THyGA Final Workshop

March 24th 2023

Testing **Hy**drogen admixture for **G**as **A**pplications

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 874983. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Clean Hydrogen Partnership

Important notice

Please note that this presentation is slightly different from the document disclosed during the THyGA final workshop of the 24th of March 2023

Indeed, late results came up, especially regarding delayed ignition, which incited us to slightly modify the project’s conclusions.

Slides 111-113 are modified and slides 163-164 are added

We greatly encourage interested stakeholders to read the project reports, especially D3.8 to have a complete understanding of our analysis.

Agenda

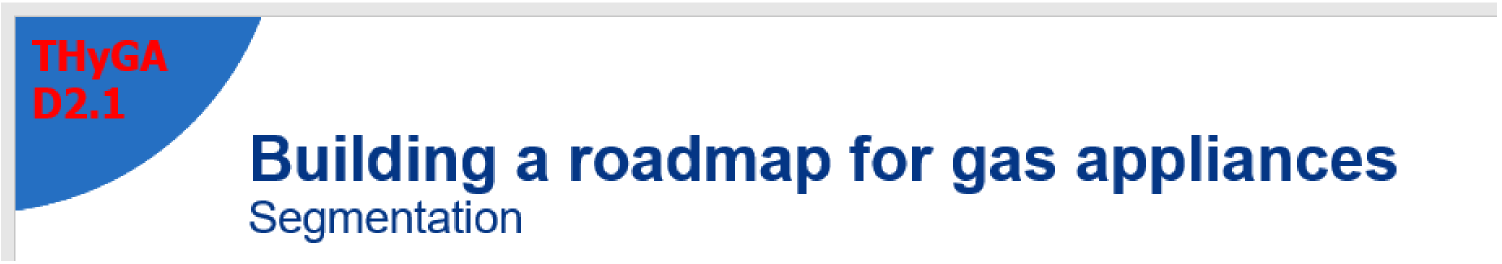
9h00 / 9h15	Welcome, Introduction and rules to the workshop	Alexandra Kostereva
9h15 / 9h30	THyGA - Objectives and organization of the project	Patrick Milin
9h30 / 10h00, inc. question	WP4: certification for new appliances	Kris De Wit
10h00 / 11h20, inc. question	WP3: H2NG blends impact on appliances	Jean Schweitzer ; Henri Cuny
11h20 / 11h40	Coffee break	
11h40 / 12h30, inc. question	WP5: appliances on the field	Lisa Blanchard ; Stéphane Carpentier
12h30 / 13h00	Conclusions and perspectives	Alexandra Kostereva ; Patrick Milin

Welcome, Introduction and rules to the workshop

Some information

The workshop is recorded and will be available on the THyGA website by the end of March.

You will find the reference to the related public deliverable in the corner of slides:



Questions: please add your questions on the online chat. Speakers will take questions as time permits, and the team will respond to all questions in writing after the workshop.

Online survey: we will be using a sli.do to get some opinions from the audience

Join at

slido.com

#2963 366

Clean Hydrogen Partnership

Objectives and organization of the THyGA project

Objectives and organization of the THyGA project

Context: Hydrogen in the gas grid to decarbonise the European energy system

Hydrogen, along with green electricity from wind and solar power, is currently being discussed as a pathway to decarbonise the European energy systems. In this way, the CO_2 footprint of gas utilisation would be reduced, contributing to an overall reduction of greenhouse gas emissions.

Hydrogen injection in the gas grid

New challenge for end-use equipment…

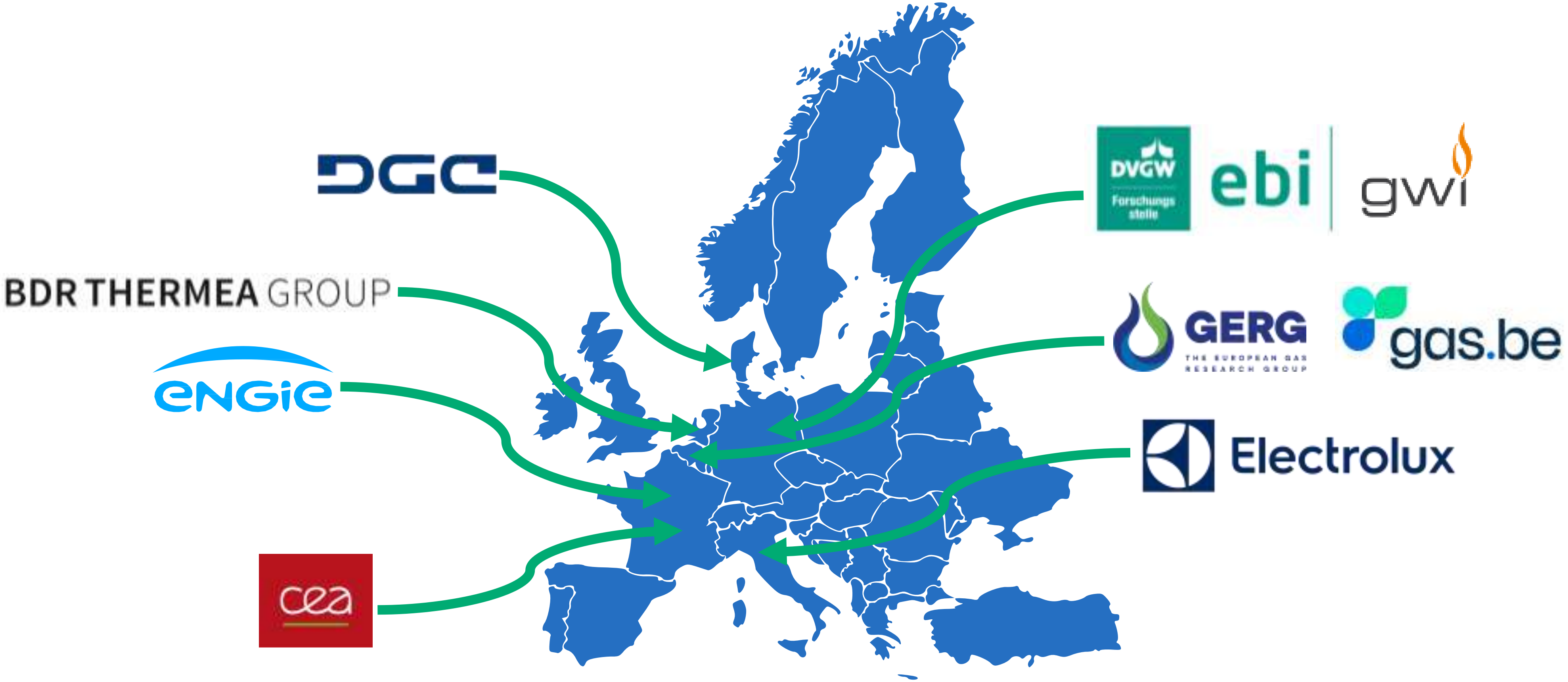
…in particular for higher % of H_2 in blends

>200 million residential and commercial gas appliances in Europe!

Objectives and organization of the THyGA project

THyGA

Project consortium: 9 partners in response to the Horizon 2020 call FCH-04-3-2019



Clean Hydrogen Partnership

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Objectives and organization of the THyGA project

Expected results

CLOSE KNOWLEDGE GAPS

related to technical impacts on residential and commercial gas appliances.

SUPPORT STANDARDIZATION ACTIVITIES

to answer the needs for new appliance operation, test gases, etc.

CLARIFY THE ACCEPTABLE HYDROGEN PERCENTAGE

that would not compromise safety and performance.

Objectives and organization of the THyGA project

Work Packages

WP3
Experimental work
What happens on the field with H2 injection?

WP4
Standardisation
How can we certify an appliance according to H2 rate in NG?

WP5
Recommendation for mitigation measures
How can we increase the acceptable H2 rate?

WP2
Status of gas utilisation technologies
Status of knowledge on H2NG blends

WP6
Communication dissemination exploitation

WP1
Project management

Advisory Panel group
Challenge of the processed results and support through wide dissemination

Appliances, burners, controls, sensors manufacturers

Associations, DSOs, research centers, standardization committees

Objectives and organization of the THyGA project

An extensive Advisory Panel Group and supporting manufacturers

The role of the Advisory Panel Group members is to advise the project to best achieve its goals of and fulfill expectations around THyGA, it implies a close follow-up of the project and its published results.

Associations, manufacturers, research centers, notified body, DSO (Europe and International)

AFECOR
APPLIA
CEFACD
CogenEurope
EFCEM
EHI
ELVHYS
Eurogas
Marcogaz

Assotermica (IT)
BDH (Germany)
HHIC (UK)
ICOM (UK)
SYNEG (FR)
UNICLIMA (FR)
APPLUS (SP)
Cadent (UK)
Enagas (SP)
GRDF (FR)

AGA (USA)
CGA (Canada)
JPA (Japan)

ARPA-E (USA)
GTI (USA)
Tokyo gas (Japan)

AGA Rangemaster
AO Smith
AristonThermo
ATAG
Bosch
Broetje

BSH
Carlieuklima
Carrier
Ebmp-papst
EC Power
Electrolux professional
Gogas
Groupe Atlantic
GWM

Immergas
Kalfire
Lacanche
MEMS
MKN
MTT
Nortek
Qtec
Percy Doughty

Rational
Remeha
Schwank
Senertec
SolidPower
Systema
Vaillant

Viessmann
Weishaupt
Wolf

But also Standardization Committees

CEN TC 49
CEN TC 58
CEN TC 62
CEN TC 106
CEN TC109

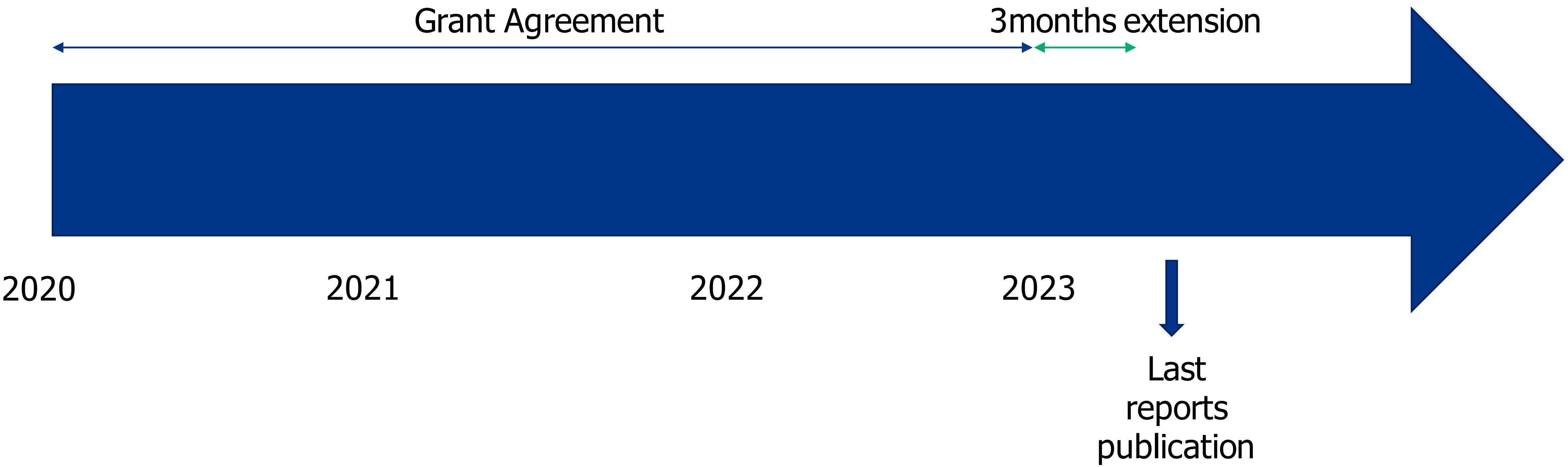
CEN TC 131
CEN TC 180
CEN TC 238 – Liaison
Sector Forum Gas – Utilisation - Liaison

And strong links with other European projects

GERG
Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users.
SUPER P2G
HIGGS Hydrogen in Gas Grids
HyDelta
HyDeploy

Objectives and organization of the THyGA project

History of the project



Objectives and organization of the THyGA project

The targets of the projects…

The consortium of the THyGA project has been built to answer a call from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) published in 2019.

- European and National strategies were not ready to provide insight on acceptable percentage of blended hydrogen
- The target set by the European Commission were to assess **<u>up to 60%</u>**<u>vol H2 </u>in NG

> Low, medium and high hydrogen concentrations in natural gas should be investigated:
>
> Low = <10% Vol.
>
> Medium = 10-30% Vol.
>
> High = 30-60% Vol.

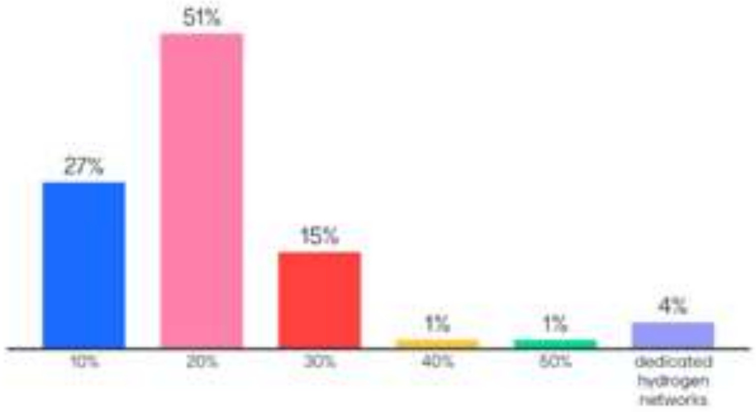
- In 2020, when the project started, the FCH 2 JU already asked for a focus on « **<u>below 40% </u>**»

Objectives and organization of the THyGA project

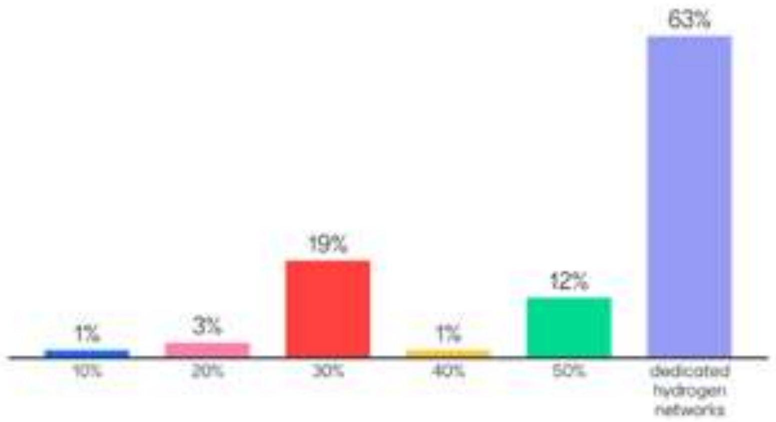
… and the Stakeholders' opinion

During the first public event, in 2020, a survey was sent to the attendees: 93% of the answers predicted blends **lower or equal to 30%H2**

Which level of hydrogen admixture do you consider realistic for 2030 in the distribution grids?



Which level of hydrogen admixture do you consider realistic for 2050 in the distribution grids?

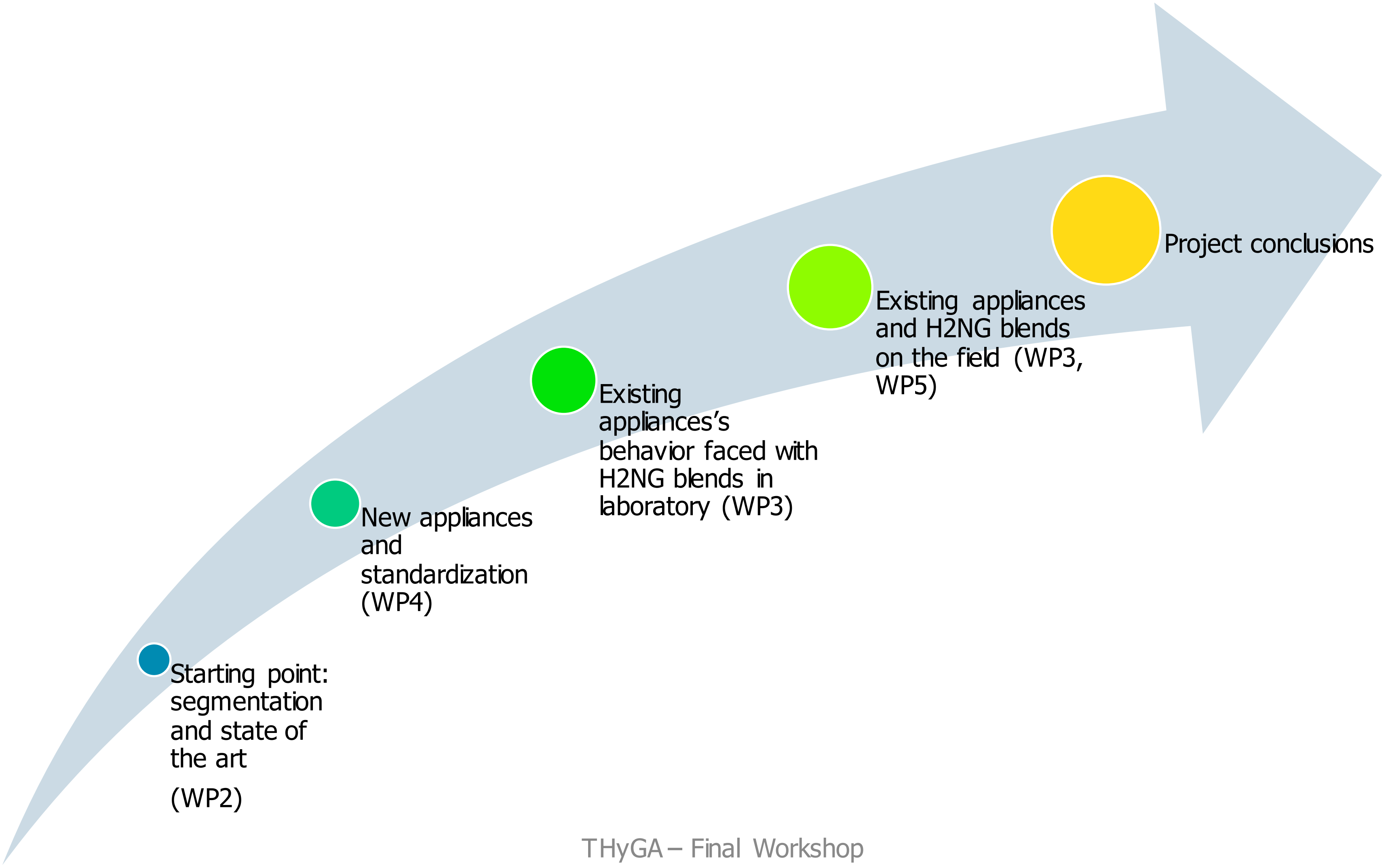


And today, in 2023, which are your perspectives ?

Online survey

Objectives and organization of the THyGA project

Plan of today's workshop



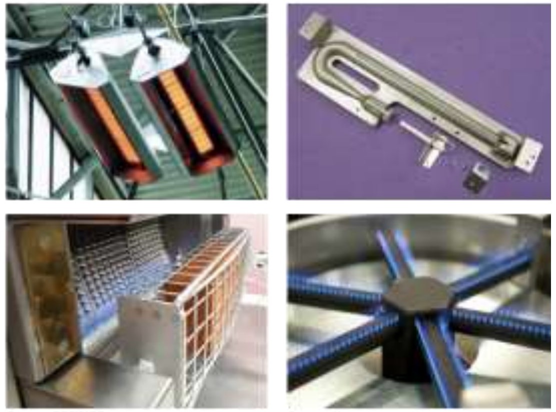
Starting point: segmentation and state-of-the-art

Segmentation (1/2)

- A wide variety of appliances on the field
- They have each their own specificities (combustion, controls, design, usage…)

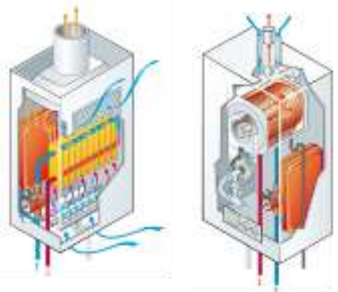
Source: GoGaS

Source: electrolux

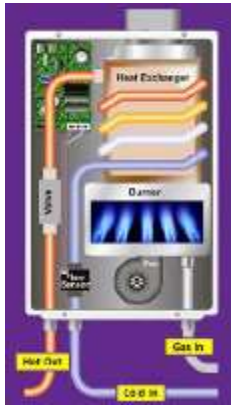


Source: SOFINOR

Source: Krampouz



Source: GRDF/CEGIBAT



Source: Brulers AEM

01-06-2023

Starting point: segmentation and state-of-the-art

Segmentation (2/2)

- We defined ~60 appliances type/technologies segments (Boilers, water heaters, cookers, catering, space heaters, CHP, GHP, others)

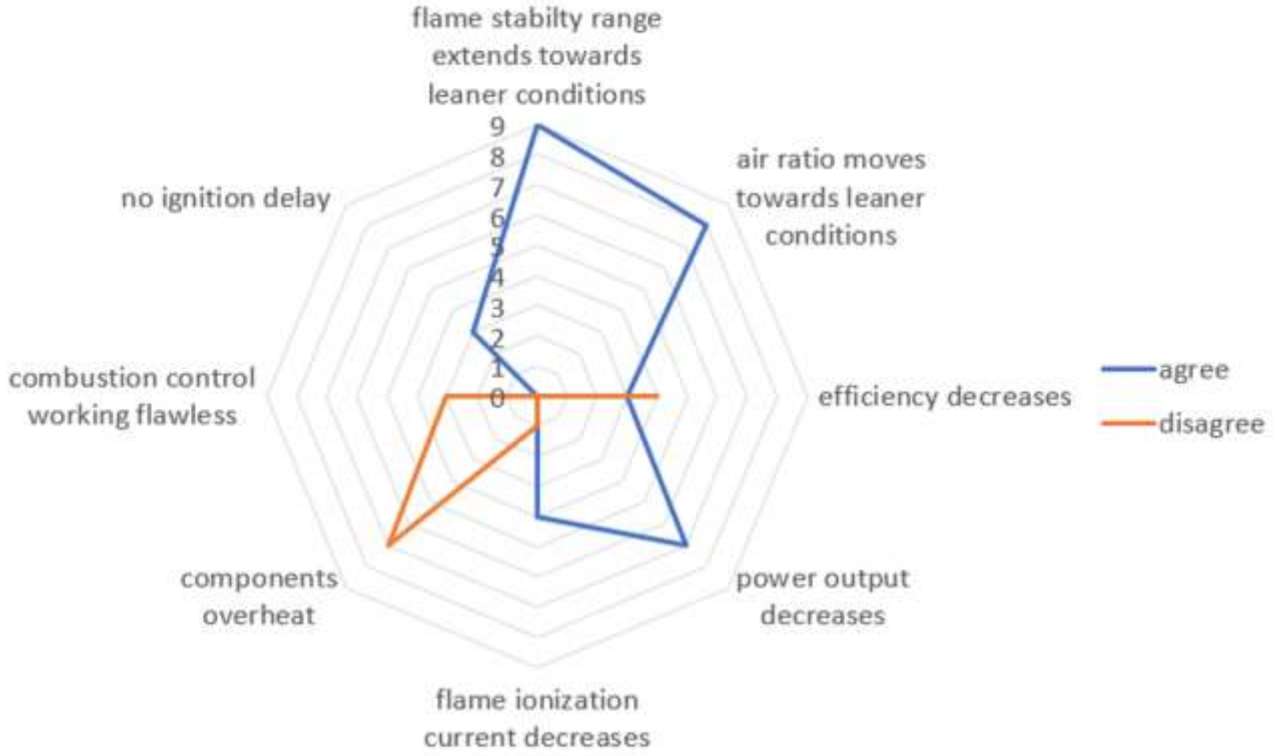
THyGA Segment	Type of appliance	Category	Burner type	Standard	Total Appliance Population
101	BOILERS	Open flued (former EN 297)	Partial premix/conv (atmos. & fanned)	EN 15502	13 588
102			Low NOx technology burners		2 012
103			Full premix		152
104		Room-sealed (former EN 483)	Partial premix/conv (atmos. & fanned)		25 333
105			Low NOx technology burners		1 972
106			Full premix		1 781
107		Condensing boiler (former EN 677)	Partial premix fanned		2 920
108			Full premix (including CCB)		56 492
109		Forced-draught / Jet burner boiler (former EN 303-3)	Jet burner		1 129
201	WATER HEATERS	Instantaneous open flued	Partial premix/atmos	EN 26	14 945
202		Instantaneous room-sealed	Partial premix/fanned		
203		Storage open flued	Partial premix/atmos	EN 89	3 121
204		Storage room-sealed	Partial premix/fanned		
501	Space Heaters	Independent gas-fired convection heaters type B	heating & decoration	EN 613	4 678
502		Independent gas-fired convection heaters type C	heating & decoration, balanced	EN 613	1 839
503		Decorative fuel-effect gas appliance/burner	heating & decoration	EN 13278 + EN 509	2 529
504		Independent gas-fired flueless space heaters	heating & decoration	EN 14829	98
601	CHP	~~Stirling Engines~~	heating & electricity production	EN 50465	15
602		Internal Combustion Engine			41
603		Micro Gas Turbine			1
604		PEM FC			5
605		SO FC			3
701	HP	Engine HP	Heating	EN 16905	60
702		Adsorption		EN 12309	
703		Absorption			

THyGA Segment	Type of appliance	Category	Burner type	Standard	Total Appliance Population
801	OTHER	Commercial Dryers		EN 12752-1 and -2	unknown
802		Infrared Radiant Heaters (former EN 416-1)	non-domestic, tube radiant heaters	EN 416	1 000
803		Infrared Radiant Heaters (former EN 419-1)	non-domestic, luminous radiant heaters	EN 419	
804		Infrared Radiant Heaters (former EN 777-1)	non-domestic, tube radiant heaters	~~EN 416~~	
804bis		Radiant strip	with fan driven burners and recirculation fans	EN 17175	
805		Air heaters (former EN 1020)	non-domestic, forced convection, fan, <300kW	EN 17082	1 000
806		Air heaters (former EN 525)	non-domestic, forced convection, <300kW	EN 17082	
807		Air Heaters <70kW (former EN778)	Ducted warm air; forced convection air heaters	EN 17082	
808		domestic washing machines		EN 1518	2
809		domestic dryers		EN 1518	2
301	COOKERS	Surface burner (cooktops) with atmospheric burner or "Venturi" burner (vertical venturi burner)	Single ring	EN 30-x	32 574
302			Single crown		
303			Multi ring (mainly double or triple ring)		
304		Surface burner (cooktops) with partially premix burner (long horizontal venturi)	Single ring		1 352
305			Single crown		
306			Multi ring (mainly double or triple ring)		
307		Cavity burner "tubular" (ovens, freestanding ranges)	Atmospheric burner		3 853
308			"Venturi" burner		
309			Partially premixed		27 712
310		Cavity burner "metal sheet" (ovens, freestanding ranges)	Atmospheric burner		13 056
311			"Venturi" burner		
312			Partially premixed		14 658
401	CATERING	Open burners and wok burners	Circular burner with vertical slots	EN 203-2-1	unknown
402			Circular burner with holes		
403		Mixed ovens	Draught burners	EN 203-2-2	
404		Ovens	Tubular or circular burners		
405		Boiling pans / pasta cookers	Microperforated burner	EN 203-2-3 EN 203-2-11	
406		Fryers	Premix burner	EN 203-2-4	
407		Salamanders / Rotisseries	Ceramic or blue flame burners	EN 203-2-7	
408		Brat pans	multi-ramp tubular slot burners	EN 203-2-8	
409		Covered burners (griddles, solid tops, pancake cookers)	Tubular burner or multi-ramp tubular burner	EN 203-2-9	
410		Barbecues	Chargrill with burner tubes w/ holes on top	EN 203-2-10	

Starting point: segmentation and state-of-the-art

Expected impact of hydrogen admixture on combustion processes

- Many phenomena were discussed in literature, but a lot of discrepancies between researcher's opinions or discoveries → it confirms the need for an extensive and documented test campaign and sets tangible potential impacts to clarify → this is THyGA's strength

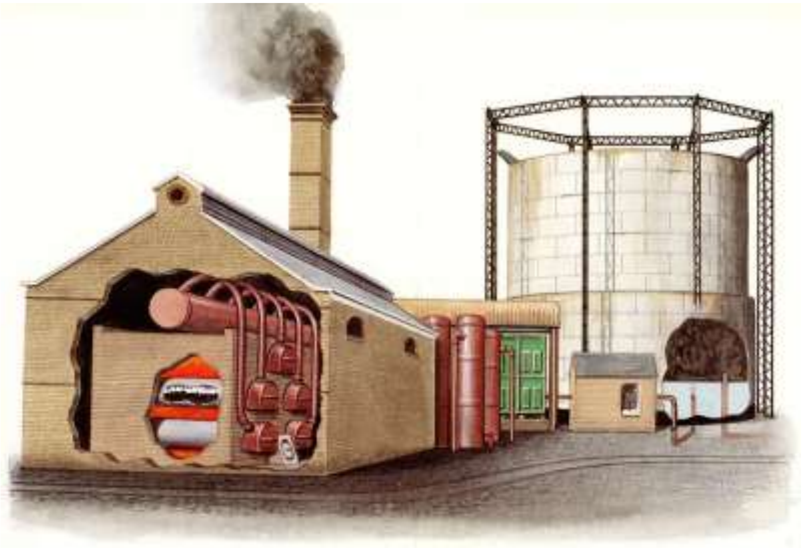


THyGA

New appliances – certification & standardization (WP4)

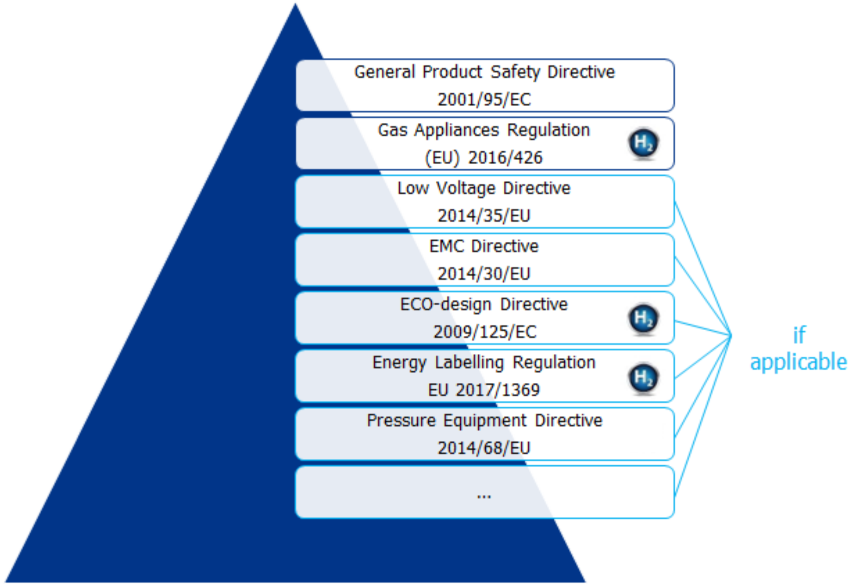
Earlier use of hydrogen

- Relevant H_2 concentrations have already been supplied to gas appliances in the past
- Town gas = 1st family of gases of EN 437
- Town gas contains about 50 % of H2
- Not used anymore in EU
- Lower supply pressure!
- Worked well, but requirements became a lot stricter, and technologies changed



CERTIFICATION
– regulatory framework –

1. Product certification
   - gas appliances:



GAR
gas safety risks & energy efficiency

ECO-design directive & Energy Labelling Regulation
energy efficiency & emissions

Onsite adjustment of combustion settings!

2. Regulation applicable to installed gas appliances
   - national/regional regulation imposing efficiency and/or emission limits to be measured onsite

CERTIFICATION
– Gas Appliances Regulation (GAR) –

- H_2NG is in the scope of Gas Appliances Regulation (EU) 2016/426
- The **composition and specifications of the types of gas** and the supply pressures **at the place where an appliance is put into service is very important for its safe and correct functioning**, therefore that aspect **should be taken into consideration at the design phase of the appliance** in order **to ensure its compatibility with the gas type(s) and supply pressure(s) it is intended for**
- Appliances shall only be made available on the market and put into service if, when **normally used**, they comply with the GAR ⇒ **used with a normal variation in the gas quality** and a normal fluctuation in the supply pressure **as set out by Member States (MS) in their communication** (cf. GAR annex II)
- H_2NG supply may compromise an existing appliance's conformity to one or more essential requirements of GAR
- **existing appliances** did not have to be designed for H_2NG supply ⇒ **H_2NG supply** can**not** be considered as '**normal use**' ⇒ **no product liability** by manufacturer
- **appropriate H_2 concentration ASAP to be adopted in quality specifications for distributed gases** (cf. annex II of GAR) for which new appliances need to be designed is recommended **for preparing** the **market ASAP** for H_2NG supply
- NOTE: light back gas G222 (77% CH_4 + 23% H_2), used for decades in the current certification framework, does not demonstrate compliance with all ER as it is only a limit gas used for assessing a specific risk (i.e. light back)

Country	Vol% H2
DE	≤ 10
FR	< 6
ES [1]	≤ 5
AT	≤ 4
LT	≤ 2
others	no information, not regulated, not measured

[1]: for non-conventional gases

H_2 concentrations communicated by MS in GAR annex II framework.

STANDARDIZATION

– current framework and H2(NG) impact –

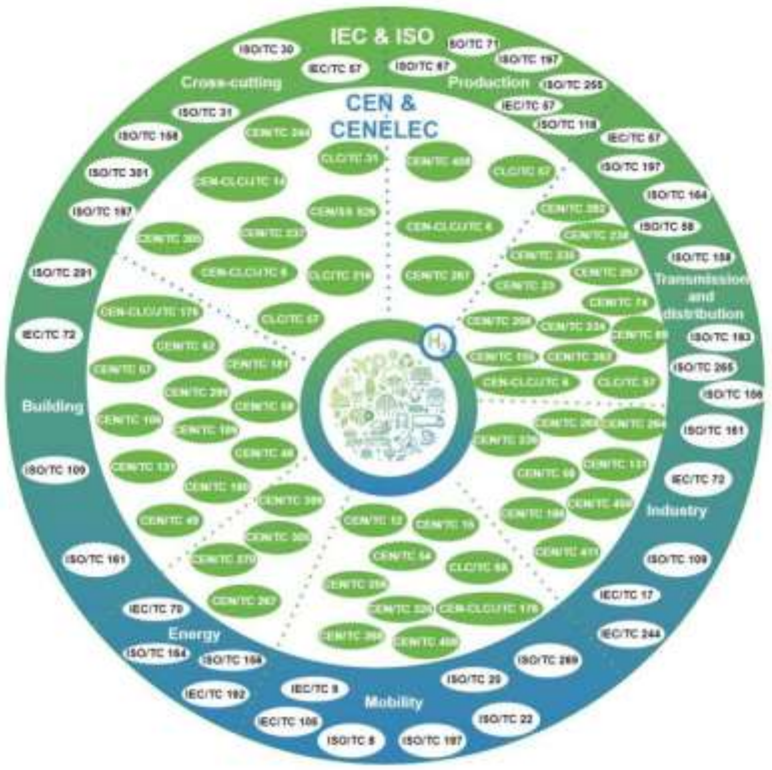


Figure 5 – European and international standardisation landscape for hydrogen topics

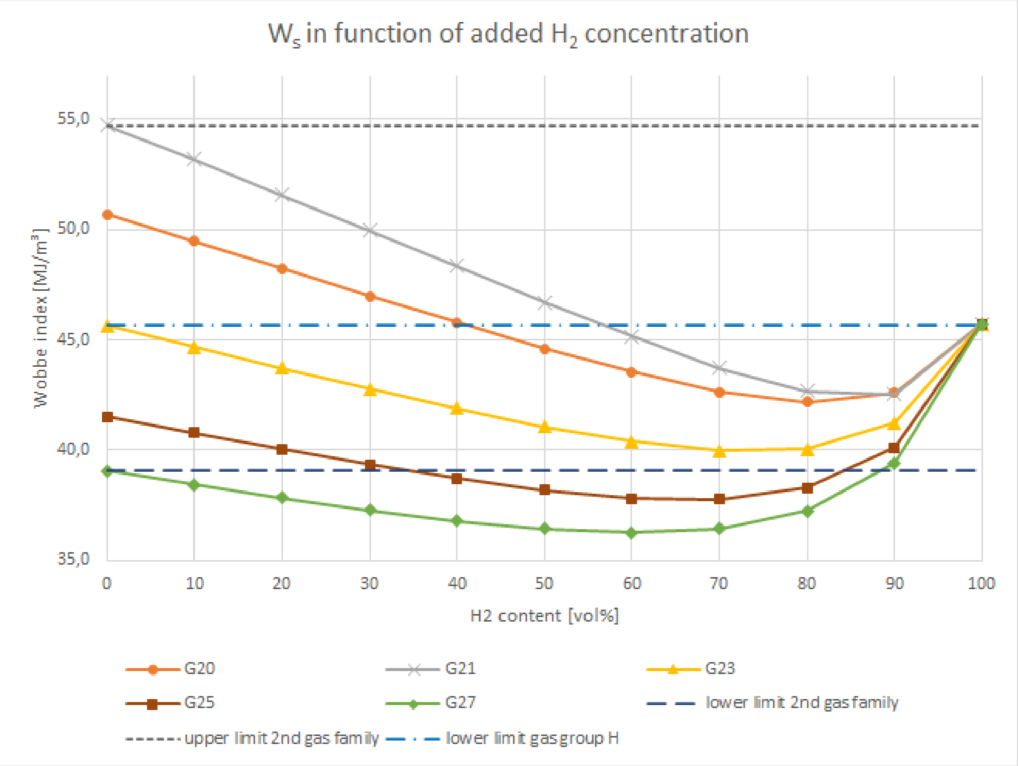
- Test gases, test pressures & appliance categories
  - TC 238 → EN 437

- Gas appliance standards
  - TC 49 – gas cooking appliances
  - TC 62 – independent gas-fired space heaters
  - TC 106 – large kitchen appliances
  - TC 109 – central heating boilers
  - TC 180 – decentralized gas heating
  - etc.

