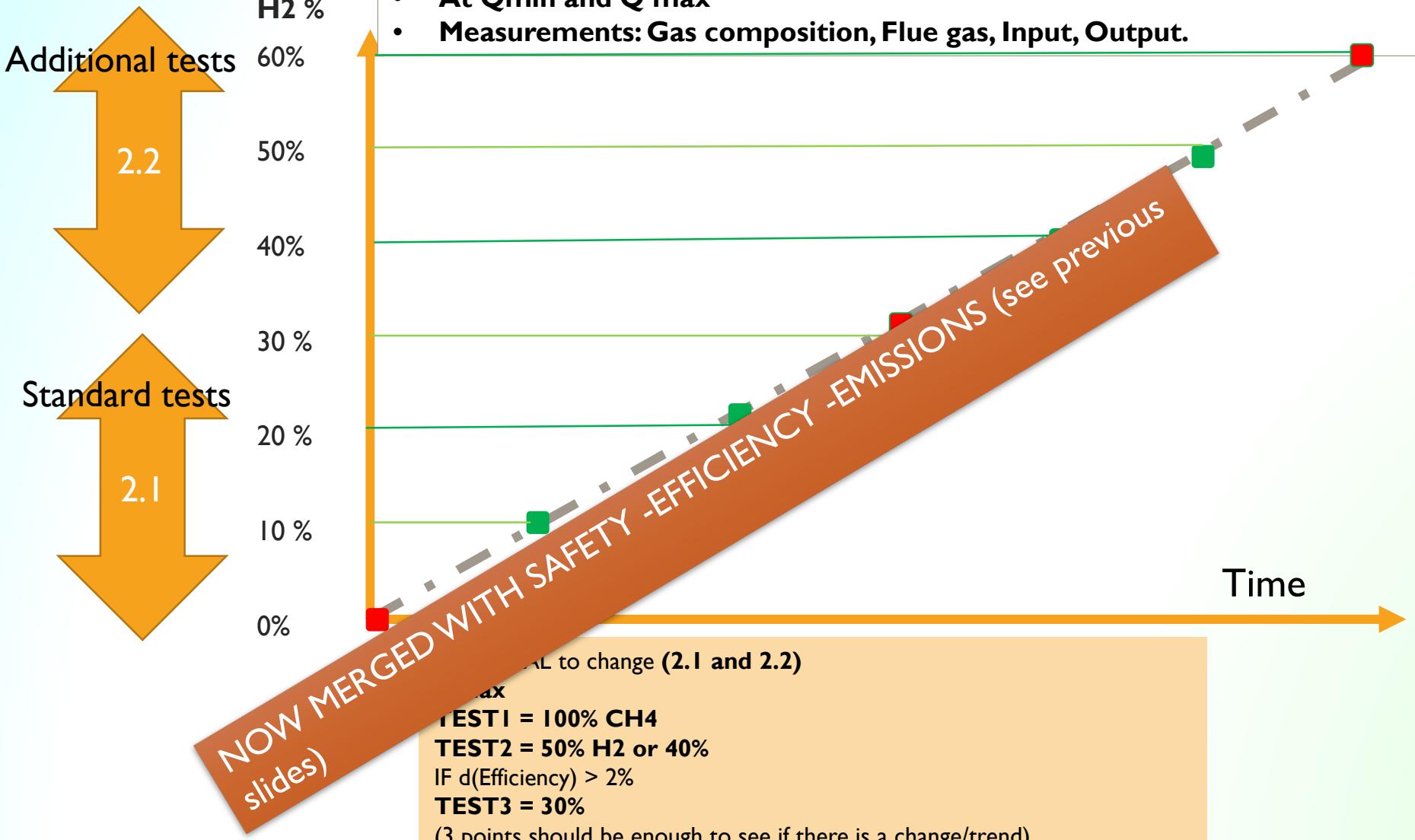
Testing 2.1 and 2.2 PERFORMANCES. Selected H2 concentrations (Safety (CO) ; Emissions ; Efficiency; Power)

TEST CONDITIONS

- **At Qmin and Q max**
- **Measurements: Gas composition, Flue gas, Input, Output.**

PROCEDURE

- Measurements
- Waiting x minutes between each point. See columns Q to T.



Continuous measurement:

Flue gas:
- Temperature
- CO, NOX, CxHy, O2, CO2

Input:
- Pg, Tg, Vg, Qin, Pel
- Gas analyse

Output:
- Tin, Tout, Qout (indicative)
- Pel (mcHP & FC)
- Condensat

Test conditions
- Tamb, Tair, Patm

Safety & operation
- Flashback
- Operation
- Overheating (T burner surface) (*)
- Ionisation (*)
- Etc

(*) For some appliances

AL to change **(2.1 and 2.2)**

ax

TEST1 = 100% CH4

TEST2 = 50% H2 or 40%

IF d(Efficiency) > 2%

TEST3 = 30%

(3 points should be enough to see if there is a change/trend)

Do the test at Qmin if there is a trend seen with Qmax

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 2 PERFORMANCE TESTS

2.2 PERFORMANCES with CH4 (extented range for H2) — S… but with H2 up to 60%

Short Description	The test is aiming at check… …2 can impact effeiciency & emissions
More detailed description	PERFORMANCES = Effi… …all appliances + and Emissions - for boilers, water heaters, and room h… …other. The first test is done with pure CH4 is the reference
Gas to be used	CH4 (N… …etting stabilization)
Execution	T… …x and Qmin with up to 60% H2. The test is done with 40,50 and 60% H2. … consider to simplify after the first appliances are tested (in view of the results)
Appliance set up	…adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditi…	See columns G to L
Time	See columns Q to T. Note that in light of the first tests the testing times may be changed

NOW MERGED WITH SAFETY -EFFICIENCY -EMISSIONS (see previous slides)

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 2 PERFORMANCE TESTS

2.3 PERFORMANCES with EU low.

SAME AS 2.[illegible] EU low instead of CH4

NOW MERGED WITH SAFETY -EFFICIENCY -EMISSIONS (see previous slides)

Short Description	The test is aiming at checki[illegible]al gas will change the conclusions from the results obtaind in 2
More detailed description	PERFORMANCES - [illegible] for all appliances + and Emissions - for boilers, water heaters, and ro[illegible]and other. The first test is done with pure CH4 is the reference[illegible]water heater efficiency are done using the **direct method**. In gene[illegible]o be done according the relevant product standards.
Gas to be used	[illegible]G OK for getting stabilization)
Execution	[illegible]e as for 2.1. We shall consider to simplify (or even delete this test) after the first appliances are tested (in view of the results)
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	See columns G to L
Time	See columns Q to T. Note that in light of the first tests the testing times may be changed

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 2 PERFORMANCE TESTS

2.4 UHC and H2 emission at start stop

Short Description	The test is aiming at measuring UHC and H2 emission during start stop phase
More detailed description	For appliances where this is possible execute 5 cycles of 10 min where appliances are on 3 min on and 7 min off. Peaks of UHC & H2 (if possible) are to be measured at start and stop. UHC & H2 are also to be measured during on time.
Gas to be used	CH4 with 0 H2% and 40% H2
Execution	At Qmin and Qmax if possible
Appliance set up	If adjustable, appliances are set up to CH4 according manufacturer instructions (no modification of the appliance setting compared to 1.1)
Other test conditions	See detail of testing in the document **Testing Hydrogen admixture for Gas Applications: Test protocol for all appliances to be tested. Deliverable: D 3.1**
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 3 ADJUSTMENT TESTS

Short Description	The test is aiming at see possible safety problem with various scenarios of adjustements
More detailed description	This test is to study what happens when appliances are wrongly adjusted (here adjusted to a given gas that is not CH4 - according the instructions of the manufacturers that are normally only valid for CH4), and used afterward with different gases. We will work with 4 adjustments. **This test is only for the appliances that can be adjusted with CO2 or O2 values given by the manufacturers, eg premix condensing boilers). This is NOT APPLICABLE TO APPLIANCES WITH AUTOMATIC COMBUSTION CONTROLS**
Gas to be used	See next slides (depends on the adjustment)
Execution	Appliances are run with the specified gas for the adjustment (see next slide) and adjusted according manufacturer instructions. **Appliances emissions** are measured for 10 minutes with different gases (see next slide). Labs shall also make visual observation and detect possible FB, etc..
Appliance set up	If adjustable, appliances are adjusted with the gas specified in next slide according manufacturer instructions
Other test conditions	
Time	

ADJUSTMENT- what was planned

CASE	EU low + 0 to 60% H2	EU low	CH4	EU high + 0 to 60% H2	EU high
A	Used	←	←	←	Adjusted
B		Adjusted	→	→	Used

CASE	EU low + 20% H2	EU low +0 to 60% H2	CH4	EU high + 20% H2	EU high + 0 to 60% H2
G	Adjusted	→	→	→	Used
H		Used	←	←	Adjusted

For test **A**: appliances are adjusted with **EU high** and tested with **EU low, and EU low + H2** (10%, 30%, 60%)
For test **B**: appliances are adjusted with **EU low** and tested with **EU high, and EU high+ H2** (10%, 30%, 60%)
For test **G**: appliances are adjusted with **EU low + 20%H2** and tested with **EU high, and EU high + H2** (10%, 30%, 60%)
For test **H**: appliances are adjusted with **EU high + 20% H2** and tested with **EU low, and EU low + H2** (10%, 30%, 60%)

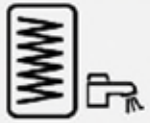
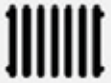
New slide 2021

Boiler D4 instruction manual

THyGA

TABELLE 1: Ventilator-Drehzahlparameter und CO_2-Werte (%)

Adjustment on CO2

	PARAMETER - Drehzahl [U/min]							Vorderer Gehäusedeckel geschlossen		
							P min	CO2% Nenn und Toleranzen		CO max
	Prime 1.24	Prime 1.24	Prime 26	Prime 30	Prime 26	Prime 30				
	DP003*	GP007*	DP003*	DP003*	GP007*	GP007*	GP008*			
	28kW	*24kW*	*26kW*	*30kW*	*20kW*	*24kW*	*4,8kW*	*Pn Max*	*P min*	*ppm*
G20	8300	7300	7800	9150	6200	7300	2200	9,0% (8,8÷9,4)	8,5% (8,1÷8,6)	<250
G30	7700	6800	7500	8700	5800	6800	2200	10,4% (10,2÷10,8)	9,8% (9,2÷9,8)	<250
G31	7700	6800	7500	8700	5800	6800	2200	10,3% (10,2÷10,8)	9,7% (9,2÷9,8)	<250

* Parameter für Drehzahländerung

Example of adjustment BOILER D4

For test **G**: appliances are adjusted with **EU low + 20%H2** and tested with **EU high, and EU high + H2** (10%, 30%, 60%)

1) Run the boiler with the gas EU low + 20% H2 at Qmax
2) Adjust the CO2 at 9,0% as indicated in the technical instructions (see previous slide) (*)
3) Execute the measurements for about 10 minutes
4) Change the gas to EU high without stopping the boiler **and do NOT modify any setting of the boiler**
5) Execute the measurements for about 10 minutes
6) Repeat from 4 with EU high + 10%
7) Repeat from 4 with EU high + 30%
8) Repeat from 4 with EU high + 60%
9) Repeat from 1) with Qmin (adjusting now at 8,5% as indicated in the manual)

Do the same for any other adjustments if performing the test

As one see in the example of next slides the initial values from test 2) are more or less the same for all adjustments

(*) For boilers instructions are either on CO2 or O2, just conform exactly to what the manual states.
In case there are instructions to adjust any other parameter than air excess, lets discuss this.

New slide 2021

Eg D4 : Initial test (NOT adjustment test)

		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..								Gas Parameters (Calculated)					Gas (Measured)			Gas (Calculated)	Ambient (Measured)							
	TEST Nr.	Test conditions: Q_{set}	Gas Pressure	Fires (F)	Cookers (C)	W heaters	Boilers (B) Tin/Tout	Gas: Nominal Test Gas	H2 set (% vol)	W_s (15/15\) [MJ/m³]	d (-)	Hi [MJ/m³]	Hs [MJ/m³]	CO2n %	p_{gas} [mbar]	T_{gas} [°C]	Qgas gas flow rate (at [m³/h]	Q_{test} meas. + corr. [kW]	$T_{ambient}$ [°C]	Patm [mbar]	rel. Hum [%]	CO_2 [%]	O_2 [%]	CO [ppm]	NO_x [ppm]	NO_2 [ppm]
		Dont modify those columns															(at 0,1013)									
		1.1 SAFETY- EMISSIONS and EFFICIENCY with the test procedure- see below)																								
		Qmax - GAS CH4 with increasing H2%. STOP IN CASE OF FLASHBACK BEFORE 60% H2								ON AVG (DATA FILE) AND NOT INSTANTANEOUS DATA NOTED MANUALLY																
		STABILISATION with Natural gas				Adjust. with CH4 according the man. Instructions		BILISATION wit		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 at 10 C +	Details in development (made by 1st lab testing)	Tw 40/60C	CH4	0	50.54	0.556	35.819	39.748	11.638	20.28	19.84	2.017	20.06	19.9	1009	10.8	9.07	4.77	64.3	21.5	8.95
	2								10	49.40	0.511	33.497	37.243	11.381	20.43	19.44	2.086	19.41	19.5	997	11.8	8.34	5.38	45.3	15.6	7.15
	3								20	48.23	0.465	31.133	34.693	11.075	20.42	19.33	2.182	18.87	19.5	997	12.3	7.82	5.99	30.8	11.8	6.29
Mandatory	4						Tr = 40C (constant water flow rate for boilers & Wh)		23	47.89	0.452	30.443	33.950	10.976	20.21	19.48	2.237	18.92	19.5	1008	10.7	7.75	6.18	26.4	10.8	5.94
	5								30	47.06	0.418	28.739	32.111	10.707	20.35	19.95	2.296	18.33	20.6	996	15.2	7.25	6.59	20	8.58	5.18
Mandatory	6								40	45.84	0.369	26.211	29.385	10.233	20.38	19.34	2.435	17.73	19.7	997	13.4	6.66	7.26	13.6	6.69	4.67
	7								50	44.62	0.319	23.618	26.589	9.621	20.42	19.81	2.6	17.06	19.5	996	11.7	5.97	7.97	8.58	4.79	3.77
	8								60	43.47	0.262	20.743	23.489	8.720	20.36	19.69	2.854	16.45	19.8	1007	9.15	5.32	8.38	6.71	4.66	3.9
		Additional test if flash back occurs at H2 = X FR % make a test at X FR -5% (refining the Fme H2. Check aslo the gas pressure influence																								
		Testing of the gas pressure influence								LY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE INCREASE OF CO, air excess change and or combustion impact																
	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%	43.47	0.262	20.737	23.481	8.718	0	0	0	0.00	0	0	0	0	0	0	0	0
	10		Pmax				Tr = 40C	CH4		43.46	0.262	20.714	23.457	8.709	0	0	0	0.00	0	0	0	0	0	0	0	0
	11		Pmin1				Tr = 40C	CH4		43.47	0.262	20.733	23.478	8.717	0	0	0	0.00	0	0	0	0	0	0	0	0
	12		Pmin2				Tr = 40C	CH4		43.48	0.263	20.759	23.506	8.726	0	0	0	0.00	0	0	0	0	0	0	0	0
		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				ON AVG (DATA FILE) AND NOT INSTANTANEOUS DATA NOTED MANUALLY																
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	50.54	0.556	35.820	39.749	11.638	19.88	19.42	0.437	4.35	20.1	1004	8.86	8.11	6.42	0.53	7.63	3.03
	14								10	49.31	0.507	33.312	37.044	11.359	19.8	19.49	0.459	4.25	20.4	1005	9.5	7.6	7.05	0.53	5.28	2.13
	15								20	48.14	0.461	30.932	34.477	11.047	19.78	20.03	0.477	4.10	20.9	1005	9.82	7.07	7.67	0.13	4.06	1.86
Mandatory	16								23	47.77	0.447	30.192	33.679	10.938	19.83	19.79	0.486	4.08	19.3	1004	7.67	6.91	7.86	0.78	3.85	1.82
	17								30	46.92	0.413	28.459	31.810	10.659	19.77	19.65	0.502	3.97	20.8	1004	9.34	6.54	8.29	0.44	3.08	1.53
Mandatory	18						Tr = 40C (constant water flow rate for boilers & Wh)		40	45.91	0.372	26.371	29.558	10.266	19.84	19.77	0.526	3.85	19.2	1005	9.58	6.08	8.79	0.2	2.43	1.31
	19								50	44.73	0.323	23.842	26.830	9.680	19.74	19.89	0.563	3.73	19.3	1004	8.83	5.46	9.36	0.1	1.88	1.08
	20								60	43.57	0.267	20.988	23.752	8.808	19.89	20	0.618	3.60	20	1008	6.34	4.99	9.24	0.72	1.52	0.7

D4 : adjustment test A

INITIAL VALUES ADJUSTED ACCORDING THE MANUAL

3.1 ADJUSTMENT A (mostly to see FB & CO).

Qmax - GAS set to EU high and used with EU low with increasing H2%.																								LY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE: high CO, abnormal operation, etc... NOTING OBSERVATIONS AR
STABILISATION AFTER ADJUSTMENT CH4 (at Qmax and Q min)																								nances is required
84	Q_{max}	Pnom	NR	NR	NR		EU high	0	52.52	0.620	39.437	43.623	11.941				0.00	20.6	1016.7	20.6	9.0	5.2	56.6	17.9	7.9
85			NR	NR	NR		EU low	0	48.66	0.577	35.143	38.981	11.679				0.00	20.7	1016.7	20.7	7.8	6.8	19.8	6.8	4.6
86			NR	NR	NR		EU low	10	46.58	0.526	32.050	35.639	11.363				0.00	20.4	1016.6	20.4	7.3	7.4	14.2	5.2	3.9
87			NR	NR	NR		EU low	30	44.48	0.428	27.447	30.684	10.635				0.00	20.2	1016.6	20.2	6.4	8.4	7.4	3.3	3.0
88			NR	NR	NR		EU low	60	41.57	0.271	20.131	22.808	8.631				0.00	20.1	1016.5	20.1	4.5	10.1	3.7	1.9	1.8
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																								
89	Q_{max}	Pnom	NR	NR	NR		EU low	X1	#######	0.000	0.000	0.000	#####				##########								
90			NR	NR	NR		EU low	X2	#######	0.000	0.000	0.000	#####				##########								
Qmin - GAS set to EU high and used with EU low with increasing H2%.																								
STABILISATION AFTER ADJUSTMENT CH4 (at Qmax and Q min)																								nances is required
91	Q_{min}	Pnom	NR	NR	NR		EU high	0	52.76	0.621	39.667	43.873	11.950				0.00	21.1	1017.0	21.1	8.4	6.1	1.7	8.5	3.4
92			NR	NR	NR		EU low	0	47.88	0.574	34.485	38.264	11.646				0.00	20.3	1017.0	20.3	7.4	7.5	1.6	4.5	2.3
93			NR	NR	NR		EU low	10	46.57	0.525	32.028	35.616	11.360				0.00	19.9	1017.0	19.9	7.0	8.1	1.4	3.2	1.7
94			NR	NR	NR		EU low	30	44.46	0.427	27.416	30.650	10.630				0.00	19.7	1016.9	19.7	6.0	9.2	1.1	2.0	1.2
95			NR	NR	NR		EU low	60	41.55	0.270	20.087	22.761	8.613				0.00	19.8	1016.9	19.8	4.4	10.6	0.8	1.2	0.9
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																								
96	Q_{min}	Pnom	NR	NR	NR		EU low	X1	#VÆRDI	#####	#####	#####	#####				#VÆRDI!								
97			NR	NR	NR		EU low	X2	#VÆRDI	#####	#####	#####	#####				#VÆRDI!								