- Fitting standards
  - TC 58 – safety and control devices

STANDARDIZATION

– EN 437 definitions vs. H2NG –



- <u>Gas family</u>
  - group of gaseous fuels with **similar burning behaviour** linked together by a range of Wobbe indices
- <u>Gas group</u>
  - specified range of Wobbe index within that of the family concerned
    - this range is determined on the general principle that **appliances** using this gas group **operate safely when burning all gases within this range without adjustment**
    - adjustment of the **appliance may be permitted in accordance with the special national or local conditions** that apply in some countries
  - **H-group:** 46,44 MJ/m³ (= **lower limit** of the **EASEE-gas CBP** on H-gas) **only allows for injecting 7 % of H_2**
- <u>Appliance category</u>
  - means of identifying the **gas families and/or gas groups** for which a **gas appliance** is **designed to operate safely** and to the **desired performance level**
  - a **fluctuating H_2 concentration** may compromise the above definition as
    - it **widens the potential WI range** of the gases supplied to the appliance
    - relevant **H_2 presence increases existing risks** (cf. light-back, delayed ignition, …)

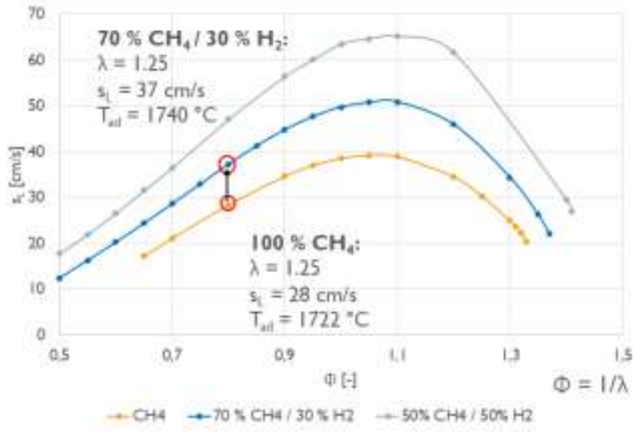
STANDARDIZATION

– EN 437 test gases: limit gases –

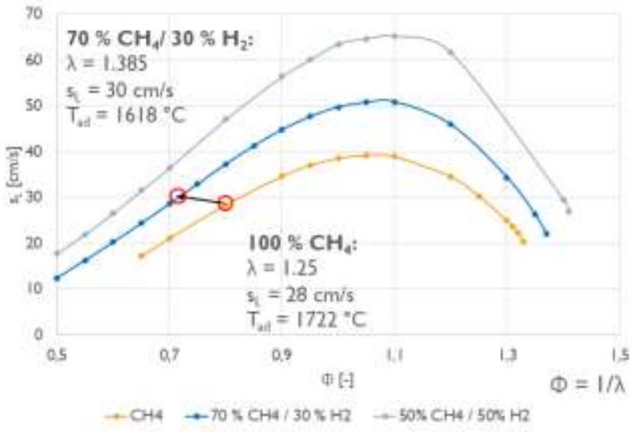
Limit gas purpose	Natural gas (2nd family – group H)	H_2NG (with 20% H_2)	Comment
incomplete combustion and sooting	G21 (87% CH_4 + 13% C_3H_8)	G21	as H_2 concentration may vary between 0 and 20%)
flame lift (flame instability)	G23 (92,5% CH_4 + 7,5% N_2)	G23 or Gxx	H_2 lowers WI, but flame speed increase compensates⇒ to be calculated
light-back (flashback)	G222 (77% CH_4 + 23% H_2)	G22 (65% CH_4 + 35% H_2)	only for partial premixed burners + fully premixed burners equipped with combustion control
		Gyy (G21 and/or G24 proposed)	for fully premixed burners
overheating	G24 (68% CH_4 + 12% C_3H_8 + 20% H_2)	G24 **?**	overload + increased flame speed

Same flame speed increase to be calculated as between G20 and G222?

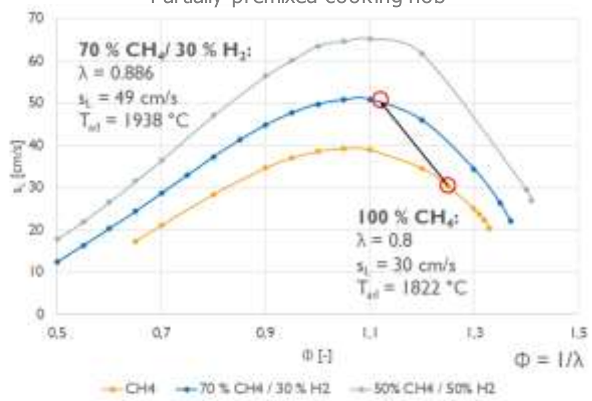
Premixed burner with comb. control



Premixed burner without comb. control



Partially premixed cooking hob



STANDARDIZATION

– EN 437 test gases: reference gases –

- Test gases: **reference gas**
  - test gas with which **appliances operate under nominal conditions when they are supplied at the corresponding normal pressure**
  - current reference gas (for groups H and E):
    - G20 100% CH4 → used for assessing most of risks apart from extreme variations in characteristics of gases the appliance has been designed for
  - H_2 presence may impact risks assessed with G20 ⇒ need for a 2nd reference gas
  - 2nd ref. gas: CH_4 with max. H_2 concentration

But what about nominal settings? Specific for each ref. gas or 1 setting for both?

THyGA
D4.1
D4.3

STANDARDIZATION
– risks related to H2NG supply –

- Starting from the **properties** differences between $\mathbf{H_2}$ and $\mathbf{CH_4}$

- Risks related to
  - **safety**
  - **performance**
  - **fitness for purpose**

of appliances not specifically designed for H_2NG supply with H_2 concentration varying between 0 and 20 %.

- linked to table of **GAR essential requirements** and the **findings of WP3** testing **for 20% $\mathbf{H_2NG}$**

- NOTE: **some** of the **risks** may be (partially) **compensated by other $\mathbf{H_2}$ properties**

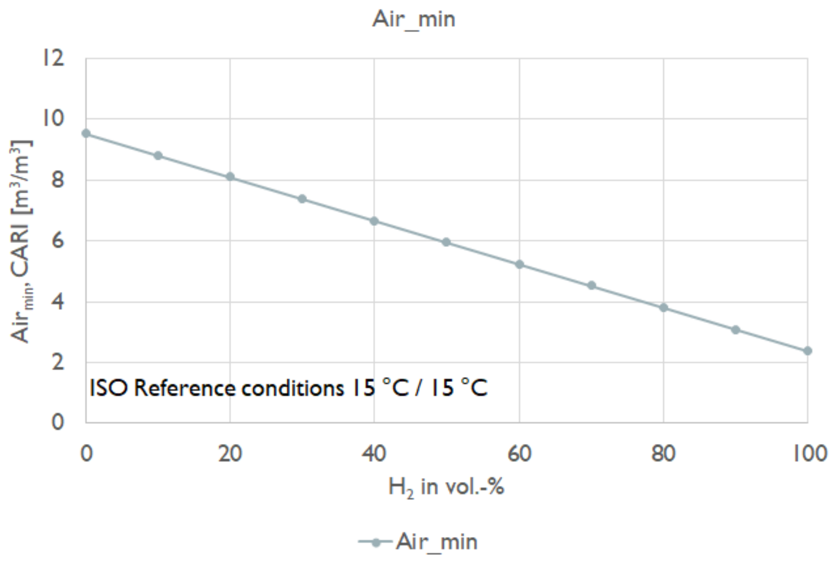
Hydrogen vs. methane

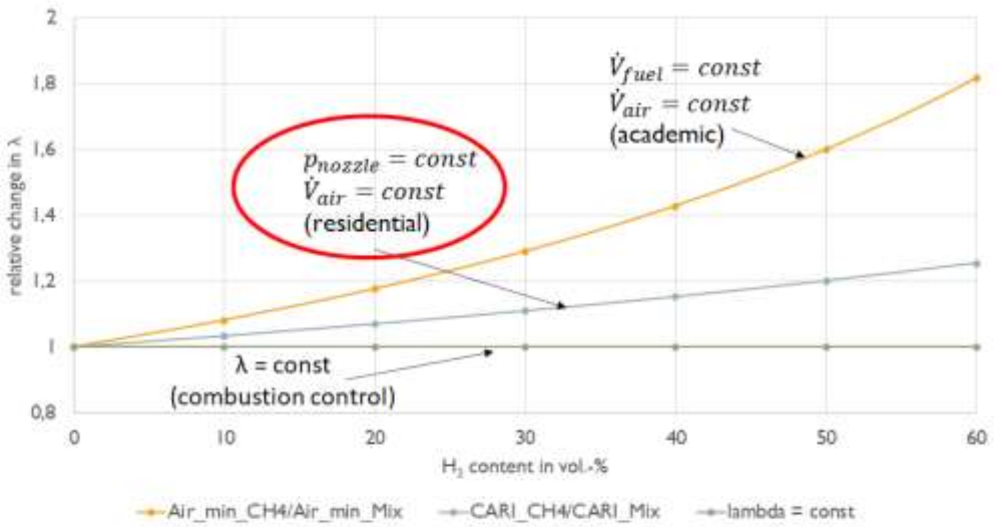
Property	Unit	CH_4	H_2
Atomic radius	Å	H 0,25 C 0,70	H 0,25
Bond length	Å	1,09 (C-H bond)	0,74
Gross Calorific Value	MJ/m³	37,78	12,1
Net Calorific Value	MJ/m³	34,02	10,2
Relative density	-	0,56	0,07
Wobbe index (using GCV)	MJ/m³	50,72	45,88
Laminar flame speed at $\lambda = 1$	cm/s	38,6	209,8
Adiabatic flame temperature $\lambda = 1$	°C	1.946	2.101
Flammability range in air	vol%	5 - 15	4 - 75
Min. air quantity for complete comb.	m³/m³	9,52	2,38
Min. ignition energy	mJ	0,28	0,02
Auto-ignition temperature	°C	595	560
Dewpoint temperature at $\lambda = 1$	°C	59	72
Explosion pressure (stoichiometric mixture)	bar	8	
Methane number	-	100	0
100 year GWP	x CO_2	28	11
Other	-	-	pale blue flame

15/15°C and 1013,25 mbar

Significantly different properties of H2 introduces **risks** for **appliances not designed for** supply with gases containing **relevant H2 concentrations**!

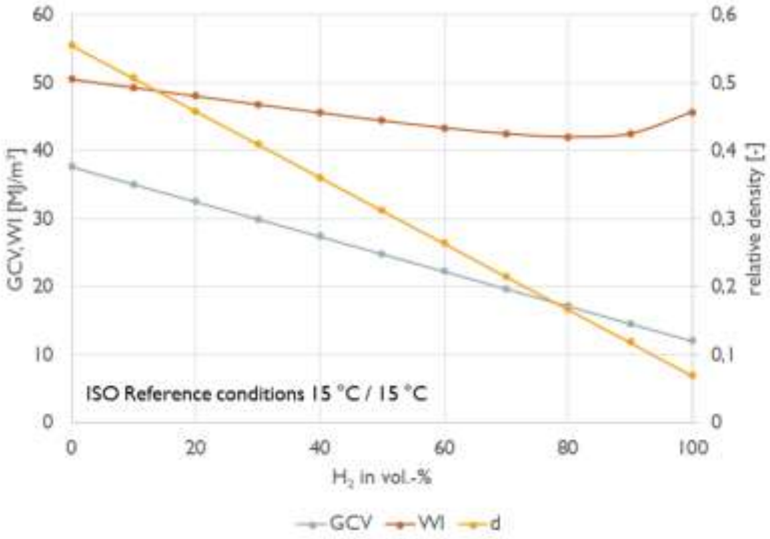
STANDARDIZATION
– risks related to H2NG supply –

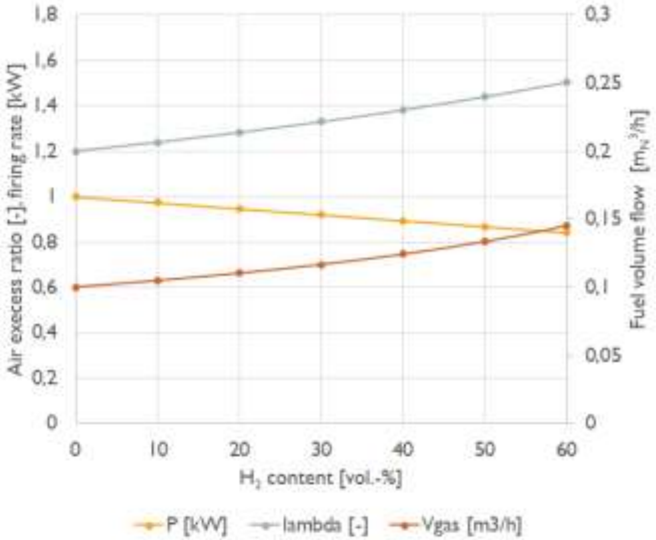




H_2 property	Risk	Cause	Comments + evaluation for 20% H_2NG
Lower min. air requirement	CO conc. too high	Flame instability due to increased air excess	20% H_2NG: generally no issue on factory settings
	Shutdowns	Flame lift due to air excess	20% H_2NG: generally no issue on factory settings
	Lower efficiency	Increased air excess lowering combustion (product) temperature	

STANDARDIZATION
– risks related to H2NG supply –

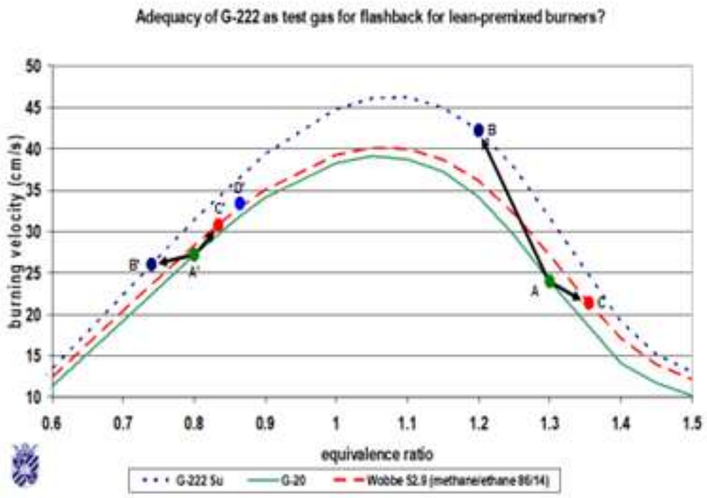




H_2 property	Risk	Cause	Comments + evaluation for 20% H_2NG
H_2 lowers Wobbe index (W_s) of NG	Insufficient heat output	Lower heat input	20% H_2NG: 14% lower GCV partially compensated by increased gas flow ⇒ heat output – 5% → no issue for most appliances
	CO conc. too high	Inappropriate onsite adjustment due to wider local W_s range	Full-premixed appliances: 20% H_2NG leads to issues. 10% H_2NG seems to be OK.
	Overheating		
	No ignition/extinction		

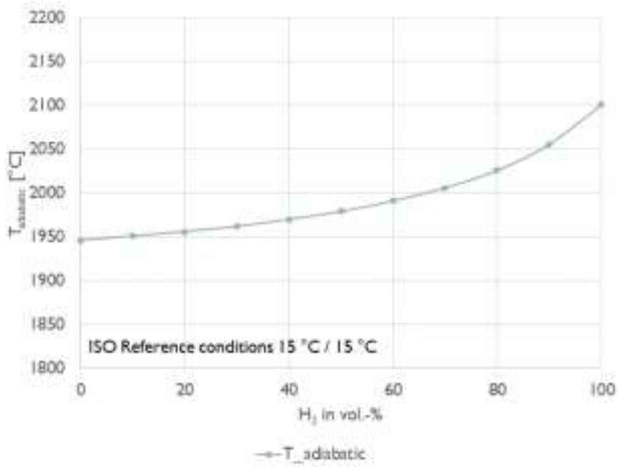
STANDARDIZATION

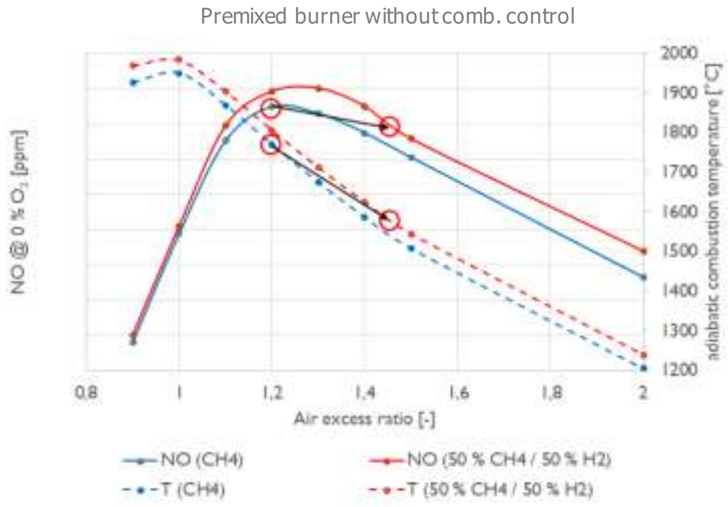
– risks related to H2NG supply –

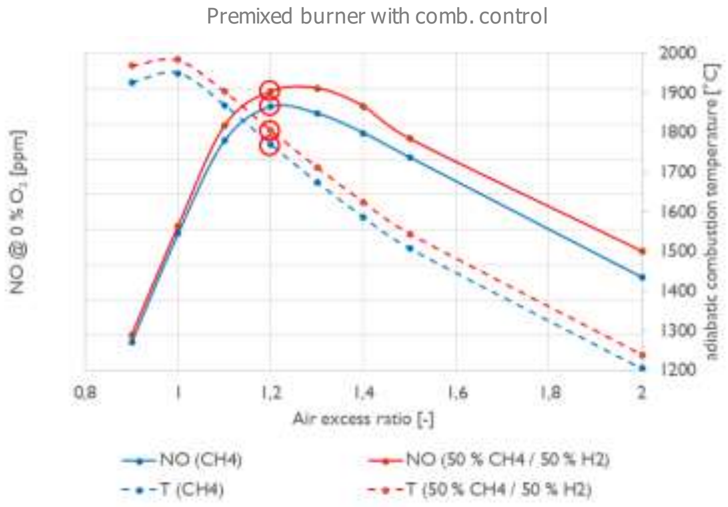


H_2 property	Risk	Cause	Comments + evaluation for 20% H_2NG
High flame speed	Light-back (flashback)	Flame entering into burner due to faster propagation of flame front ⇒ disturbed equilibrium between flame speed and gas flow speed	Partially premixed appliances and appliances with combustion control more sensitive. Full-premixed appliances more sensitive for light-back with gases with higher W_s
	Material/product deterioration	Higher burner surface temperature due to flame front closer to orifice(s)	20% H_2NG: no issues detected, but case by case evaluation required

STANDARDIZATION
– risks related to H2NG supply –



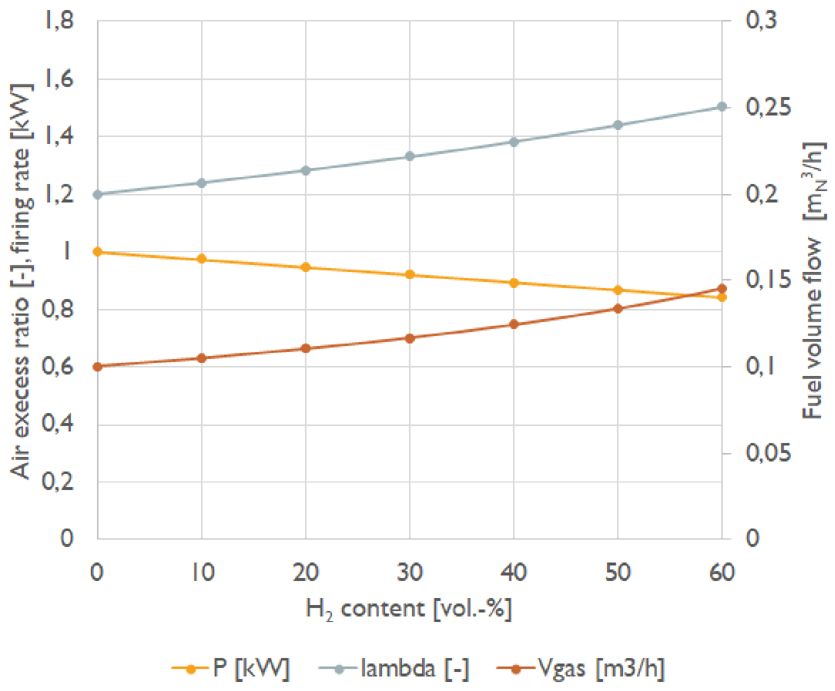




H_2 property	Risk	Cause	Comments + evaluation for 20% H_2NG
Higher flame temperature	Higher NO_x emissions	Thermal NO_x formation	Impact may be (partially) compensated by air excess increase 20% H_2NG: NOx emissions decreasing apart from some exceptions
	Material/product deterioration	Material does not resist the higher temperature	Impact increased by the higher flame speed, but (partially) compensated by air excess increase 20% H_2NG: no issues detected, but case by case evaluation required

STANDARDIZATION

– risks related to H2NG supply –



H_2 property	Risk	Cause	Comments + evaluation for 20% H_2NG
Higher fuel volume flow	Hypoxia/CO poisoning	Combustion products entering living spaces due to inappropriate device functioning	E.g. inappropriate position of thermal safety device (TTB) on B11BS appliances 20% H_2NG: no issues detected

STANDARDIZATION

– other properties and risks to be assessed –

- delayed ignition
- chemical impact on materials
- lower combustion products temperature
- wider flammability range
- lower emissivity
- pale blue flame
- lower ionization current
- lower carbon content
- higher pressure drop
- ventilation requirements
- methane number = 0
- …

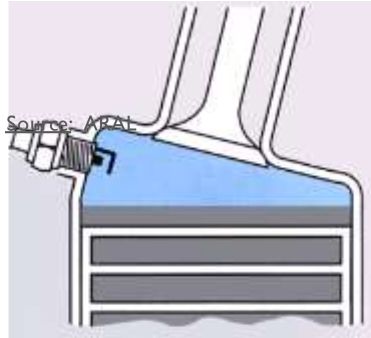
Delayed ignition test on premix boiler

Test results:

Test No.	Boiler setting: Gas	Boiler setting: CO_2 [%] O_2 [%] Max-Min	Boiler setting: CO DAF [ppm] Max-Min	Test gas	CO_2 [%] O_2 [%] Max-Min	CO DAF [ppm] Max-Min	delayed ignition time [s]: 1	2	3	4	5	6
1	G20	CO_2: 8,7-8,4 O_2: 5,4-5,9	CO: 155-8	G20	CO_2: 8,7-8,4 O_2: 5,4-5,9	CO: 155-8						
2	G20	CO_2: 8,7-8,4 O_2: 5,4-5,9	CO: 155-8	G20 +30%H2	CO_2: 6,9-6,6 O_2: 7,0-8,0	CO: 29-2						
3	G20 +30%H2	CO_2: 8,7-8,4 O_2: 3,8-4,4	CO: 192-6	G20 +30%H2	CO_2: 8,6-8,4 O_2: 4,2-5,1	CO: 192-6						
4	G20 +30%H2	CO_2: 8,7-8,4 O_2: 3,8-4,4	CO: 192-6	G20	CO_2: 10,6-10,4 O_2: 2,3-3,0	CO: 678-27						

- smooth ignition
- small detonation
- noisy detonation without damages
- very noisy detonation without damages
- boiler deterioration - hazard for user
- No ignition

Note:
an external timer has been connected between the burner control and the igniter in order to delay the ignition of the gas/air mixture inside the combustion chamber from 1s to Ignition Safety Time [TSA].



Source: ARAL

WP3 - Experimental Work

WP3 - Experimental Work

Agenda

- Objectives of the WP3 (experimental work)
- WP3 - Testing protocol and parameters studied
- Working method
- Results for the short-term tests
- Results for the long-term tests
- Conclusions

WP3 - Objectives of the WP3

The main goals of WP3 are

- To define a **detailed test protocol** based on WP2 input in order to
  - define accurately the details of the testing
  - to guarantee the best possible reproducibility of testing
  - and making sure that all elements needed for the analyse are included in the reports.

- To execute **short- and long- term testing** on as many appliance as possible in order to achieve conclusions on sensitivity to H2 by segments of technologies.

- To check the **tightness of present indoor installation** and appliances components to H2/NG mix (*this aspect of the project will be discussed in the next part of the workshop*)

WP3 - Experimental Work
Agenda

- Objectives of the WP3 (experimental work)
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THyGA 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.

WP3 - Testing protocol and parameters studied

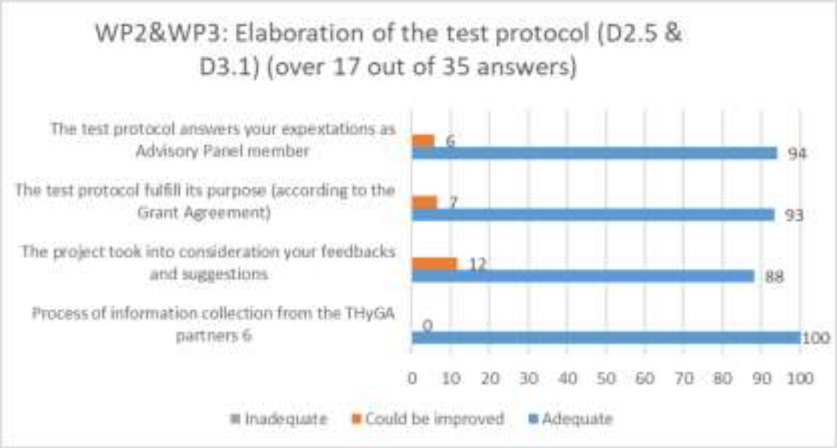
Preparation of the test protocol

- The **test protocol** defines accurately the details of the testing
  - The protocol consist in operative instructions needed for managing all the aspects related to the task from receiving the appliances, the testing, the reporting etc.

- It includes the details of the **test programme** & the **reporting templates for laboratories**

- **Stakeholders** have been involved in this process from the beginning (consensus on the tests)

Feedbacks from the Advisory Panel Group (July 2021)



THyGA
D3.5
D3.8

WP3 - Testing protocol and parameters studied

Preparation of the test protocol… and adaptation to a moving context

Since the project was designed, a lot has happened on H2 front!

CEN TCs starting to work on "H2 ready" certification	"H2 ready" concept discussed in regulation ErP (Ecodesign & Labelling)
Manufacturers H2 road maps pushed by the "Primemovers" initiative	**DSO / TSO are clearer about of possible %H2 in the NG grid (up to 20 to 30%)**

READJUSTING THyGA testing to give the best value to the industry (focus on 20 to 30% H2)

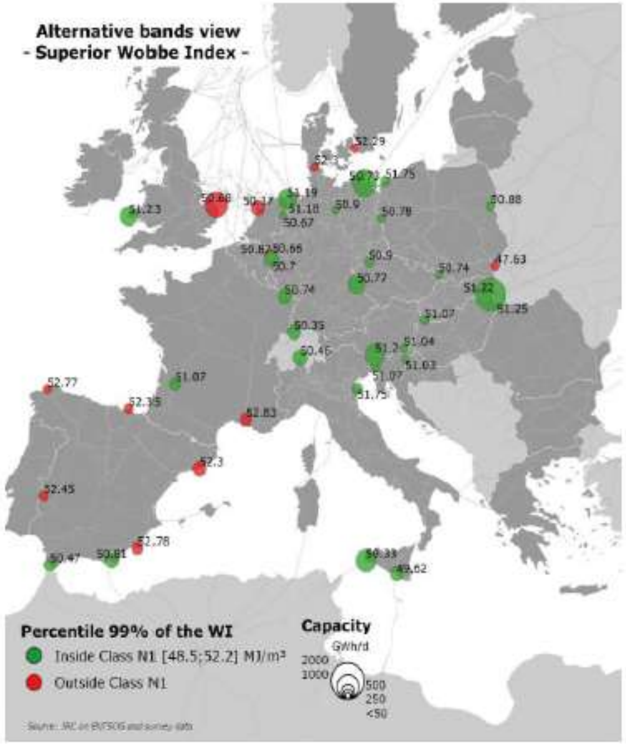
THyGA
D3.5
D3.8

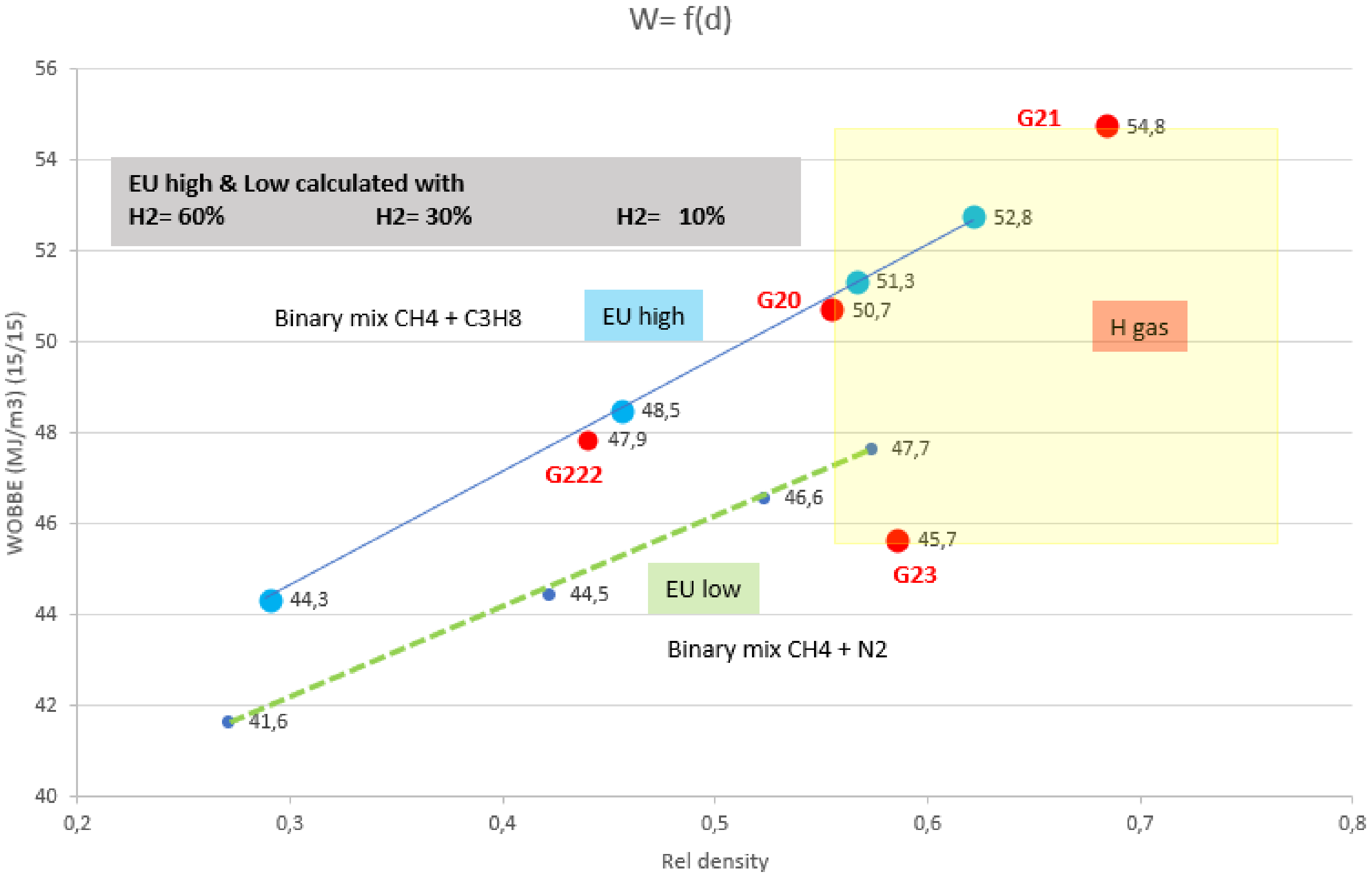
WP3 - Testing protocol and parameters studied

Specification of the gases used for the testing

Based on real distributed gases (EU High and EU Low)

100% percentile = 47,63 (EU LOW) à 52,78 (EU HIGH) MJ/m3





WP3 - Testing protocol and parameters studied

Parameters studied during the short-term tests

Objective: to understand how appliances react in the short term (few minutes to few hours) with different H2NG blends. The evaluation will cover **safety, energy efficiency, emissions & operational aspects**

Parameters to measure

- Combustion/emissions
- Efficiency
- Safety
- Operational aspects (Normal operation of the appliances or not)

Parameters to vary

- % H2 according
- H2 Rate of change (ROC)
- Natural gas composition
- Pressure
- Adjustment or not.

Picture DGC

The philosophy of the test in lab is to simulate a situation that is found on the field:
Gas quality variation with H2 on appliances that are not modified between the changes.

WP3 - Testing protocol and parameters studied

Test programme

Performances (Emissions & Efficiency) — P

Safety — S

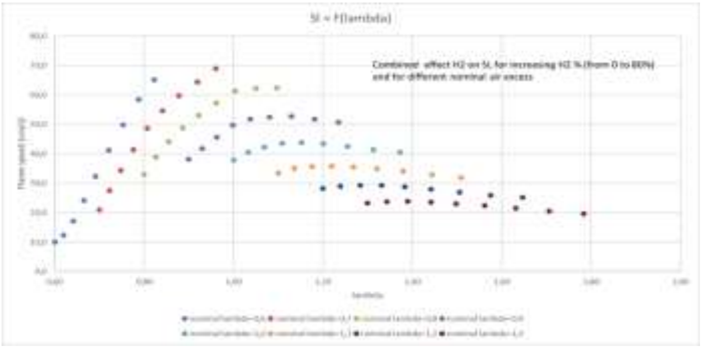
Operational aspects — O

TESTING PROGRAMME (all tests with H2 added at different %)

- SAFETY & PERFORMANCES CH4
- SAFETY & PERFORMANCES EULOW
- SAFETY & PERFORMANCES G23
- Low air temperature (- 10 C)
- Flue gas pipe length
- **ROC (PLUGG FLOW)**
- **Impact of H2 on flame detection**
- **Flashback**
- **ADJUSTMENT A, B, H, G**
- **Delayed ignition test.**
- Quick variation Qmin-Qmax Shut-off
- Cooker hob test with 4 burners on
- Influence of wind
- Long term (limited time)
- Fluctuation of the aux. energy
- Fluctuation of pressure
- Cold start
- Hot start
- Other test

CO, NOx, Efficiency

The testing programme was elaborated carefully, taking into acount the existing knowledge and the specificity of H2 as for exemple the flame speed.



WP3 - Testing protocol and parameters studied

Adjustment

- In practice, most of appliances in the category H (High calorific gas – widely distributed in the EU) are adjusted by the manufacturers with CH4 before being sold on the market. Some appliances are also re-adjusted **on the field** according to manufacturer instructions either during the commissioning or after a service or a reparation. **This is done with the gas distributed locally and not CH4**.
- What we call **adjustment in THyGA is the operation of field adjustment to reach a certain air excess according the O2 or CO2 value** that is given by the boiler manufacturer in technical instructions.
- Usually, appliances are adjusted to an air excess that is a **compromise** to achieve the best possible efficiency with the lowest possible emissions.