New slide 2021

Eg D4 : adjustment test B

INITIAL VALUES ADJUSTED ACCORDING THE MANUAL

3.2 ADJUSTMENT B (mostly to see FB & CO)

Qmax - GAS set to EU low and used with EU high with increasing H2%.									LY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE: high CO, abnormal operation, etc... NOTING OBSERVATIONS ARI																		
STABILISATION AFTER ADJUSTMENT EU low									nances is required																		
98	Q_{max}	Pnom	NR	NR	NR		EU low	0	47.63	0.574	34.295	38.056	11.638				0.00	19.5	1004.5	19.5	9.0	4.6	71.2	22.8	9.1		
99			NR	NR	NR		EU high	0	51.65	0.615	38.609	42.723	11.904				0.00	20.0	1004.5	20.0	10.5	2.7	206.4	69.7	19.5		
100			NR	NR	NR		EU high	10	51.12	0.568	36.674	40.644	11.694				0.00	19.8	1004.5	19.8	9.8	3.4	160.8	53.1	17.5		
101			NR	NR	NR		EU high	30	48.38	0.461	31.131	34.670	11.042				0.00	19.7	1004.5	19.7	8.4	4.8	64.6	26.3	11.3		
102			NR	NR	NR		EU high	60	44.14	0.291	22.260	25.111	9.191				0.00	19.5	1004.4	19.5	6.1	7.2	15.5	9.2	6.3		
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																											
103	Q_{max}	Pnom	NR	NR	NR		EU high	X1	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!										
104			NR	NR	NR		EU high	X2	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!										
Qmin - GAS set to EU low and used with EU high with increasing H2%.																											
STABILISATION AFTER ADJUSTMENT EU low									nances is required																		
105	Q_{min}	Pnom	NR	NR	NR		EU low	0	47.59	0.574	34.266	38.025	11.637				0.00	20.2	1017.6	20.2	8.4	5.7	1.9	10.1	3.7		
106			NR	NR	NR		EU high	0	51.48	0.611	38.368	42.465	11.887				0.00	20.1	1017.5	20.1	9.8	3.9	3.3	23.5	6.9		
107			NR	NR	NR		EU high	10	51.18	0.568	36.729	40.703	11.697				0.00	20.0	1017.6	20.0	9.2	4.5	2.2	18.0	6.1		
108			NR	NR	NR		EU high	30	48.39	0.460	31.080	34.615	11.031				0.00	20.0	1017.6	20.0	7.9	6.0	1.4	9.6	4.1		
109			NR	NR	NR		EU high	60	44.21	0.291	22.298	25.152	9.197				0.00	20.0	1017.7	20.0	5.8	8.2	0.8	4.0	2.3		
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																											
110	Q_{min}	Pnom	NR	NR	NR		EU high	X1	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!										
111			NR	NR	NR		EU high	X2	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!										

New slide 2021

Eg D4 : adjustment test H

INITIAL VALUES ADJUSTED ACCORDING THE MANUAL

3.3 ADJUSTMENT H (mostly to see FB & CO)

Qmax - GAS set to EU high + 20% H2 and used with EU low with increasing H2%.									LY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE: high CO, abnormal operation, etc... NOTING OBSERVATIONS AR																	
STABILISATION AFTER ADJUSTMENT EU high									nances is required																
112	Q_{max}	Pnom	NR	NR	NR		EU High	20	49.85	0.514	33.945	37.705	11.398				0.00	20.2	1015.0	20.2	9.0	4.3	90.5	32.1	11.3
113			NR	NR	NR		EU low	0	48.11	0.573	34.630	38.423	11.649				0.00	20.1	1014.9	20.1	8.9	4.7	66.2	21.5	8.9
114			NR	NR	NR		EU low	10	46.58	0.525	32.032	35.620	11.361				0.00	20.0	1014.9	20.0	8.3	5.3	45.8	16.1	7.4
115			NR	NR	NR		EU low	30	44.49	0.427	27.438	30.674	10.632				0.00	19.9	1014.7	19.9	7.2	6.5	22.0	9.3	5.5
116			NR	NR	NR		EU low	60	41.56	0.270	20.090	22.763	8.614				0.00	19.7	1014.7	19.7	5.2	8.4	6.4	4.3	3.7
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																									
117	Q_{max}	Pnom	NR	NR	NR		EU low	X1	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!								
118			NR	NR	NR		EU low	X2	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!								
Qmin - GAS set to EU high+ 20% H2 and used with EU low with increasing H2%.																									
STABILISATION AFTER ADJUSTMENT EU high									nances is required																
119	Q_{min}	Pnom	NR	NR	NR		EU High	20	49.85	0.514	33.929	37.688	11.395				0.00	20.3	1015.8	20.3	8.5	5.2	2.0	11.8	3.9
120			NR	NR	NR		EU low	0	48.05	0.573	34.592	38.382	11.648				0.00	20.2	1015.7	20.2	8.4	5.5	1.7	10.2	3.6
121			NR	NR	NR		EU low	10	46.57	0.526	32.042	35.631	11.363				0.00	20.1	1015.5	20.1	7.9	6.1	1.8	7.7	3.0
122			NR	NR	NR		EU low	30	44.49	0.428	27.467	30.705	10.639				0.00	19.9	1015.4	19.9	6.9	7.3	1.7	4.4	2.0
123			NR	NR	NR		EU low	60	41.57	0.271	20.148	22.826	8.638				0.00	19.9	1015.4	19.9	5.1	8.9	1.6	2.1	1.2
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																									
124	Q_{min}	Pnom	NR	NR	NR		EU low	X1	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!								
125			NR	NR	NR		EU low	X2	#VÆRDI!	#####	#####	#####	#####				#VÆRDI!								

D4 : adjustment test G

INITIAL VALUES ADJUSTED ACCORDING THE MANUAL

3.5 ADJUSTMENT G2 (mostly to see FB & CO)

Qmax - GAS set to EU low + 20% H2 and used with EU high with increasing H2%. LY IN THE TABLE INSTANTANEOUS DATA: FOCUS ON POSSIBLE: high CO, abnormal operation, etc... NOTING OBSERVATIONS AI

STABILISATION AFTER ADJUSTMENT EU low + H2 — nances is required

126	Q_{max}	Pnom	NR	NR	NR		EU Low	20	45.55	0.478	29.791	33.207	11.038						20.5	1017.5	20.5	9.0	3.8	111.3	40.8	14.2
127			NR	NR	NR		EU high	0	52.49	0.621	39.456	43.642	11.944						20.5	1017.4	20.5	11.6	0.4	1024.9	135.2	22.6
128			NR	NR	NR		EU high	10	51.21	0.569	36.781	40.760	11.702				0.00		20.5	1017.3	20.5	11.1	1.1	929.2	130.4	28.8
129			NR	NR	NR		EU high	30	48.42	0.461	31.146	34.687	11.042				0.00		20.2	1017.2	20.2	9.6	2.7	231.6	81.4	24.8
130			NR	NR	NR		EU high	60	44.21	0.292	22.325	25.182	9.209				0.00		20.1	1017.2	20.1	6.9	5.3	48.3	29.8	13.8
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																											
131	Q_{max}	Pnom	NR	NR	NR		EU high	X1	#VÆRDI	#####	#####	#####	#####				#VÆRDI!										
132			NR	NR	NR		EU high	X2	#VÆRDI	#####	#####	#####	#####				#VÆRDI!										
Qmin - GAS set to EU low + 20% H2 and used with EU high with increasing H2%.																											
STABILISATION AFTER ADJUSTMENT EU low + H2 — nances is required																											
133	Q_{min}	Pnom	NR	NR	NR		EU Low	20	45.55	0.476	29.755	33.168	11.030				0.00		20.0	1017.1	20.0	8.4	4.8	1.9	14.8	5.4
134			NR	NR	NR		EU high	0	52.43	0.619	39.330	43.507	11.934				0.00		19.9	1017.0	19.9	11.0	1.7	11.1	51.4	11.1
135			NR	NR	NR		EU high	10	51.15	0.567	36.651	40.620	11.689				0.00		19.8	1017.0	19.8	10.5	2.3	7.2	42.2	10.6
136			NR	NR	NR		EU high	30	48.35	0.458	30.998	34.528	11.021				0.00		19.9	1017.0	19.9	9.0	3.8	2.9	22.5	7.3
137			NR	NR	NR		EU high	60	44.17	0.290	22.242	25.093	9.182				0.00		19.7	1016.9	19.7	6.5	6.4	1.1	8.1	3.8
Additional test if flash back occurs at H2 = X FB % make a test between the two last points																											
138	Q_{min}	Pnom	NR	NR	NR		EU high	X1	#VÆRDI	#####	#####	#####	#####				#VÆRDI!										
139			NR	NR	NR		EU high	X2	#VÆRDI	#####	#####	#####	#####				#VÆRDI!										

Low Wobbe + H2
High Wobbe

ADJUSTMENT: what to measure

Continuous measurement:

Flue gas:
- Temperature
- CO, NOX, O2, CO2

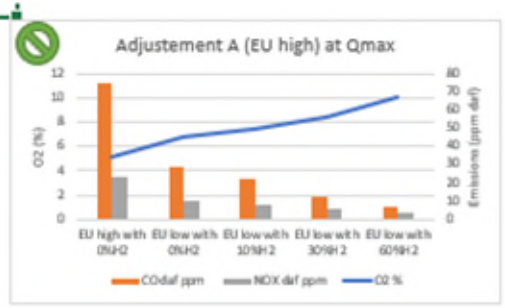
Input:
- Pg, Tg, Vg, Qin,
- Gas analyse

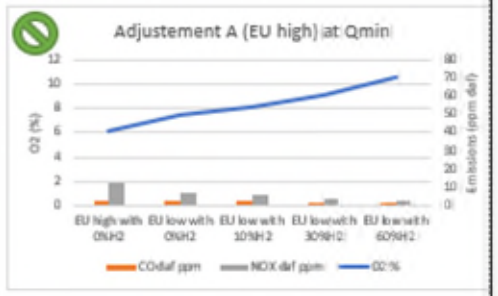
Test conditions
- Tamb, Tair, Patm

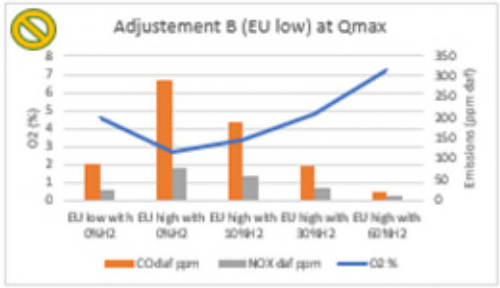
Safety & operation
- Flashback
- etc

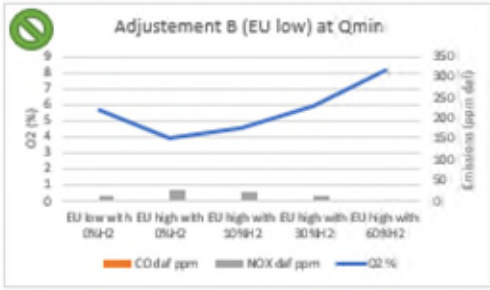
FOCUS IS ON CO and FB

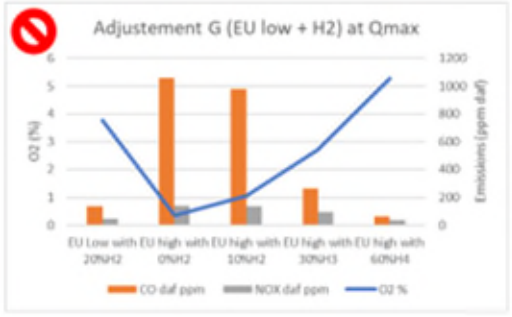
ADJUSTMENT- what we see from the first tests

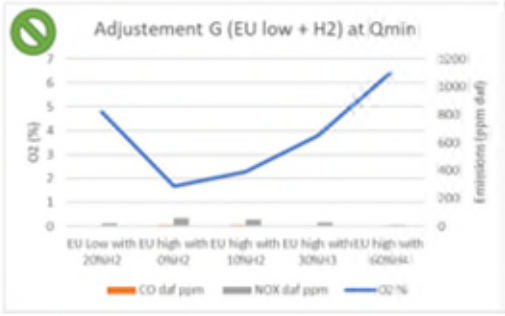


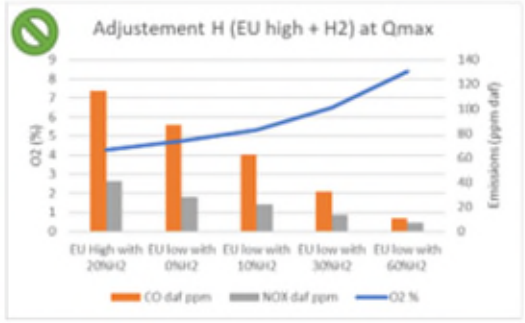


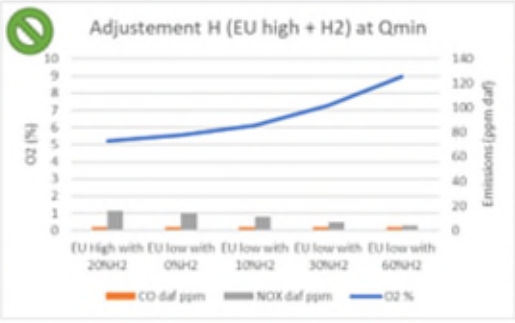












Adjustment G is the most problematic:
(high CO)
A,B,H showing only positive H2 impact

New options for testing:

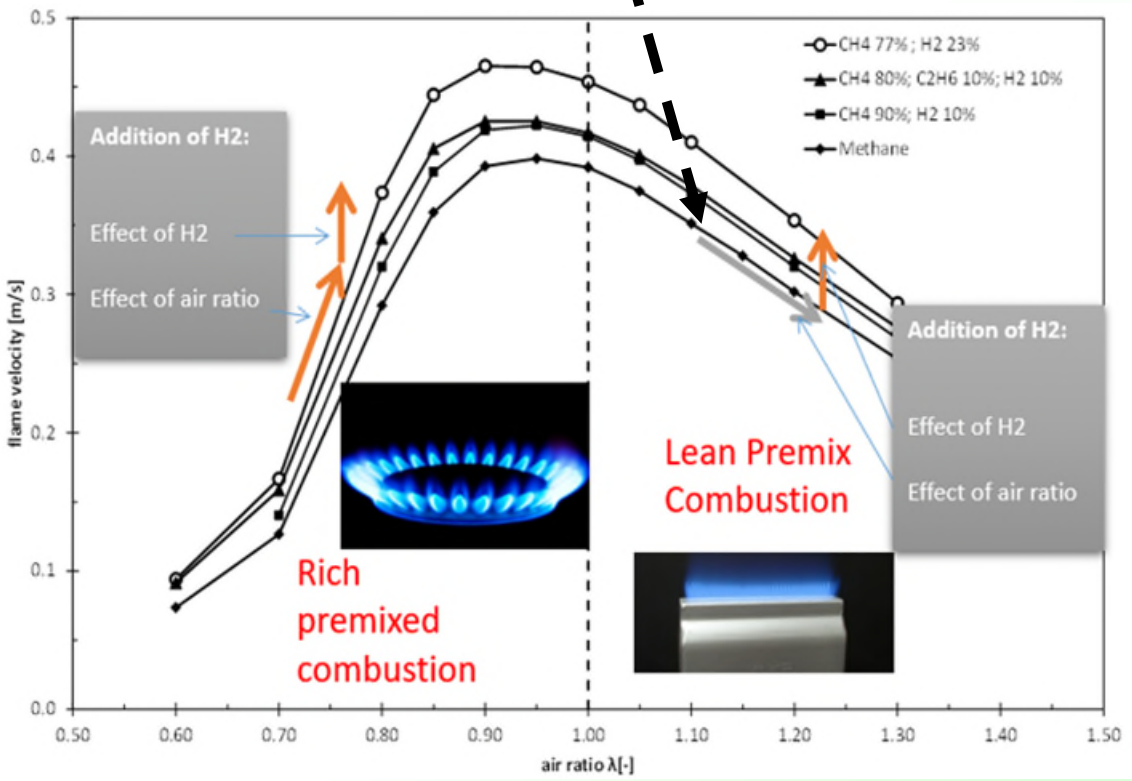
- 10% and 30% H2 instead of 20%
- Adjustment with O2 instead of CO2

Will be implemented in the new datasheet

ADJUSTMENT- what we see from the first tests

The reduction of the FV due to air ratio increase will not take place if the air ratio is maintained constant

Appliances with combustion controls that can keep air ratio more or less constant may see high flame velocity and combustion safety issues



Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 4 OTHER TESTS

4.3 Quick variation Qmin-Qmax Shut-off condition (cookers and fires only). Qualitative test (observation)

Short Description	The test is aiming at checking possible issues with quick variations between Qmin and Qmax (an the other way round)
More detailed description	
Gas to be used	CH4 + 30% H2
Execution	
Appliance set up	NR
Other test conditions	
Time	

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 4 OTHER TESTS

4.4 Overheat. Measurement of the temperature

Short Description	The test is aiming at checking possible overheat of the burners
More detailed description	This will require the collaboration with the manufacturer, to ensure the probes installed are not interacting with the appliance
Gas to be used	CH4 + 30% H2
Execution	
Appliance set up	For cookers: Test with a metal plate on burner to check increase in surface temperature. Note that we have not yet done this test, it could also be done with a pot with water?
Other test conditions	
Time	

5. Open questions; Old / new appliances

5.1 Old / new appliances

- We cannot perform extensive test with used/unused appliances but we suggest that a preliminary short term test is done on appliances for the long term testing and that the short term test (or part of it) is repeated after the long term to see possible impact.