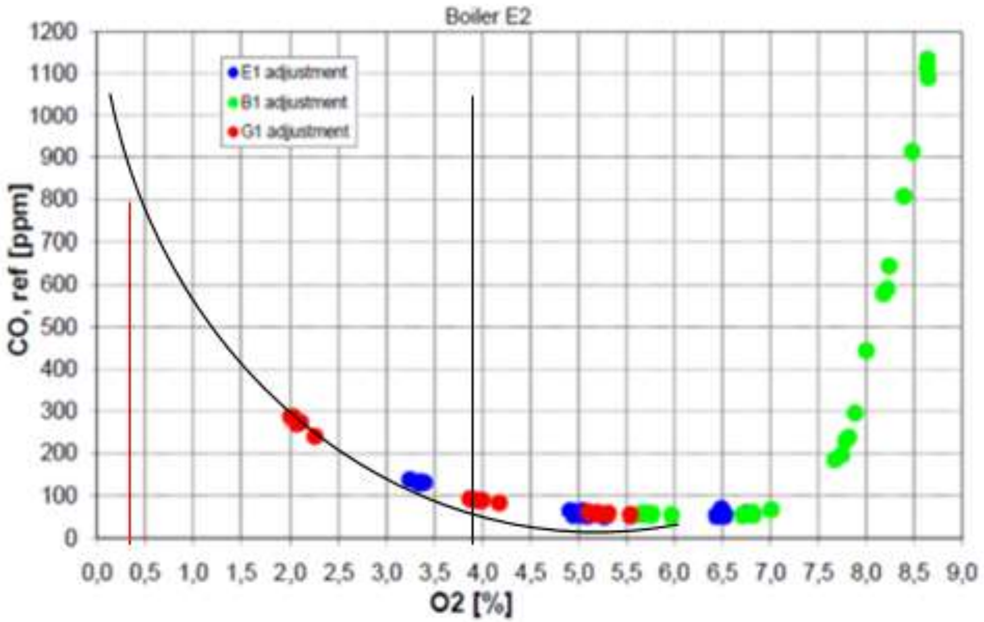
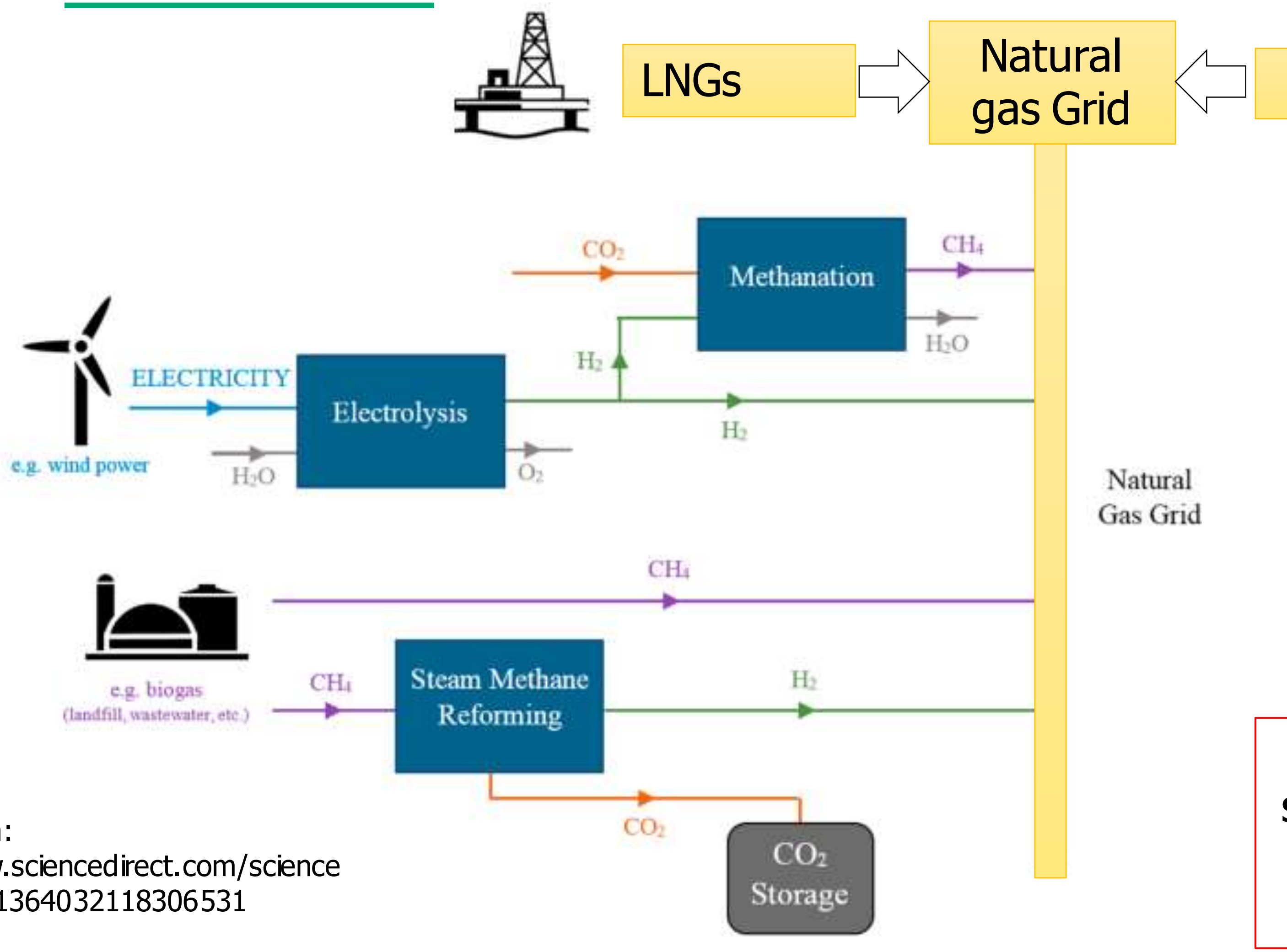
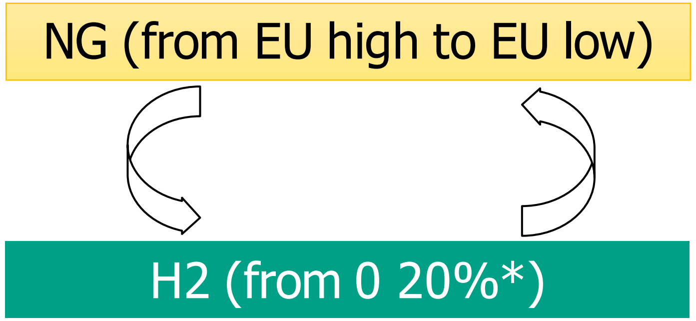


Figure DGC - GASQUAL

WP3 - Testing protocol and parameters studied

Adjustment: set because of fluctuations of the gas quality in the grid





** During adjustment and from 0 to 20%, or more after*

The philosophy of THyGA is to simulate real situation where gas can change from day to day without the appliance setting being changed

Picture from: https://www.sciencedirect.com/science/article/pii/S1364032118306531

WP3 - Testing protocol and parameters studied

Adjustment: scenario implemented in THyGA

Several scenarios of adjustment were tested in THyGA. **The test simulates a possible realistic situation where**:

1. The **appliance is adjusted** (without taking into account the real gas quality distributed) with O2 or CO2 value according the present instructions of the boiler manufacturer (that are based on natural gas type H without presence of H2).

2. **The gas quality changes** at any time after the adjustment.

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	

Example for test **G**:

1. Appliances are adjusted with EU low + 20%H2 (with CO2 and or O2)
2. And **tested with**:
   - EU high (without H2)
   - EU high + H2 (10%)
   - EU high + H2 (30%)
   - EU high + H2 (60%)

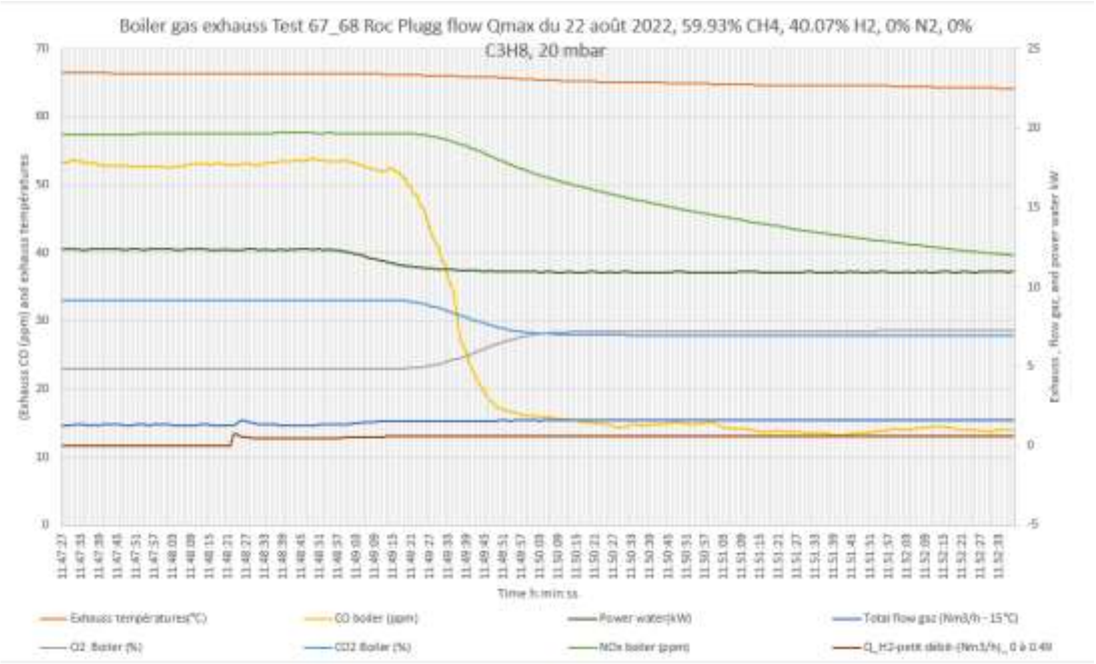
WP3 - Testing protocol and parameters studied

Rate of Change (ROC)

The "rate of change" test consist in a **sudden change of the gas distributed** to the appliance in order to check how it can possibly react in such situation.

The test consists in:

- Observing possible operational problems with the appliance.
- Measuring emissions.

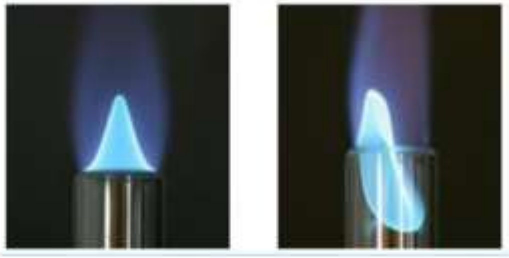


Picture ROC ENGIE (EN01)

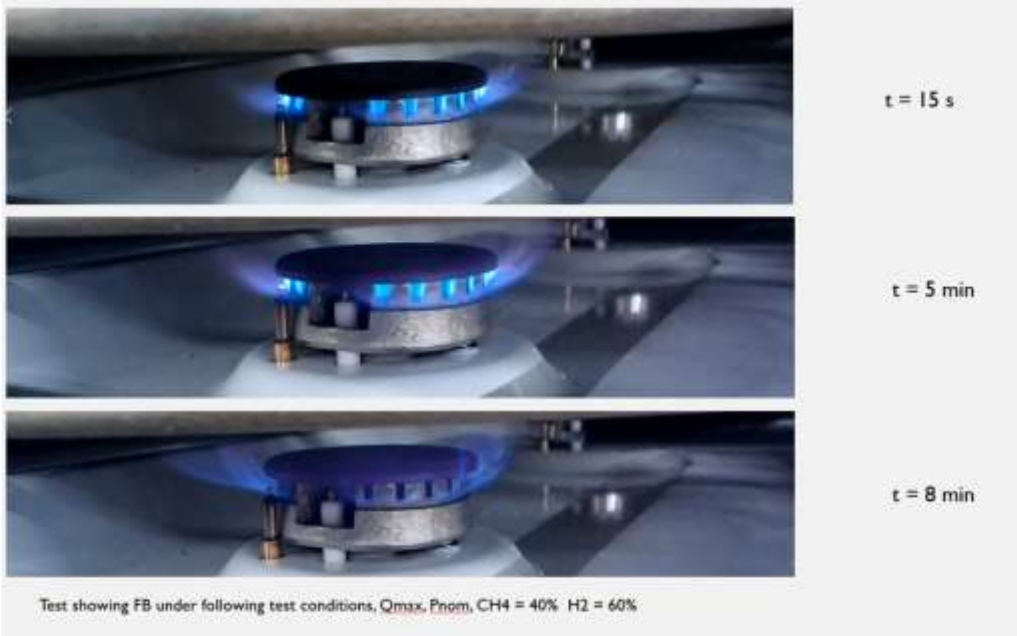
Gas mixing station Picture DGC

WP3 - Testing protocol and parameters studied

Flashback



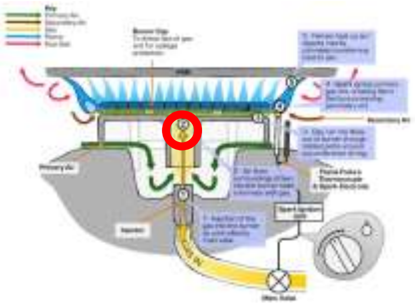
Flame with Flash back (picture THyGA application)

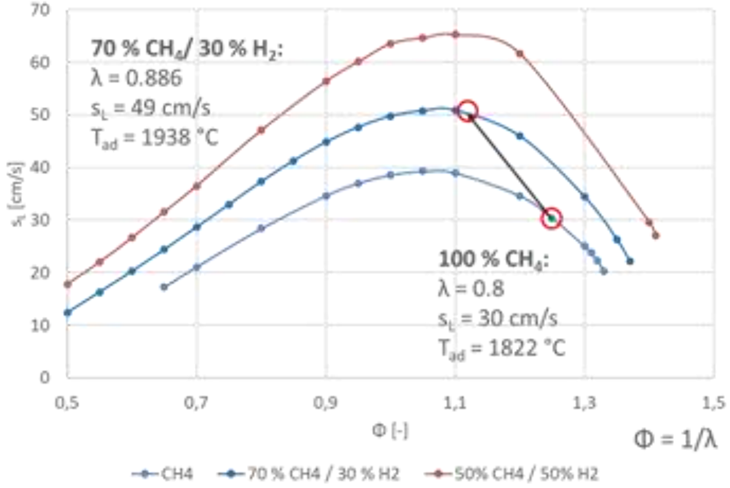


Flame with partial flash back on a cooker hob (picture THyGA test DGC)

The "Flash back" or "light back" is associated with the flame speed which is impacted by Hydrogen.

Flash back results in the flame burning below the burner surface either entirely or partially.





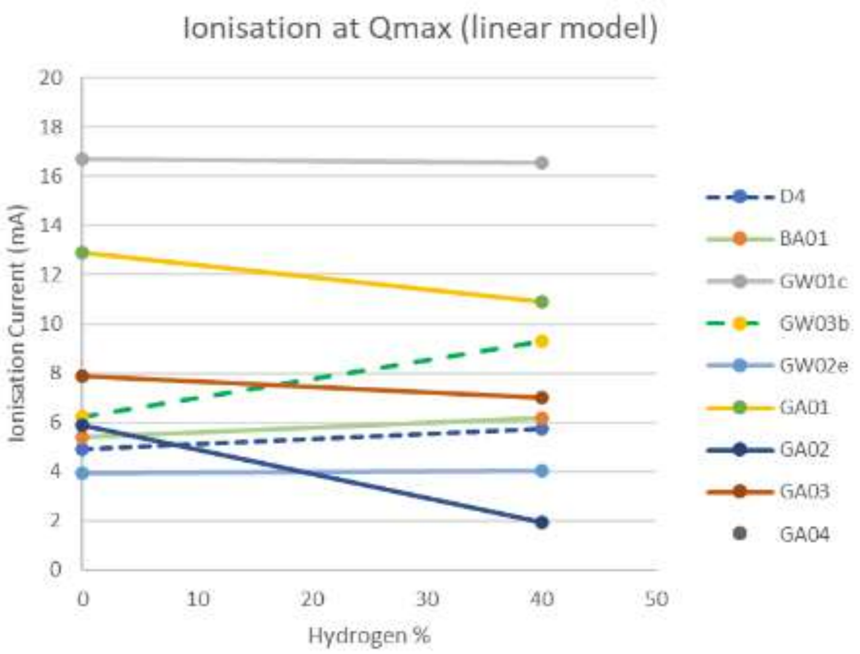
WP3 - Testing protocol and parameters studied

Flame detection

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

The ionisation works surprisingly well with the level of H2 tested (60% in many cases) for flame detection while we expected problems since the hydrogen flame is supposed to generate a lower ionisation current.

- It should be pointed out, however, that if the flame ionisation signal is also used for combustion control purposes, this approach is insufficient and unable to maintain a constant air excess ratio.
- The reason for this is that due to the presence of hydrogen, the position of the flame relative to the sensor shifts significantly and the control logic is confronted with conflicting signals.



THyGA measurement of ionisation signal on boilers

WP3 - Experimental Work
Agenda

- Objectives of the WP3 (experimental work)
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WP3 – Working method

Working by SEGMENT GROUPS

Objective: to gather the appliances in groups by technologies enabling conclusions on similar technologies.

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 100b Boilers other
- 200 Water heaters
- 300 Cookers domestic
- 400a Catering equipment – Premix
- 400b Catering equipment – Not premix
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

Example: all data for water heaters are gathered in the same chapter even if we have differences between sub-segments

201	WATER HEATERS	Instantaneous open flued	Partial premix/atmos	EN 26
202		Instantaneous room-sealed	Partial premix/fanned	
203		Storage open flued	Partial premix/atmos	EN 89
204		Storage room-sealed	Partial premix/fanned	

The goal of the following chapters is to provide a synthetic view, more specific details available in the reports

WP3 – Working method

From individual "ID Cards"

Results are compiled in a simple table showing results at a glance.

THyGA Appliance ID card for	D6_SEGM_108							
Appliance	EN 15502 Gas-fired heating boiler							
Burner	Premix							
Origin	New appliance (2021)							
Segment	108							
Max. power input (net) [kW]	22							
Min. power input (net) [kW]	3							
SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
1.1 SAFETY- with CH4	X	X	X	X	X	X	X	X
1.2 SAFETY- with EULOW								
1.3 SAFETY- with G23								
1.4 Cold start.						X		X
1.5 Hot start.								X
1.6 Low air temperature (- 10 C)								
1.7 Flue gas pipe length					X			
1.8 ROC (PLUGG FLOW)						X		
1.9 Impact of H2 on flame detection.						X		
1.10 Flash back	X	X	X	X	X	X	X	X

X = Point tested by the Lab

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

SAFETY ASSESMENT. H2 % tested	0	10	20	23	30	40	50	60
3.1 ADJUSTMENT A	NA	NA	NA	NA	NA	NA	NA	NA
3.2 ADJUSTMENT B	NA	NA	NA	NA	NA	NA	NA	NA
3.3 ADJUSTMENT H	NA	NA	NA	NA	NA	NA	NA	NA
3.4 ADJUSTMENT G	NA	NA	NA	NA	NA	NA	NA	NA
4.1 Delayed ignition test.					X			
4.2 Soundness								
4.3 Quick variation Qmin-Qmax Shut-off								
4.4 Overheat. Meas. of temp.								
4.5 Cooker hob test with 4 burners on	NA	NA	NA	NA	NA	NA	NA	NA
4.6 Influence of wind								
4.7 Long tem (limited time)								
4.8 Fluctuation of the aux. energy			X					
4.9 Fluctuation of pressure						X		

WP3 – Working method

From individual “ID Cards”… to a global view for the group

	segment		EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02	GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	Segment		106	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108
	Qmin (kW)		8,3	6,9	2,5	4,3	4,8	2,5	6	4,5	6	/	2,5	2,9	5,1	4,8	2,1	6,1	3,3	25	4,5	4,4
	Qmax (kW)		41,6	24	22	20,8	20	22	21	15,3	22	22,5	32	20	32	30	12,5	17,8	30,3	3,2	15,2	20,4
	Combustion control feature (Y/N)		N	Y		Y	Y	Y	Y	N	N	Y	Y	0	N	Y	N	n	Y	Y	Y	Y
	Appliance category		II2Esi3P I2Esi	II2ELL	II2H3P	II 2H3B/P	II 2H3B/P	II 2H3B/P	II2N3P	II2N	II2ELL 3P	II2L3P	II2N3P	2N3P	II2H3P	I2E(S)	II2Esi3P	I2E(S)	II2H3P	II2N3P	I2H	II2N3P
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		EU LOW		x			x					x				x		x				
		G23							x	x	x	x	x	x	x			x		x		
	%H2 in test gas	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
		0-10	x	x		x	x	x			x	x	x		x	x	x			x	x	x
		10-20	x			x	x	x				x				x	x	x				
		20-23	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		23-30	x	x		x	x	x			x	x	x		x	x	x	x		x	x	x
		30-40	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
		40-50	x		x	x	x	x	x		x		x	x	x	x				x	x	x
		50-60	x		x	x	x	x	x		x	x	x	x	x	x				x	x	x
CS	1.4 Cold start	CH4+40%H2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)			x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2		x						x												
FGP	1.7 Flue gas pipe length	CH4+30%H2		x				x								x						
ROC	1.8 ROC (Plug flow)	CH4+40%H2		x	x	x	x	x		x		x	x	x	x	x	x	x	x	x		
FD	1.9 Impact H2 flame detection.		x	x		x	x	x	x		x	x	x	x	x	x	x	x	NA			
FB	1.10 Flash back				x	x	x	x	x			x		x	x	x		x				x
AD_A	3.1 Adjustment A	EU HighEU Low+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_B	3.2 Adjustment B	EU lowEU high+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	x	NA	NA	x	x	NA	NA			x	NA	NA		x	x	x	x	NA		
DI	4.1 Delayed ignition test.	CH4+30%H2																				
S	4.2 Soundness																	x				
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2				NA	NA					x					x	x				
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2																				
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA	NA	NA	NA	NA		NA		NA		NA	NA	NA	NA	NA	NA		
W	4.6 Influence of wind																	x				
LT	4.7 Long time (limited time)	depends on manufacturer									x					x						
AUX	4.8 Fluctuation of the aux.							x														
P	4.9 Fluctuation of pressure	CH4+40%H2			x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		
O	Other /Operational		x		x			x				x										

Tested appliance

How we make a conclusion per parameter

≡

Simple assesment:
All Green = Green
One Red = Red

THyGA
D3.5
D3.8

WP3 – Working method

From individual "ID Cards"… to a global view for the group… to a final result

	segment		EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02	GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	Segment		106	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108
	Qmin (kW)		8,3	6,9	2,5	4,3	4,8	2,5	6	4,5	6	/	2,5	2,9	5,1	4,8	2,1	6,1	3,3	25	4,5	4,4
	Qmax (kW)		41,6	24	22	20,8	20	22	21	15,3	22	22,5	32	20	32	30	12,5	17,8	30,3	3,2	15,2	20,4
	Combustion control feature (Y/N)		N	Y		Y	Y	Y	Y	N	N	Y	Y	0	N	Y	N	n	Y	Y	Y	Y
	Appliance category		II2Esi3P I2Esi	II2ELL	II2H3P	II 2H3B/P	II 2H3B/P	II 2H3B/P	II2N3P	II2N	II2ELL 3P	II2L3P	II2N3P	2N3P	II2H3P	I2E(S)	II2Esi3P	I2E(S)	II2H3P	II2N3P	I2H	II2N3P
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		EU LOW		x			x					x				x		x				
		G23							x	x	x	x	x	x	x			x		x		
	%H2 in test gas	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
		0-10	x	x		x	x	x			x	x	x		x	x	x			x	x	x
		10-20	x			x	x	x				x				x	x	x				
		20-23	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		23-30	x	x		x	x	x			x	x	x		x	x	x	x		x	x	x
		30-40	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
		40-50	x		x	x	x	x	x		x		x	x	x	x				x	x	x
		50-60	x		x	x	x	x	x		x	x	x	x	x	x				x	x	x
CS	1.4 Cold start	CH4+40%H2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)			x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2		x						x												
FGP	1.7 Flue gas pipe length	CH4+30%H2		x				x								x						
ROC	1.8 ROC (Plug flow)	CH4+40%H2		x	x	x	x	x		x		x	x	x	x	x	x	x	x	x		
FD	1.9 Impact H2 flame detection.		x	x		x	x	x	x		x	x	x	x	x	x	x	x	NA			
FB	1.10 Flash back				x	x	x	x	x			x		x	x	x		x				x
AD_A	3.1 Adjustment A	EU HighEU Low+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_B	3.2 Adjustment B	EU lowEU high+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2		NA	NA		x	NA	NA			x	NA	NA		NA		x	NA	NA		
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	x	NA	NA	x	x	NA	NA			x	NA	NA		x	x	x	x	NA		
DI	4.1 Delayed ignition test.	CH4+30%H2																				
S	4.2 Soundness																	x				
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2				NA	NA					x					x	x				
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2																				
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA	NA	NA	NA	NA		NA		NA		NA	NA	NA	NA	NA	NA		
W	4.6 Influence of wind																	x				
LT	4.7 Long time (limited time)	depends on manufacturer									x					x						
AUX	4.8 Fluctuation of the aux.							x														
P	4.9 Fluctuation of pressure	CH4+40%H2			x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		
O	Other /Operational		x		x			x				x										

Final result for a group of appliances (here Segment 100a Fully premix boilers)

		H2 % Tested							
		0	0-10	10-20	20-23	23-30	30-40	40-50	50-60
100a Boilers fully premix	*Safety*			simple mitigation (3)	mitigation to be defined		5	8	11
	Safety with mitigation			Dedicated adjustment methodology			2	5	8
	Operational								

- No issues
- Safety issues
- Potential issue
- Operational issue
- Not tested extensively
- Not tested

WP3 - Experimental Work

Agenda

- Objectives of the WP3 (experimental work)
- WP3 - Testing protocol and parameters studied
- Working method
- Results for the short-term tests
- Results for the long-term tests
- Conclusions

PLEASE NOTE THAT there are open discussions and the results presented are not yet final.

The extended report with all details will be publicly available in early April

WP3 – Results for the short-term tests

Discussion on types of segments

THyGA's Segments / Type of appliance

- 100a Boilers fully premix → **Detailed result**
- 300 Cookers domestic → **Detailed result**
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

Detailed result (100a, 300): Because of the large market share

overall result (100b, 200, 400, 500, 600, 700, 800): Because of lack of time to treat extensively all segments

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix

THyGA's Segments / Type of appliance

- 100a Boilers fully premix → **Detailed result**
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

Discussion on types of segments: how to read the tables ?

	segment		EN01v01
	Segment		108
	Qmin (kW)		2,1
	Qmax (kW)		12,5
	Combustion control feature (Y/N)		N
	Appliance category		II2Eri3P
Tested: reference gas + %H2 used	Reference gas	CH4	x
		EU LOW	
		G23	
	%H2 in test gas	0	x
		0-10	x
		10-20	x
		20-23	x
		23-30	x
		30-40	x
		40-50	
		50-60	

→ Lab Name + Ref of test

→ Autoadaptative combustion control feature or not

→ Category according to EN437

Appliance tested up to 40%H2

Problem occurred at 20%H2

→ To understand which problem, see the next slide

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (1/6)

x	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
x	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
x	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

			EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02	GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	segment		EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02	GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	Segment		106	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108
	Qmin (kW)		8,3	6,9	2,5	4,3	4,8	2,5	6	4,5	6	/	2,5	2,9	5,1	4,8	2,1	6,1	3,3	25	4,5	4,4
	Qmax (kW)		41,6	24	22	20,8	20	22	21	15,3	22	22,5	32	20	32	30	12,5	17,8	30,3	3,2	15,2	20,4
	Combustion control feature (Y/N)		N	Y		Y	Y	Y	Y	N	N	Y	Y	0	N	Y	N	n	Y	Y	Y	Y
	Appliance category		II2Esi3P I2Esi	II2ELL	II2H3P	II 2H3B/P	II 2H3B/P	II 2H3B/P	II2N3P	II2N	II2ELL 3P	II2L3P	II2N3P	2N3P	II2H3P	I2E(S)	II2Esi3P	I2E(S)	II2H3P	II2N3P	I2H	II2N3P
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		EU LOW		x			x					x				x		x				
		G23							x	x	x	x	x	x	x			x		x		
	%H2 in test gas	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
		0-10	x	x		x	x	x			x	x	x		x	x	x			x	x	x
		10-20	x			x	x	x				x				x	x	x				
		20-23	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		23-30	x	x		x	x	x			x	x	x		x		x	x		x	x	x
		30-40	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
		40-50	x		x	x	x	x	x		x		x	x	x	x				x	x	x
		50-60	x		x	x	x	x	x		x	x	x	x	x	x				x	x	x
CS	1.4 Cold start	CH4+40%H2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)			x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2		x						x												
FGP	1.7 Flue gas pipe length	CH4+30%H2		x				x								x						
ROC	1.8 ROC (Plug flow)	CH4+40%H2		x	x	x	x	x		x		x	x	x	x	x	x	x	x	x		
FD	1.9 Impact H2 flame detection.		x	x		x	x	x	x		x	x	x	x	x	x	x	x	NA			
FB	1.10 Flash back				x	x	x	x	x			x		x	x	x		x				x

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (2/6)

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

	segment		EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02
	Segment		106	108	108	108	108	108	108	108	108	108
	Qmin (kW)		8,3	6,9	2,5	4,3	4,8	2,5	6	4,5	6	/
	Qmax (kW)		41,6	24	22	20,8	20	22	21	15,3	22	22,5
	Combustion control feature (Y/N)		N	Y		Y	Y	Y	Y	N	N	Y
	Appliance category		II2Esi3P I2Esi	II2ELL	II2H3P	II 2H3B/P	II 2H3B/P	II 2H3B/P	II2N3P	II2N	II2ELL 3P	II2L3P
AD_A	3.1 Adjustment A	EU HighEU Low+H2		NA	NA		X	NA	NA			X
AD_B	3.2 Adjustment B	EU lowEU high+H2		NA	NA		X	NA	NA			X
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2		NA	NA		X	NA	NA			X
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	X	NA	NA	X	X	NA	NA			X

	segment		GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	Segment		108	108	108	108	108	108	108	108	108	108
	Qmin (kW)		2,5	2,9	5,1	4,8	2,1	6,1	3,3	25	4,5	4,4
	Qmax (kW)		32	20	32	30	12,5	17,8	30,3	3,2	15,2	20,4
	Combustion control feature (Y/N)		Y	0	N	Y	N	n	Y	Y	Y	Y
	Appliance category		II2N3P	2N3P	II2H3P	I2E(S)	II2Esi3P	I2E(S)	II2H3P	II2N3P	I2H	II2N3P
AD_A	3.1 Adjustment A	EU HighEU Low+H2	NA	NA		NA		X	NA	NA		
AD_B	3.2 Adjustment B	EU lowEU high+H2	NA	NA		NA		X	NA	NA		
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2	NA	NA		NA		X	NA	NA		
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	NA	NA		X	X	X	X	NA		

Main issue = adjustment G

- This is not a systematic issue
  - Not all labs did the requested test (Blank cells)
  - NA is for appliances with combustion controls when manufacturers expressely asked not to make adjustments in the technical documentation
  - Note that test where done for some boilers with combustion controls, when manufacturers allowed it (eg in case of the replacement of a component) (see example below).