- Also we shall integrate as many relevant appliances as possible and age is an important parameter. In case of used appliances this may however be a problem to get some, but we will have few

- We may even have a possibility to have a cooker in two versions (used / unused) for testing (in discussion- to be confirmed)

5. Open questions;

THYGA plans

5.2 delayed ignition

1) Late ignition test (with NG/H2 blends) according product standards. ONLY IN ONE LAB (for the moment) Labs are requested to check whether they may do it with adequate safety considerations (Labs)
2) Evaluation from theory (GWI/ENGIE) possible theoretical evaluation of the risk.
3) We could also ask external expertise. Eg. the lab from BAM? We know that DNVGL has done a lot of experimental work on H2/NG mix. Maybe the project can contact them.
4) We shall also look at the safety strategies of appliances; as the risk will be related how the appliance is reacting in case of missing flame after ignition (who can help here?) (TC109 & other TCs?)

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 4 OTHER TESTS

4.1 Delayed ignition test.

Short Description	The test is aiming at checking that the safety for delayed ignition is not compromised by the addition of H2
More detailed description	The test is done with increasing gas release times until the test is considered to be unsafe
Gas to be used	CH4 + 30% H2
Execution	
Appliance set up	
Other test conditions	
Time	

5.3 Open questions; Soundness test

8.2 Soundness

8.2.1 Soundness of the gas circuit

Requirements:

The gas circuit shall be sound. Internal soundness requirements for the controls are given in Clause 7.

The external soundness of the gas circuit in the boiler is verified before and after all the tests of this standard.

External soundness is assured if, under the test conditions below, the leakage of air does not exceed 0,14 dm^3/h.

Test conditions:

The tests are carried out at ambient temperature using air.

The following test is carried out when the boiler is delivered and before any other test, and again on completion of all the tests in the standard, after removing and replacing the assemblies 5 times in the gas circuit that have gas-tight joints whose removal is provided for in the manufacturer's instructions regarding routine servicing.

The leakage rate is checked with all the valves open, as if the boiler were in operation, and the gasway blocked off by the use of suitable parts, to be supplied by the manufacturer, in place of the injectors.

The upstream pressure is 50 mbar for boilers which do not use third family gas and 150 mbar for boilers which do use third family gas.

It is checked that the above requirement is met.

Eg testing procedure from CEN standards gas boilers.

Test is done with air:

- There is no meaning to repeat the test with air (the appliances are supposed to have gone through the test for CE approval)
- Testing wih NG/H2 mix is possible, but we don't have an element of comparison unless we also test with NG alone.

Instructions to perform the test following the sheet "DATA SHEET)

TESTING PART 4 OTHER TESTS

4.5 Coooker hob test with 4 burners on

Short Description	4 burners at Qmax with 30% H2
More detailed description	The test is done according the standards
Gas to be used	CH4 + 30% H2
Execution	
Appliance set up	
Other test conditions	
Time	

ANNEXES

Annex I

Justification of the testing proposal (Choice of gases, etc.)

Annex 1: Justification of the testing proposal

Change of gas composition: impact on laminar flame speed , Wobbe and density. Lessons for defining test gases.

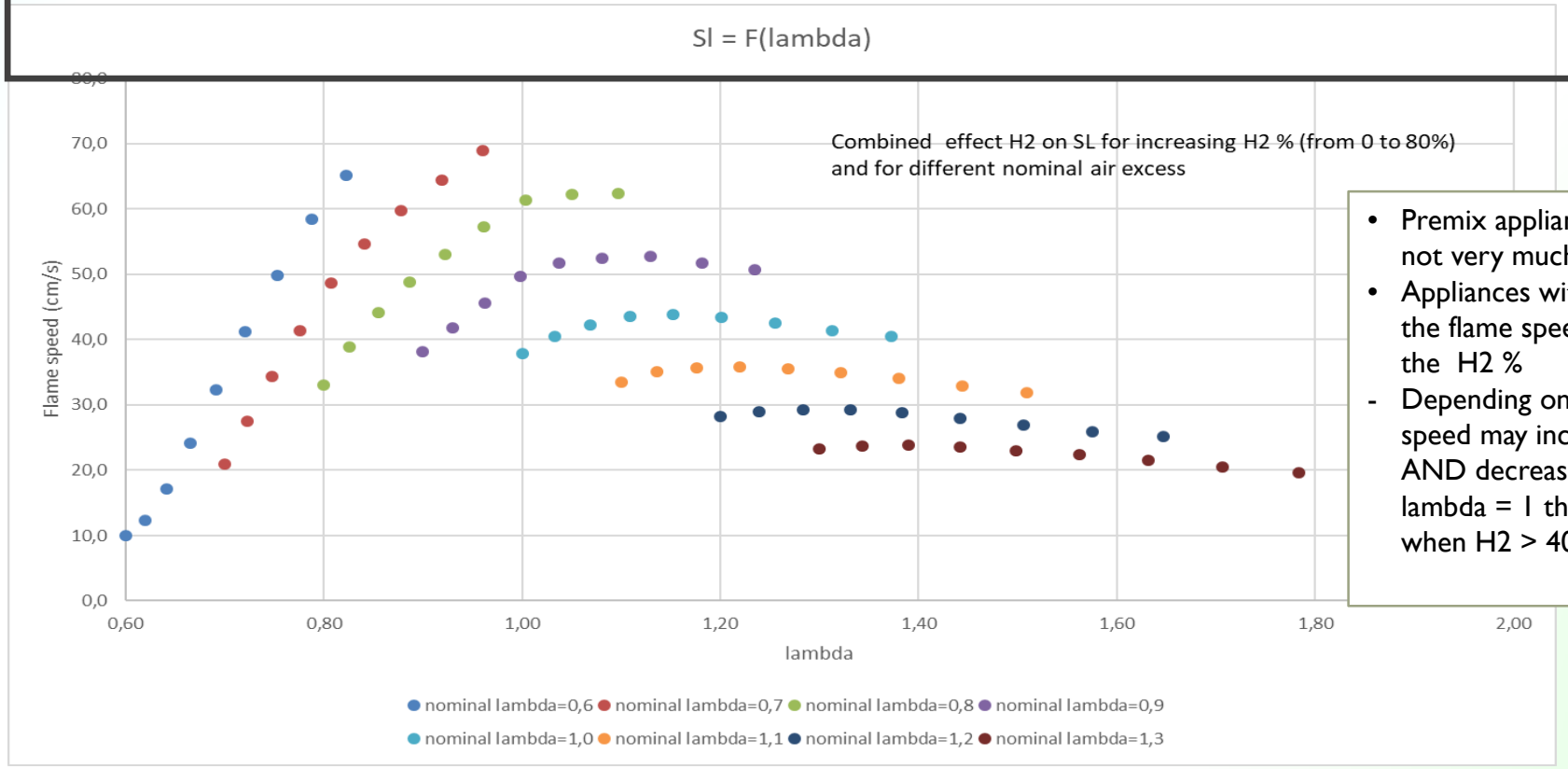
Rough calculations in view of helping the choice of test gases for THyGA (DGC febr 2020)

Conditions:

- Tool used: simple model DGC based on dutch model (OK with flame speed from literature, other parameters OK compared to NaturalHY tests)
- Constant air flow
- No adjustment of gas flow
- Lambda given in this note is the initial air excess without H2
- EU high and EU low (see slides WP3 Kick off meeting)

Annex 1: Justification of the testing proposal

FLAME SPEED
OBSERVATIONS 1: THE FLAME SPEED IS VERY MUCH DEPENDING ON THE INITIAL AIR EXCESS (LAMBDA) IN THE FRONT FLAME

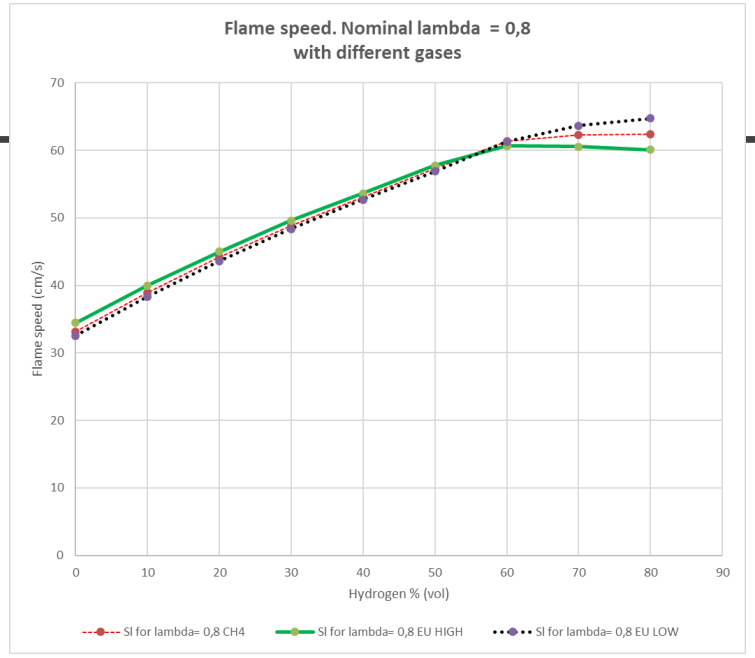


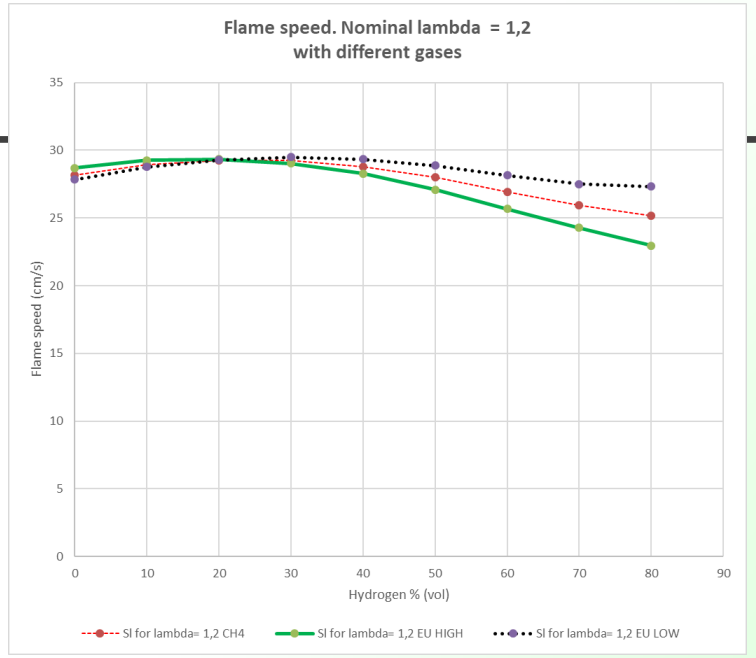
- Premix appliances (eg. Lambda = 1,2) are not very much impacted by the H2
- Appliances with atmospheric burners see the flame speed increasing very fast with the H2 %
- Depending on the burner type the flame speed may increase when injecting H2 AND decrease after a certain % (eg for lambda = 1 the flame speed is reducing when H2 > 40%)

Annex 1: Justification of the testing proposal

FLAME SPEED

OBSERVATIONS 1: THE FLAME SPEED IS ONLY IMPACTED BY THE GAS USED FOR H2 > 40 TO 60% . THE IMPACT REMAINS MUCH LOWER THAT THE INITIAL AIR EXCESS. POOR GASES (EG. EU LOW) ARE MORE IMPACTED.





According to ENGIE, there is no certainty about the difference when > 60% because the models may include defaults at this high rte(Telco March 2020)

Annex 1: Justification of the testing proposal

Wobbe Index and density

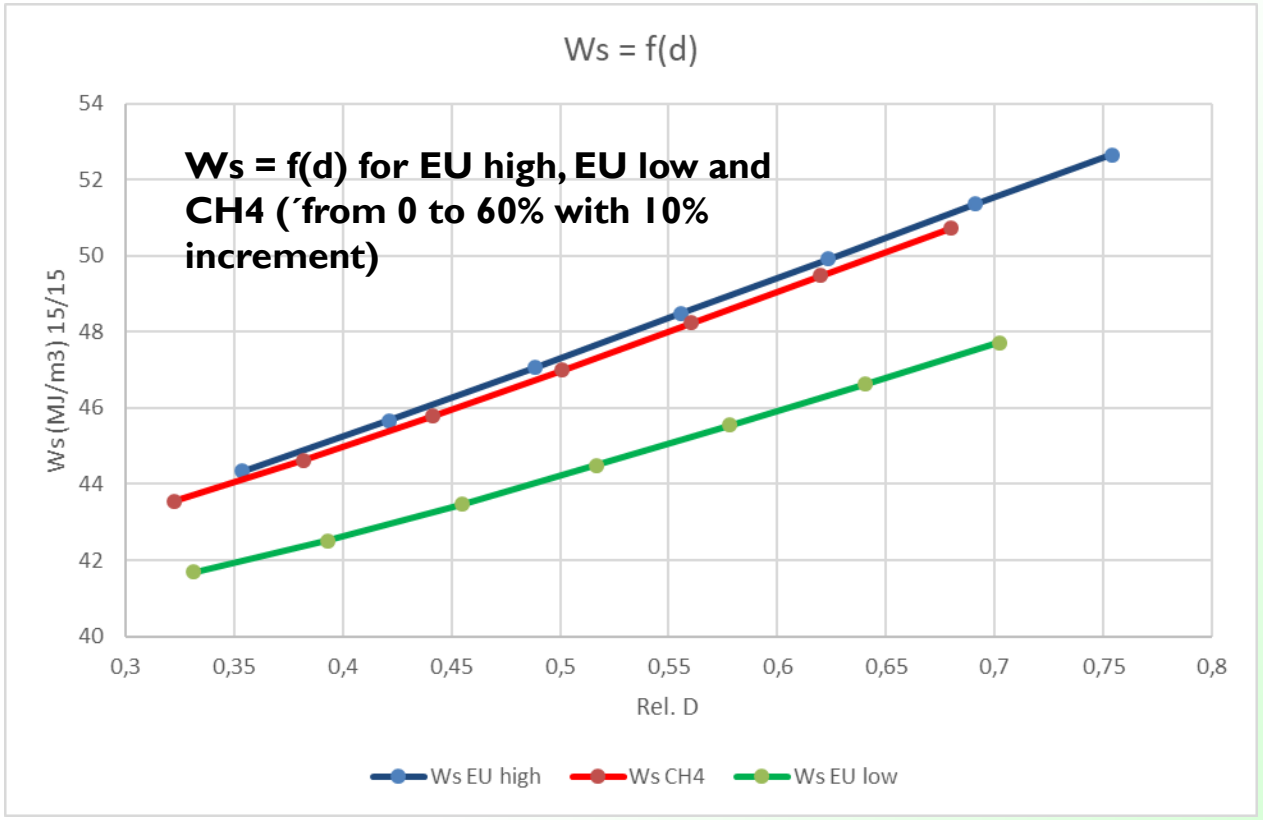
The Wobbe and the density are strongly impacted by the H2.

CH4 Wobbe is between “EU high” and “EU low”, but CH4 density is lower that “EU low”.

The figure shows how the Wobbe and density are impacted by H2 injection.

- Injecting H2 to EU_high will generate W,d line close to the G20 line (Shifted) (see lines red & blue).
- However starting with G20 will be more challenging as both Ws and d will end at lower values with 60% H2 mix!

Therefore for the investigation of (W,d) alone, it make sense to test with G20

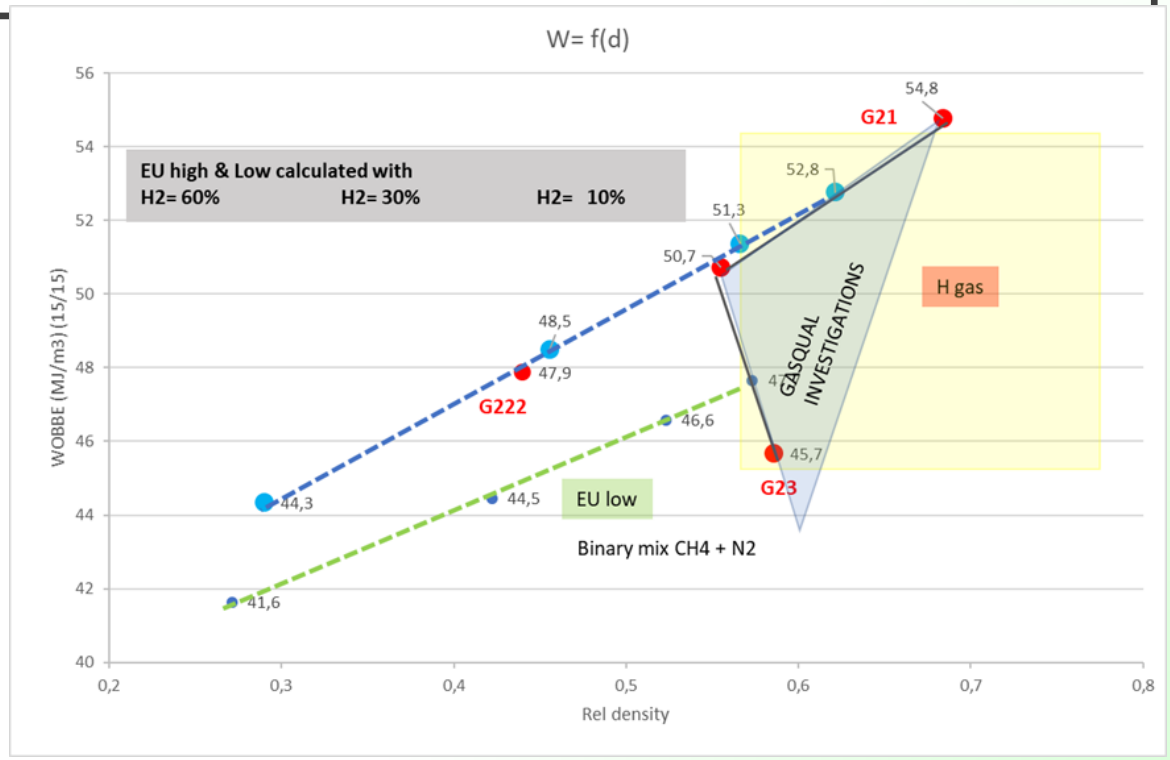


Annex 1: Justification of the testing proposal

CONCLUSIONS FOR TEST GASES
THE INITIAL GAS COMPOSITION IS IMPORTANT FOR THE WOBBE AND THE DENSITY, IT IS LESS IMPORTANT FOR THE FLAME SPEED (SLIGHT IMPACT AND ONLY H2 > 40%.)
IT IS THEREFORE QUITE IMPORTANT TO DEFINE THE % OF H2 THAT NEED TO BE INVESTIGATED.