CASE	EULOW + 10, 20, 30% H2	EU low +0 to 60% H2	CH4	EU high + 20% H2	EU high + 0 to 60% H2
G	Adjusted →				Used

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (3/6)

Issue with adjustment

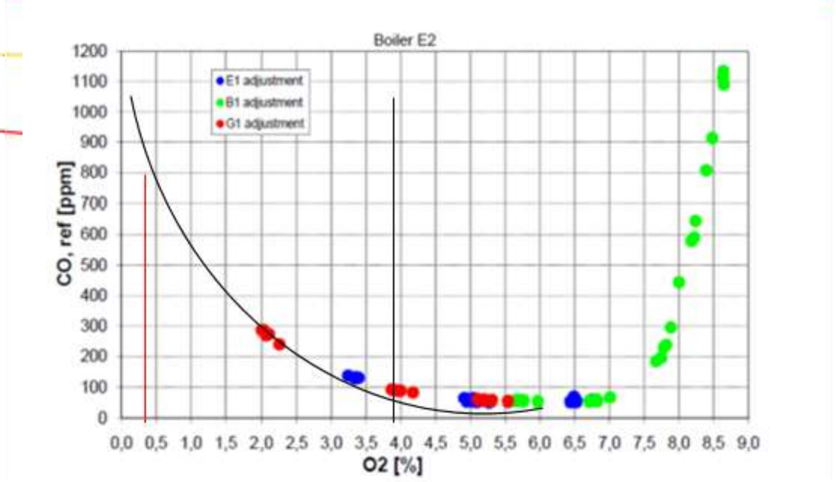
- Most critical situation = appliance set with a low Wobbe Index gas, including H2, and used suddenly with a high Wobbe Index gas (bringing combustion close to stoechiometry)

	Tair	Patm	Tamb	CO2	O2	CO	NOx	NO2
Low Wobbe + H2	20.5	1017.5	20.5	9.0	3.8	111.3	40.6	14.2
High Wobbe	20.5	1017.4	20.5	11.6	0.4	1024.9	135.2	22.6

Example of test data obtained at EU High after Adjustment G

Very high CO

Typical CO evolution with air excess (GASQUAL)



- Potential consequence on the market → some leads in WP5 activities

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (4/6)

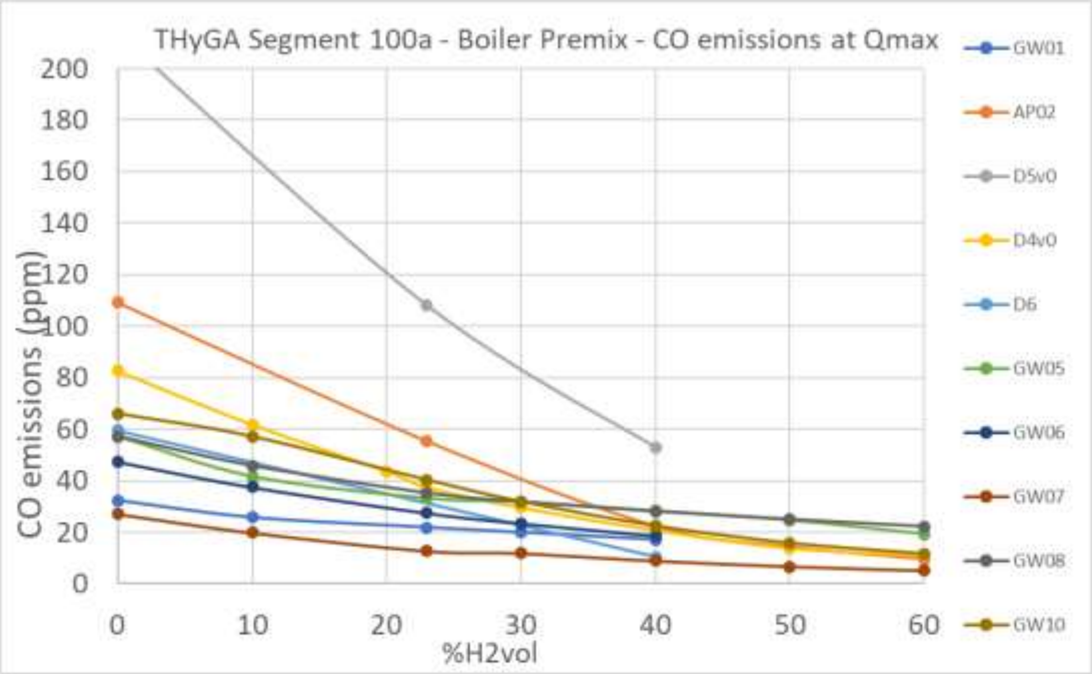
X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

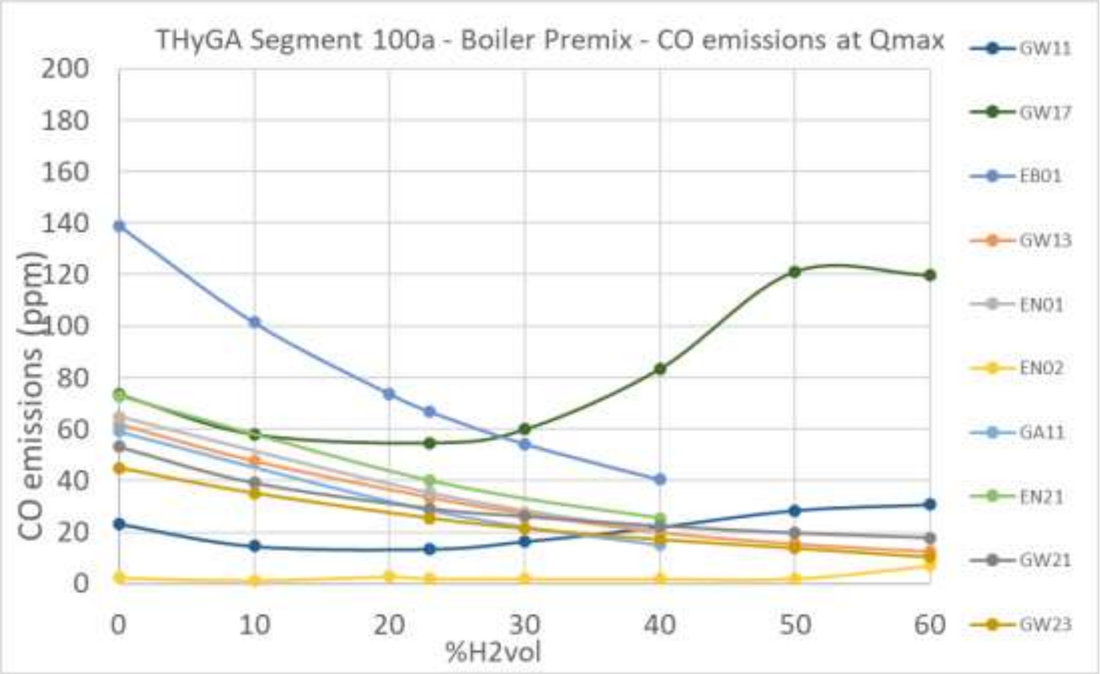
	segment		EN02v01	GW01V04	AP02V03	D5v02	D4v03	D6	GW05V04	GW06V03	GW07V02	GW08V02	GW10V02	GW11V02	GW17	EB01V04	EN01v01	GA11V03	EN21	GW13V02	GW23	GW21
	Segment		106	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108	108
	Qmin (kW)		8,3	6,9	2,5	4,3	4,8	2,5	6	4,5	6	/	2,5	2,9	5,1	4,8	2,1	6,1	3,3	25	4,5	4,4
	Qmax (kW)		41,6	24	22	20,8	20	22	21	15,3	22	22,5	32	20	32	30	12,5	17,8	30,3	3,2	15,2	20,4
	Combustion control feature (Y/N)		N	Y		Y	Y	Y	Y	N	N	Y	Y	0	N	Y	N	n	Y	Y	Y	Y
	Appliance category		II2Esi3P I2Esi	II2ELL	II2H3P	II 2H3B/P	II 2H3B/P	II 2H3B/P	II2N3P	II2N	II2ELL 3P	II2L3P	II2N3P	2N3P	II2H3P	I2E(S)	II2Esi3P	I2E(S)	II2H3P	II2N3P	I2H	II2N3P
DI	4.1 Delayed ignition test.	CH4+30%H2																				
S	4.2 Soundness																	x				
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2				NA	NA					x					x	x				
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2																				
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA	NA	NA	NA	NA		NA		NA		NA	NA	NA	NA	NA	NA		
W	4.6 Influence of wind																	x				
LT	4.7 Long time (limited time)	depends on manufacturer									x					x						
AUX	4.8 Fluctuation of the aux.							x														
P	4.9 Fluctuation of pressure	CH4+40%H2			x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		
O	Other /Operational		x		x			x				x										

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (5/6)

CO emissions Qmax (data is split in 2 graphs for visibility)

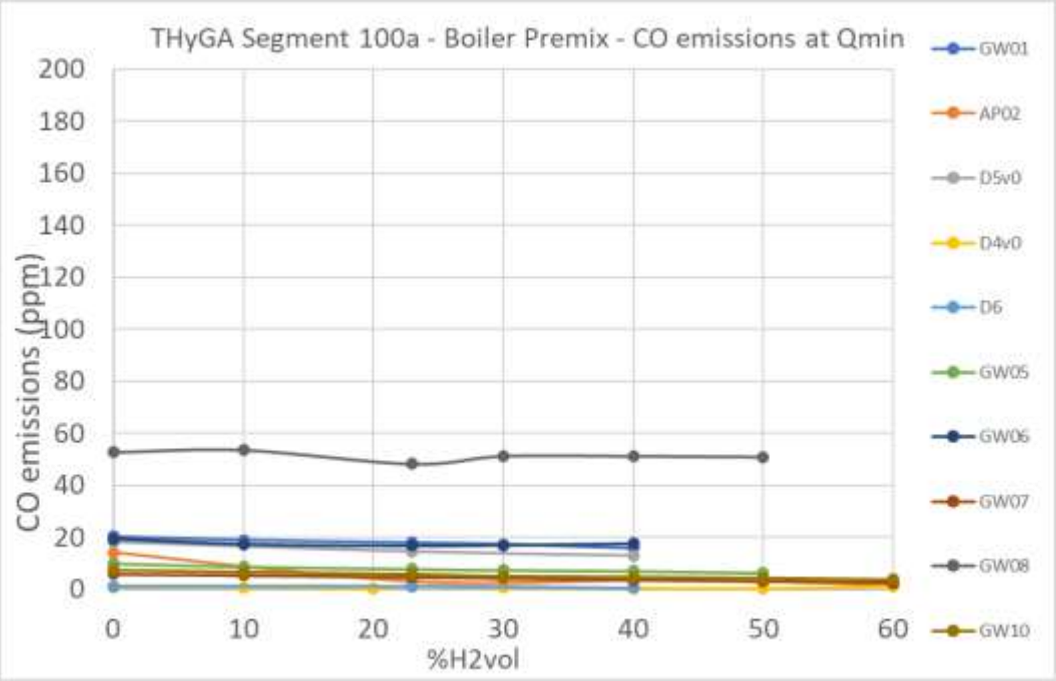


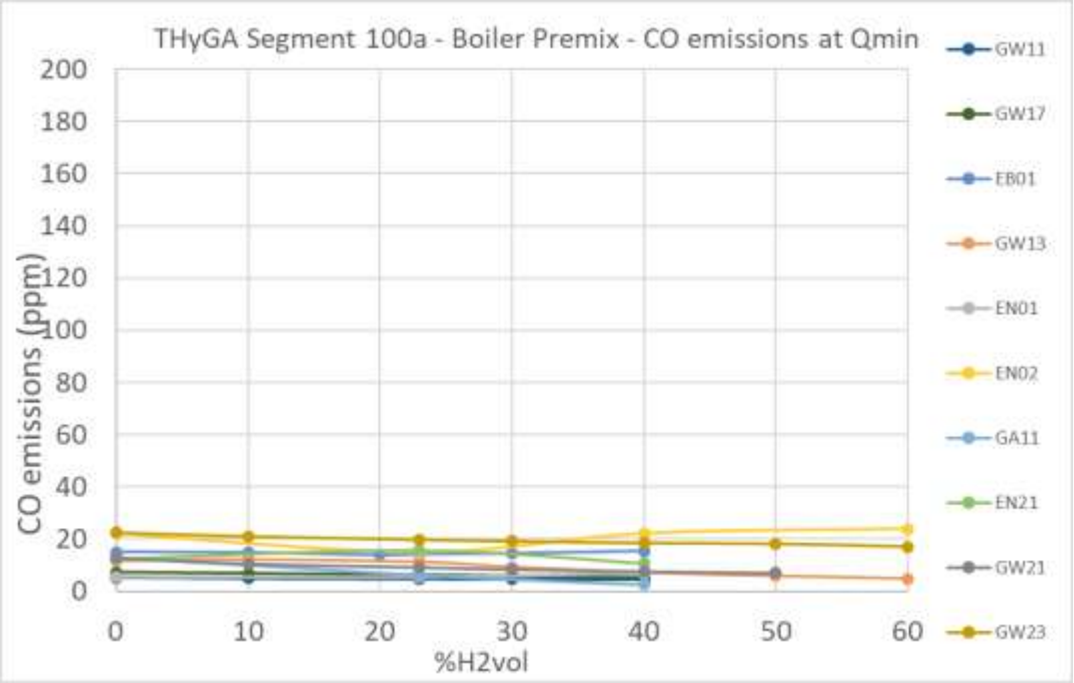


WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: details of results for safety (6/6)

CO emissions Qmin

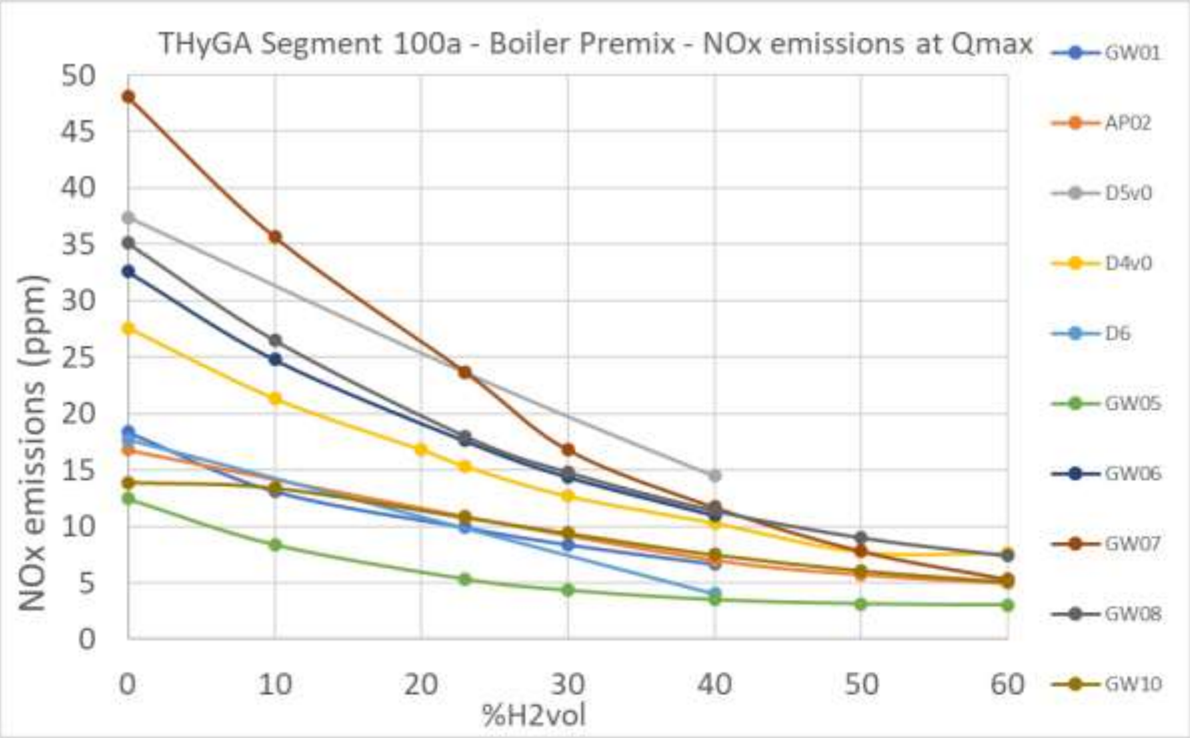


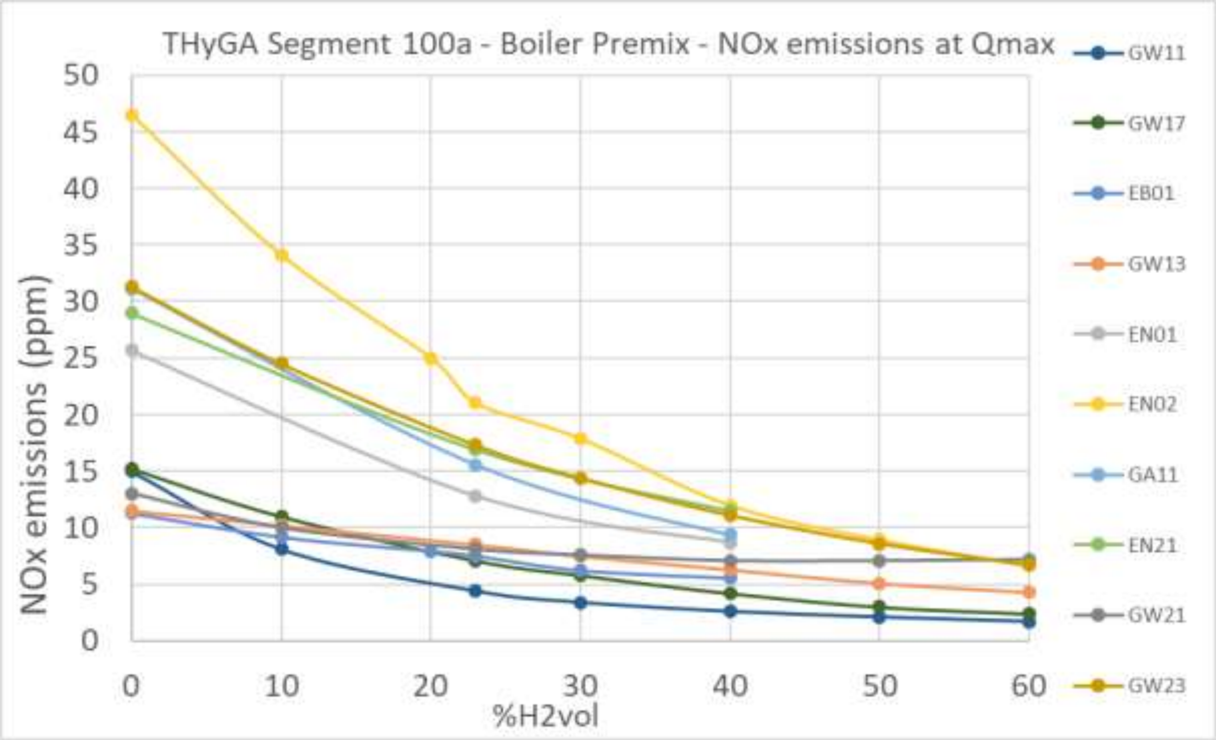


WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: other results

NOx Qmax

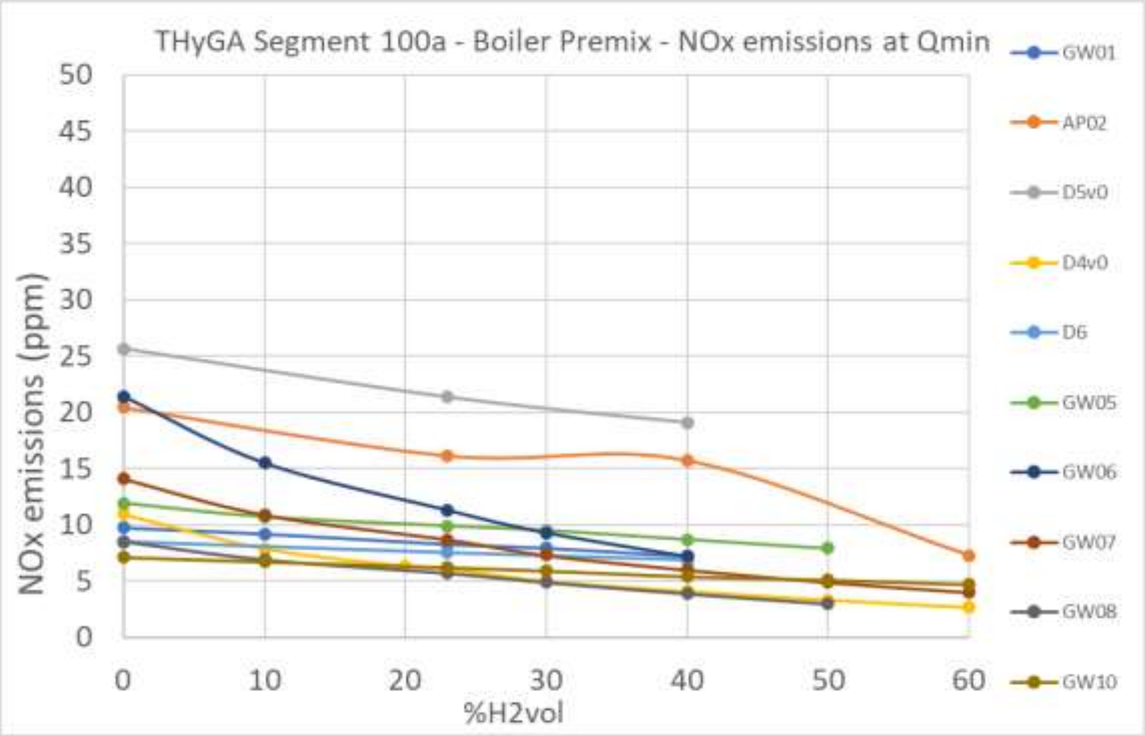


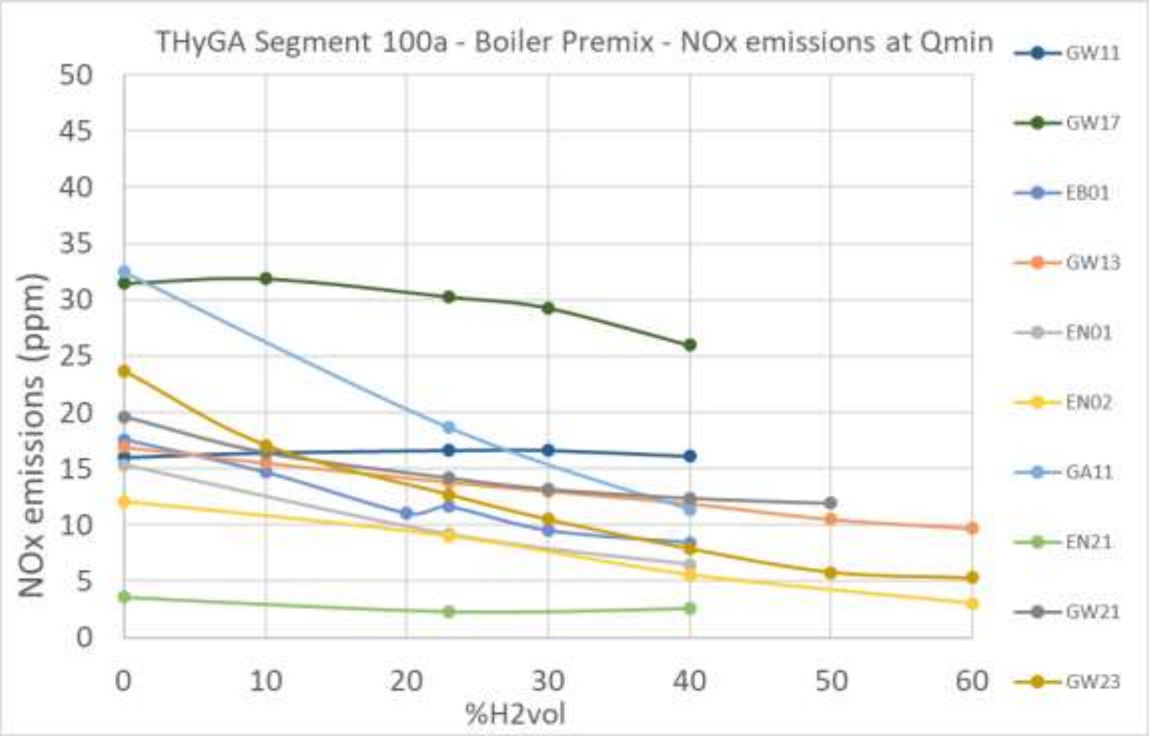


WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: other results

NOx Qmin

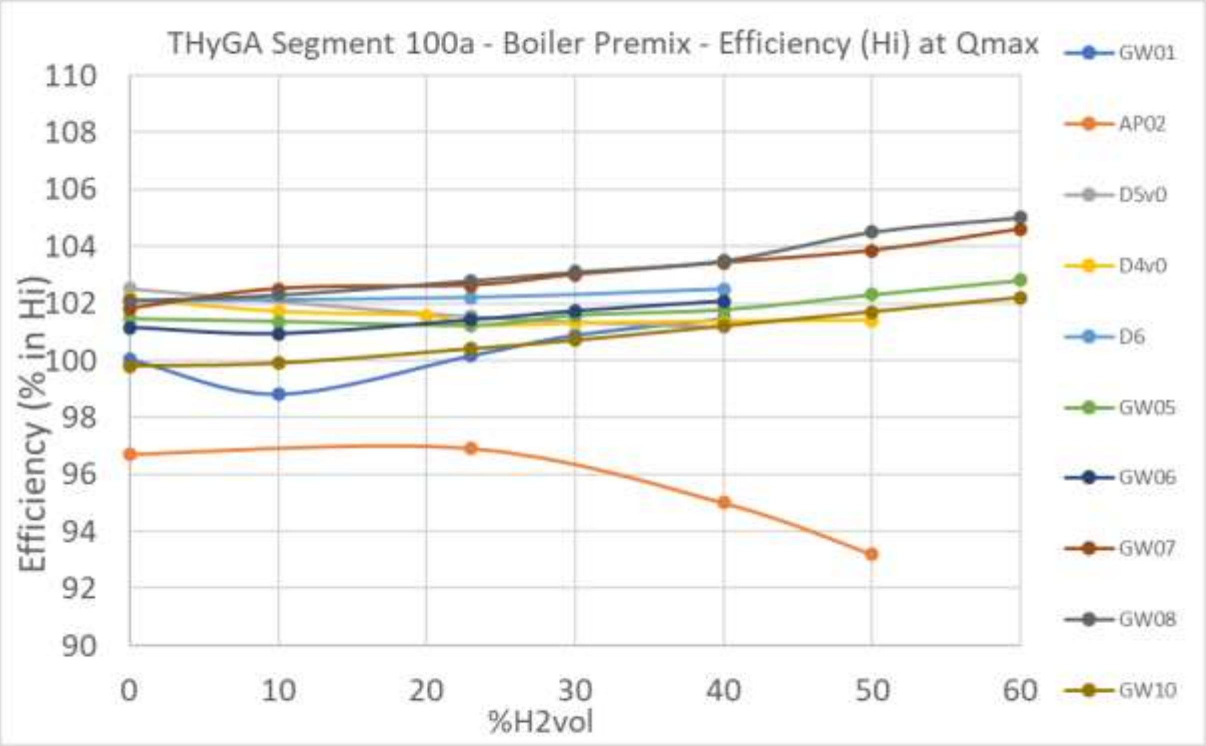


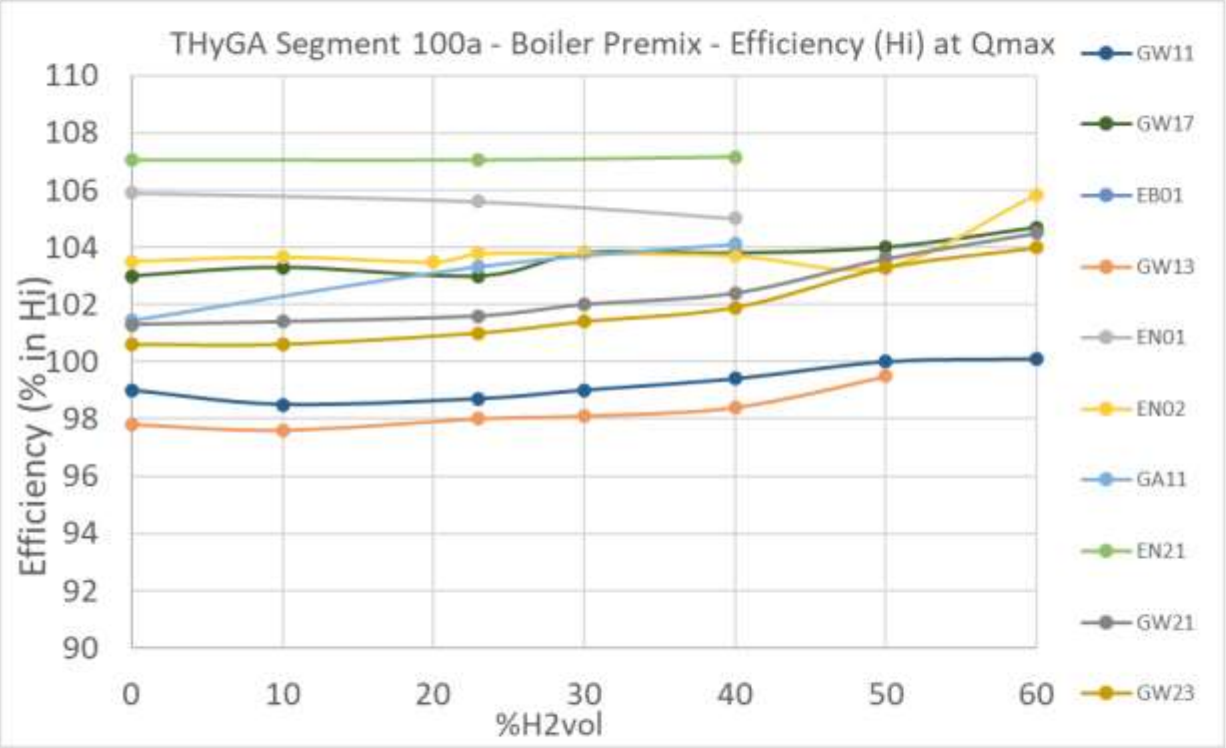


WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: other results

Eff. Qmax

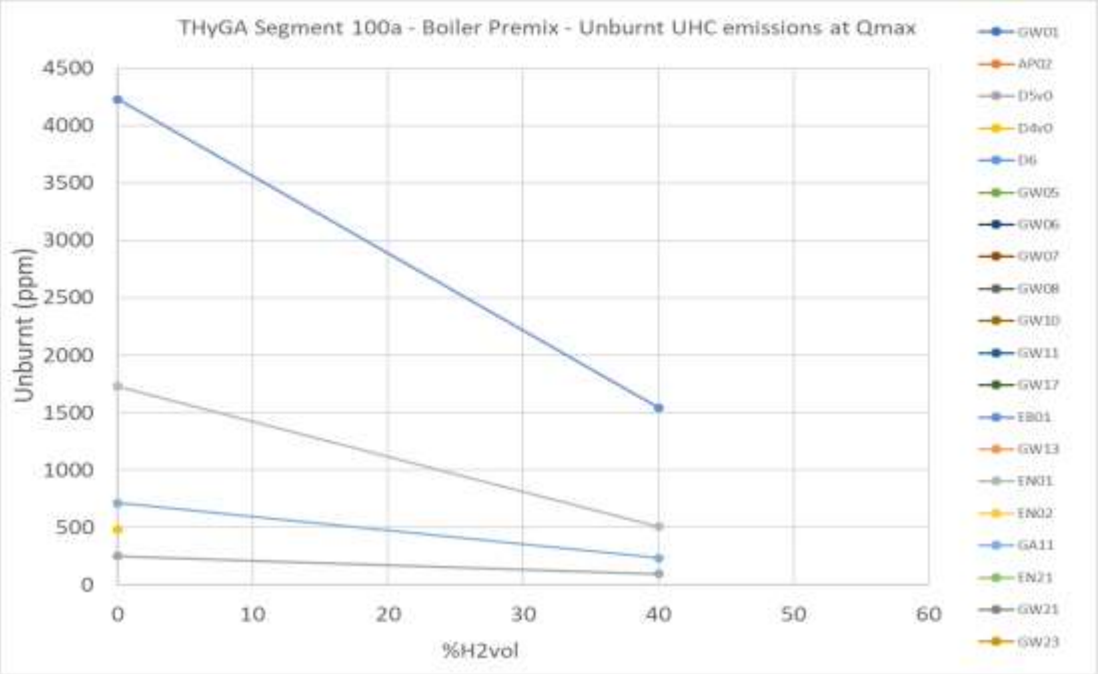




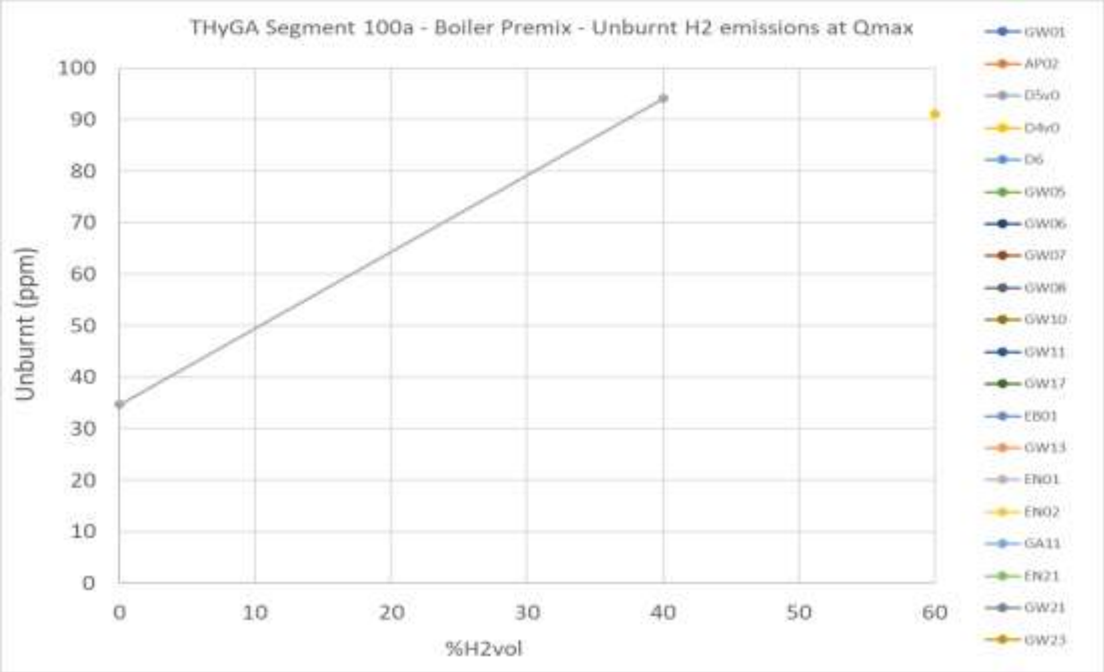
WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: other results

UHC emissions (mg/kWh for the operation conditions of the test)



H2 emissions (mg/kWh for the operation conditions of the test)



WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: conclusions (1/2)

(light green)	No issues
(pink)	Safety issues
(yellow)	Potential issue
(light grey)	Operational issue
(grey-blue)	Not tested extensively
(white)	Not tested

		H2 % Tested							
		0	0-10	10-20	20-23	23-30	30-40	40-50	50-60
100a Boilers fully premix	*Safety*			simple mitigation (3)	mitigation to be defined		5	8	11
	Safety with mitigation			Dedicated adjustment methodology			2	5	8
	Operational								

1. Possible issue already **at 20% H2 if adjustment is still allowed when H2 in the grid and present procedure is not changed** (= same CO2% or O2% as for NG).
2. Adjusting with O2 instead of CO2 may solve a great part of the issue
3. Not allowing adjustments in presence of H2 in the grid will resolve the problem and the tolerance will be increased to 40% H2
4. There can be operational issues starting between 30 and 40% H2 (cold or hot start, noise, etc.)

Flash back was only observed for very high H2 %

WP3 – Results for the short-term tests

Segment 100a Boilers fully premix: conclusions (1/2)

Other safety aspects which are not an issue

- **Flue pipe length** (tested with 4m and 8m long pipe) and external air temperature (down to 0C)
- **Quick variation between Qmin and Qmax**, does not seem to be a problem.
- **ROC** (PLUG FLOW test is performed by changing brutally gas composition coming to the tested appliance) (*but one result is in discussion*)
- **Gas pressure variations**, does not seem to be a problem, note that appliances are probably all equipped with pressure regulators.
- **Fluctuation of the auxiliary energy** was tested on 8 appliance, without impact on safety.
- The **influence of wind** on exhaust ducts was tested on 6 appliances (no impact).

WP3 – Results for the short-term tests

Segment 300a cookers domestic

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic → **Detailed result**
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

Segment 300a cookers domestic: appliances and % of H2 tested

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

Tested: reference gas + %H2 used		Appliance ID	D1	D2c	D7v02	D8v02	EB10v03	EN05v03	EN06v04	EN10v03	EN08v04	EN11V02	EN12aV02	EN12bV02	EN13	EN14	EN22
		Segment	301	301	301	301	301	301	301	301	301	301	301	301	301	301	301
		Qmin (kW)	0,76	0,48	0,67567568	0,31531532	0,6	0,33	0,75	0,33	1,2	1,2	0,5	0,5	not said	not said	not said
		Qmax (kW)	3	1	2,7027027	0,9009009	2,8	1	2,95	1	3,7	2,9	1	1	1	1,0	4
		Combustion control feature (Y/N)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		EU LOW	x	x	x												
		G23		x													
	%H2 in test gas	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		0-10			x												
		10-20															
		20-25			x	x	x	x	x	x	x	x	x	x	x	x	x
		25-30									x						
		30-40			x	x	x	x	x	x	x	x		x	x	x	x
		40-50	x														
		50-60	x	x													

Tested: reference gas + %H2 used		Appliance ID	D3	EB07V03	EB08v04	EB09v03	EB11v03	BS01	BS02	EN07v04	EN09v04	EB15V03	EB18V03	EN18	D9v02	D10v02	EN15
		Segment	301	301 & 302	303	303	303	303	303	303	303	304	304	309	311	311	311
		Qmin (kW)	1	0,41	0,3	0,3	0,33	1,64	1,64	4	1,4	1,2	0,5	not said	0,81081081	not relevant	not said
		Qmax (kW)	2,5	1,75	5	6,1	1,1	10,75	11,8	1,4	4	2,9	1	2,5	2,43243243	1,71171171	2,75
		Combustion control feature (Y/N)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		EU LOW	x	x		x						x	x				
		G23	x														
	%H2 in test gas	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		0-10															
		10-20															
		20-25		x	x	x	x	x	x	x	x	x	x	x	x	x	x
		25-30	x														
		30-40	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		40-50						x	x								
		50-60	x														

Some specificities for cooking appliances

- Several burners on a same hob (cookers, oven, grill…)
- Tests must be done individually, but also with all fires ignited which multiplies the number of tests

WP3 – Results for the short-term tests

Segment 300a cookers domestic: details of results for safety (1/2)

x	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
x	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
x	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

	Appliance ID		D1	D2c	D7v02	D8v02	EB10v03	EN05v03	EN06v04	EN10v03	EN08v04	EN11V02	EN12aV02	EN12bV02
	Segment		301	301	301	301	301	301	301	301	301	301	301	301
	Qmin (kW)		0,76	0,48	0,67567568	0,31531532	0,6	0,33	0,75	0,33	1,2	1,2	0,5	0,5
	Qmax (kW)		3	1	2,7027027	0,9009009	2,8	1	2,95	1	3,7	2,9	1	1
	Combustion control feature (Y/N)		N	N	N	N	N	N	N	N	N	N	N	N
CS	1.4 Cold start	CH4+40%H2		x		x	x	x	x	x	x (issue)	x	x	x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)			x	x	x					x		x
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2			NA	NA						NA		
FGP	1.7 Flue gas pipe length	CH4+30%H2			NA	NA	NA					NA		
ROC	1.8 ROC (Plug flow)	CH4+40%H2			x	x	x	x	x		x	x		x
FD	1.9 Impact H2 flame detection.		x	x	x	x								
FB	1.10 Flash back		x	x (issue)	x	x		x	x		x (issue)			
DI	4.1 Delayed ignition test.	CH4+30%H2			NA	NA						NA		
S	4.2 Soundness													
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2			x	x	x	x	x		x (issue)	x	x	x (issue)
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2								x				
4B	4.5 Cooker hob test with 4	CH4+30%H2			NA			x	x	x	NA	NA	NA	NA
W	4.6 Influence of wind													
LT	4.7 Long time (limited time)	depends on manufacturer					x	x	x	x	x	x	x	x
AUX	4.8 Fluctuation of the aux.													
P	4.9 Fluctuation of pressure	CH4+40%H2			x (potential issue)	x	x	x	x	x	x	x		x
O	Other /Operational													

	Appliance ID	EN13	EN14	EN22	D3	EB07V03	EB08v04	EB09v03	EB11v03	BS01	BS02	EN07v04	EN09v04	EB15V03	EB16V03	EN18	D9v02	D10v02	EN15
	Segment	301	301	301	301	301 & 302	303	303	303	303	303	303	303	304	304	309	311	311	311
	Qmin (kW)	not said	not said	not said	1	0,41	0,3	0,3	0,33	1,04	1,64	4	1,4	1,2	0,5	not said	0,81081081	not relevant	not said
	Qmax (kW)	3	1.0	4	2,5	1,75	5	6,1	1,1	10,75	11,8	1,4	4	2,9	1	2,5	2,43243243	1,71171171	2,73
	Combustion control feature (Y/N)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
CS	1.4 Cold start	x	x	x	x (issue)	x	x	x	x	x (issue)	x (issue)	x	x (issue)	x	x	x	x		x
HS	1.5 Hot start.	x	x	x	x (issue)	x	x	x (potential issue)	x					x (potential issue)	x	x	x	x	x
Lo T	1.6 Low air temperature (- 10 C)				x (issue)												NA		
FGP	1.7 Flue gas pipe length					NA	NA	NA	NA								NA		
ROC	1.8 ROC (Plug flow)	x	x	x		x	x (potential issue)	x (potential issue)	x			x		x	x	x	x		x
FD	1.9 Impact H2 flame detection.																x		
FB	1.10 Flash back				x (issue)		x (issue)			x (issue)	x (issue)	x	x (issue)				x		
DI	4.1 Delayed ignition test.																NA		
S	4.2 Soundness									x	x								
QV	4.3 Quick variation Qmin-Qmax	x	x	x		x	x	x	x	x (issue)	x (issue)	x		x	x	x			x
OH	4.4 Overheat. Meas. of temp.																		
4B	4.5 Cooker hob test with 4	x	x				x (potential issue)			NA	NA	x	x	x			NA		
W	4.6 Influence of wind																		
LT	4.7 Long time (limited time)	x	x	x		x	x (issue)	x (potential issue)	x			x	x	x	x	x			x
AUX	4.8 Fluctuation of the aux.													x	x				
P	4.9 Fluctuation of pressure	x (issue)	x (issue)	x	x	x	x	x	x			x	x	x	x	x	x (issue)		x
O	Other /Operational																		

The main issues observed (for H2 > 30%) are the following:

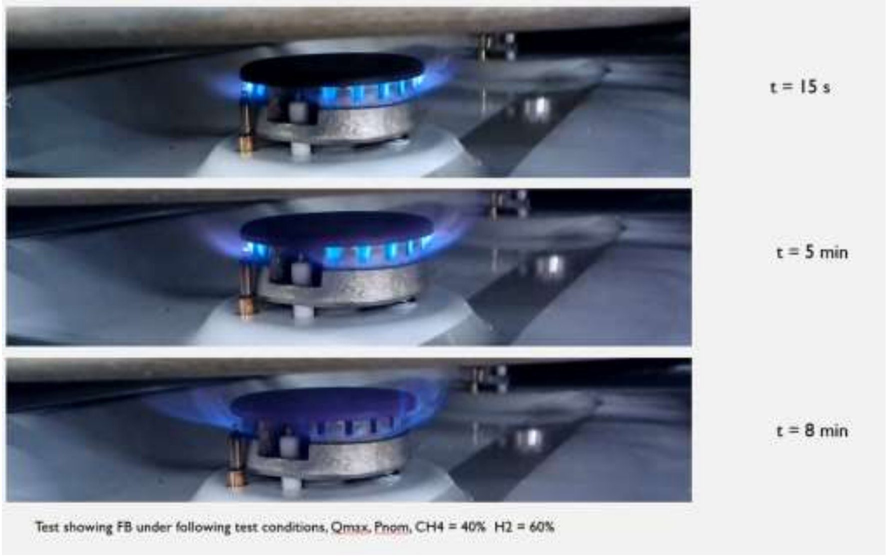
- Flash back (7 out of 25) (for H2 > 30/40%)
- Cold start with 40%H2 (1)
- Hot start (3)
- Quick variation of heat input (4)
- Issue when 4 burners are on (1)
- Issue with pressure change (2)

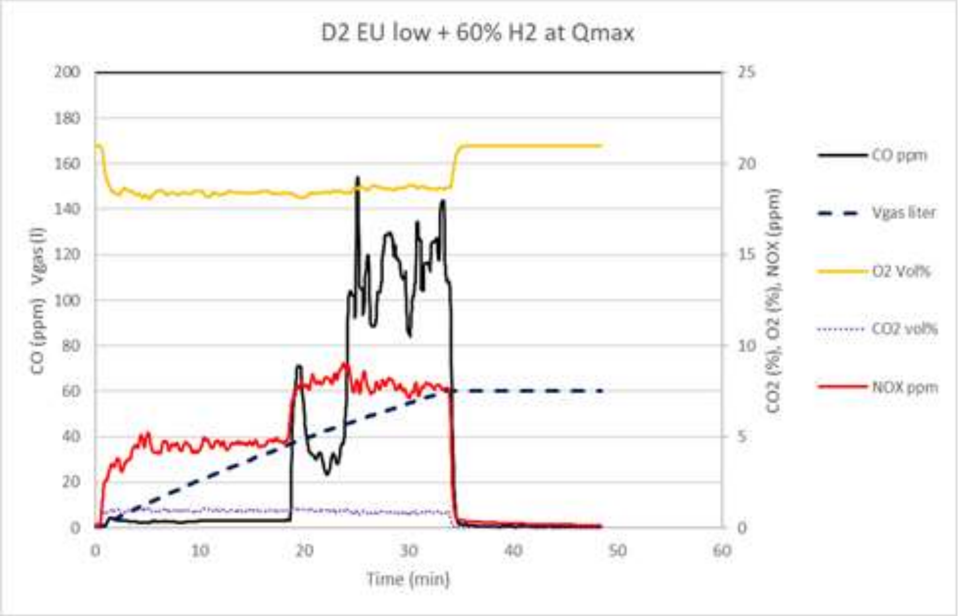
WP3 – Results for the short-term tests

Segment 300a cookers domestic: details of results for safety (2/2)

Flashback:

- Flashback was observed during efficiency test with 40 & 60% H2 after **long running time of the cooker** (50 minutes or so). In some cases (with 60% H2) it has resulted in damages making the rest of the test impossible
- **Present CEN procedures for flash back shall be adapted to H2**



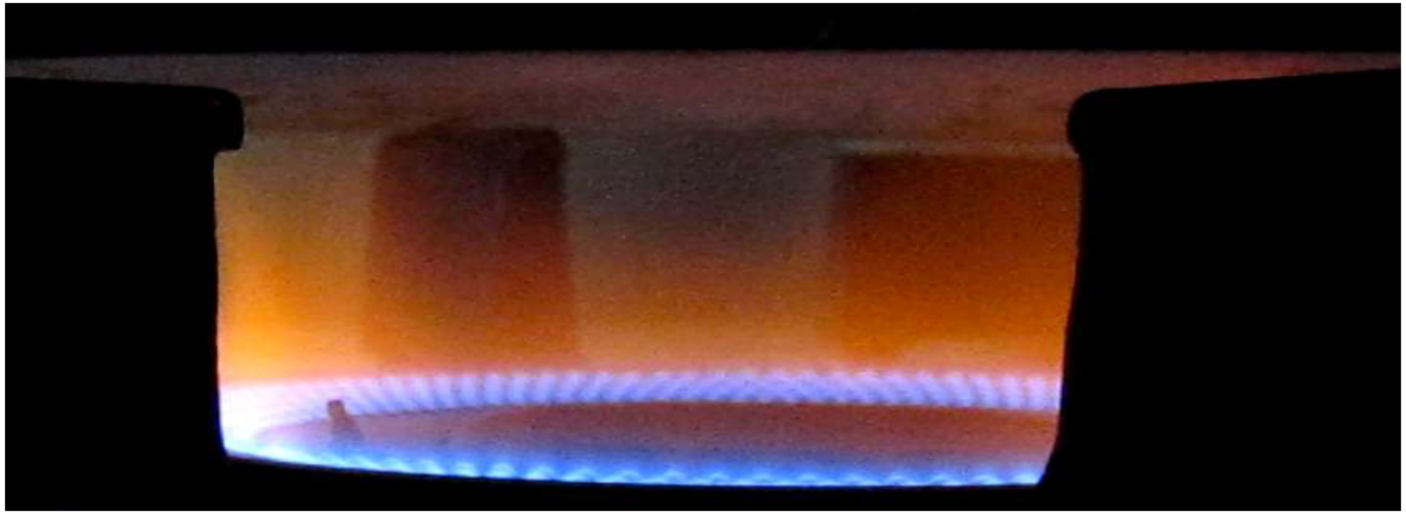


WP3 – Results for the short-term tests

Segment 300a cookers domestic: flame aspects (1/2)

Yellow flame during test of several hours

- **Flame instability** and change of aspect observed with 40% H_2 (EB15V03)

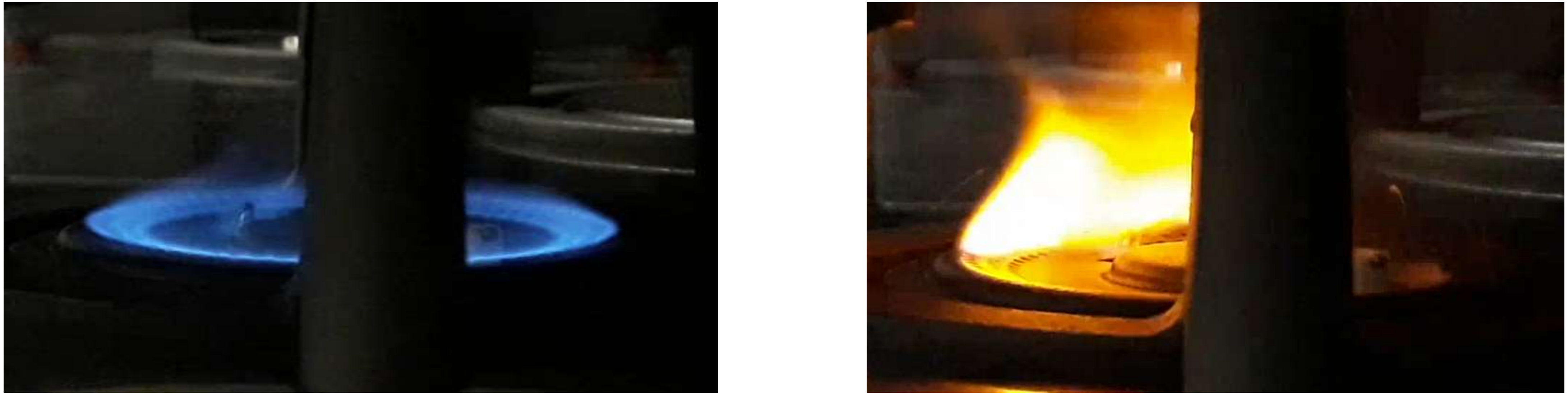


WP3 – Results for the short-term tests

Segment 300a cookers domestic: flame aspects and other observations (2/2)

Water condensates that create partial extinction

- With hydrogen and cold water in the pan, **condensation appears on the bottom of the pan**.
- When the droplets hits the burner, it causes a partial extinction of the flame. The flame turns orange for a few seconds and becomes blue again when water has fully evaporated.

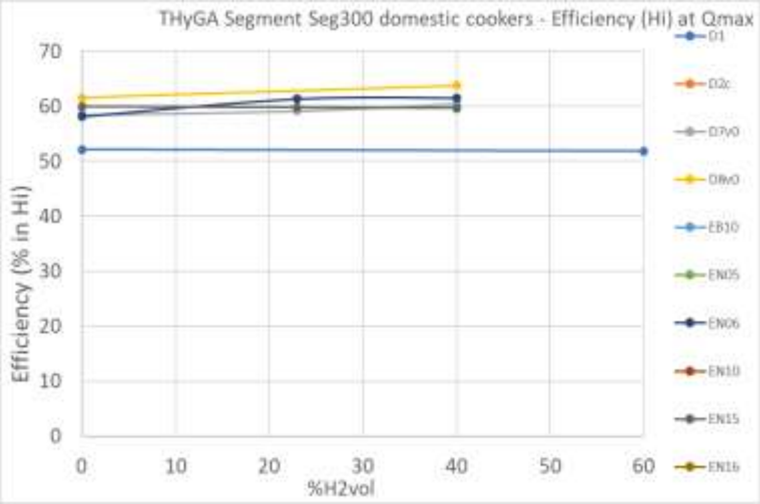


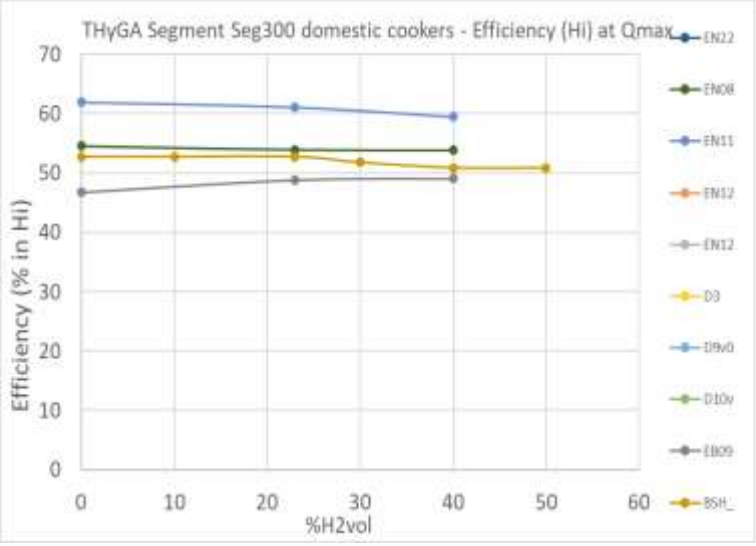
EN12 burner under normal operation and with water falling into the flame

WP3 – Results for the short-term tests

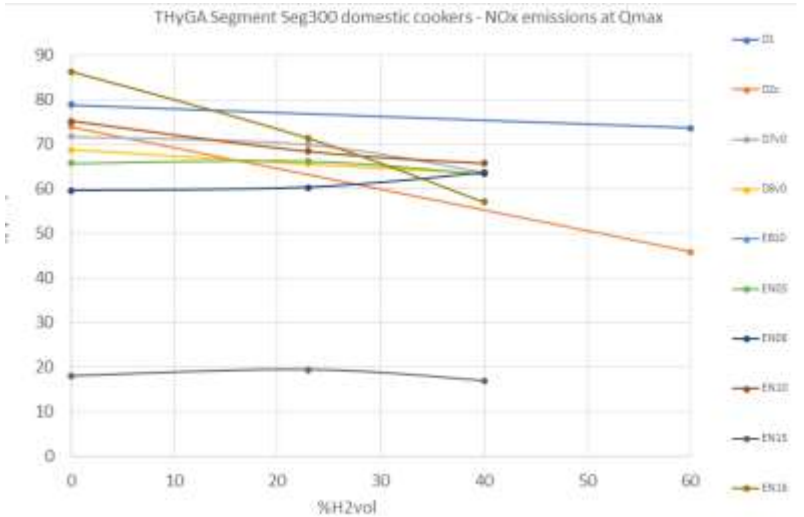
Segment 300a cookers domestic: other results (1/3)

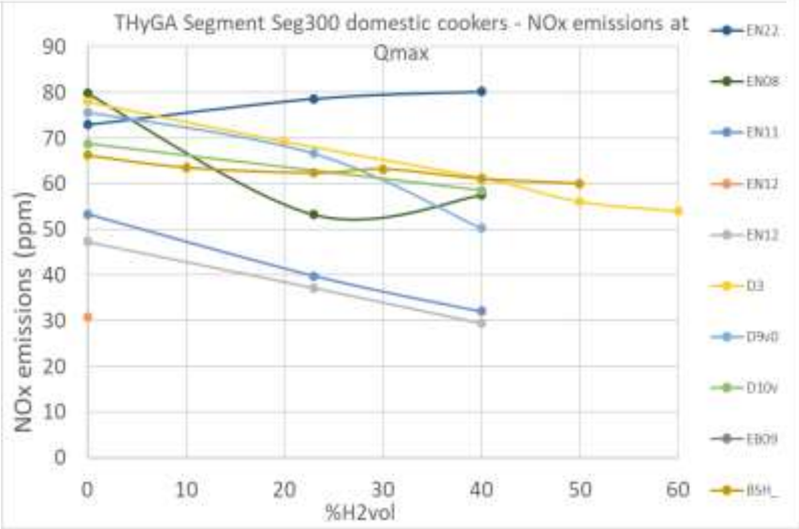
Efficiency



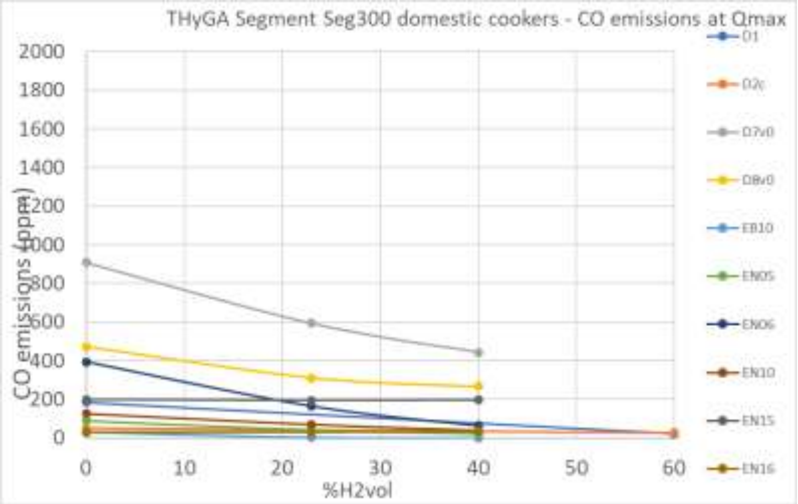


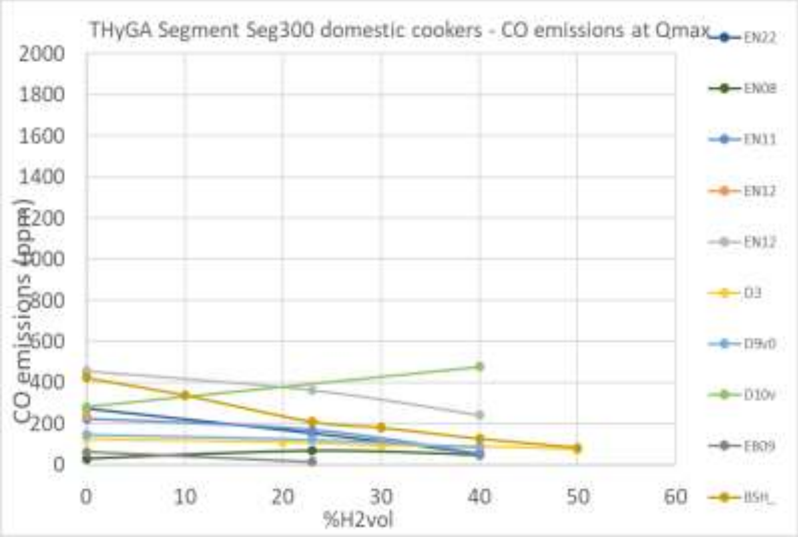
NOx





CO



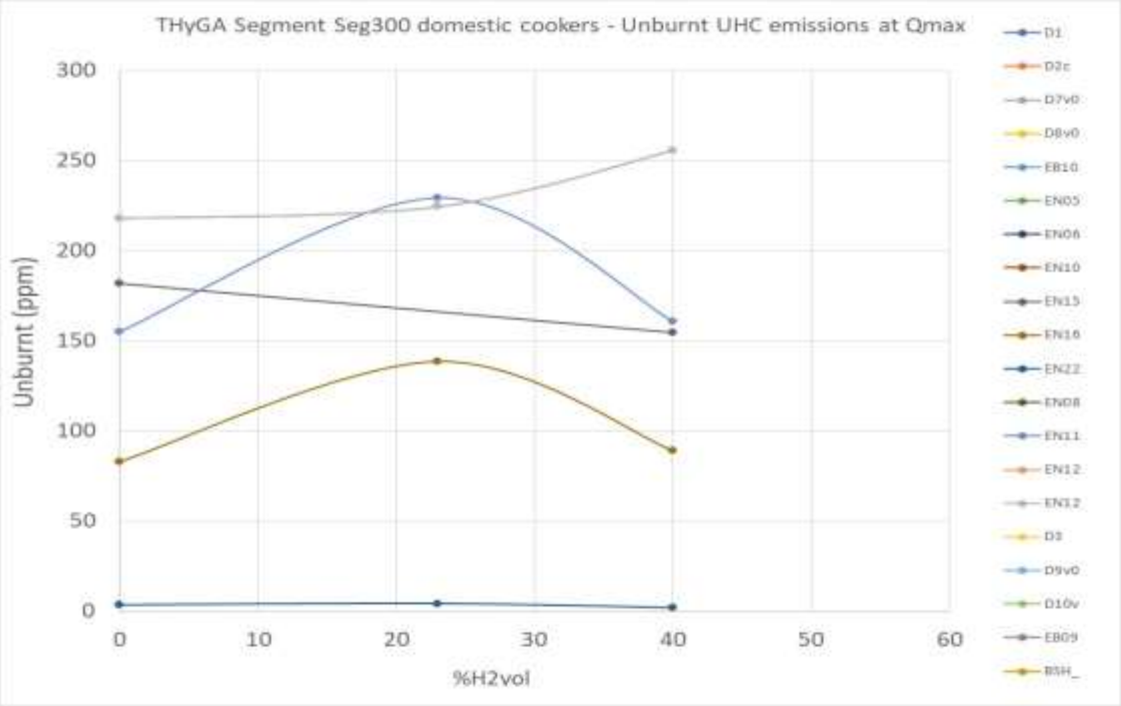


THyGA
D3.8

WP3 – Results for the short-term tests

Segment 300a cookers domestic: other results (2/3)

UHC emissions (mg/kWh for the operation conditions of the test)

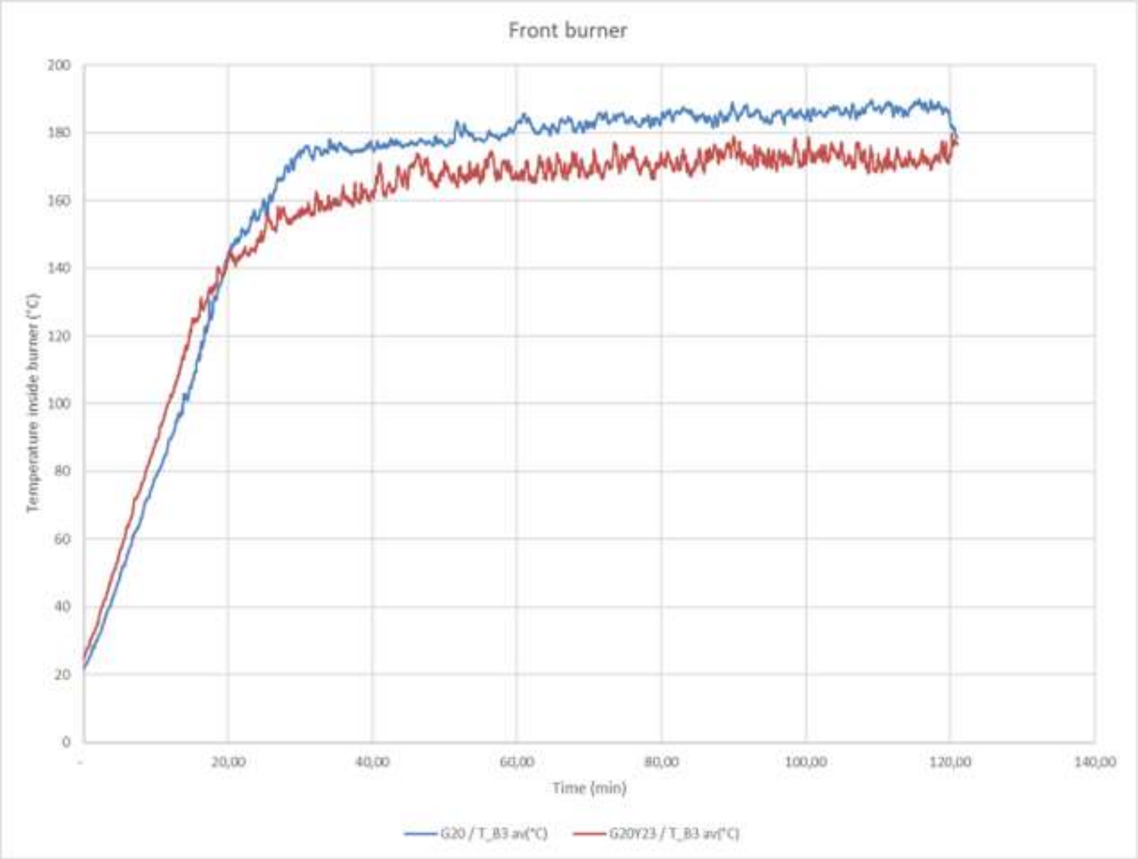


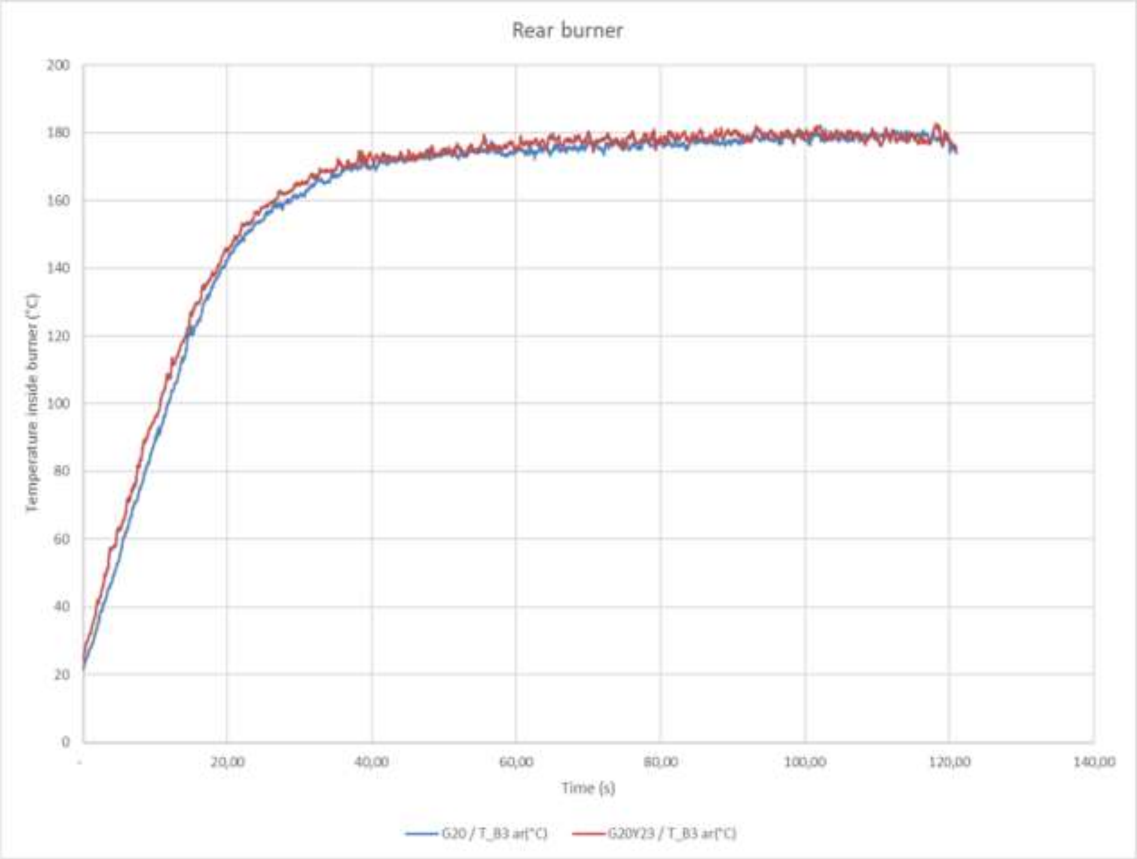
THyGA
D3.8

WP3 – Results for the short-term tests

Segment 300a cookers domestic : other results (3/3)

Temperature at burner surface- Cooking hobs EN08





WP3 – Results for the short-term tests

Segment 100b Boilers other

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- **100b Boilers other**
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

100b Boilers other: Discussion of the segment group results

			GA01	EN03V01	GA16v01	EB02v04	GW02V04	GW03V04	GW04V04	GW12V03	GW16V01	BA01	GW18
	Segment		101	101	102	102	102	103	105	107	107	107	109
	Qmin (kW)		11	0	na	12	8,9	0	12	15	9,1	10,6	29
	Qmax (kW)		25,8	34,87	27,5	26,5	22,2	17	22,2	25	22,6	24,8	232
	Combustion control feature (Y/N)		N	N	N	Y	N	N	N	N	N	Y	Y
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x	x
		EU LOW	x		x							x	
		G23	(*)				x	x	x		x		
	%H2 in test gas	0		x	x	x	x	x	x	x	x	x	x
		0-10		x		x	x			x		x	
		10-20		x		x	x					x	
		20-23		x		x	x	x	x	x	x	x	x
		23-30		x		x	x		x	x		x	
		30-40		x	x	x	x	x	x	x	x	x	x
		40-50	x			x	x	x	x	x	x	x	
		50-60				x		x	x	x	x	x	x
CS	1.4 Cold start	CH4+40%H2		x	x	x	x	x	x		x	x	x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)		x	x	x	x	x	x		x	x	x
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2					x						
FGP	1.7 Flue gas pipe length	CH4+30%H2										x	
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x	x	x	x	x		x		x	x	x
FD	1.9 Impact H2 flame detection.		x	x	x	x	x	x				x	x
FB	1.10 Flash back		x	x	x	x		x			x	x	
DI	4.1 Delayed ignition test.	CH4+30%H2										x	
S	4.2 Soundness												
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2	x		x								
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2			x								
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA			NA		NA	NA	NA	NA
W	4.6 Influence of wind												
LT	4.7 Long time (limited time)	depends on manufacturer		x	x	x							
AUX	4.8 Fluctuation of the aux.				x							x	
P	4.9 Fluctuation of pressure	CH4+40%H2	x		x			x	x		x	x	x
O	Other /Operational				x			x					

(*) performed without H2

x	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
x	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
x	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

Open discussion – Not final results

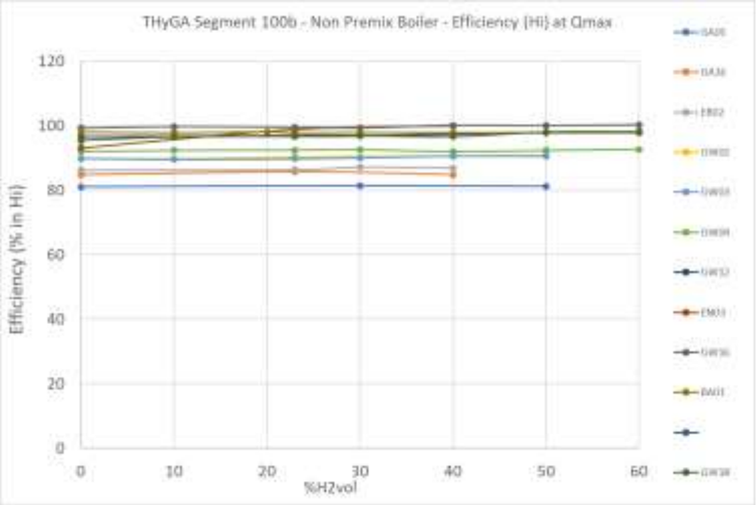
- **Cold start (1) at 60 % H2**
- **Hot start (1) at 40% H2**
- **Flash back (3) at 40%**

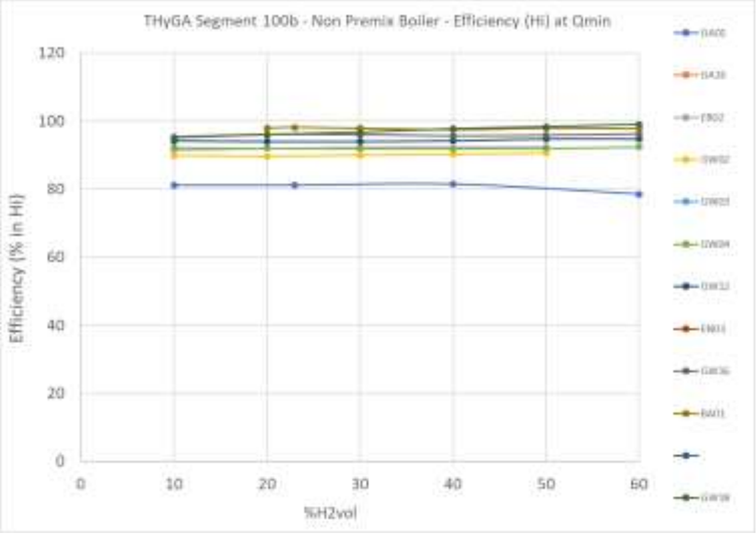
No issue below 40%

WP3 – Results for the short-term tests

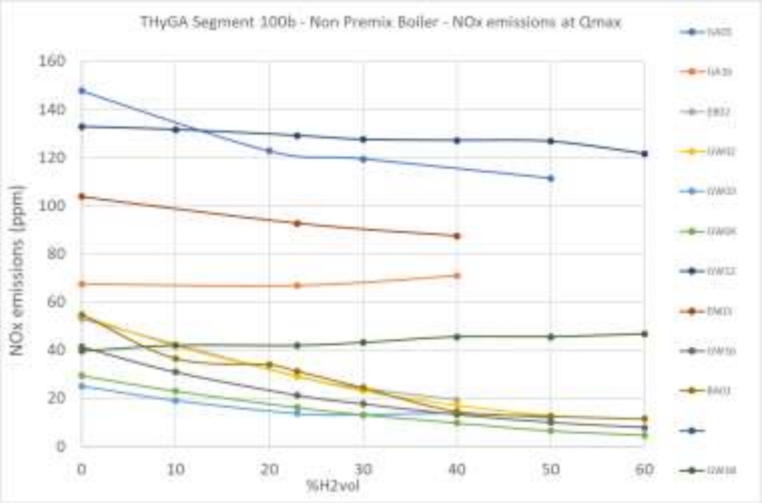
100b Boilers other: Discussion of the segment group results

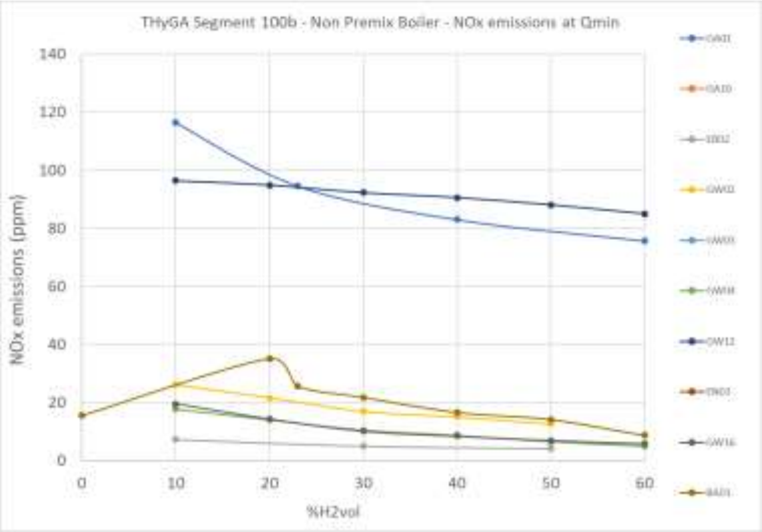
Efficiency





NOx





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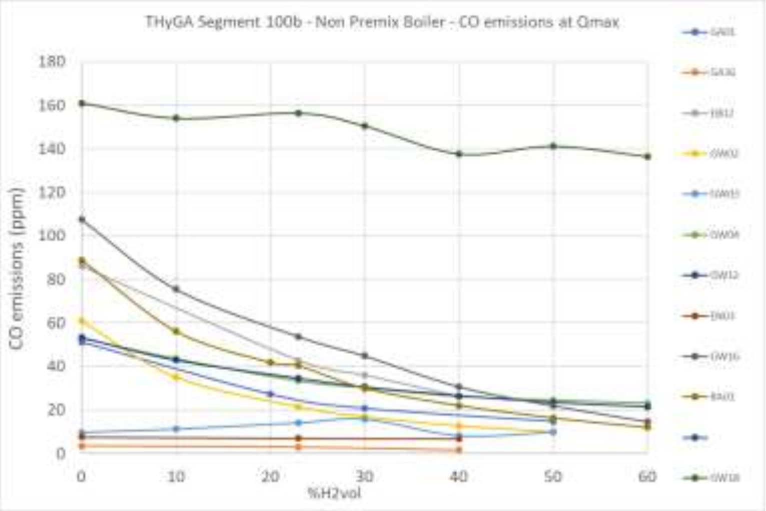
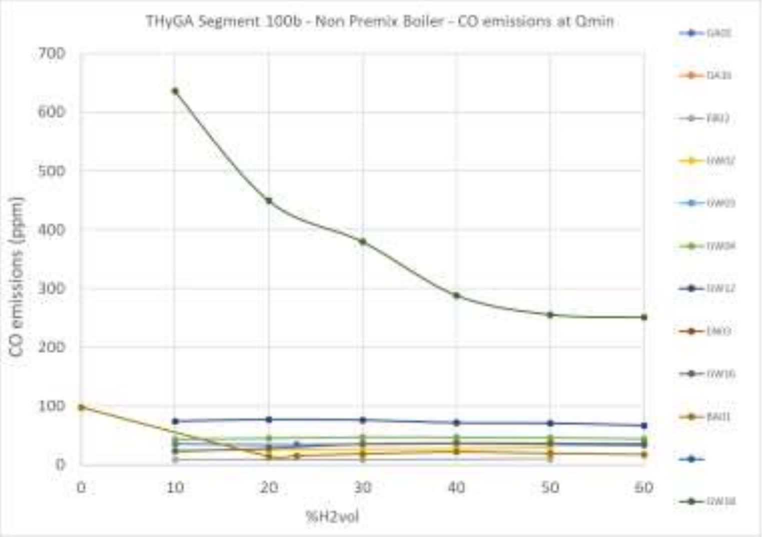




WP3 – Results for the short-term tests

Segment 200 water heaters

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

200 Water heaters: Discussion of the segment group results

			GA09V03	GA10v01	GW14V01	GW19	GA05
	Appliance ID		GA09V03	GA10v01	GW14V01	GW19	GA05
	Segment		201	201	201	201	201
	Qmin (kW)		5,3	5,3	5,3	5,3	5,3
	Qmax (kW)		10,5	10,5	10,5	10,5	10,5
	Combustion control feature (Y/N)		N	N	N	N	N
Tested: reference gas + %H2 used	Reference gas	CH4	X	X	X	X	X
		EU LOW					X
		G23			X	X	
	%H2 in test gas	0	X	X	X	X	X
		0-10			X	X	(*)
		10-20					
		20-23	X	X	X	X	
		23-30			X	X	
		30-40	X	X	X	X	X
		40-50			X		
		50-60			X		
CS	1.4 Cold start	CH4+40%H2	X	X	X	X	X
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	X	X	X	X	
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2					
FGP	1.7 Flue gas pipe length	CH4+30%H2					
ROC	1.8 ROC (Plug flow)	CH4+40%H2	X	X	X	X	X
FD	1.9 Impact H2 flame detection.		X	X	X		X
FB	1.10 Flash back		X				X
AD_A	3.1 Adjustment A	EU HighEU Low+H2	NA	NA	NA	NA	NA
AD_B	3.2 Adjustment B	EU lowEU high+H2	NA	NA	NA	NA	NA
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2	NA	NA	NA	NA	NA
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	NA	NA	NA	NA	NA
DI	4.1 Delayed ignition test.	CH4+30%H2					
S	4.2 Soundness						
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2		X			X
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2					
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA	NA		NA	NA
W	4.6 Influence of wind						X
LT	4.7 Long time (limited time)	depends on manufacturer					
AUX	4.8 Fluctuation of the aux.		NA				
P	4.9 Fluctuation of pressure	CH4+40%H2	X	X	X	X	X
O	Other /Operational		X				

(*) Issue with CH4 test and H2 test

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

Open discussion – Not final results

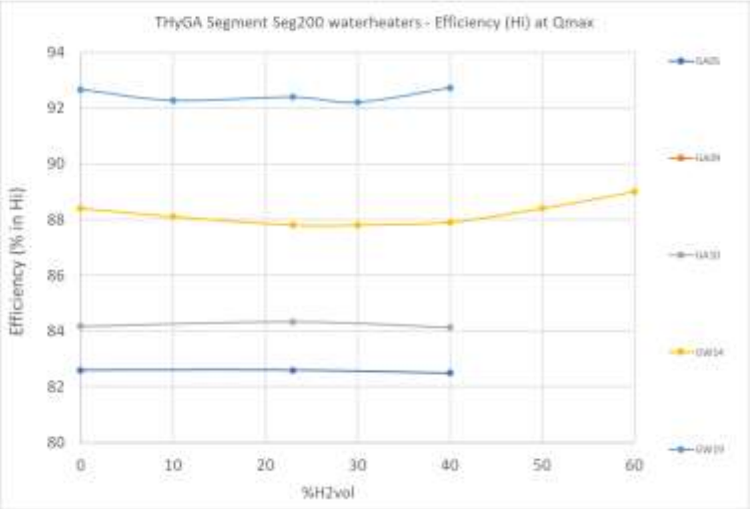
- **Appliance not Conform with CH4: will not be used for the conclusion**

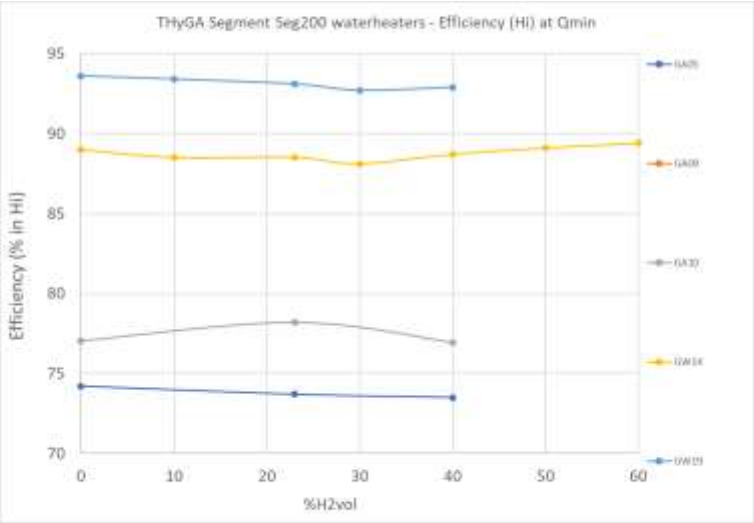
No premix appliances on this list.