All in all

- The impact of H2 on Wobbe and density (and resulting effects on safety and performances) may be an issue for both the premix and atmospheric appliances.
- The impact of flame speed is probably not a big issue for premix appliances.
- The gas EU-low is more impacted by flame speed increase with H2
- G20 is more challenging for (Ws,d) that EU-high
    - The impact of flame speed over 40% should be done with EU-low gas
    - Learning from GASQUAL on (W,d) influence may not integrate all aspects inherent to H2, but for premix appliances the GASQUAL results trend may very well apply still. The density of the gases used for test in GASQUAL are not covering the whole range to be investigated if 60% H2 is considered.

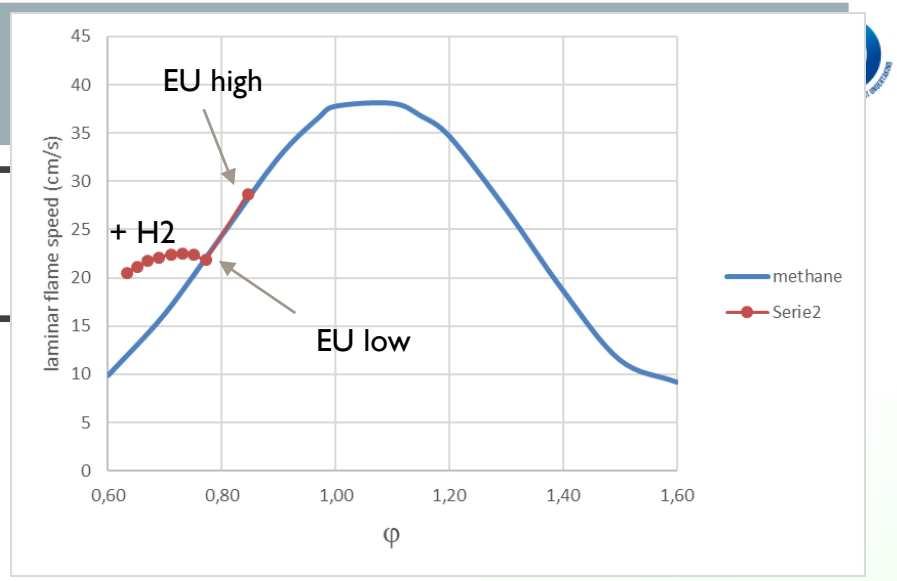


Annex I: Justification of the testing proposal

A) ADJUSTMENT EU HIGH FOR PREMIX (LAMBDA NOM = 1,2)
GAS USED= EU LOW + H2

This situation results first in a decrease of the SL (due to the increase of lambda). SL is more or less stable with H2 injection due to counterbalancing effects (H2 & air excess).

H2 not critical for this situation



input

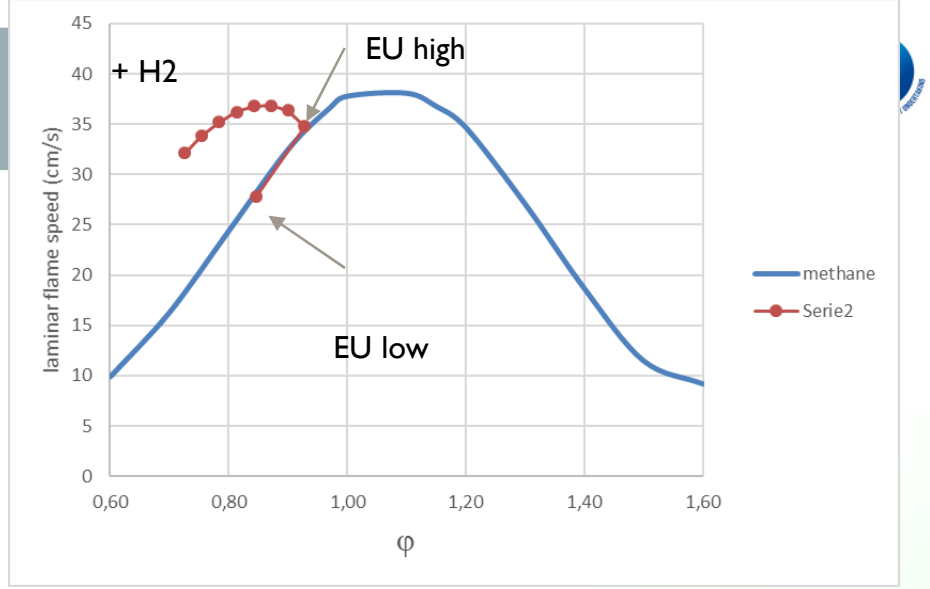
mol-%
vol-%

		EU high	EU low	EU low +10 %H2	EU low +20 %H2	EU low +30 %H2	EU low +40 %H2	EU low +50 %H2	EU low +60 %H2	EU low +70 %H2	
		not normalised									
		x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%
methane	CH_4	93,40	95,60	86,04	76,48	66,92	57,36	47,80	38,24	28,68	
ethane	C_2H_6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
propane	C_3H_8	6,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
isobutane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-butane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
neopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
isopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-pentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-hexane	C_6H_{14}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
nitrogen	N_2	0,00	4,40	3,96	3,52	3,08	2,64	2,20	1,76	1,32	
carbon dioxide	CO_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
oxygen	O_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
hydrogen	H_2	0,00	0,00	10,00	20,00	30,00	40,00	50,00	60,00	70,00	
	$\Sigma x'_i$	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	0,00

Annex I: Justification of the testing proposal

b) ADJUSTMENT EU LOW for premix (lambda nom = 1,2) Gas used= EU HIGH + H2

This situation results first in an increase of the SL (due to the decrease of lambda). SL is more or less stable with H2 injection due to counterbalancing effects (H2 & air excess). **This case is more critical for increase of risk of FB, but not due to H2 injection (mainly air excess influence). However in GASQUAL much higher dWobbe were tested and there has been no occurrence of FB. However severe increase of CO may occur.**



input

mol-%
vol-%

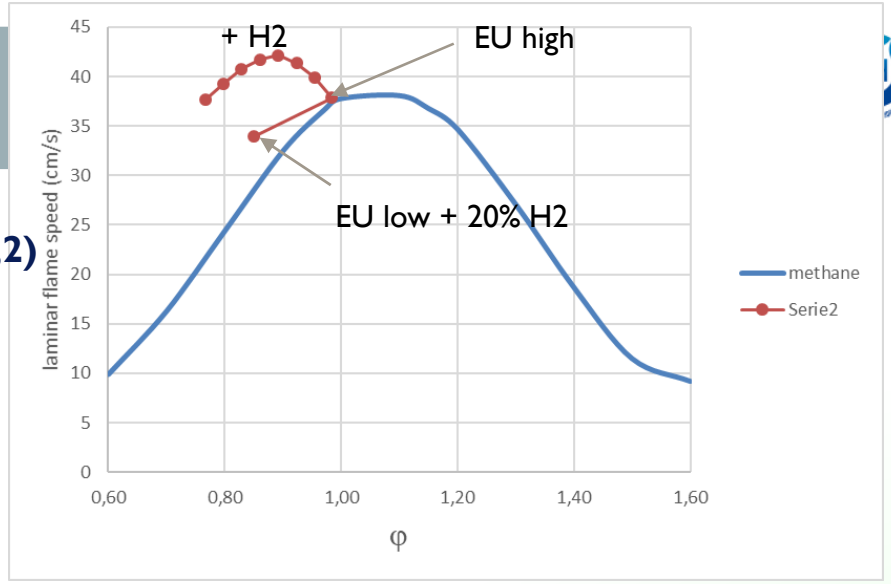
		EU Low	EU high	EU high + 10 % H2	EU high + 20 % H2	EU high + 30 % H2	EU high + 40 % H2	EU high + 50 % H2	EU high + 60 % H2	EU high + 70 % H2	
		not normalised									
		x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%
methane	CH_4	95,60	93,40	84,06	74,72	65,38	56,04	46,70	37,36	28,02	
ethane	C_2H_6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
propane	C_3H_8	0,00	6,60	5,94	5,28	4,62	3,96	3,30	2,64	1,98	
isobutane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-butane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
neopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
isopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-pentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-hexane	C_6H_{14}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
nitrogen	N_2	4,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
carbon dioxide	CO_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
oxygen	O_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
hydrogen	H_2	0,00	0,00	10,00	20,00	30,00	40,00	50,00	60,00	70,00	
	$\Sigma x'_i$	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	0,00

Annex I: Justification of the testing proposal

c) ADJUSTMENT EU LOW +20%H2 for premix (lambda nom = 1,2)
Gas used= EU HIGH + H2

This situation results first in a moderate increase of the SL (20% H2 has already increase the SL over the pure CH4 curve)

This case less critical for increase of risk of FB, compared to the previous one. Increasing to 40 % H2 is even less critical



input

mol-%
vol-%

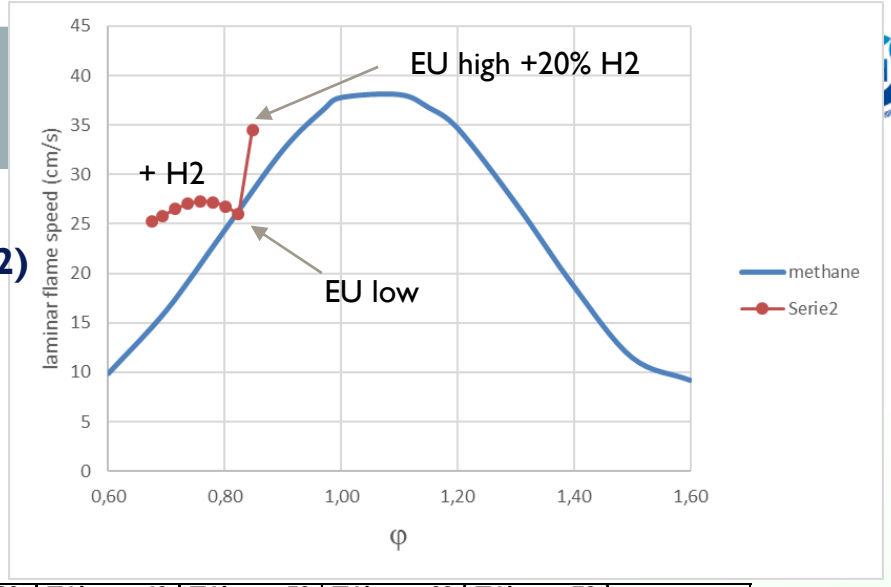
		EU Low+20%H2	EU high	EU high + 10 % H2	EU high + 20 % H2	EU high + 30 % H2	EU high + 40 % H2	EU high + 50 % H2	EU high + 60 % H2	EU high + 70 % H2	
		not normalised									
		x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%
methane	CH_4	76,48	93,40	84,06	74,72	65,38	56,04	46,70	37,36	28,02	
ethane	C_2H_6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
propane	C_3H_8	0,00	6,60	5,94	5,28	4,62	3,96	3,30	2,64	1,98	
isobutane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-butane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
neopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
isopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-pentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
n-hexane	C_6H_{14}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
nitrogen	N_2	3,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
carbon dioxide	CO_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
oxygen	O_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
hydrogen	H_2	20,00	0,00	10,00	20,00	30,00	40,00	50,00	60,00	70,00	
	$\Sigma x'_i$	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	0,00

Annex I: Justification of the testing proposal

d) ADJUSTMENT EU HIGH +20%H2 for premix (lambda nom = 1,2)
Gas used= EU LOW + H2

This situation results first in a lower increase of the SL (20% H2 has already increase the SL over the pure CH4 curve)

This case seems not critical for increase of risk of FB.



input

mol-%
vol-%

		EU high+20%H2	EU low	EU low + 10 % H2	EU low + 20 % H2	EU low + 30 % H2	EU low + 40 % H2	EU low + 50 % H2	EU low + 60 % H2	EU low + 70 % H2	
		not normalised									
		x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%	x mol-%
methane	CH_4	74,72	95,60	86,04	76,48	66,92	57,36	47,80	38,24	28,68	19,12
ethane	C_2H_6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
propane	C_3H_8	5,28	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
isobutane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
n-butane	C_4H_{10}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
neopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
isopentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
n-pentane	C_5H_{12}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
n-hexane	C_6H_{14}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
nitrogen	N_2	0,00	4,40	3,96	3,52	3,08	2,64	2,20	1,76	1,32	0,88
carbon dioxide	CO_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
oxygen	O_2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
hydrogen	H_2	20,00	0,00	10,00	20,00	30,00	40,00	50,00	60,00	70,00	80,00
	$\Sigma x'_i$	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

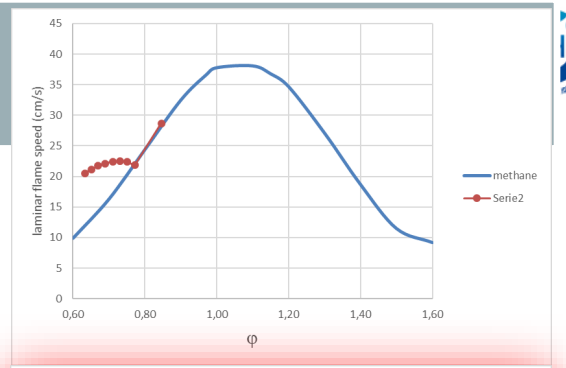
Annex 1: CONCLUSION ON ADJUSTMENT
(based on lambda = 1,2)

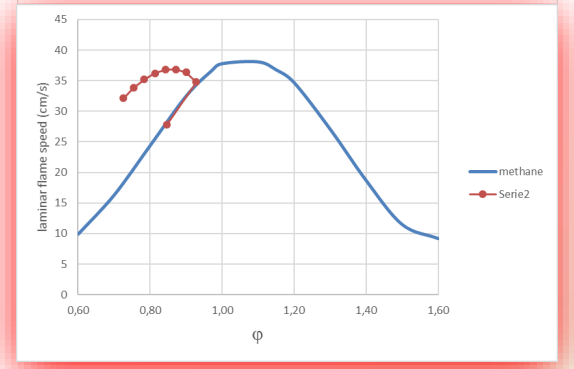
a) ADJUSTMENT EU HIGH for premix Gas used= EU LOW + H2

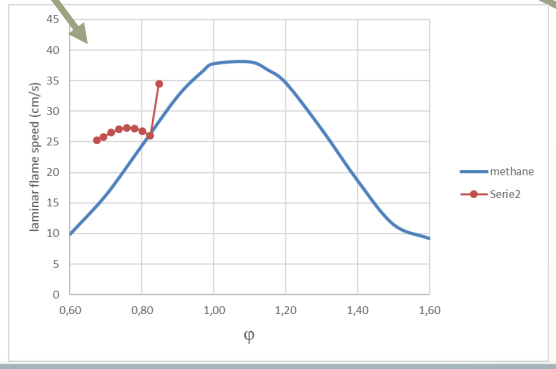
b) ADJUSTMENT EU LOW for premix Gas used= EU HIGH + H2

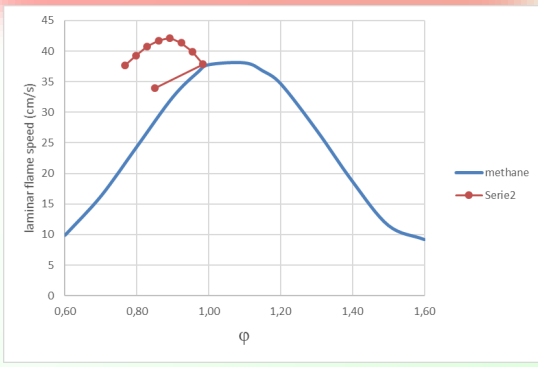
c) ADJUSTMENT EU LOW + 20% H2 for premix Gas used= EU HIGH + H2

d) ADJUSTMENT EU High + 20% H2 for premix Gas used= EU low + H2









CASE b) is the case for which we see the highest impact →**in increase of SL.**

Adjusting with H2 in the NG is in principle not worthening the problem with Flame speed increase compared to adjustment without H2.

Conclusion for test with adjustment:
Test b) for FB
Test a), b), c), d) to be considered for possible CO increase

Adjustments

Appliance adjustment (for a given gas) (only few segments can be adjusted!)

Lessons from the project Gasqual *(http://www.gasqual.eu/)*

- Appliances that are adjustable are generally adjusted to G20 during production
- Appliances are delivered with instructions on O2 or CO2 % to be achieved for the servicing
- Discrepancies between the reality and the national regulation related to adjustment policies
- Adjustement is one of the most critical point impacting the safety of gas appliances when gas quality is changing
- Adjusting appliances to G20 whatever the gas is distributed seems to be the safest option (implemented in DK)
- Adjustement method to perform this have been developpe

Only few segments from the Gasqual segmentation are adjustable

Testing part 3 Adjustments

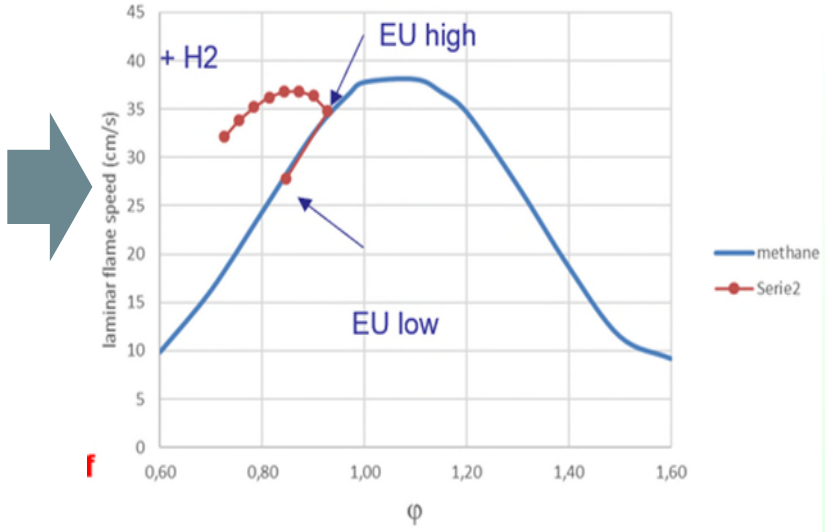
TEST OF THE IMPACT OF ADJUSTMENT (PREMIX APPLIANCES)

a) ADJUSTMENT EU HIGH -> Gas used= EU LOW + H2

b) **ADJUSTMENT EU LOW -> Gas used= EU HIGH + H2 (this test is the most critical for appliances that can be adjusted)**

c) ADJUSTMENT EU LOW + 20% H2 -> Gas used= EU HIGH + H2

d) ADJUSTMENT EU High + 20% H2 -> Gas used= EU low + H2



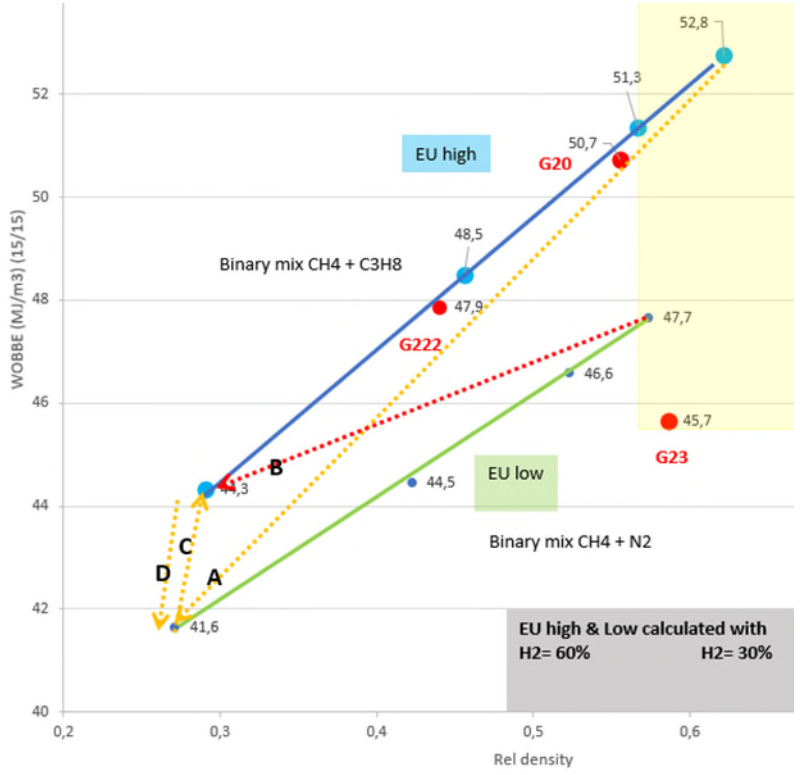
SAFETY TEST ONLY (same condition as for the "regular" test)

- **Test b) for FB**
- **Test a), b), c), d) for possible CO increase**

REVIEW THIS ONCE 1 or 2 TESTS have been done

CASE	EU low + H2	EU low	CH4	EU high + H2	EU high
A	Used	←	←	←	Adjusted
B		Adjusted	→	Used	
C	Adjusted	→	→	Used	
D	Used	←	←	Adjusted	

Investigation of Flame speed impact and or CO

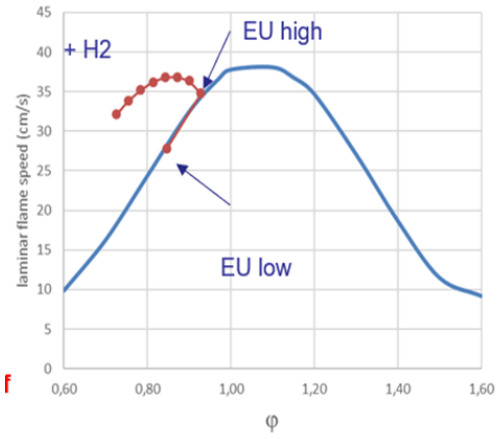


Simplification proposal:

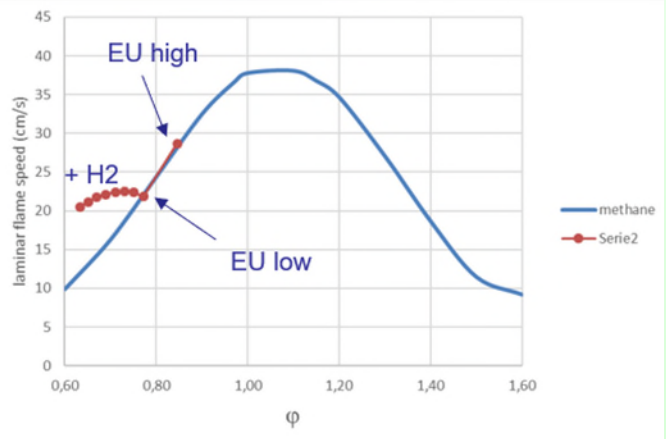
We may remove the 2 test points C & D if we assume **that no adjustments are allowed in grids with H2** (However those are not the most critical and could also be tested on one appliance during experimental phase).

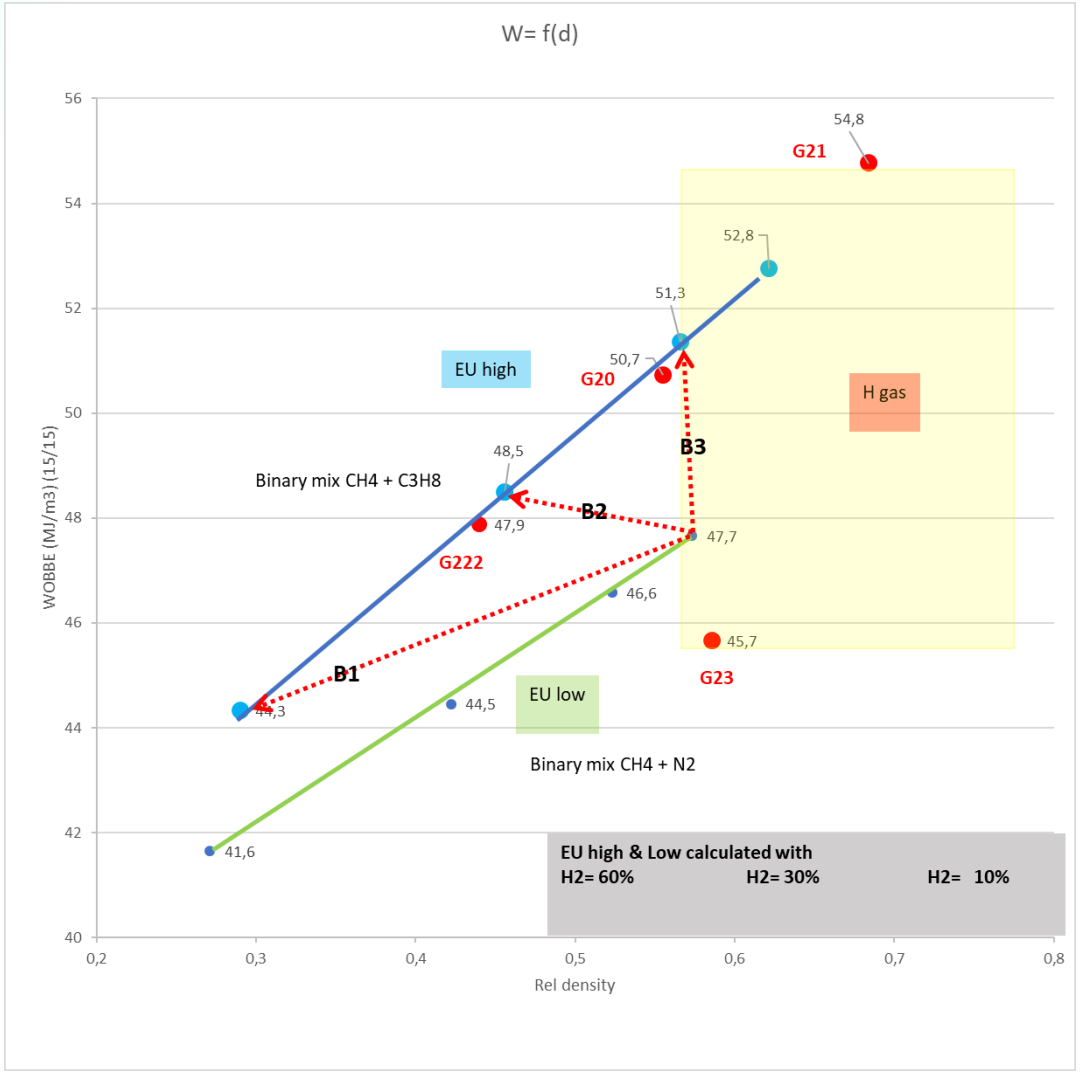
→ **We keep them and discuss possible removal at later stage**

B



A





a) Adjustment EU low
b) Test EU high + 60%

If issues (*):

c) Test EU high + 30%

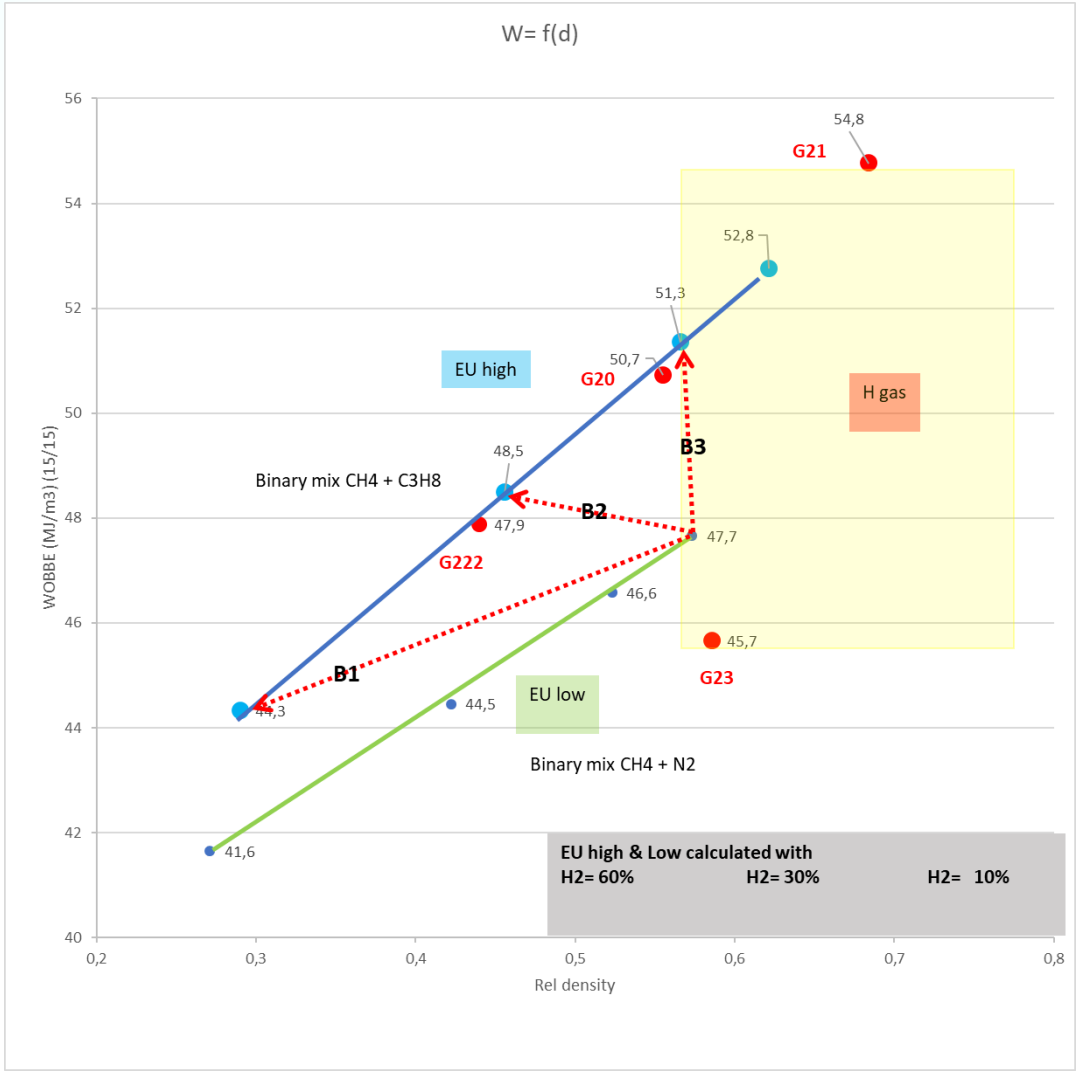
If issues:

d) Test EU high + 10%

If no issue :

Stop

(*) Issue = Flashback or and CO > 1000 ppm



a) Adjustment EU low
b) Test EU high + 60%

If issues (*):

c) Test EU high + 30%

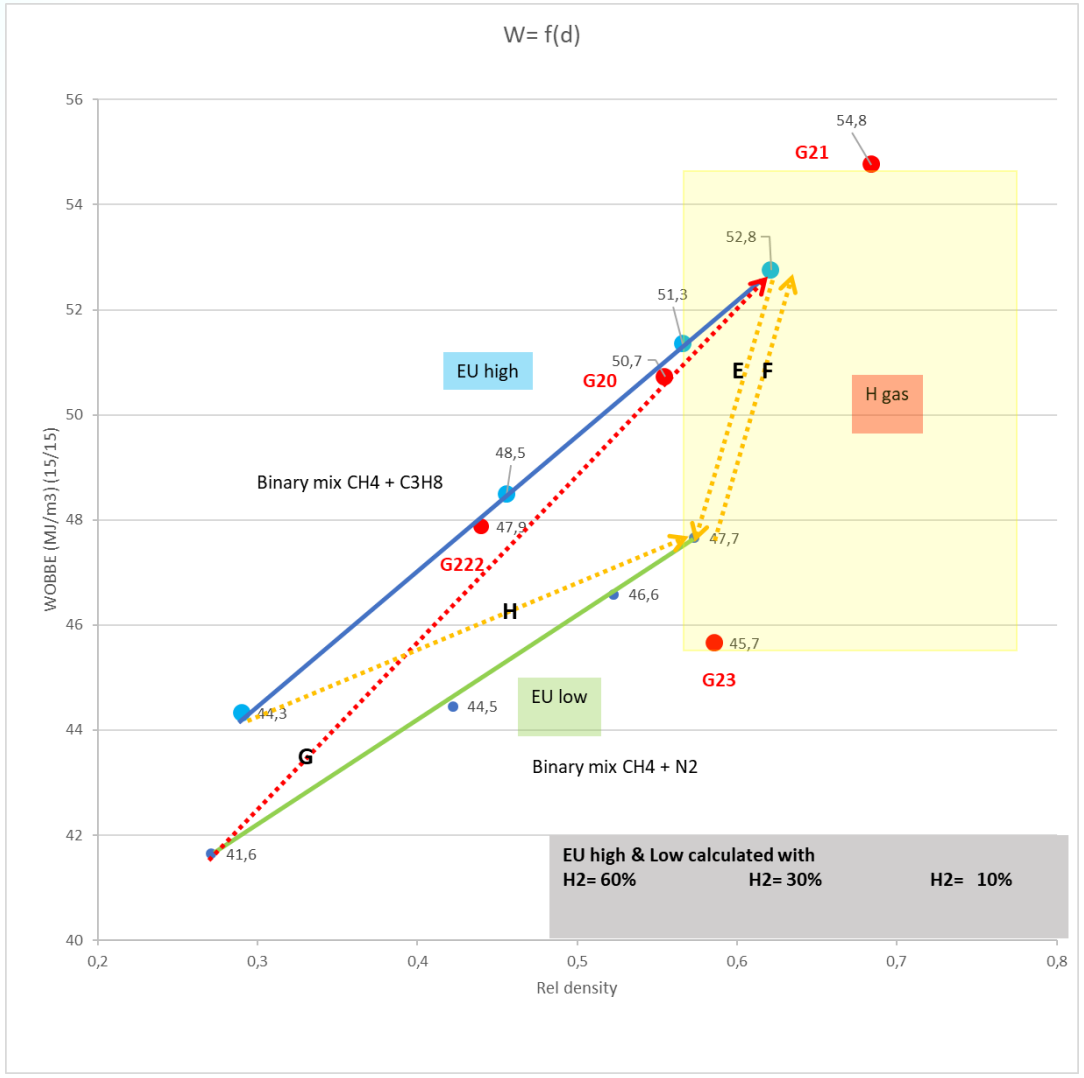
If issues:

d) Test EU high + 10%

If no issue :

Stop

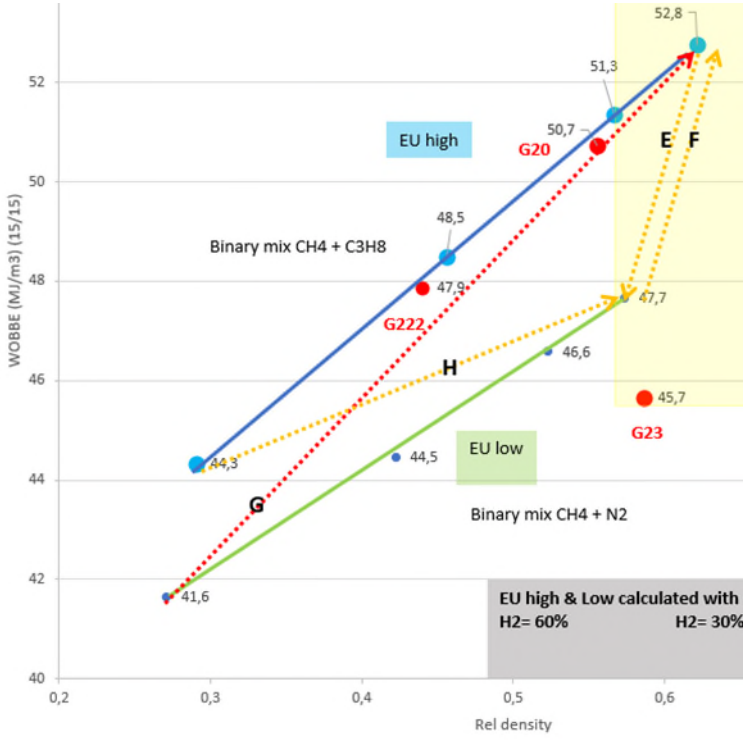
(*) Issue = Flashback or and CO > 1000 ppm



This is not specific to THyGA and was extensively tested in GASQUAL

CASE	EU low + H2	EU low	CH4	EU high + H2	EU high
E	NOT SPECIFIC THyGA	Used	←		Adjusted
F	(was tested in GASQUAL)	Adjusted	→		Used
G	Adjusted	→			Used
H		Used	←	Adjusted	

Other adjustments tests with focus on CO



Description

- E & F have been tested in GASQUAL (can be removed from the test program)
- G & H are tests where flame speed should not be an issue (the H2 % is decreased after adjustment), but CO could be the problem

Simplification proposal:

1. We may remove the 2 test points E & F as this is not involving H2.
2. We may ALSO remove the 2 test points G & H if we assume that no adjustments are allowed in grids with H2. However those are probably, in this case, the most critical and should be tested at least during experimental phase, so we suggest NOT to remove those 2 for the moment.