WP3 – Results for the short-term tests

200 Water heaters: Discussion of the segment group results

Efficiency





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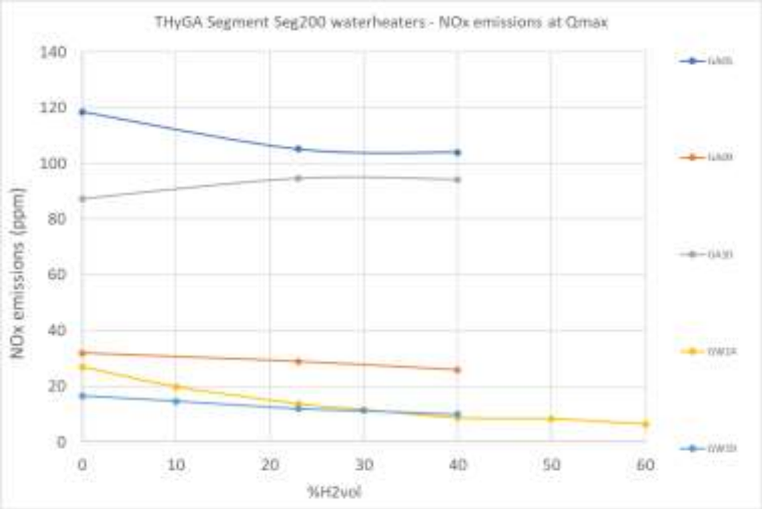

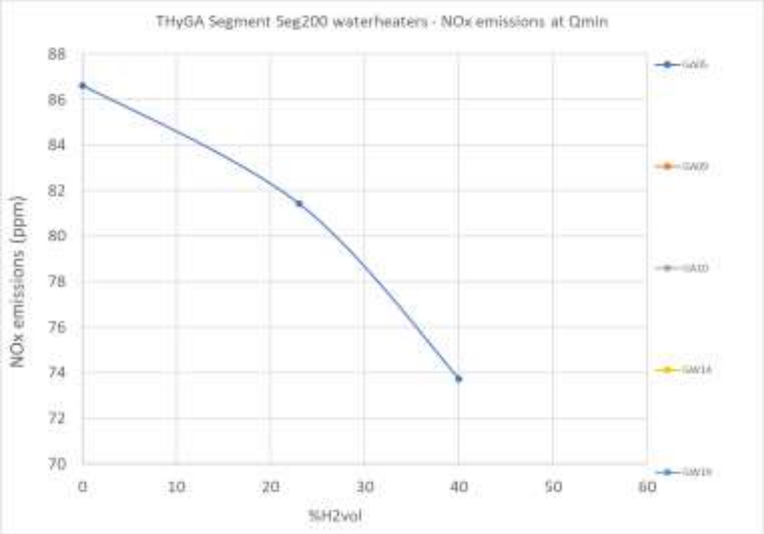

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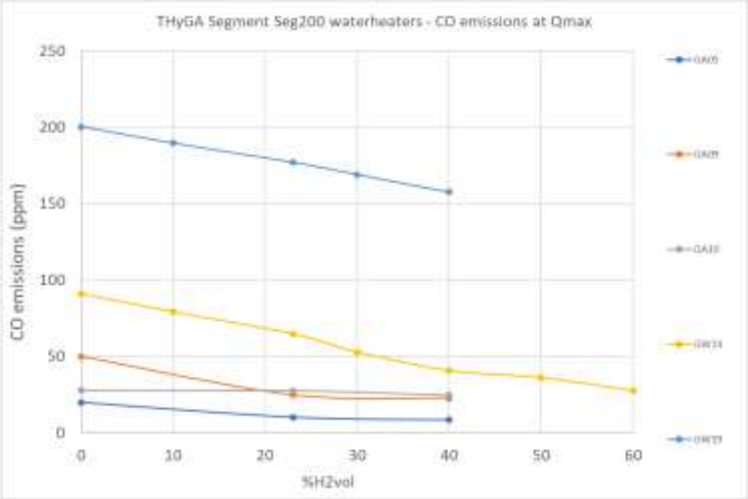
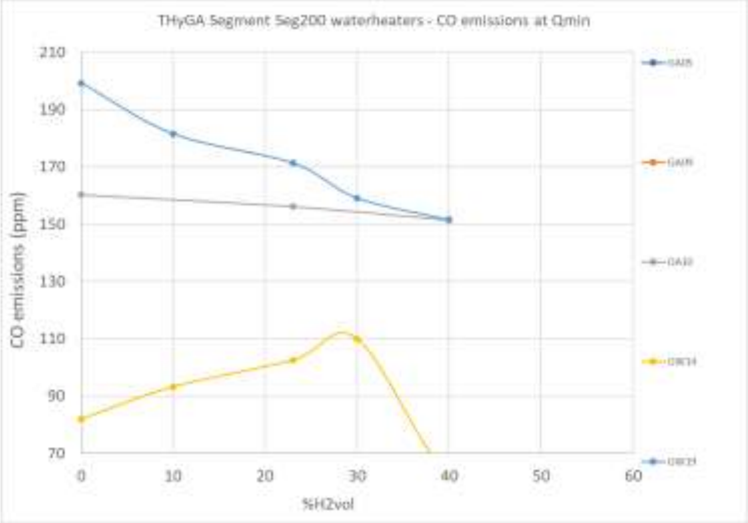




WP3 – Results for the short-term tests

Segment 400 catering equipment

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- **400 Catering equipment**
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

400a Catering equipment- PREMIX: Discussion of the segment group results

	Appliance ID		EB22V01	EB23V01	EB24V01	EB19V02	EB20V02	EB03v03	EB17v01	GA04	EB18v01	EB21V01
	Segment		402	402	404	404	404	404	405	406	409	410
	Qmin (kW)		2	1	-	5	5	NA	3	16	-	12
	Qmax (kW)		7	3,5	6	13	13	19	20	31	10,8	20
	Combustion control feature (Y/N)		N	N	N	Y	Y	N	N	Y	N	N
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x	x	x
		EU LOW	x	x	x	x	x		x	x	x	x
		G23										
	%H2 in test gas	0	x	x	x	x	x	x	x		x	x
		0-10				x	x	x				
		10-20				x	x	x		x		
		20-23	x	x	x	x	x	x	x	x	x	x
		23-30	x	x	x	x	x	x			x	x
		30-40	x	x	x	x	x	x	x		x	x
		40-50										
		50-60										
CS	1.4 Cold start	CH4+40%H2	x	x	x	x	x	x	x	x	x	x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	x	x	x	x	x	x	x	x	x	x
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2										
FGP	1.7 Flue gas pipe length	CH4+30%H2										
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x	x	x	x	x		x	x	x	x
FD	1.9 Impact H2 flame detection.					x	x		x	x		
FB	1.10 Flash back									x		
AD_A	3.1 Adjustment A	EU HighEU Low+H2						NA		x		
AD_B	3.2 Adjustment B	EU lowEU high+H2						NA		x		
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2						NA				
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2				x	x	NA		x		
DI	4.1 Delayed ignition test.	CH4+30%H2										
S	4.2 Soundness											
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2	x	x	x				x	x		x
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2										
4B	4.5 Cooker hob test with 4	CH4+30%H2	x	NA	NA	x			NA	NA	NA	
W	4.6 Influence of wind											
LT	4.7 Long time (limited time)	depends on manufacturer	x	x	x	x	x	x	x		x	x
AUX	4.8 Fluctuation of the aux.					x	x		x			x
P	4.9 Fluctuation of pressure	CH4+40%H2	x	x	x	x	x		x	x	x	x
O	Other /Operational											

x	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
x	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
x	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

Open discussion – Not final results

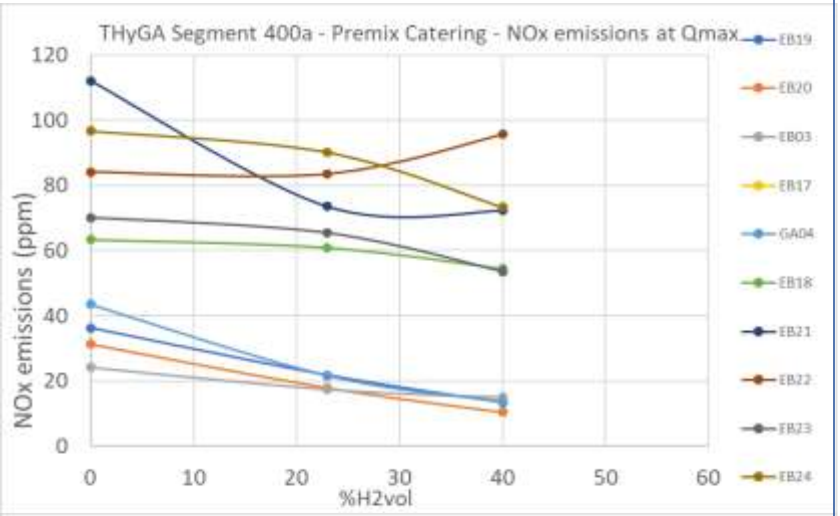
- **Adjustment (3)**

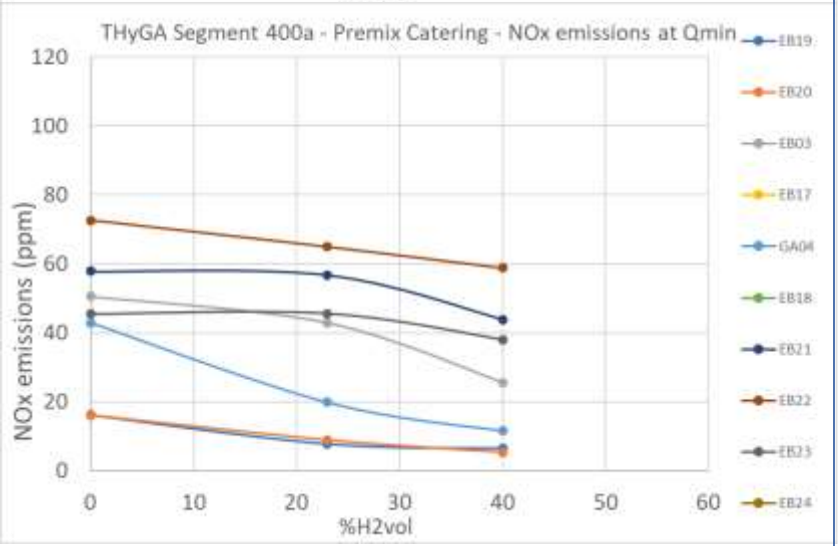
WP3 – Results for the short-term tests

400a Catering equipment PREMIX: Discussion of the segment group results

Efficiency

NOx





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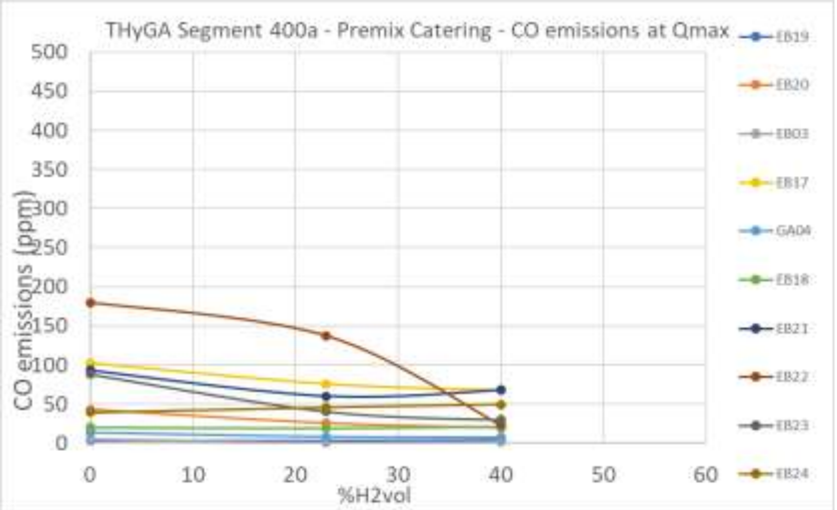
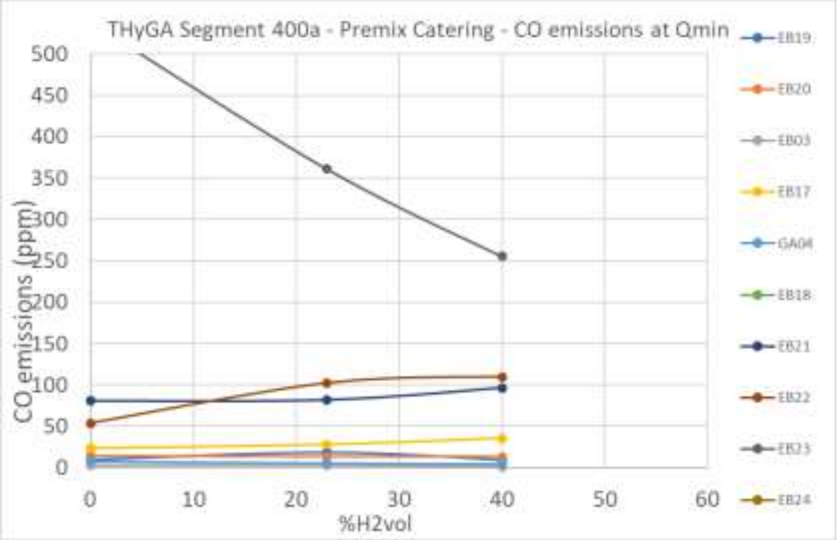




THyGA

WP3 – Results for the short-term tests

400b Catering equipment- NOT PREMIX: Discussion of the segment group results

			EB14v01	EB04v04	EB05v04	GA17v03	GA03	EB06v03
	Appliance ID		EB14v01	EB04v04	EB05v04	GA17v03	GA03	EB06v03
	Segment		401	402	402	406	407	408
	Qmin (kW)		4,15	1,55	2,5	na	Not specified	NA
	Qmax (kW)		12	6	10	15	5,9	21
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x
		EU LOW	x			x	x	x
		G23						
	%H2 in test gas	0	x	x	x	x	x	x
		0-10	x	x	x			x
		10-20		x	x			x
		20-23	x	x	x	x	x	x
		23-30	x	x	x	x		x
		30-40	x	x	x	x	x	x
		40-50						
		50-60						
CS	1.4 Cold start	CH4+40%H2	x	x	x	x	x	x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	x	x	x	x	x	x
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2						
FGP	1.7 Flue gas pipe length	CH4+30%H2						
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x	x	x	x	x	x
FD	1.9 Impact H2 flame detection.					x	x	
FB	1.10 Flash back			x	x	x	x	
AD_A	3.1 Adjustment A	EU HighEU Low+H2	NA	NA	NA	NA	NA	NA
AD_B	3.2 Adjustment B	EU lowEU high+H2	NA	NA	NA	NA	NA	NA
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2	NA	NA	NA	NA	NA	NA
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	NA	NA	NA	NA	NA	NA
DI	4.1 Delayed ignition test.	CH4+30%H2						
S	4.2 Soundness					x		
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2	x	x	x	x	x	
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2						
4B	4.5 Cooker hob test with 4	CH4+30%H2		x	x	NA	NA	NA
W	4.6 Influence of wind					x	x	
LT	4.7 Long time (limited time)	depends on manufacturer	x	x	x			x
AUX	4.8 Fluctuation of the aux.		x					x
P	4.9 Fluctuation of pressure	CH4+40%H2	x			x	x	x
O	Other /Operational					x		x

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

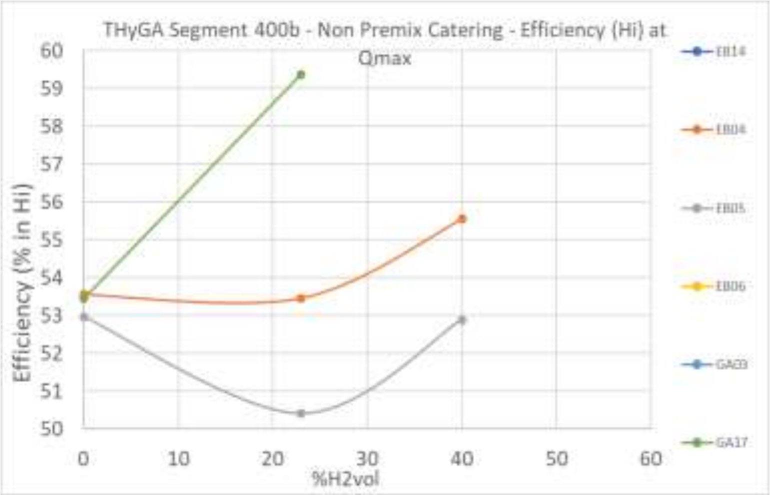
Open discussion – Not final results

- **Flashback at 30%**

WP3 – Results for the short-term tests

400b Catering equipment- NOT PREMIX : Discussion of the segment group results

Efficiency



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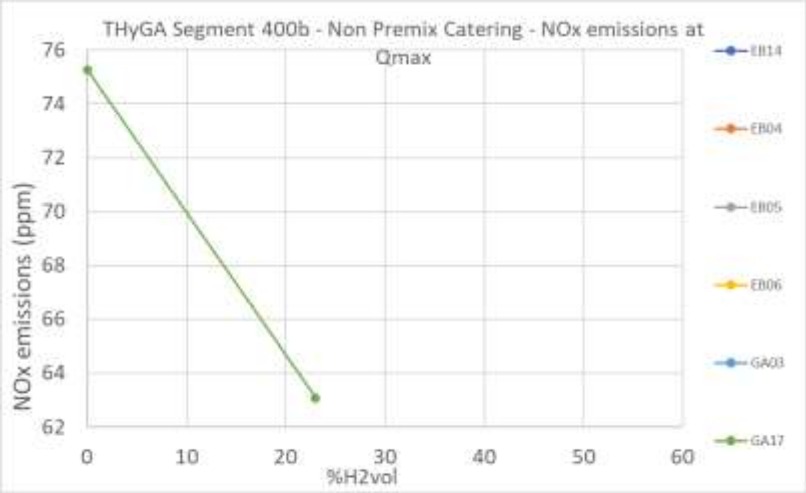

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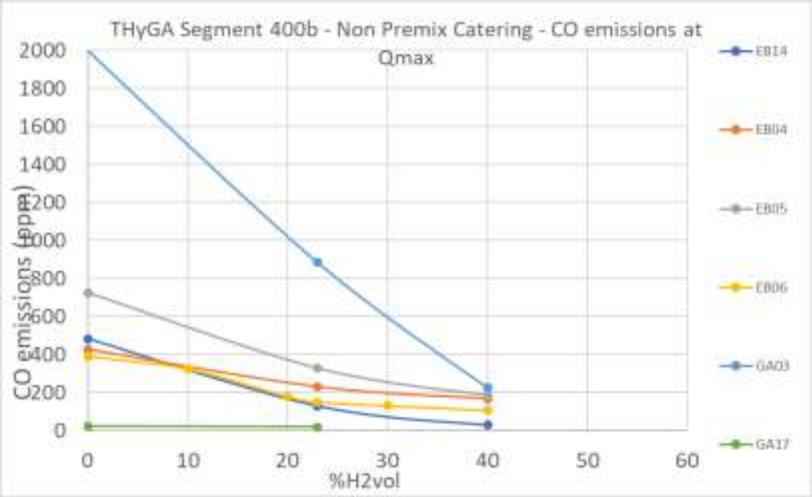
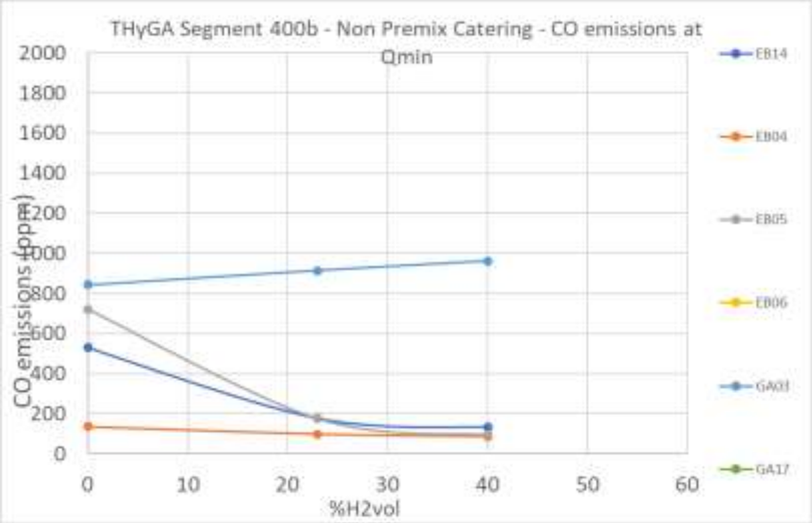




WP3 – Results for the short-term tests

Segment 500 space heaters

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- **500 Space Heaters**
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

500 Space Heaters: Discussion of the segment group results

			GA02	GA07v03	GA08v02	GA06V03
	Appliance ID		GA02	GA07v03	GA08v02	GA06V03
	Segment		503	503	504	507
	Qmin (kW)		3,1	Not specified	3,3	NA
	Qmax (kW)		5,8	10,2	10	5,36
	Combustion control feature (Y/N)		N	NA	N	N
Tested: reference gas + %H2 used	Reference gas	CH4	X	X	X	X
		EU LOW		X		
		G23				
	%H2 in test gas	0	X	X	X	X
		0-10	X	X		X
		10-20	X			
		20-23	X	X	X	
		23-30	X	X		
		30-40	X	X	X	X
		40-50	X		X	X
		50-60	X		X	X
CS	1.4 Cold start	CH4+40%H2		X	X	X
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)			X	X
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2		X		
FGP	1.7 Flue gas pipe length	CH4+30%H2		X		
ROC	1.8 ROC (Plug flow)	CH4+40%H2		X	X	X
FD	1.9 Impact H2 flame detection.		X	X		X
FB	1.10 Flash back				X	X
AD_A	3.1 Adjustment A	EU HighEU Low+H2		NA	NA	
AD_B	3.2 Adjustment B	EU lowEU high+H2		NA	NA	
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2		NA	NA	
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	X	NA	NA	X
DI	4.1 Delayed ignition test.	CH4+30%H2				
S	4.2 Soundness					
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2				NA
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2				
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA	NA
W	4.6 Influence of wind					
LT	4.7 Long time (limited time)	depends on manufacturer				
AUX	4.8 Fluctuation of the aux.					
P	4.9 Fluctuation of pressure	CH4+40%H2			X	X
O	Other /Operational		X		X	

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

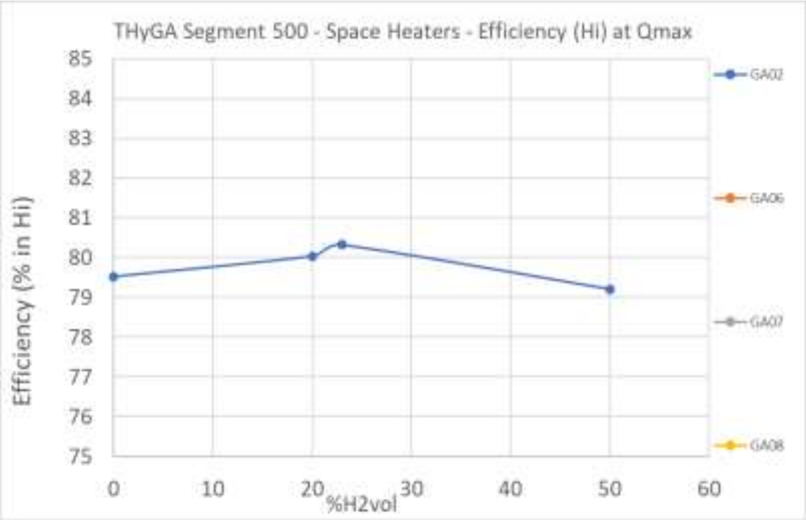
Open discussion – Not final results

- **Flashback (from 40%)**

WP3 – Results for the short-term tests

500 Space Heaters: Discussion of the segment group results

Efficiency



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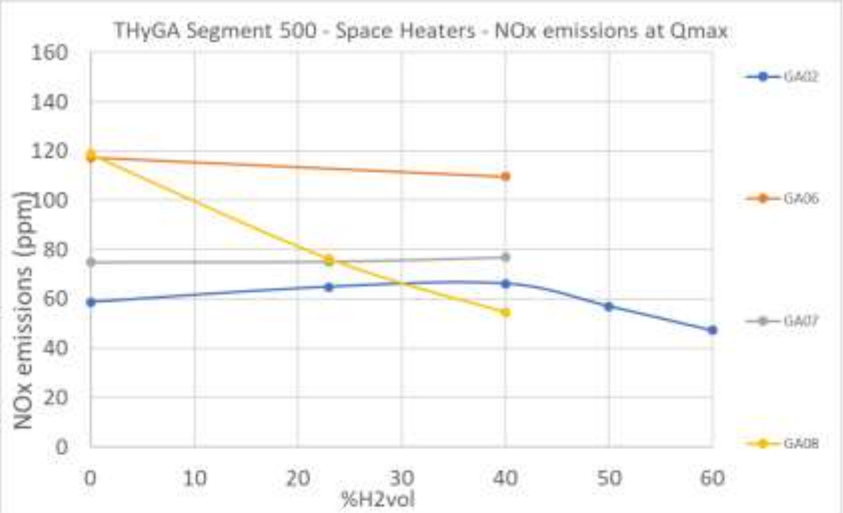

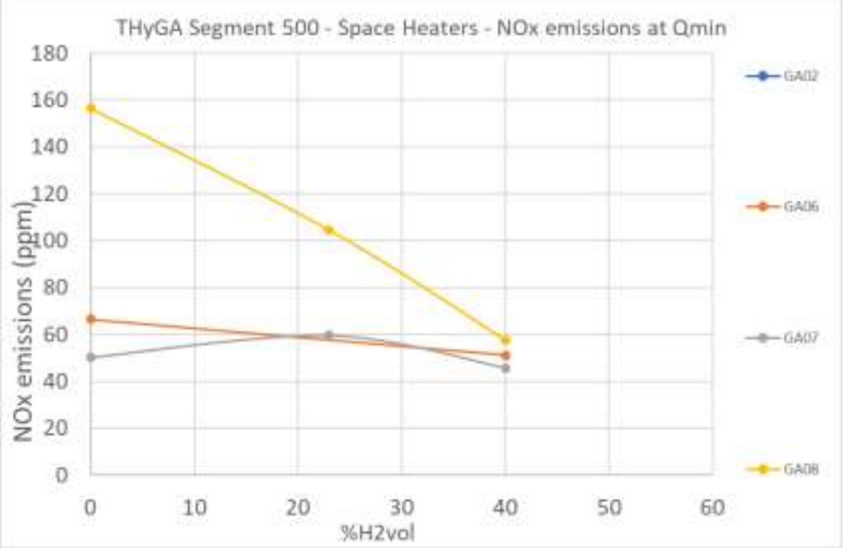

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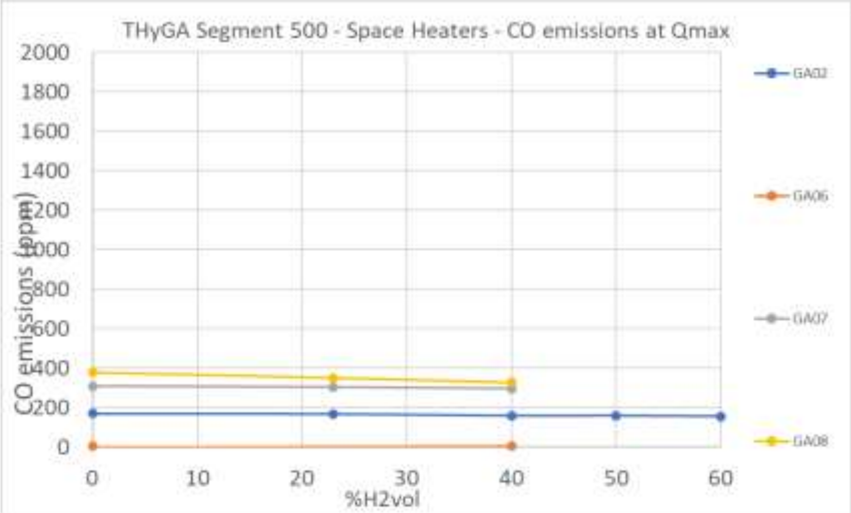
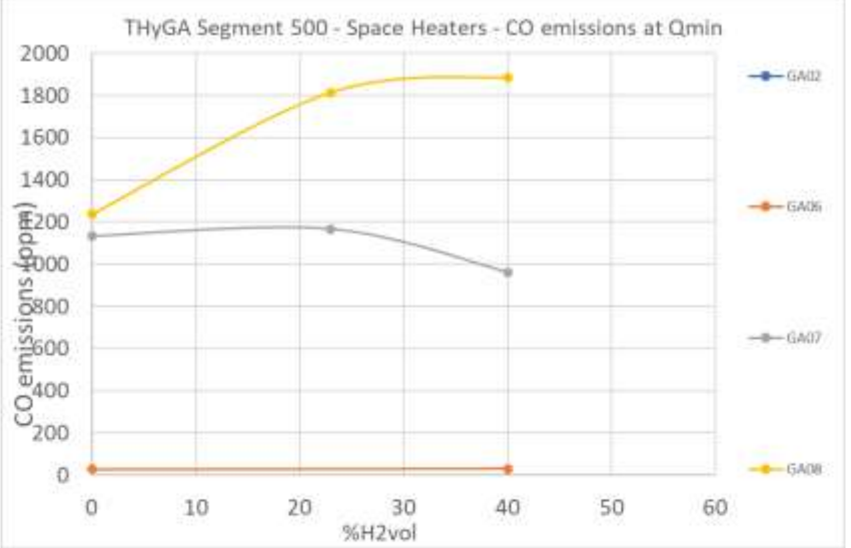




WP3 – Results for the short-term tests

Segment 600 Combined Heat and Power (CHP)

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

600 Combined Heat and Power (CHP): Discussion of the segment group results

			ICE	ICE	MT	PEMFC	SOFC
	Appliance ID		D11	GW09V03	EN20V01	GA12V03	GA13V01
	Segment		602	602	603	604	605
	Qmin (kW)		30.5 (50 % Power Modulation)	9.7	9.4	NA	1.1
	Qmax (kW)		49.6 (100 % Power Modulation)	19.5	20	2	3.2
	Combustion control feature (Y/N)		Y	N	Y	NA	N
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x
		EU LOW				x	
		G23		x		x	
	%H2 in test gas	0	x	x	x	x	x
		0-10		x	x	x	x
		10-20				x	x
		20-23	x	x	x	x	x
		23-30		x		x	
		30-40	x	x			
		40-50	x				
		50-60					
CS	1.4 Cold start	CH4+40%H2	x	x	x	x	
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	x	x	x		
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2					
FGP	1.7 Flue gas pipe length	CH4+30%H2					
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x	x	x	x	x
FD	1.9 Impact H2 flame detection.		x			x	x
FB	1.10 Flash back		x			x	x
AD_A	3.1 Adjustment A	EU HighEU Low+H2	x	NA	NA	NA	NA
AD_B	3.2 Adjustment B	EU lowEU high+H2		NA	NA	NA	NA
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2		NA	NA	NA	NA
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	x	NA	NA	NA	NA
DI	4.1 Delayed ignition test.	CH4+30%H2					
S	4.2 Soundness						
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2				x	x
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2					
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA		NA	NA	NA
W	4.6 Influence of wind						
LT	4.7 Long time (limited time)	depends on manufacturer					x
AUX	4.8 Fluctuation of the aux.						
P	4.9 Fluctuation of pressure	CH4+40%H2				x	x
O	Other /Operational						