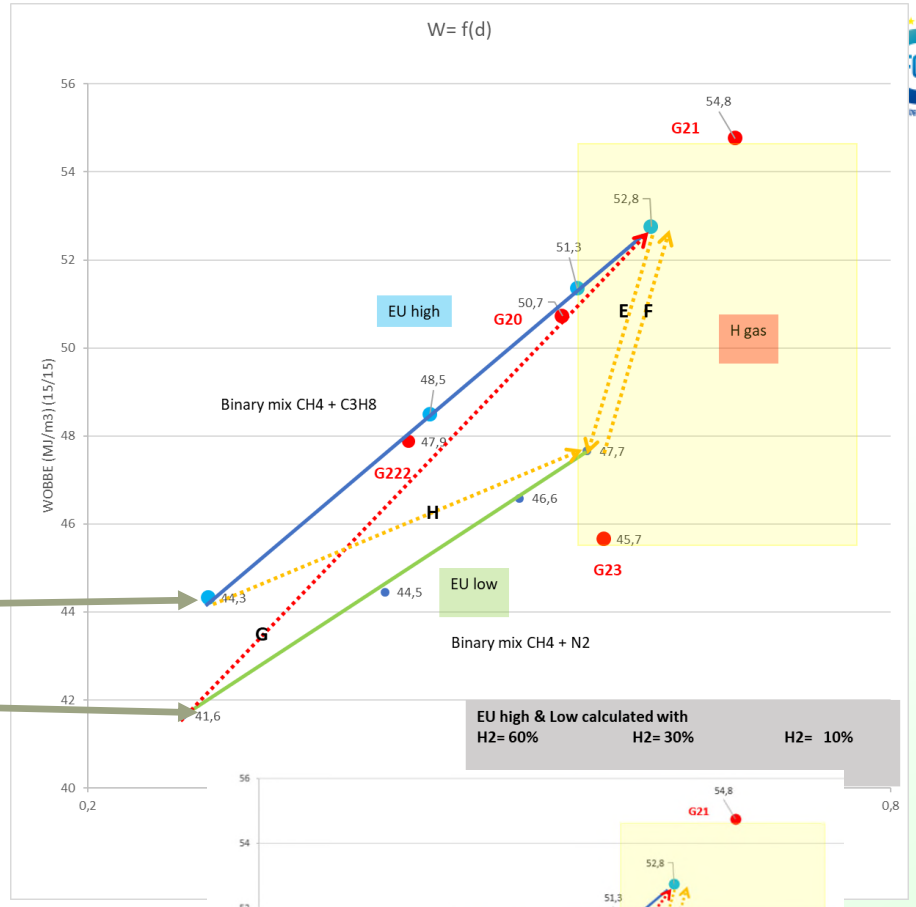
THyGA

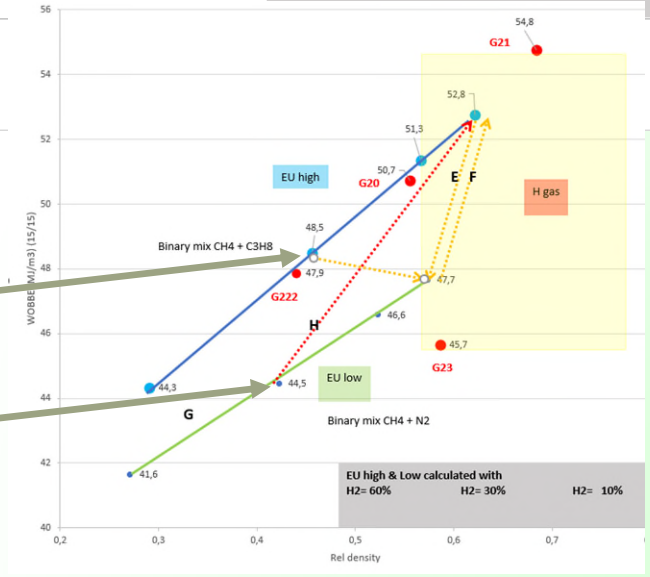
IMPORTANT

In the examples given from the previous figures,

- EU high + H2
- EU low + H2

are with 60% H2





This is unlikely to happen in the next 20 years therefore we suggest that for the Adjustment we use a gas with 20 or 30% H2 at max (more realistic situation).

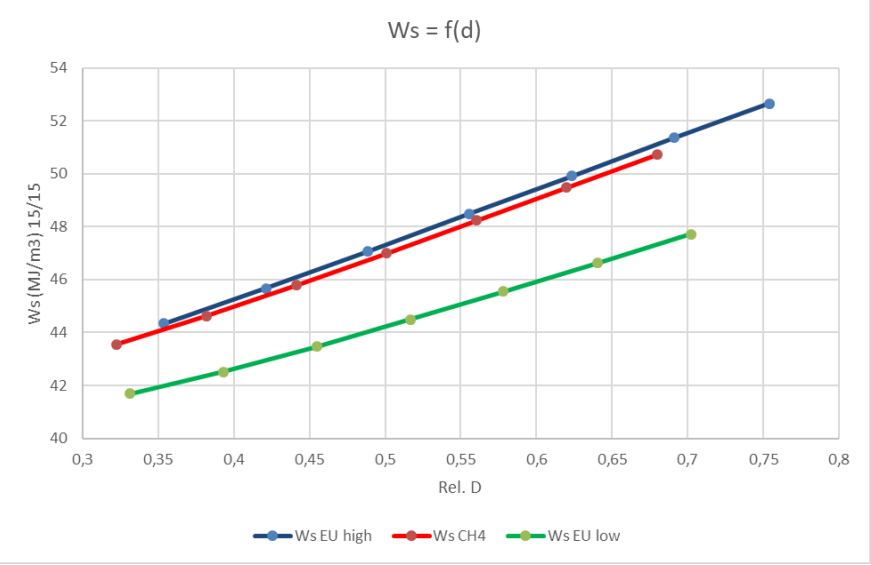
TEST GASES FOR THYGA: Short term tests

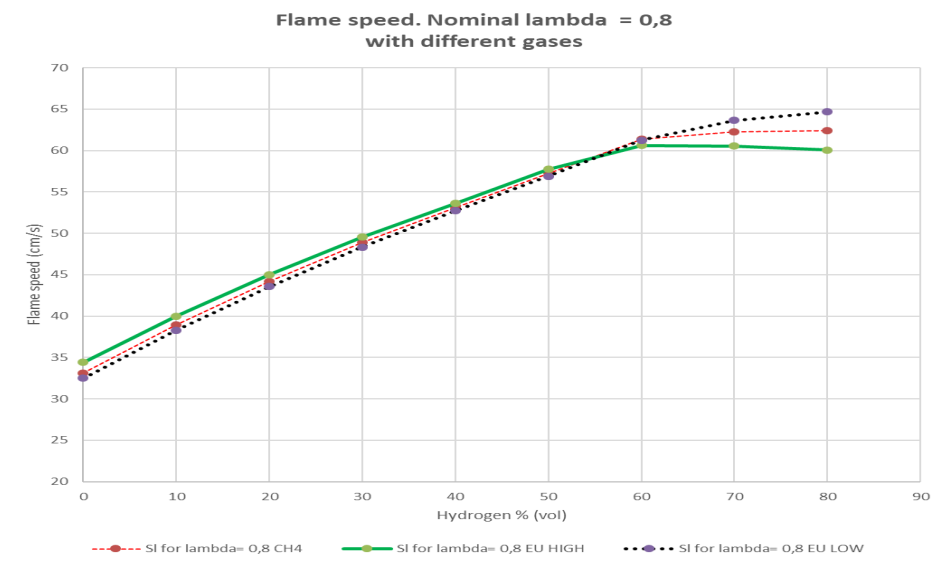
Results from preliminary investigation on flame speed:

1. **Original Gas quality has only very little influence on flame speed**. H2 % (and resulting lambda change) is the determining parameter.
2. **EU low will be the more challenging gas** when adding H2 as both Ws and d are getting more far from CH4 (and flame speed slightly higher for H2 > 60%)
3. **CH4 may be more challenging compared to EU high** as addition of H2 will bring the density to a lower value than EU high

Conclusion: Nominal gases chosen for the tests are *CH4 and EU low* and *EU high for appliances that can be adjusted)*

EU high & EU low are binary mix with CH4, N2 and for exemple C3H8





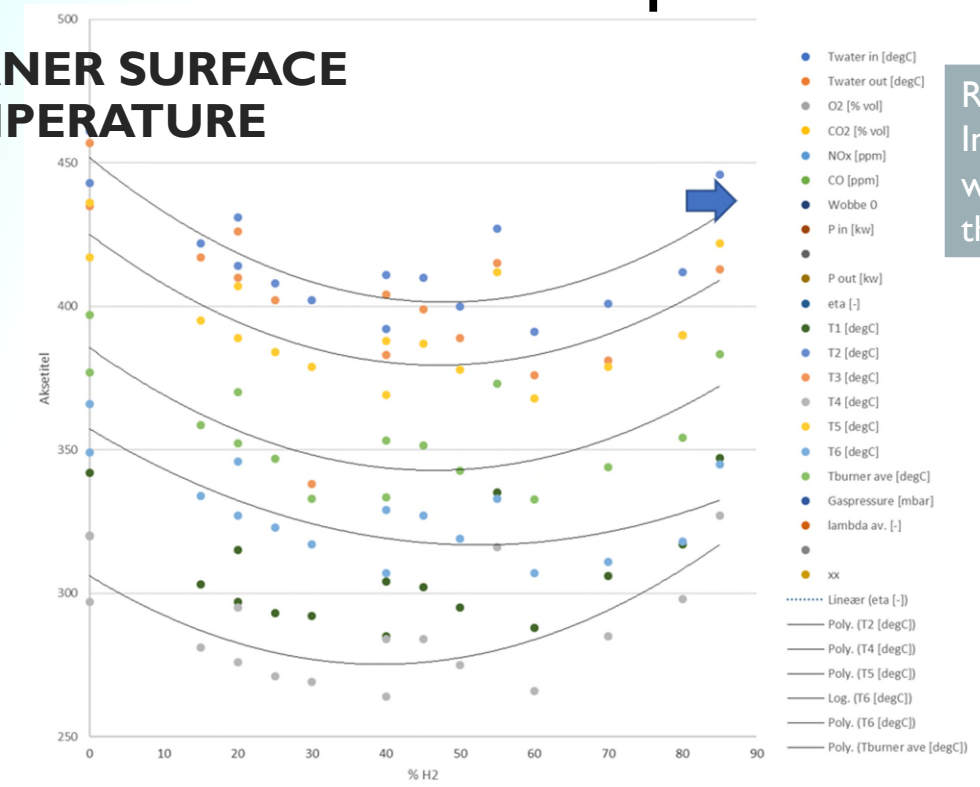
INITIAL NATURAL GAS COMPOSITION

According the calculations made, the initial Gas quality /composition variation has not much influence on SI, so no extensive test are foreseen.

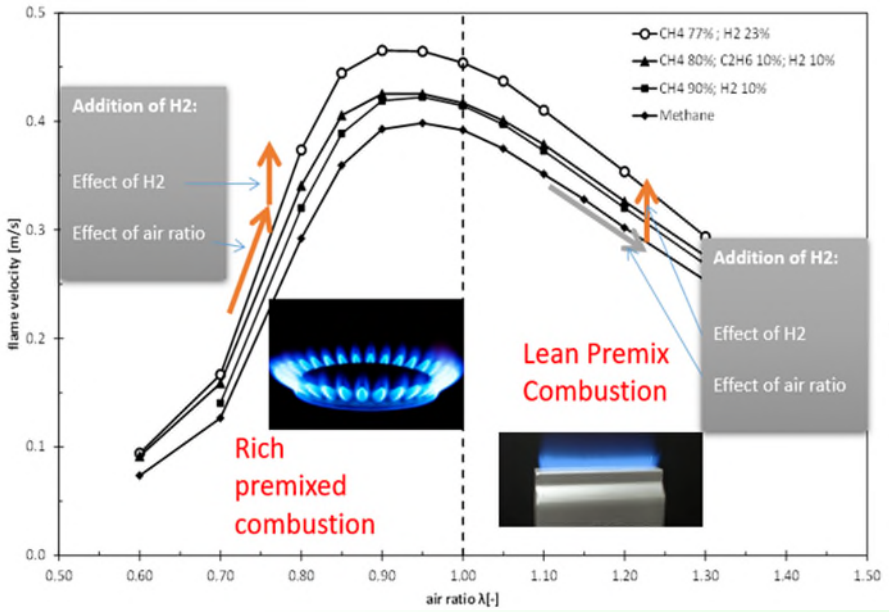
ANNEX 2
OBSERVATION FROM PREVIOUS TESTS

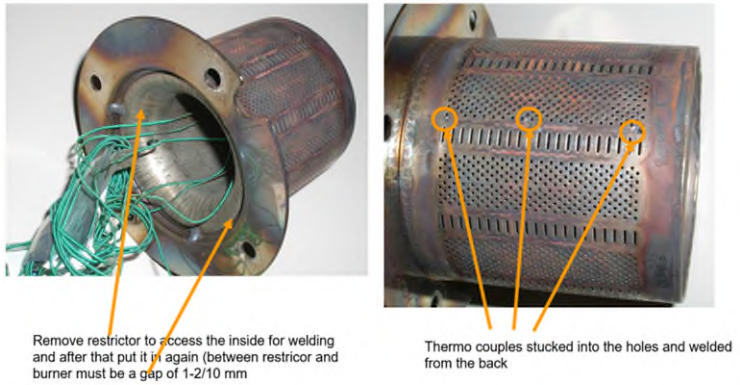
OBSERVATIONS from NATURALHY (cond. premix boiler test) that could help the making of the test protocol

BURNER SURFACE TEMPERATURE



Results In line with theory



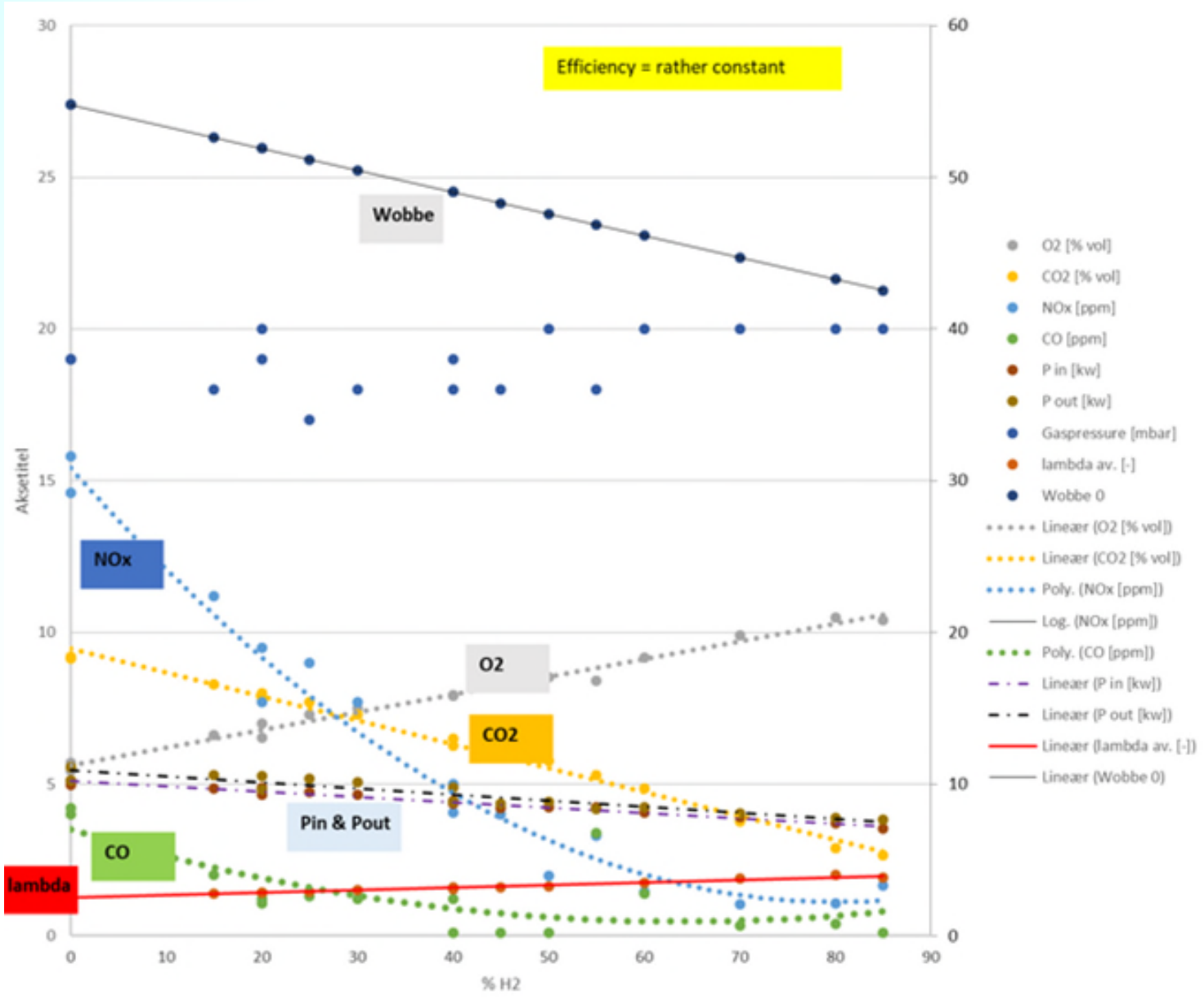


Remove restrictor to access the inside for welding and after that put it in again (between restricor and burner must be a gap of 1-2/10 mm

Thermo couples stucked into the holes and welded from the back

No need to measure (extensively) burner temperature for full premix ?