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

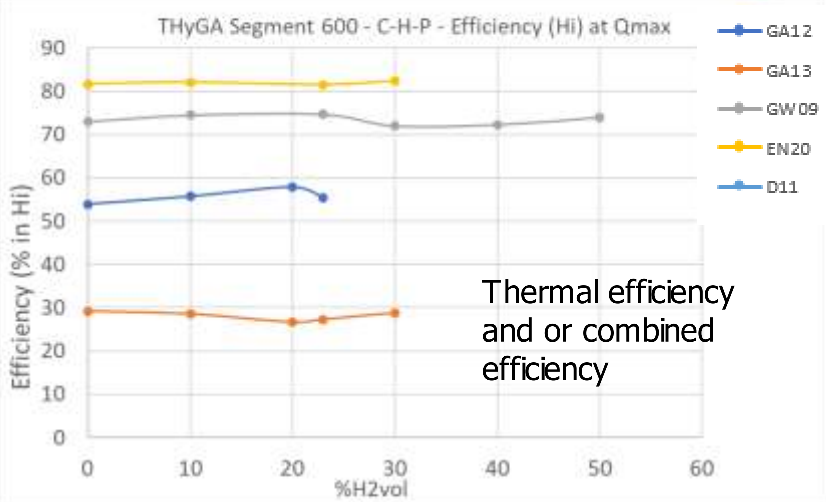
Open discussion – Not final results

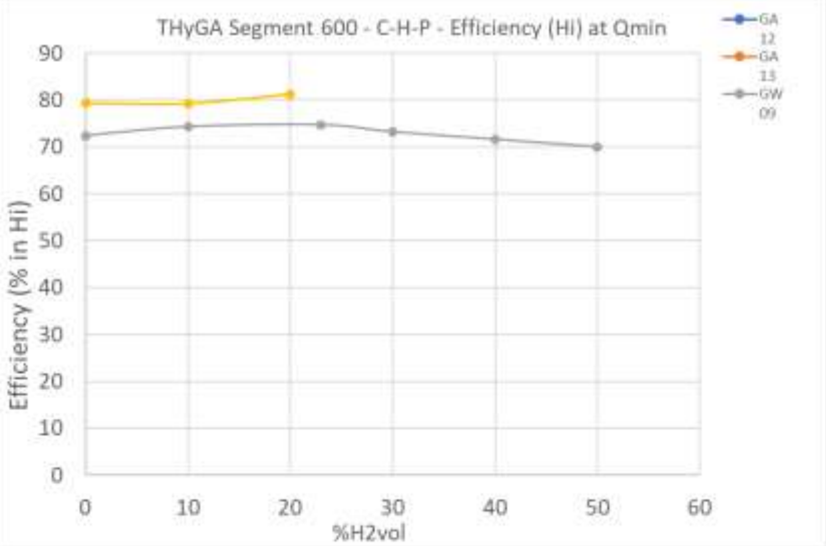
- **High CO for > 30% H2 (SOFC)**
- Results in discussion for PEMFC

WP3 – Results for the short-term tests

600 Combined Heat and Power (CHP): Discussion of the segment group results

Efficiency





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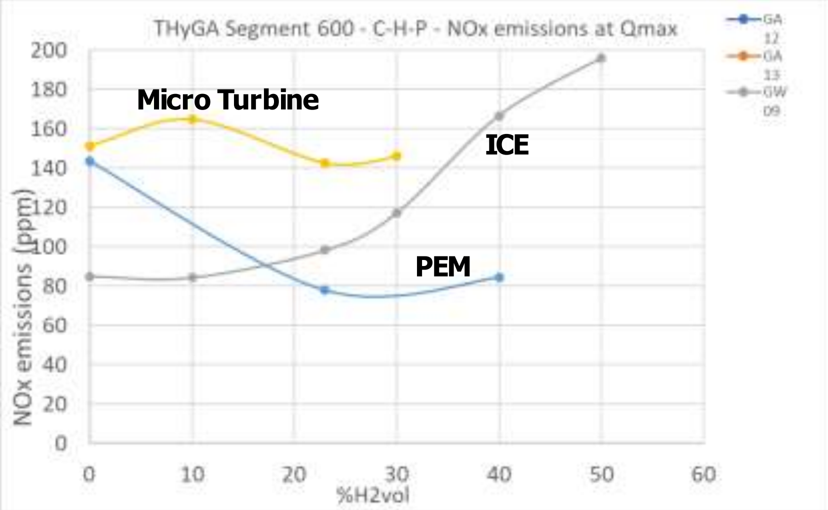

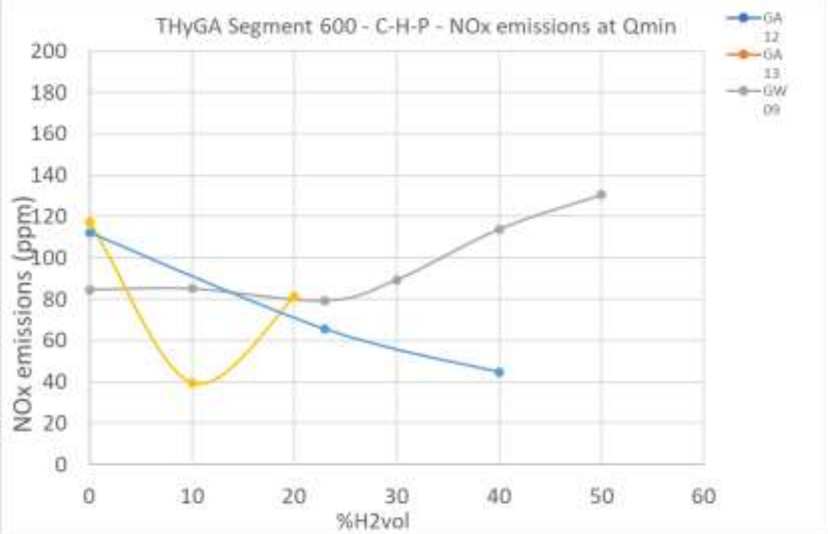

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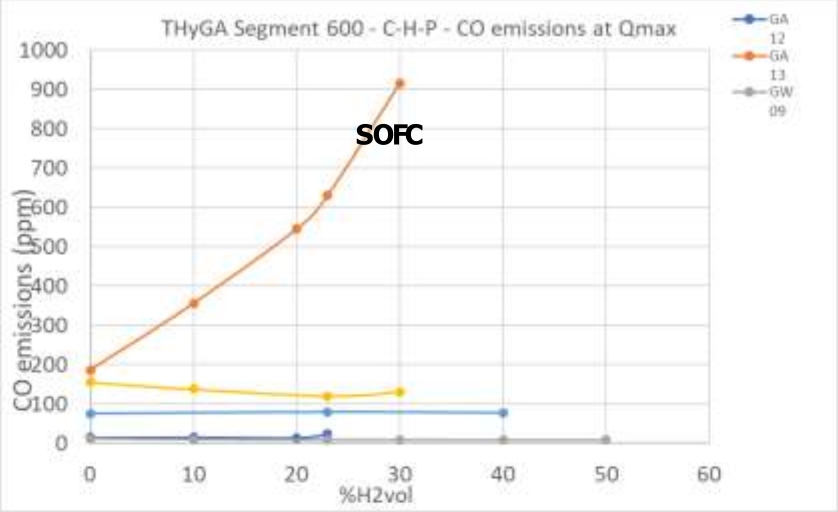
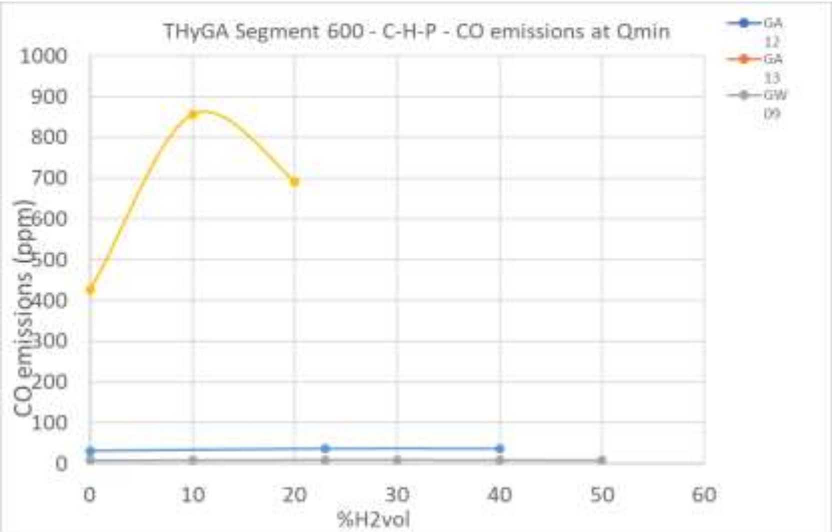




WP3 – Results for the short-term tests

Segment 700 Gas Heat Pumps (GHP)

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

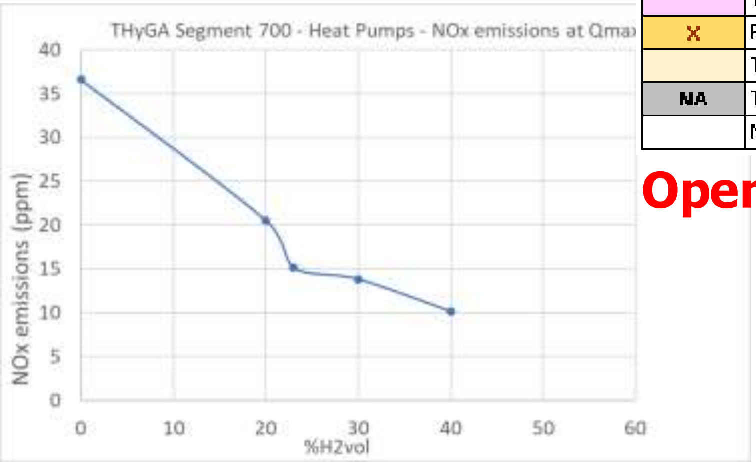
700 Gas Heat Pumps (GHP): Discussion of the segment group results

	Appliance ID		GA14V01
	Segment		703
	Qmin (kW)		6
	Qmax (kW)		11,2
	Combustion control feature (Y/N)		N
Tested: reference gas + %H2 used	Reference gas	CH4	x
		EU LOW	
		G23	
	%H2 in test gas	0	x
		0-10	
		10-20	x
		20-23	x
		23-30	x
		30-40	x
		40-50	
		50-60	
CS	1.4 Cold start	CH4+40%H2	x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	x
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2	
FGP	1.7 Flue gas pipe length	CH4+30%H2	
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x
FD	1.9 Impact H2 flame detection.		x
FB	1.10 Flash back		x
AD_A	3.1 Adjustment A	EU HighEU Low+H2	NA
AD_B	3.2 Adjustment B	EU lowEU high+H2	NA
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2	NA
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	NA
DI	4.1 Delayed ignition test.	CH4+30%H2	
S	4.2 Soundness		
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2	x
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2	
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA
W	4.6 Influence of wind		
LT	4.7 Long time (limited time)	depends on manufacturer	x
AUX	4.8 Fluctuation of the aux.		x
P	4.9 Fluctuation of pressure	CH4+40%H2	x
O	Other /Operational		

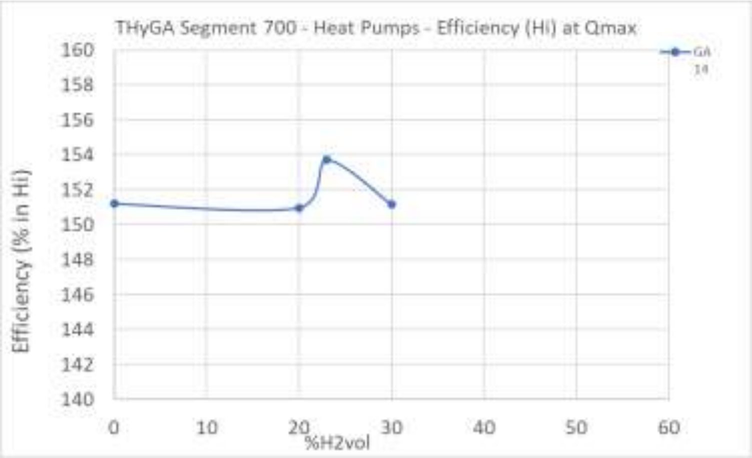
X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
X	Test realized and issue
	Test has not been done with this %H2, but at lower and higher %H2, we consider "issue"
X	Potential issue (noise, atypic behavior) but not linked to safety
	Test has not been done with this %H2, but at lower and higher %H2, we consider "potential issue"
NA	Test non applicable
	Not tested

Open discussion – Not final results

NOx



Efficiency



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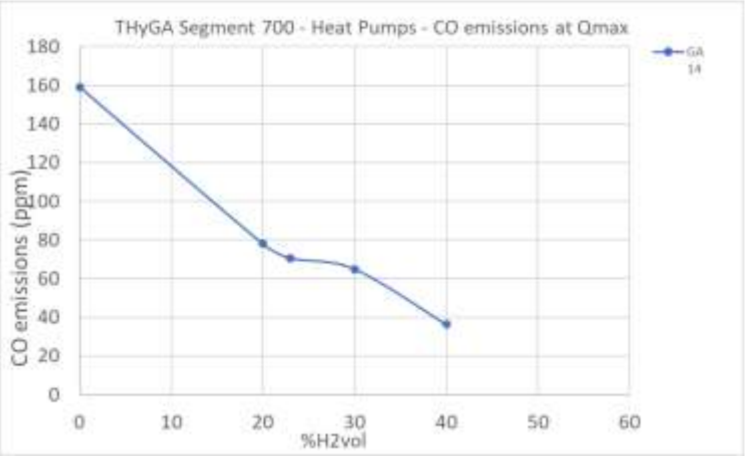

WP3 – Results for the short-term tests

Segment 800 Radiant heater & commercial air heaters

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

WP3 – Results for the short-term tests

800 Radiant heater & commercial air heaters: Discussion of the segment group results

	Appliance type		IR radiant heater	IR radiant heater	IR radiant heater	IR radiant heater	Air heater	Air heater	Air heater <70kW	Domestic dryer
	Appliance ID		EB13V03	EB25V02	EB26V02	EB12V03	GW24V02	GW25V02	GW26V02	GA15v03
	Segment		802	802	802	803	805	806	807	809
	Qmin (kW)		7	30	-	11,9	22	0	15	na
	Qmax (kW)		10	60	54	15,4	36	98	50	4
	Combustion control feature (Y/N)		N	N	Y	N	N	N	N	na
Tested: reference gas + %H2 used	Reference gas	CH4	x	x	x	x	x	x	x	x
		EU LOW	x			x				x
		G23								
	%H2 in test gas	0	x	x	x	x	x	x	x	x
		0-10					x	x	x	x
		10-20								x
		20-23	x			x	x	x	x	x
		23-30	x			x	x	x	x	x
		30-40	x	x	x	x	x	x	x	x
		40-50					x	x	x	
		50-60					x	x	x	
CS	1.4 Cold start	CH4+40%H2	x	x	x	x				x
HS	1.5 Hot start.	CH4+23% H2+40%H2(min)	x	x	x	x				
Lo T	1.6 Low air temperature (- 10 C)	CH4 + H2		x						
FGP	1.7 Flue gas pipe length	CH4+30%H2								
ROC	1.8 ROC (Plug flow)	CH4+40%H2	x	x	x	x				x
FD	1.9 Impact H2 flame detection.		x	x	x					x
FB	1.10 Flash back				x					x
AD_A	3.1 Adjustment A	EU HighEU Low+H2	NA	NA		NA	NA	NA	NA	NA
AD_B	3.2 Adjustment B	EU lowEU high+H2	NA	NA		NA	NA	NA	NA	NA
AD_H	3.3 Adjustment H	EU Low+H2EU high+H2	NA	NA		NA	NA	NA	NA	NA
AD_G	3.4 Adjustment G	EU Low+H2EU high+H2	NA	NA		NA	NA	NA	NA	NA
DI	4.1 Delayed ignition test.	CH4+30%H2			NA					
S	4.2 Soundness									
QV	4.3 Quick variation Qmin-Qmax	CH4+30%H2	x	NA	NA	x				x
OH	4.4 Overheat. Meas. of temp.	CH4+30%H2		x	x					
4B	4.5 Cooker hob test with 4	CH4+30%H2	NA	NA	NA	NA	NA	NA	NA	NA
W	4.6 Influence of wind				NA					
LT	4.7 Long time (limited time)	depends on manufacturer	x	x	x	x				
AUX	4.8 Fluctuation of the aux.									
P	4.9 Fluctuation of pressure	CH4+40%H2	x		x	x				x
O	Other /Operational									

X	Test realized and no issues
	Test has not been done with this %H2, but at lower and higher %H2, we consider "no issue"
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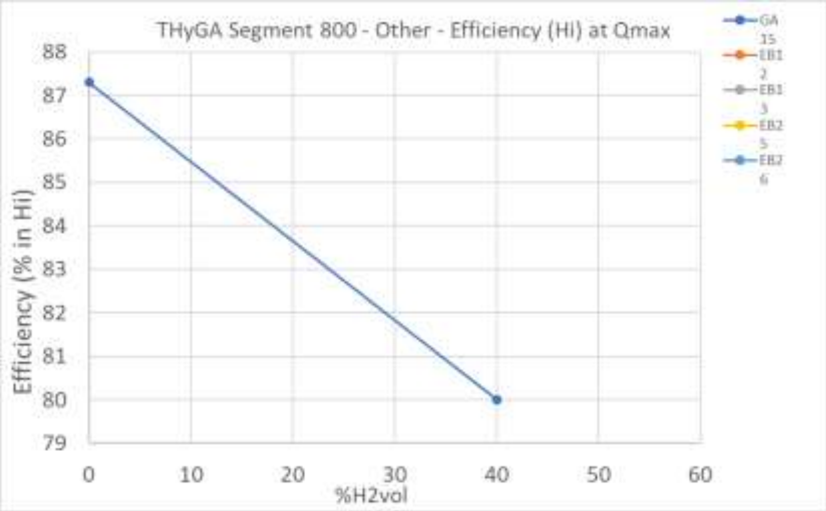
	Not tested

Open discussion – Not final results

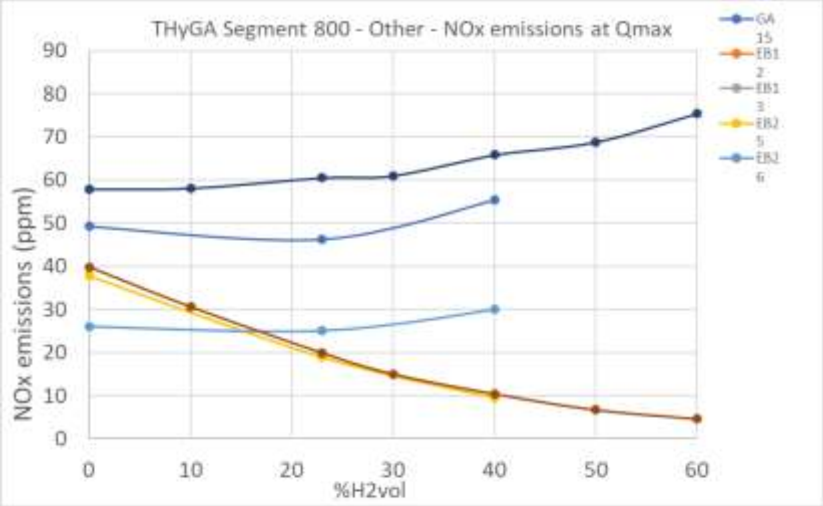
WP3 – Results for the short-term tests

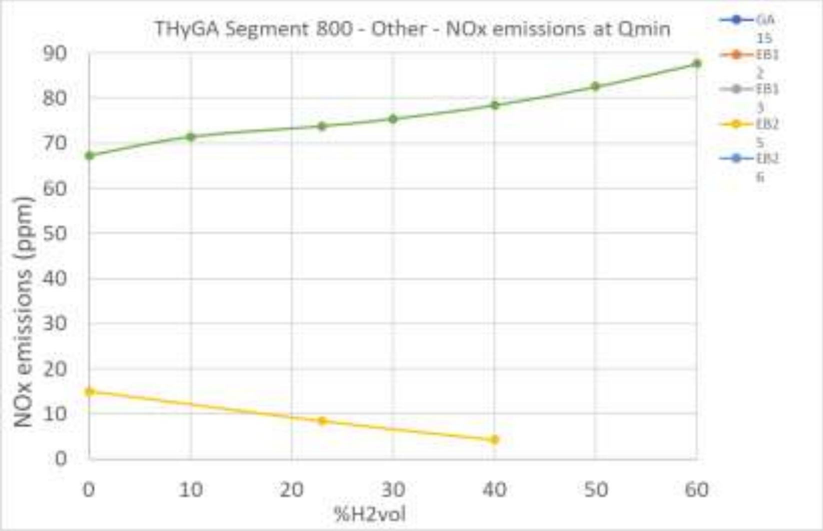
800 Radiant heater & commercial air heater: Discussion of the segment group results

Efficiency



NOx





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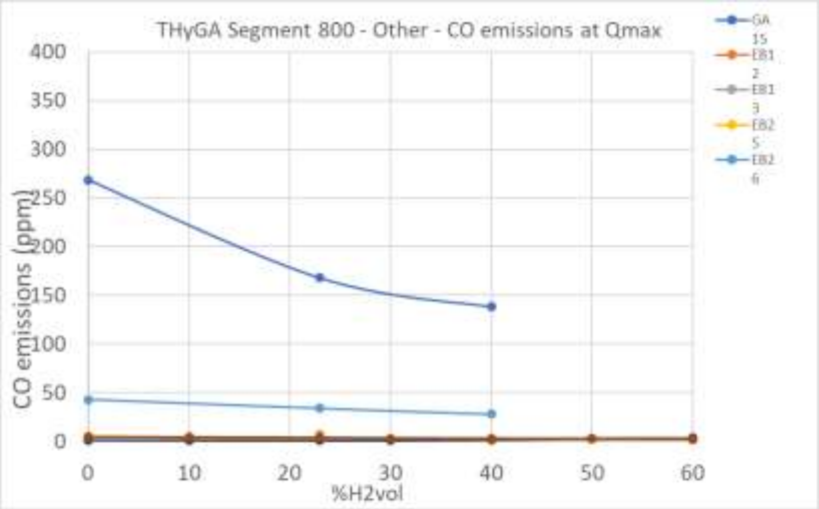
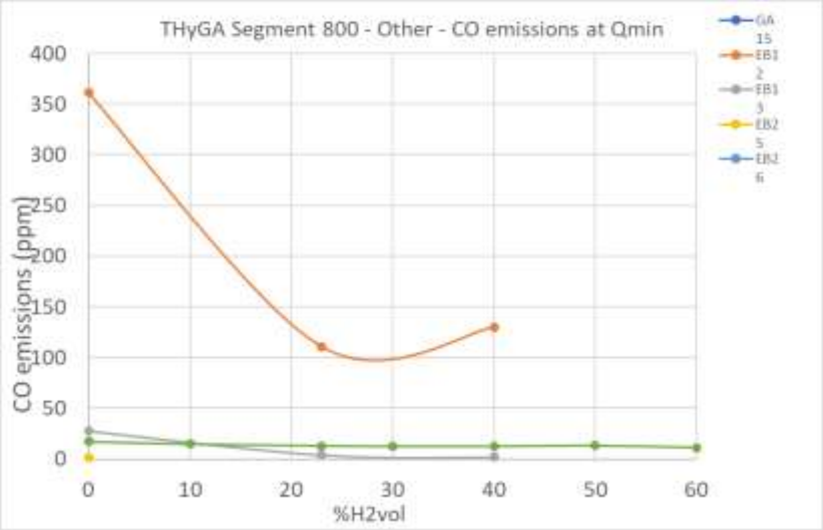




WP3 - Experimental Work
Agenda

- Objectives of the WP3 (experimental work)
- WP3 - Testing protocol and parameters studied
- Working method
- Results for the short-term tests
- Results for the long-term tests
- Conclusions

WP3 – Results for the long-term tests

Objectives

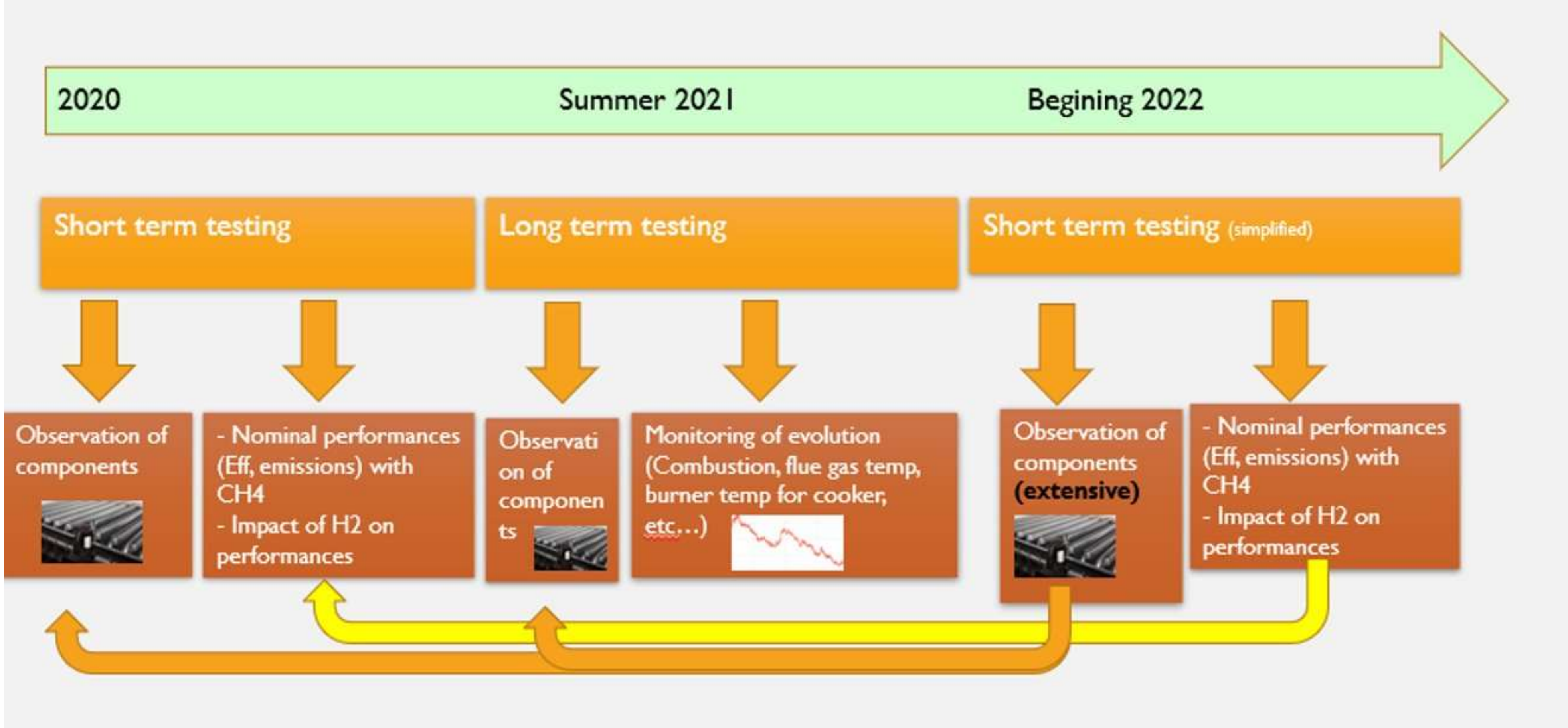
Long term: to observe possible appliances alterations (performances or physical alteration) in the long term (few month) with given H2NG blends.

- Possible alterations are monitored by measurements in the combustion gas (flue gas).
- The appliances tested will be dismantled at the beginning and end of the tests (visual observations).
- 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.)

DGC's long term test rig is especially designed to monitor gas appliances performances over testing periods of several weeks or months.

WP3 – Results for the long-term tests

Methodology



WP3 – Results for the long-term tests

Experimental setup

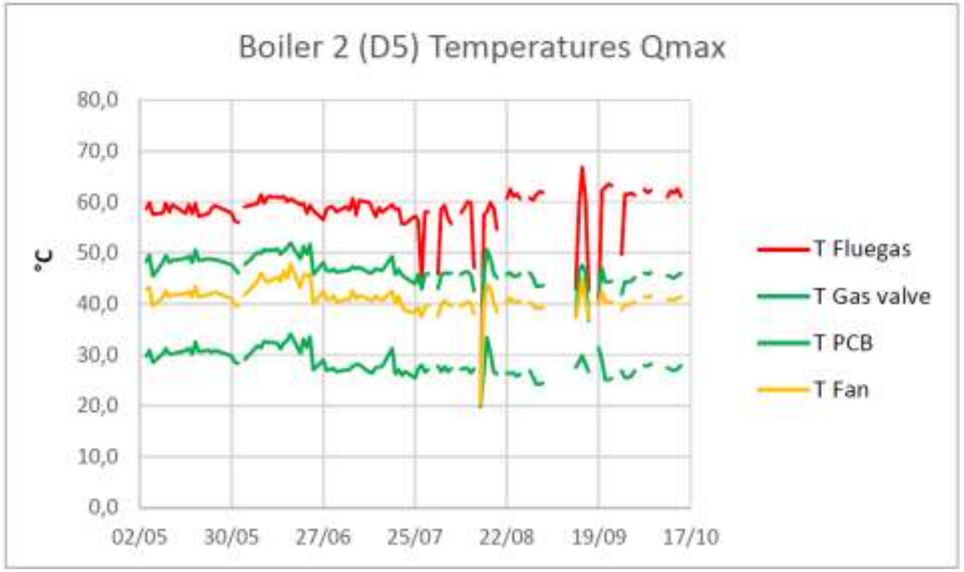
From left to right: cooker experimental setup, probes setup for cookers and boilers experimental setup

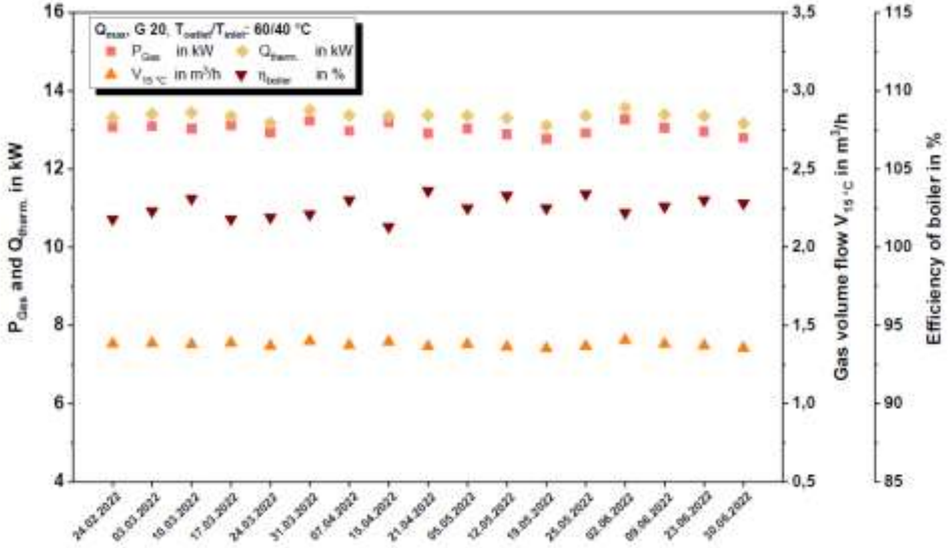
WP3 – Results for the long-term tests

Data

The peaks are not reflecting physical changes of the heat input, but points measured under transient situations.

The graph on the right shows representative and comparable measurements using pure methane as a test gas (G20). This allows to compare the data over time in order to detect changes which can be compared with the initial data.



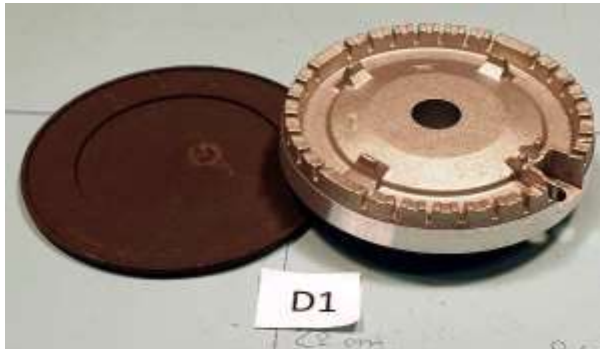


Boiler 1 operated at maximum load with pure methane (G20)

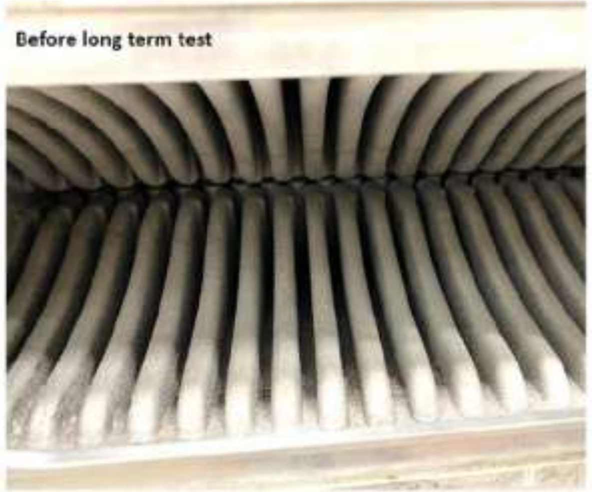
WP3 – Results for the long-term tests

Pictures Before / After

Before



After



WP3 – Results for the long-term tests

Conclusion based on the experimental setup and test duration

2 cookers and 3 boilers were tested by DGC, 2 boilers by GWI

- Cookers were tested for more than 2500 hours and boilers for more than 3000 hours (equivalent to 2-3 years use).
- **All emissions (CO, NOx) and efficiency levels stayed stable**.
- Normal signs of wear and tear and normal amount of deposit.
- 30% hydrogen has no impact on the operation of the tested appliances (validated through short-term tests before and after the long-term test).

WP3 - Experimental Work

Agenda

- Objectives of the WP3 (experimental work)
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- Results for the long-term tests
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WP3 – Results for the short-term tests

Conclusions

THyGA's Segments / Type of appliance

- 100a Boilers fully premix
- 300 Cookers domestic
- 100b Boilers other
- 200 Water heaters
- 400 Catering equipment
- 500 Space Heaters
- 600 Combined Heat and Power (CHP)
- 700 Gas Heat Pumps (GHP)
- 800 Radiant heater & commercial air heaters

THyGA
D3.8
D3.10

Modified slide taking into account late delayed ignition test results

WP3 – Results for the short-term tests

Conclusions: 1) SAFETY & OPERATIONAL

All conclusions of the single segment groups are combined on this table, using their impact card

Please not that this table provides conclusions <u>without taking into account the delayed ignition test</u>

NOT INCLUDING DELAYED IGNITION POTENTIAL ISSUES OR OTHER POSSIBLE NOT IDENTIFIED ISSUES

		H2 % Tested							
		0	0-**10**	10-**20**	20-**23**	23-**30**	30-**40**	40-**50**	50-**60**
100a Boilers fully premix	*Safety*			simple mitigation (3)	mitigation to be defined		4	7	10
	Safety with mitigation			Dedicated adjustment methodology			1	4	7
	Operational								
100b Boilers Not premix	*Safety*								3
	Operational								
200 Water heaters	*Safety*						1	1	1
	Operational								
300 Cookers domestic	*Safety*					2	8	8	10
	Operational								
400a Catering equipment – Premix	*Safety*			simple mitigation (1)	mitigation to be defined (2)				
	Safety with mitigation			Dedicated adjustment methodology					
	Operational								
400b Catering equipment – Not premix	*Safety*					1	1	1	1
	Operational								
500 Space Heaters	*Safety*								1
	Operational							flame aspect	
600 Combined Heat and Power (CHP)	*Safety*					1	1	1	1
	Operational								
700 Gas Heat Pumps (GHP)	*Safety*								
	Operational								
800 Radiant heater & commercial air heaters	*Safety*								
	Operational								

Modified slide taking into account late delayed ignition test results

WP3 – Results for the short-term tests

Conclusions: 2) SAFETY and delayed ignition

*The **delayed ignition** test was made on **few appliance only** and analysis of the results and inputs came after the workshop.*

In case of delayed ignition, relevant hydrogen concentrations in natural gas leads to more violent ignition.