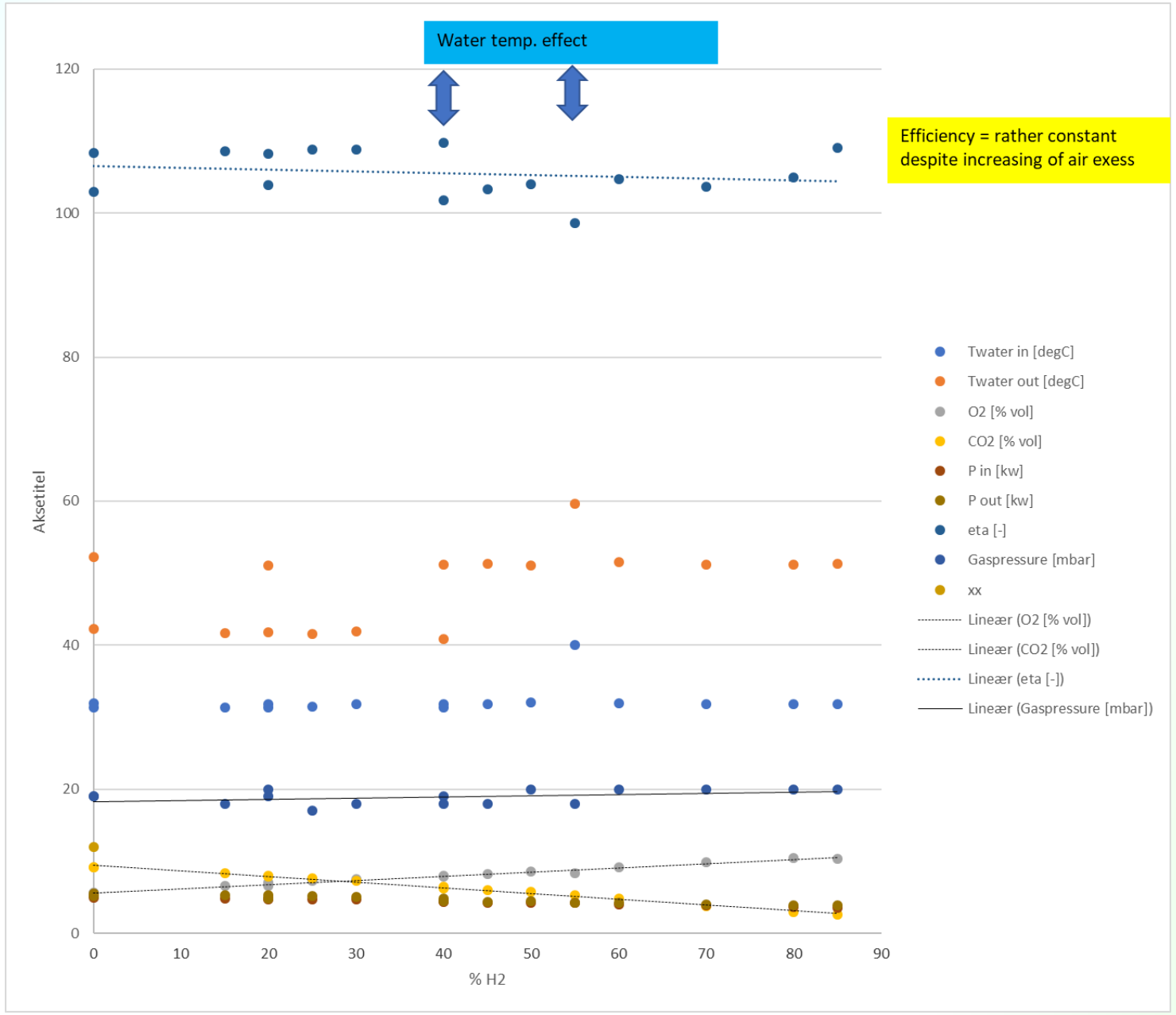
EMISSIONS



CO AND NOX DECREASE WHEN H2 INCREASING

FIGURE = MEASURED DATA, DRY AIR FREE VALUE WILL SHOW DECREASE AS WELL

EFFICIENCY



EFFICIENCY RATHER CONSTANT DESPITE LARGE AIR EXCESS VARIATIONS.

(SAME TREND SEEN ON ATM. BOILER)

OBSERVATIONS FROM NATURALHY (COND. PREMIX BOILER TEST) THAT COULD HELP THE MAKING OF THE TEST PROTOCOL

Main conclusions:

- **Burner temperature measurement** can be a critical point:
  - How to guarantee non intrusive measurements?
  - Added value for full premix appliances? ("U" curve)
  - Costs
  - Conclusion: to be decided carefully case by case.
  - Measurement can be made on few selected appliances

- **NOx and CO are decreasing with H2**.

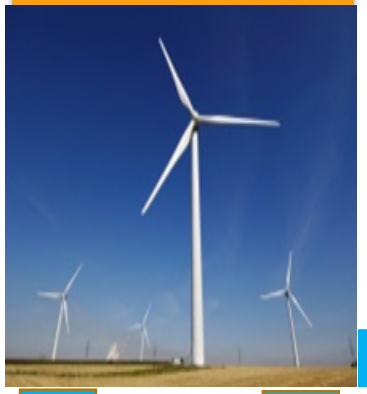
- **Efficiency is not very much impacted** for premix appliances.

- **For the efficiency and emissions** between 0 and 60% H2 a linear model could be acceptable for the real emissions & efficiency (when considering uncertainties of measurement) if only 0% and 60% are measured (interpolation would be acceptable!)

ANNEX3
SOME CONSIDERATIONS ABOUT THE LEVEL OF H2 % THYGA SHALL FOCUS ON

Overall present options with H2 injection in the grid in the EU

HYDROGEN



NATURAL GAS

Methanation ?

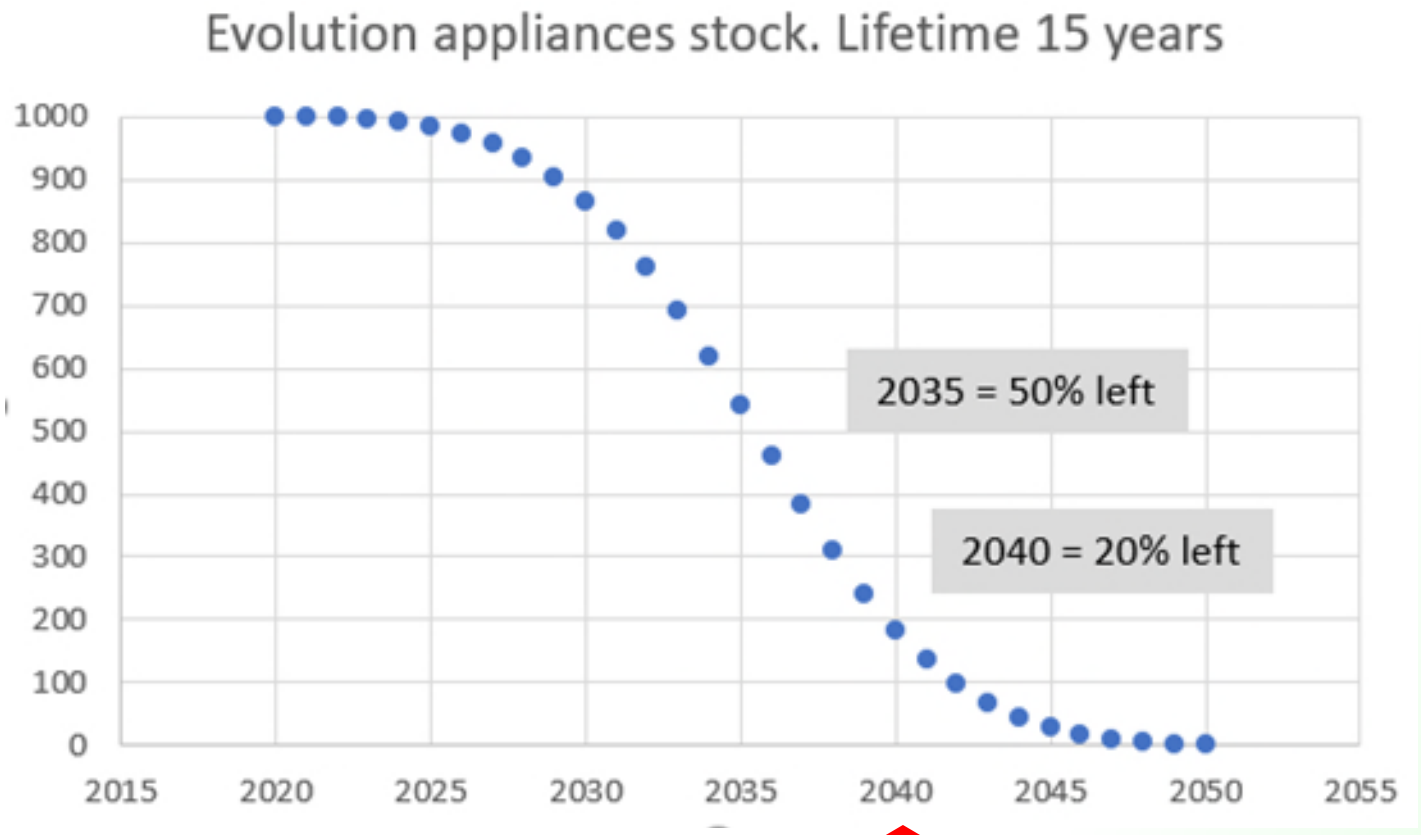
Biomethane

100% H2	High H2 mix (20 to 30% H2%?) (H2% variating)	"Natural gas spec" including NG+ LNG+biomethane + possibly low range of H2 (eg. 10%) (
Dedicated H2 grid	**NG Gas grid**	**NG Gas grid**

> 2030/35 **From 2030/40?** **from 2020**

At the moment mass injecting > 30% doesn't seem to be a realistic option at least not in the next 15-20 years

APPLIANCE STOCK



Injection > 30%?

CONCLUSIONS ABOUT THE LEVEL OF H2 % THYGA SHALL FOCUS ON:

THE MARKET WHEN > 30% WILL BE INJECTED (IF THIS WILL HAPPEN) WILL BE VERY DIFFERENT FROM 2020 MARKET/TECHNOLOGIES.

STILL THERE WILL BE SIGNIFICANT SHARE OF 2020 APPLIANCES REMAINING IN THE STOCK OF INSTALLED APPLIANCES

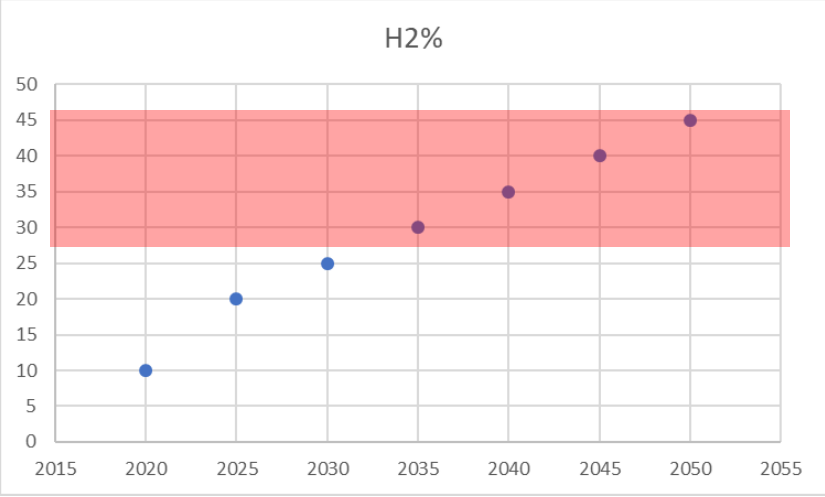
CONCLUSION = WE COVER 0 TO 60% BUT WHEN POSSIBLE WE SHALL PUT MORE EMPHASIS ON 0 -30%

Testing part 2 **PERFORMANCES.** Which H2 concentrations should we choose for the evaluation?

Open question about the exact % of H2 to be used

Contractual scope (Grant Agreement)

- Low = <10% Vol.
- Medium = 10-30% Vol.
- High = 30-60% Vol



Possible evolution of rates of acceptable H2

Due to the number of installed atmospheric appliances (most sensitive to H2), it is more likely that there will be still quite a lot of installed appliances by 2035.

- Since they may encounter issues with > 30% H2, a lot of research efforts would be wasted at if we go higher.
- The WP3's opinion is that looking at **performances of these appliances with > 30% H2 don't seem cost effective.**

The other issue is that increase of H2 will also result in a reduction of the heat input that may in some circumstances **make appliances inappropriate for the purpose they were purchased for** (cooking hot water production etc..)

The region 10-30 % H2 is the more useful for performance tests
The region > 30% has less added-value (many appliances safety will be challenged and /or some appliances will not been able to deliver enough power)

Testing part 2 PERFORMANCES. Measurements for up to 4 points with x% H2

4 measurement point

H2	CH4	EU_low
0 %	x	X
X1%		X
X2%		X
X3%	X	X

The tests don't need to be done extensively for the two gases.
Some points could be done only for one gas?

Answer will be given by the preliminary test

Option proposed (March 2020)

- 0
- X1 = 10 % Vol.
- X2 = 20 % Vol.
- X3 = 30 % Vol (*)

(*) or under the FB limit

+ Iterative Test (on selected few appliances)

- Up to 60 % Vol. (*)

(*) or under the FB limit

Possible simplifications at later stage (in light of the first results) = remove 1 or 2 measurement points and interpolate.

ANNEX 4
CALCULATION DETAILS

Unburned hydrocarbons

Conversion from ppm (dry) to mg/kWh

$$C\_UHC = 0{,}552 \cdot C(CH4)_{meas} \cdot \frac{C(CO2)_N}{C(CO2)_{meas}}$$ mg/kWh (GCV)

C_UHC = emission of unburned hydrocarbons (mg/kWh GCV)

$C(CH4)_{meas}$ = methane concentration, steady-state or average during cycle(s) (ppm dry)

$C(CO2)_{meas}$ = carbon dioxide concentration, steady-state or average during cycle(s) (% dry)

$C(CO2)_N$ = carbon dioxide concentration in dry, air-free combustion gas = 11,7 % for G20

Start/stop emissions in mg/cycle (part load test)

$$M\_UHC = C\_UHC \cdot \frac{Q}{6}$$ (mg/cycle)

M_UHC = emission of unburned hydrocarbons (mg/cycle)

C_UHC = emission of unburned hydrocarbons (mg/kWh GCV)

Q = average load during test (kW GCV)

ANNEX 5
LONG TERM TESTING

WP3 AGREEMENT

Task 3.2.2: Long-term combustion test

Subtask leader: DGC, Partner involved: GWI; Subtask duration: M10-M30

Long term test will be carried out to observe possible appliances alterations (performances or physical alteration) in the long term (few weeks to few month) with given H2/NG mix. Possible alterations will be monitored by measurements in the combustion gas (flue gas). The appliances tested will be dismantled at the beginning and end of the tests. Photos will be taken to document possible alterations. A similar test protocol used for the GASQUAL project will be adapted for the purpose.

The idea of the long term testing is to simulate a real testing in accelerating time by severe tests constrains (cycling of the burner, high temperature, possibly overload, etc.)

The costs of testing have been established with the following hypothesis:

- H2 Injection rate average: 35%
- Average nominal Heat input: 15 kW
- On time % during test period: 50 %
- Testing time allocation for one appliance: 30 weeks (= actual time when boilers is operating including on and off period)

Actual rates for natural gas, CH4, H2 and other gases have been used for the budget calculation.

BUDGET (FROM THE PROPOSAL)

LONG TERM TESTING

Calculation hypothesis		
Injection rate avg	**35**	% vol
Injection rate (energy)	**11,7**	% of Pin
Average nominal Heat input	**15**	kW
On time % during test period	**50**	%
Calculations		
Total energy used	**1260**	kWh
NG used	**1113**	kWh
H2 used	**147**	kWh
Week	**7**	days

	DGC	GWI
Number of tests	1	1
Number of appliances	5	2
Test duration	**30**	**30**

We will test with 30% the 3 or 4 first months and decide if we shall increase to 35% half way

(decision taken at the December 2020 meeting for long term test of boilers discussion)

APPLIANCES FOR THE TESTING (PROPOSAL)

- The appliances for the testing will be as follow:
- DGC: 2 cookers + 3 boilers
- GWI: 2 boilers

DGC test planning

Total 30 weeks

GWI may start at the same time (December 2020 meeting for long term test of boilers discussion)

44 of weeks in the period March 1st Dec. 31st

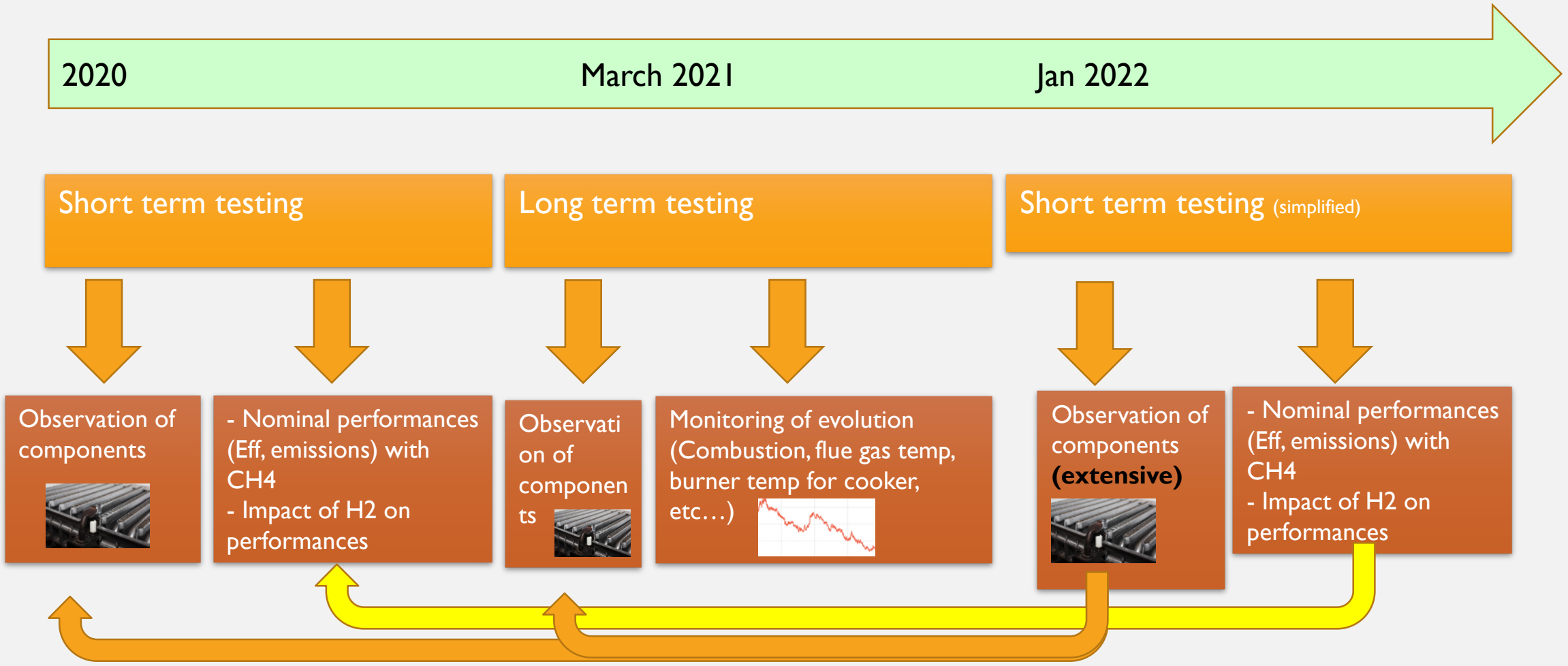
We will stop the test once we have achieved the number of hours planned (see further)

Analyse of results and possible repetition of short term test = First weeks of 2022

OVERALL PROGRAMME

1. Physical observation of the appliances before short term test (photos), etc…
2. Pre-testing nominal performances (short term test)
3. Physical observation of the appliances before long term test (photos), etc…
4. Long term test including monitoring of main parameters
5. Re testing of limited nominal performances (end of the long term test) (*)
6. Physical observation of the appliances after long term test (photos), etc…

(*) When needed: as we will make frequent tests with CH4 (every month), changes in appliance performamces may be observed under way, so the need of retesting will be evaluated in regard of the observations done.


2020
March 2021
Jan 2022
Short term testing
Long term testing
Short term testing (simplified)
Observation of components
- Nominal performances (Eff, emissions) with CH4
- Impact of H2 on performances
Observation of components
Monitoring of evolution (Combustion, flue gas temp, burner temp for cooker, etc…)
Observation of components (extensive)
- Nominal performances (Eff, emissions) with CH4
- Impact of H2 on performances

MAIN PRINCIPLES

- Accelerated time
- As simple as possible (costs)
- Based on GASQUAL

GASQUAL BOILERS MAIN PRINCIPLE

- Accelerated time = high "on time" + harsh test conditions

GASQUAL

The boilers were tested using a 4h test pattern, which is repeated continuously:

- 120 min at Qmin / 20 min off /
- 30 min Qmax / 20 min off /
- 30 min Qmax / 20 min off.

Switching between Qmin and Qmax was done by switching between 2 flows.

Temperature measurements (flue gas, etc..) were made on a continuous basis. Emissions were measured with an O2/CO analyser. **The analyser measured 6 minutes on an appliance followed by 3 minutes on air, and then switched to the next appliance.**

The appliances were tested between 4 and 5 months corresponding to approximately 12-18 months of normal use

GASQUAL BOILERS TESTING MAIN PRINCIPLE

Before testing the boilers were adjusted to the CO2 values specified by the Manufacturers.

After the long-term test the boilers were retested for short term test.

Main results form GASQUAL (for info): Impact of long term of natural gas with high Wobbe

For all boilers the final CO2 values are within the range specified by the manufacturers, and the CO emissions are acceptable (CO range 15 – 191 ppm).

The heat input of several boilers has decreased after long-term testing.

The most significant change is observed for a boiler (D13b), where a 22 % decrease has occurred. There is no explanation for this change from the examination after test or other observations during the test.

GASQUAL COOKERS Main principle

- The burners were successively tested at minimum and maximum heat input
- (approx. 20 h at Qmin, 20 h at Qmax), until a total of 100 h at each load.
- The oven was tested for 200 h at maximum input.

Setting up of appliances

- BOILERS.

Appliances are installed and adjusted for use of natural gas and are not modified specifically for the use of hydrogen.

Test will be carried out at 40/60 (to be confirmed)

(decision taken at the December 2020 meeting for long term test of boilers discussion)

BOILERS

Time shall be respected within 0,5 h

	MORNING test at Qmin (4h)		AFTERNOON at test at Qmax (4 h-breaks =2 hours)				NIGHT test at Qmin (16h)	On time
Time (h) (3)	**8.00 to 12.00**	**0,5**	**12.30 to 13.30**		**14 to 15**	**15 to 16**	**16.00 to 8.00**	
Day 1	Qmin. NG+ 30% H2	Break	Qmax + 30% H2	Break	Qmax + 30% H2	Break	Qmin. NG+ 30% H2	20
Day 2	Qmin. NG+ 30% H2	Break	Qmax + 30% H2	Break	Qmax + 30% H2	Break	Qmin. NG+ 30% H2	20
Day 3	Qmin. NG+ 30% H2	Break	**Check test with CH4 only (1)**	Break	part load test at High s/s frequency (3)	Break	Qmin. NG+ 30% H2	20
Day 4	Qmin. NG+ 30% H2	Break	Qmax + 30% H2	Break	Qmax + 30% H2	Break	Qmin. NG+ 30% H2	20
Day 5	Qmin. NG+ 30% H2	Break	Qmax + 30% H2	Break	Qmax + 30% H2	Break	Possible Break for maintenance	6
Day 6	No run in week-ends or hollidays (christmas etc....) (2)							
Day 7	No run in week-ends or hollidays (christmas etc....) (2)							

(1) Once in a month to check Emission level

(3) 1min off/ 1 min on for 1 hour

(2) No run planed, but can run when possible

runing hours /week in total 86

(programme approved at the December 2020 meeting for long term test of boilers discussion)

		Pin		running hours (one day)		
Appliance Qmin		**3,5**	**kW**	**18**	**90%**	
Appliance Qmax		**18**	**kW**	**2**	**10%**	
runing hours /week in total		**86**	**hours**		**425,7**	kWh/w
during		30	weeks			
TOTAL running hours		**2580**	**Hours**			
Avg power during on time		4,95	kW			
Cons 30 week		12771	kWh			
ON time planned		**2520**	**h**			

The proposal is respecting the contractual "on time" total of 2520 hours.
The gas consumption should be lower due to the higher weight on Qmin (justified by the higher sensitivity to H2 + more real working time) The exact gas consumption will depend Qmin/Qmax

COOKER HOBS

Time (h)	8 – 12	12 – 12,5	12,5 – 16
Day 1	Burner 1 + Burner 2 + oven (all at Qmin) NG+ 30% H2	Break	Burner 1 + Burner 2 + oven (Qmin) 30% H2 – Stop
Day 2	Burner 1 + Burner 2 + oven (all at Qmin) NG+ 30% H2	Break	Burner 1 + Burner 2 + oven (Qmin) 30% H2 – Stop
Day 3	Burner 1 + Burner 2 + oven (all at Qmin) NG+ 30% H2	**Check test with CH4 only (**)**	B1 + B2 + O (Qmin) 30% H2 – Stop
Day 4	Burner 1 + Burner 2 + oven (all at Qmin) NG+ 30% H2	All 4 burners on (*)	B1 + B2 + oven (Qmin) 30% H2 – Stop
Day 5	Burner 1 + Burner 2 + oven (all at Qmin) NG+ 30% H2	Break	B1 + B2 + oven (Qmin) 30% H2 – Stop
Day 6	Break		
Day 7	Break		

(programme approved by the manufacturer of Cookers in WP3)

	35 hours /week
during	30 weeks
TOTAL	**1050 Hours**
TOTAL (2 b + O)	**3150 Hours**
Avg power	5 kW
Cons 30w	5250 kWh
ON time planned	**2520 h**

All tests done with cooking pots with water

(**) TEST CAN BE DONE ANY TIME DURING THE DAY. Once every month. Can be any day in the week

(*) TEST IS NOT DONE ALL WEEKS BUT ONLY once a month. Can be any day in the week

VISUAL INSPECTION (PICTURES WITH THE SAME ANGLE, LIGHT ETC..)

	LONG TERM TEST VISUAL INSPECTIONS BEFORE/AFTER		
	BEFORE LONG TERM TEST	AFTER LONG TERM TEST	COMMENTS
Burner			
Burner gasket (pakking)			

DGC will prepare a short guideline for the execution of the visual documentation

(decision taken at the December 2020 meeting for long term test of boilers discussion)

MANUFACTURERS are invited to send spare parts that may be needed for replacing the components (Gaskets, seals) to LABS

(decision taken at the December 2020 meeting for long term test of boilers discussion)

PARAMETERS TO MEASURE

Continuous measurement of combustion parameters (mandatory)

- Gas quality (dayly)
- Flue gas composition (O2, CO2) (sampling <= 1 minute)
- Flue gas temp.
- Emissions (CO, NOx) (sampling < =1 minute)
- Test conditions (Tamb, Patm, humidity)

Continuous Monitoring of temperature

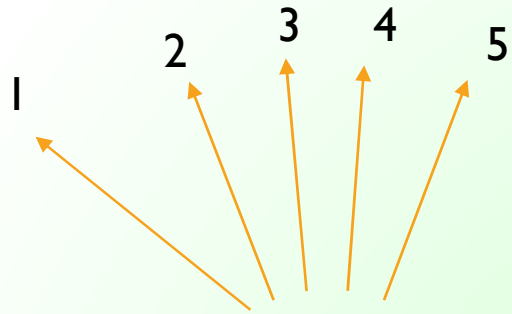
- Back burners (cookers), Oven
- Where possible in combustion rooms (boiler)

MANUFACTURERS may inform LABS of perticula measurement points for the temperature

(decided at December 2020 meeting for long term test of boilers discussion)

Other measurements when possible (not mandatory) :

- Gas flow
- Gas T, P
- Water flow



Measurement 9 minutes followed by 3 minutes on air, and then switching to the next appliance (cycle = 1 hour for 5 appliances)

Sampling time

-Measurement at least each minute (to be discussed)

Reporting of the parameters above

-Daily averages+ Hourly avg (based on the 9 minutes measurement)

MONITORING PROCEDURE. CONTINUOUS MONITORING OF THE TEST

Abnormal evolution of temperature, emission etc.. shall be observed

In such situation, the cause of the change shall be investigated asap (test may be stope for this purpose)

The test will continue unless the appliance is becoming unsafe. In the last case we shall discuss what should be done.

Spotting possible evolution

Emission Test with CH4 (control with nominal gas)

Check test (see table) with CH4 shall be done:

- Once a day (first week)
- Once a week the first month
- Once a month after

To be adapted during test when needed

This is to be done as evolution of NG in the grid is possible and may not necessarily allow to spot small changes during testing with blends NG/H2

REPORTING LONG TERM TEST

Visual inspection report with comments from manufacturers

List of components to be established

- Burner above & under
- Combustion room / heat exchanger
- Ignition
- Safety monitoring device
- Flue gas pipe
- Other

Extension of the short term test

LABS will inform manufacturers of intermediate results in a way t be decided

ANNEX 6
EFFICIENCY OF HOT WATER HEATERS & COMBI BOILERS

Efficiency of Hot water Heaters & Combi boilers for THyGA. Introduction

Appliances producing sanitary hot water should in principle be tested according EN 13203 standard. The standard includes several tapping patterns that are giving scenarios of daily use.

However the procedure with a lot of tapping, will probably generate a number of uncertainties due to the dynamic conditions of testing. At the end, the uncertainties maybe larger than the impact of H2 on the efficiency that we believe is small.

Therefore, for the project sake we believe it is best to measure the efficiency for hot water production under stable condition where the measurements are done under constant water flow.

Proposal 1

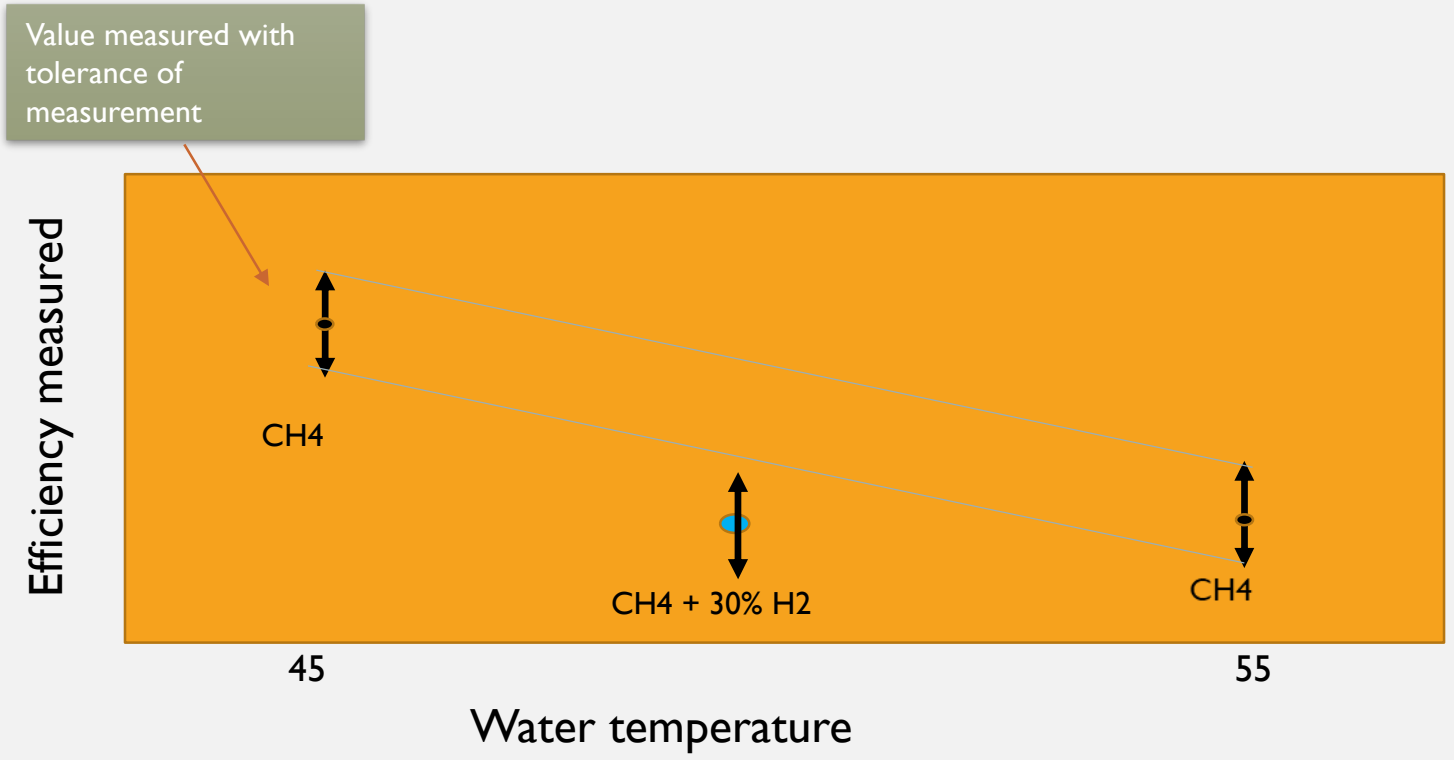
Efficiency of Hot water Heaters & Combi boilers for THyGA. Protocol proposal

The thermostat of the appliance shall be set so to have a stable water temperature. A water flow is chosen in a way that the appliance is running continuously. This mean that the resulting load of the appliance shall be within the modulation range. When possible the flow will be adjusted so the appliance works more or less in the middle range of the modulation.

- Test Nr 1 = Test with CH4 with an output water temperature of 55 +/- 3 K
- Test Nr 2 = Test with CH4 with an output water temperature of 45 +/- 3 K with the same water flow
- Test Nr 3 = Test with CH4 and H2 (30%) with an output water temperature between 45 and 55 with the flow adjusted to get the same heat input compared to test 1 & 2.
- *We fear it can be difficult to reach the same temperature, therefore we suggest to measure two set of temp with CH4 and one of H2 that will be compared on a graph with the two first (see next slide)*

Proposal 1

Efficiency of Hot water Heaters & Combi boilers for THyGA. Evaluation



If the value obtained with the blend is within the 2 lines we will conclude there is no noticeable impact of H2.

Proposal 2

Efficiency of Hot water Heaters & Combi boilers for THyGA. Protocol proposal

The thermostat of the appliance shall be set so to have a stable water temperature. A water flow is chosen in a way that the appliance is running continuously. This mean that the resulting load of the appliance shall be within the modulation range. When possible the flow will be adjusted so the appliance works more or less in the middle range of the modulation.

- Test Nr 1 = Test with CH4 with an output water temperature of 55 +/- 3 K
- Test Nr 2 = Test with CH4 and H2 (30%) without changing any of the parameter (only the gas is changed)

ANNEX 7
WP 4-5

Flashback on cooker, relation between time & H2 %

Initial set up

- Chose the burner where we know we had FB
- Test condition: The FB observed was during an efficiency test with 60% H2 and Qmin or Qmax ? (check with IMO) on the small burner of the D1 appliance. The FB appears after 50 min or so. In order to make the test easier we suggest to use a metal plate used for the long term test. Alternatively use the pot with water. In any case the flue gas sampling shall be done (To be discussed how to do that in the most convenient way)

A - Preliminary test. Validation of the method how to identify a FB situation. We need to have a measurement that indicated when FB appears. There are two options that can be used and compared

- 1) using temperature measurements behind the burner surface as a detection of the FB
- 2) using flue gas measurements (Tf, CO, NOx, CO2; O2)
- **Test:** with 60% H2. Follow the evolution of the parameters measured and flame aspect (film) → evaluate the method based on the data measure, what is best & more reproducible.
- Discussion in view of the results what is most suitable

B- Testing (see next slide)

Flashback on cooker, relation between time & H2 %

B- Testing

Proposal:

- Test with 60% H2 (we suppose we can use the one done to develop the method)
- Test with 50% H2
- Test with 40% H2
- Test with 70% H2?

Cooker hobs test with “H2 injectors”

Testing

- A) Test of **NG injector** with 0, 10, 20, 40, 60 % H2 (increase every 10 minutes)
- - measurement of CO, NOx, Tf at Qmax
- - measurement of CO, NOx, Tf at Qmin
- - Check flashback with Qmax/Qmin fast changes
- Test 1,5 h at 60% with metal plate. Stop when FB (at Qmin)

- B) Test of “**H2 injector”** with 0, 10, 20, 40, 60 % H2 (increase every 10 minutes)
- - measurement of CO, NOx, Tf at Qmax
- - measurement of CO, NOx, Tf at Qmin
- - Check flashback with Qmax/Qmin fast changes
- Test 1,5 h at 60% with metal plate. Stop when FB (at Qmin)