- For concentrations up to 20% H2, the impact has proven not to be detrimental or dangerous on the tested appliances equipped with a fan in the combustion circuit, but…
- … inappropriate onsite adjustment, if possible, may increase the risk on an unacceptable impact (material deterioration and/or user hazard) of delayed ignition due to accumulation of a flammable mixture with a higher energy content.

Appliances equipped with specific partially premixing burners without a fan in the combustion circuit (i.e. appliance type B11BS) used in certain types of boilers and water heaters **seem to be sensitive to delayed ignition**. No light-back occurs, but the unburned gas accumulates also downstream of the burner. When this accumulated unburned gas is lighted it creates a flame at the injector

Modified slide taking into account late delayed ignition test results

WP3 – Results for the short-term tests

Conclusions: 2) SAFETY (excluding delayed ignition)

20% H2 should not be an issue

With appropriate mitigation this could be higher, but above 30% more issues are appearing (FB etc.)

Other safety aspects which do not present problems

- Both impacts of "**low air temperature (- 10 °C)**" and "**Flue gas pipe length**" have been tested on few appliances (boilers) and the results from the test done show no impact of hydrogen.
- **ROC (PLUG FLOW)** is generally not showing issue (generally variation from 0 to 40% H2 and the other way round). *However for some cooking hobs the test has revealed issues that seems more related to the percentage of H2 rather than the Plug Flow.*
- The **delayed ignition** test was made on **few appliance only** with 30% H2.
- **Fluctuation of the auxiliary energy** was tested, without impact on safety.
- **Long-term** (limited time) consisted in testing appliances for few hours when possible. Some tests were

WP3 – Results for the short-term tests

Conclusions: 3) PERFORMANCES

In general, under the conditions of the THyGA testing (= copy the reality of the field):

- **H2 has no or only small impact on efficiency** but for boilers where we see a slight increase of efficiency on Hi due to higher heat recuperation on condensation with the testing conditions used.
- **Heat output decreases with H2 injection** which could prove to bring comfort issue for domestic hot water or cooking appliances
- **NOx is decreasing** with H2
- **CO is decreasing** with H2

Overall Impact of H2 on					
SEGMENT		Efficiency	NOX	CO	CH4
100a	Boiler premix	+	-	-	
100b	Boiler NOT premix	0	-	-	
200	Water heater	0	-	-	
300	Cooker dom	0	- (*)	-	
400a	Catering premix	NM	-	-	
400b	Catering NOT premix	unclear	-	-	
500	Space heaters	0	-	unclear	
600	CHP	0	unclear	unclear	
700	GHP	0	-	-	
800	Radiant heater & commercial air heaters	-	unclear	-	

(*) can suddenly increase for H2 >40%

Agenda

9h00 / 9h15	Welcome, Introduction and rules to the workshop	Alexandra Kostereva
9h15 / 9h30	THyGA - Objectives and organization of the project	Patrick Milin
9h30 / 10h00, inc. question	WP4: certification for new appliances	Kris De Wit
10h00 / 11h20, inc. question	WP3: H2NG blends impact on appliances	Jean Schweitzer ; Henri Cuny
11h20 / 11h40	Coffee break	
11h40 / 12h30, inc. question	WP5: appliances on the field	Lisa Blanchard ; Stéphane Carpentier
12h30 / 13h00	Conclusions and perspectives	Alexandra Kostereva ; Patrick Milin

THyGA

WP3 & 5 – Appliances installed on the field

Gas line tightness

WP3 – Gas line tightness in 40%H_2 + 60%CH_4

Objectives

Evaluate of the tightness of the components located on domestic and commercial gas lines from the gas meter to the end user appliance, in presence of a mixture 40%H_2+60%CH_4.

- Components taken from installations being used currently in Germany, Denmark, Belgium and France.
- Testing pressure: 35 mbar.
- Comparison with admissible standard leakage rates: 1 $l.h^{-1}$ (NEN 7244-7, gas distribution network) and 0.1 $l.h^{-1}$ (EN 30-1-1:2021, cooking appliances burning gas).

WP3 – Gas line tightness in 40%H_2+60%CH_4

Background on similar projects

HYDelta

Evaluate if tightness requirements need to evolve between NG and 100% H_2.

Measure the pressure drop from 30 mbar, 100 mbar and 200 mbar in N_2, NG and 100%H_2 for 1min.

No clear variations of flow rate between the couplings. Pressure drop at 30 mbar is less accurate.

Ukrainian consortium

Tightness and safety of the gas distribution network: 100% H_2 and mixture CH_4/H_2

Fig. 2. A fragment of the equipment at the test site

Pressure drop at high pressure: 3-6 bar for 7 days and low pressure tests: ~100 mbar for 7 days.

Difficulty to measure at low pressure due to the strong influence of the temperature.

WP3 – Gas line tightness in 40%H_2+60%CH_4

Testing methodology

Pressure drop testing

Short term test

P = 35 mbar

Gas: Air, He, 60%CH_4 + 40%H_2

Stabilisation duration : 15 min

Test duration: 10 min

RT

Monitoring the temperature

Long term test

P = 35 mbar

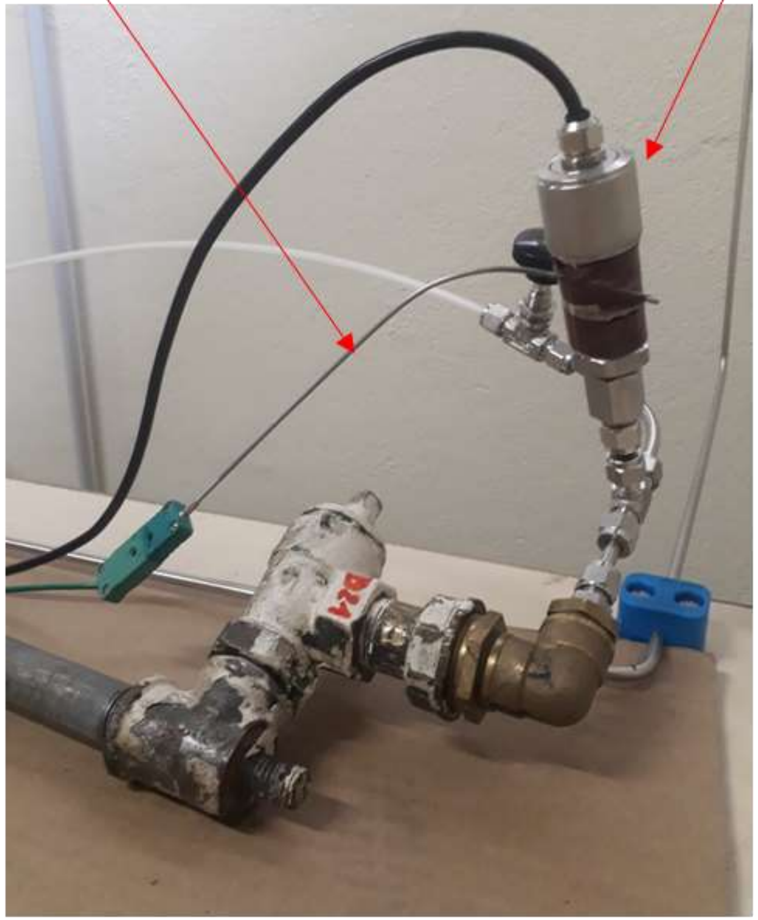
Gas: Air, He, 60%CH_4 + 40%H_2

Stabilisation duration : 15 min

Test duration: Up to 10 days

RT

Monitoring the temperature

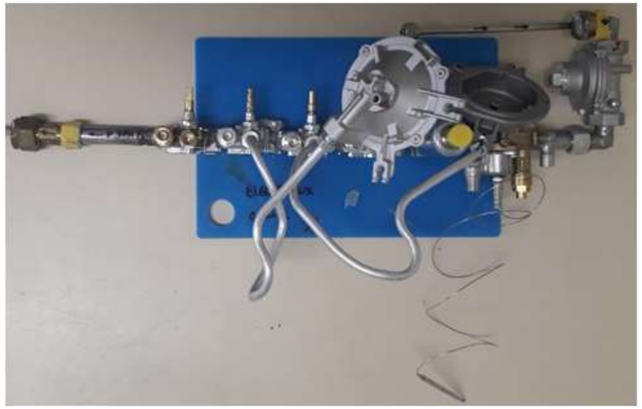


End of a line under testing

WP3 – Gas line tightness in $40\%H_2+60\%CH_4$

Presentation of the gas lines (1/2)

N°1



N°2

N°3

N°4

N°5

Connexions were all cleaned, and most of them were tightened with loctite before the tests.

WP3 – Gas line tightness in 40%H_2+60%CH_4

Presentation of the gas lines (2/2)

N°6

N°7

N°8

N°9

N°10

THyGA D3.7

WP3 – Gas line tightness in 40%H_2+60%CH_4

Results – 10min tests

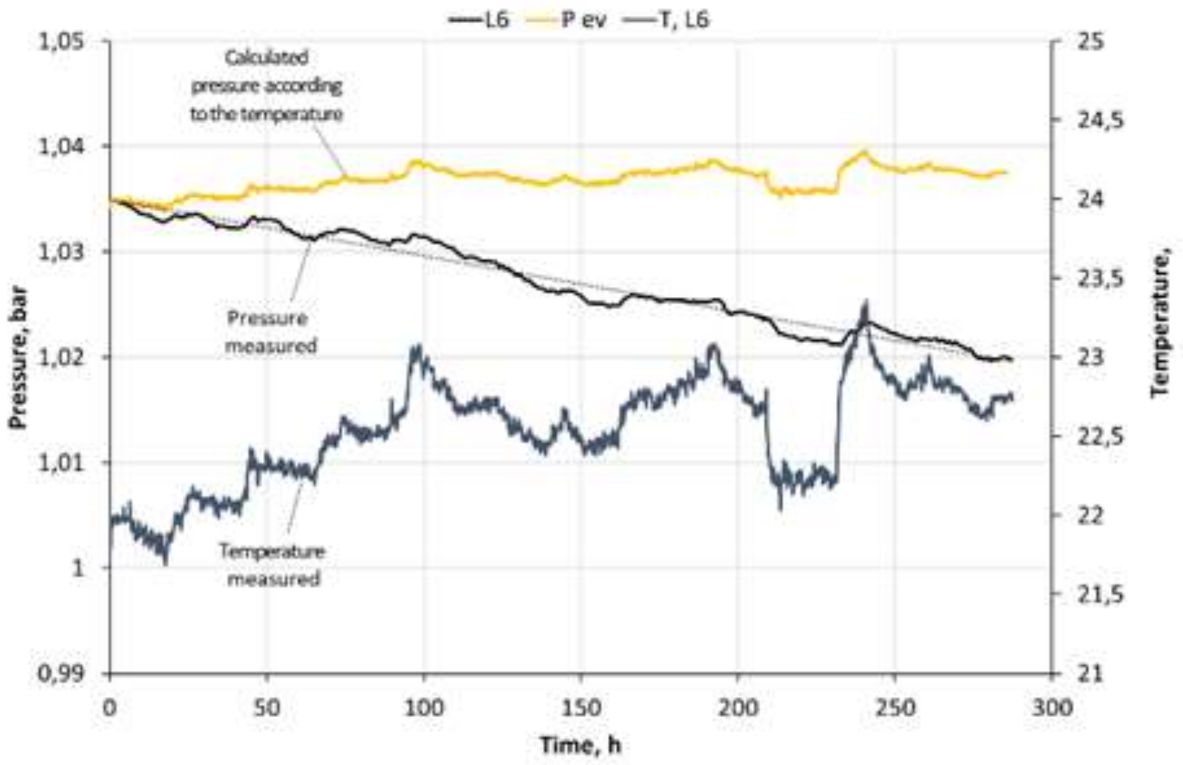
Line	Volume	He ΔP	He Leakage flow	Air ΔP	Air Leakage flow	60% CH_4 + 40% H_2 ΔP	60% CH_4 + 40% H_2 Leakage flow
	l	mbar	$Nl.h^{-1}$, $x10^{-4}$	mbar	$Nl.h^{-1}$, $x10^{-4}$	mbar	$Nl.h^{-1}$, $x10^{-4}$
1	0.18	0,63	**6.24**	0,62	**6.1**	-	**-**
2	1.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**-**
3	3.32	[illegible]	[illegible]	[illegible]	[illegible]	05	**-9.9**
4	0.46	[illegible]	[illegible]	[illegible]	[illegible]	45	**-11.3**
5	10.5	[illegible]	[illegible]	[illegible]	[illegible]	04	**-24.1**
6	8.24	[illegible]	[illegible]	[illegible]	[illegible]	25	**111.5**
7	0.22	[illegible]	[illegible]	[illegible]	[illegible]	35	**4,2**
8	0.74	[illegible]	[illegible]	[illegible]	[illegible]	06	**2.6**
9	0.35	0,40	**8.0**	0,40	**7.9**	-0,19	**-3.8**
10	0.42	0,48	**11.1**	-0,07	**1.7**	0,48	**11.2**

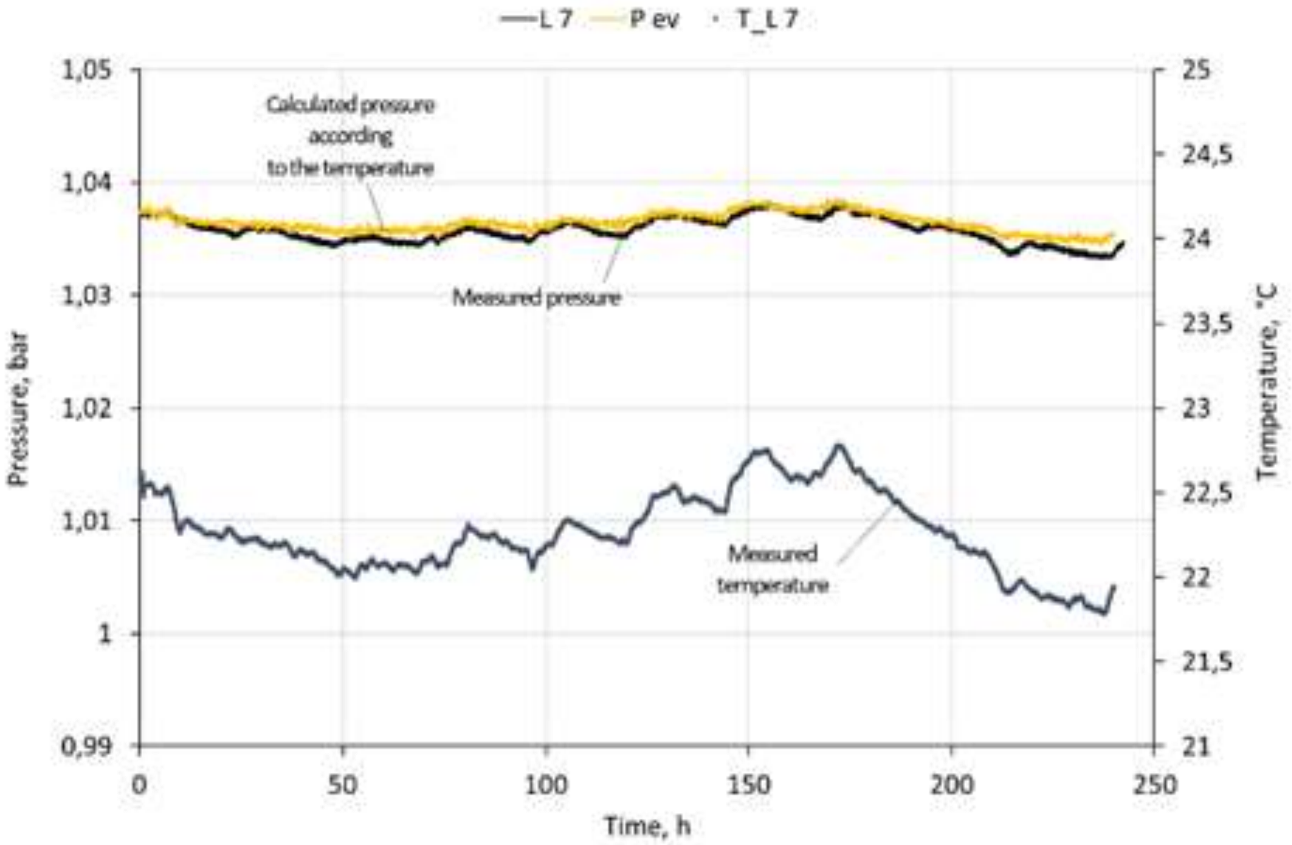
Main findings:

- Difficulty to obtain accurate results at low pressures (*supported by other projects*).
- No significant difference between the three gases.
- All the measured leakage rates are below 0,1 $l.h^{-1}$

WP3 – Gas line tightness in 40%H_2+60%CH_4

Results – 100 hours tests





Strong influence of the temperature (*supported by other projects*).

WP3 – Gas line tightness in 40%H_2+60%CH_4

Results – 100 hours tests

Line number	P1	P2	T1	T2	ΔP	Duration of the test	ΔP
	bar	bar	°C	°C	bar	h	Nl.h^{-1}, x10^{-4}
L1	1,0260	0,999	21,447	21,702	0,028	30	1.66
L2	1,0342	[illegible]	[illegible]	[illegible]	[illegible]	80	4.0
L3	1,0358	[illegible]	[illegible]	[illegible]	[illegible]	284	1.4
L4	1,0358	[illegible]	[illegible]	[illegible]	[illegible]	69	0.8
L5	1,0335	1,03265	23,561	23,774	0,002	70	2.4
L6	1,0349	1,02205	21,984	22,816	0,016	251	5.1
L7	1,0372	1,03585	22,54	22,231	0,000	200	2.9E-3
L8	1,0360	1,00105	22,443	22,108	0,034	80	3.1
L9	1,0355	1,0072	22,4	22,324	0,028	70	1.4
L10	1,0355	1,0357	22,078	22,058	0,000	71	-1.6E-2

Main findings:

- All the measured leakage rates are below 0,1 l.h^{-1}

WP3 – Gas line tightness in 40%H_2+60%CH_4

Tightness test conclusions

- At those low pressures:
  - No differences observed between leakage rates in air, He and in the H_2NG blend;
  - If no leaks in NG and air --> no leak in H_2 *(HYDelta results)*

- After about 200 hours of test, no deterioration of the components or loss of tightness was observed.

- Generally the pressure drop measured on the reviewed lines were under the standard criterion (1l.h^{-1}; 0,1%.h^{-1}).

WP3 & 5 – Appliances installed on the field

Condensates

WP5 – Condensates

Does H2 injection involve extra condensation in flue duct ?

Problem: H2 +O2 → H2O. MORE WATER ? MORE CONDENSATION ?

Target: non condensing boiler--> may alter duct material not designed to handle it

%H2O calculated from measured lambda and flue/fuel gas compositions

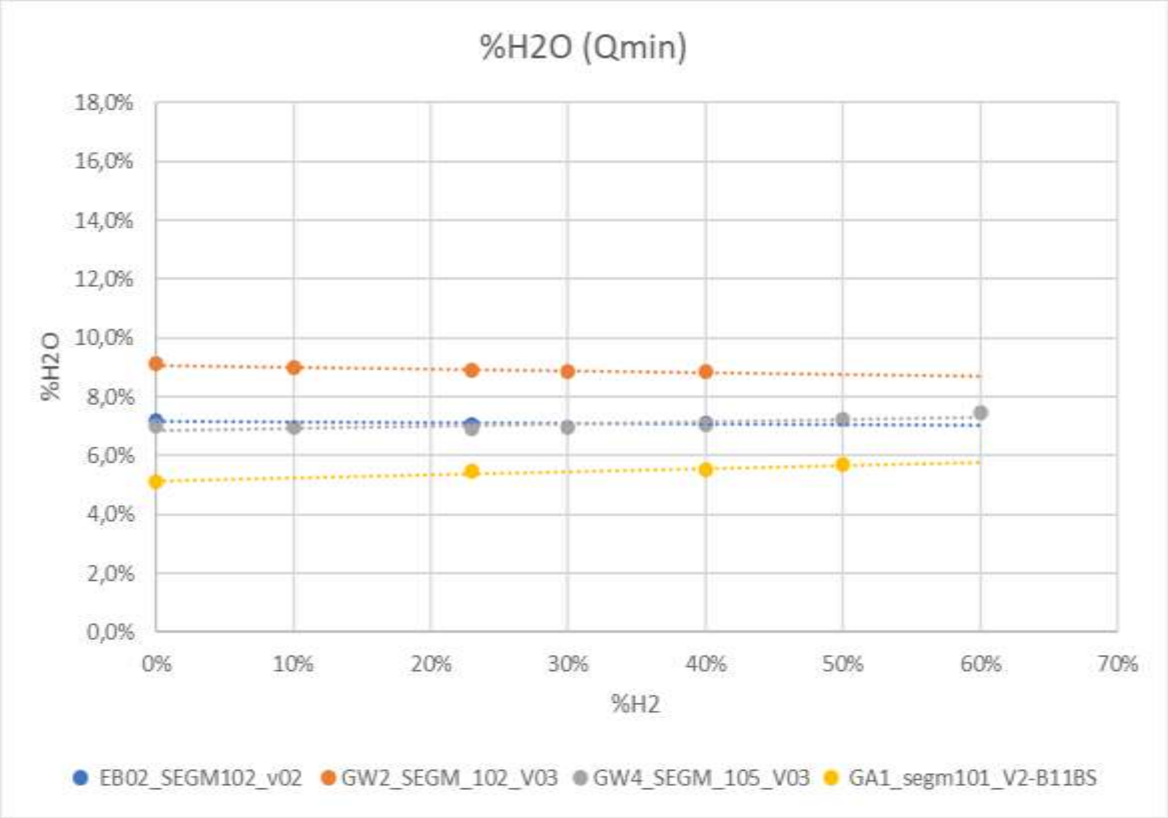
Dew point temperature calculated from Antoine's law

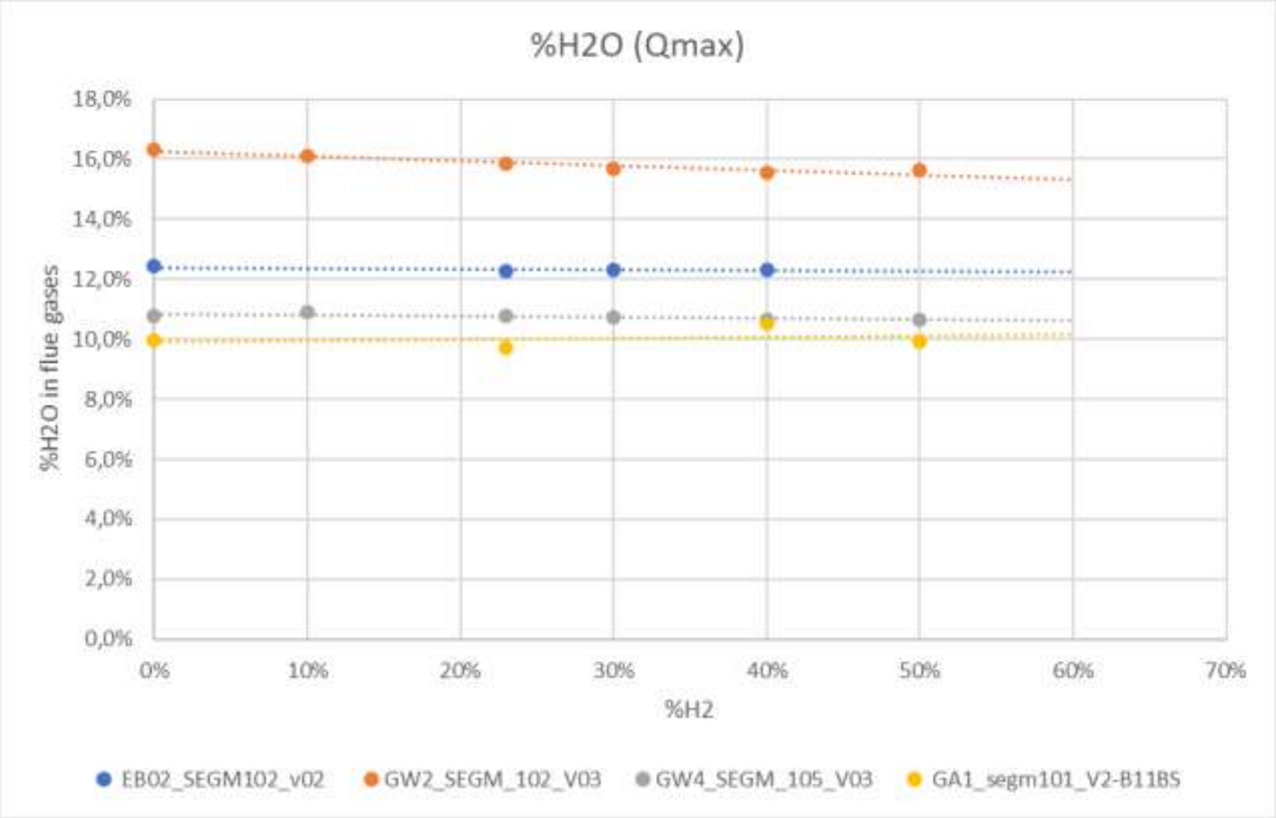
- Depends on %H2O only
- https://en.citizendium.org/wiki/Water_dew_point

$$T = \frac{1668.21}{7.09171 - \log_{10}\, p_w^o} + 45.15$$

WP5 – Condensates

%H2O in flue gases

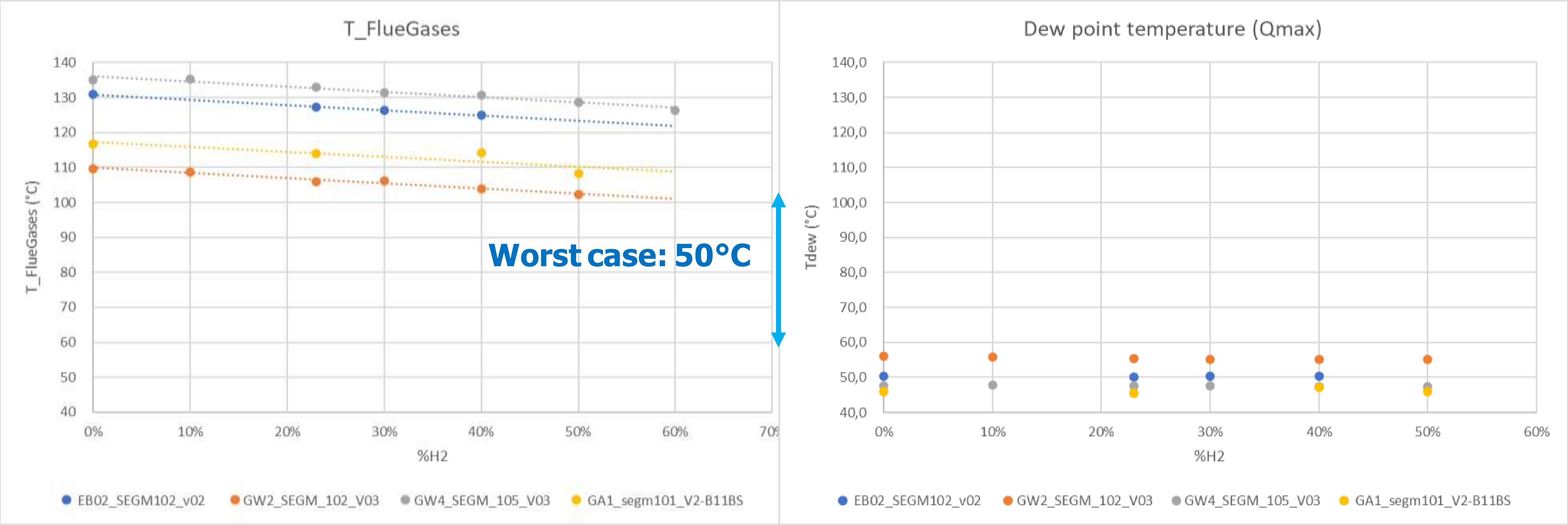




%H2O usually decreases with %H2 → caused by the increase of the air excess

WP5 – Condensates

Condensation at Qmax ?

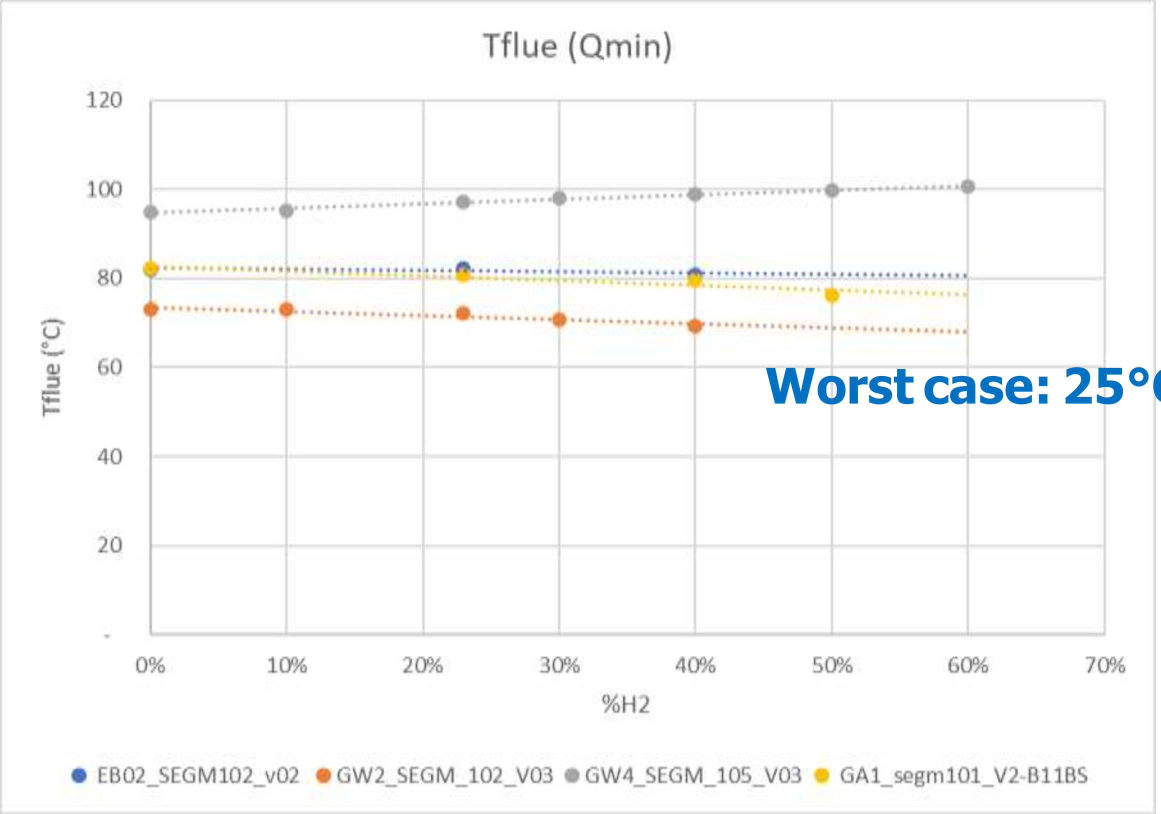


Little impact of %H2 in gas on dew point temperature

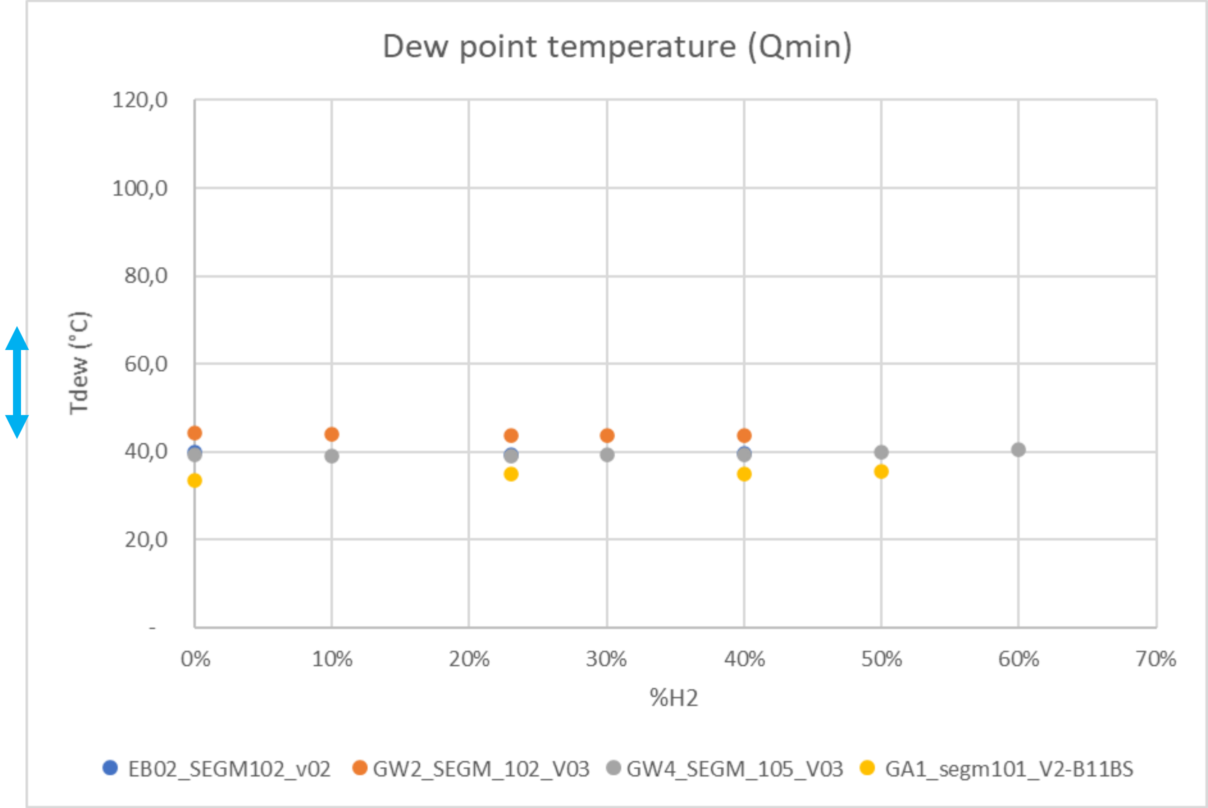
At Qmax, Tflue are much higher than dew point temperature → **no risk**

WP5 – Condensates

Condensation at Qmin ?



Worst case: 25°C



0%-20%H2 , there is not much difference → no action required

On some boilers, temperature difference between Tflue and dew point temperature is not so high, even for CH4.

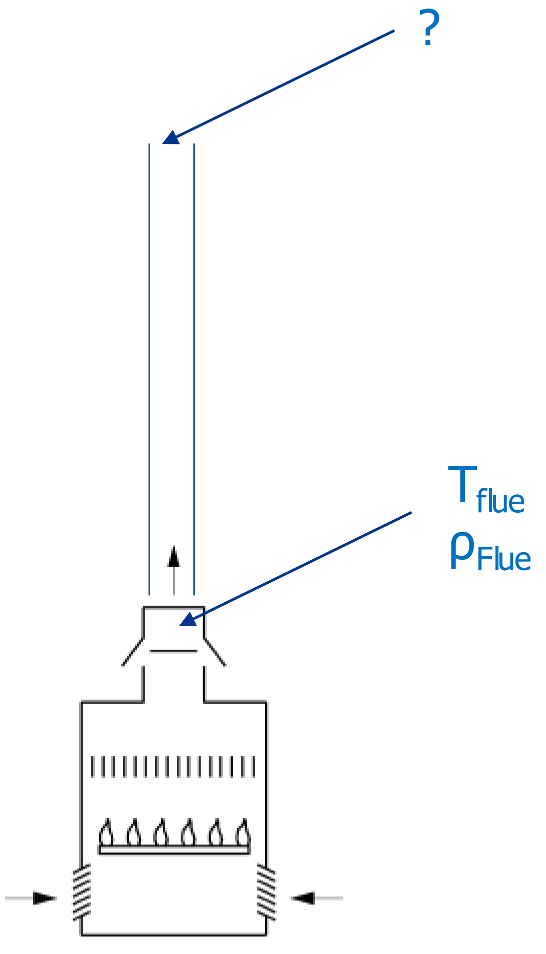
- What are the « good practices » of installers/manufacturers ?
- Possible mitigation: increase Qmin for the most critical boilers to avoid condensation in flue duct ? →higher Tflue

Natural draught

WP5 – Natural draught

Considerations

- Two phenomena are considered here
- Buoyancy:
  - When $\rho_{FlueGases} << \rho_{Air}$ → flue gases go up
  - When $\rho_{Air} < \rho_{FlueGases}$ flue gases can't go up → no natural draft
- Flue gases flowrate
  - if Qflue(H2NG) <= Qflue(natural gas) → no problem
  - if Qflue(H2NG) > Qflue(natural gas) → increase of pressure drop: requires attention
- Not treated here: Impact of flue duct (on temperature)



a) Type B_{11}

WP5 – Natural draught

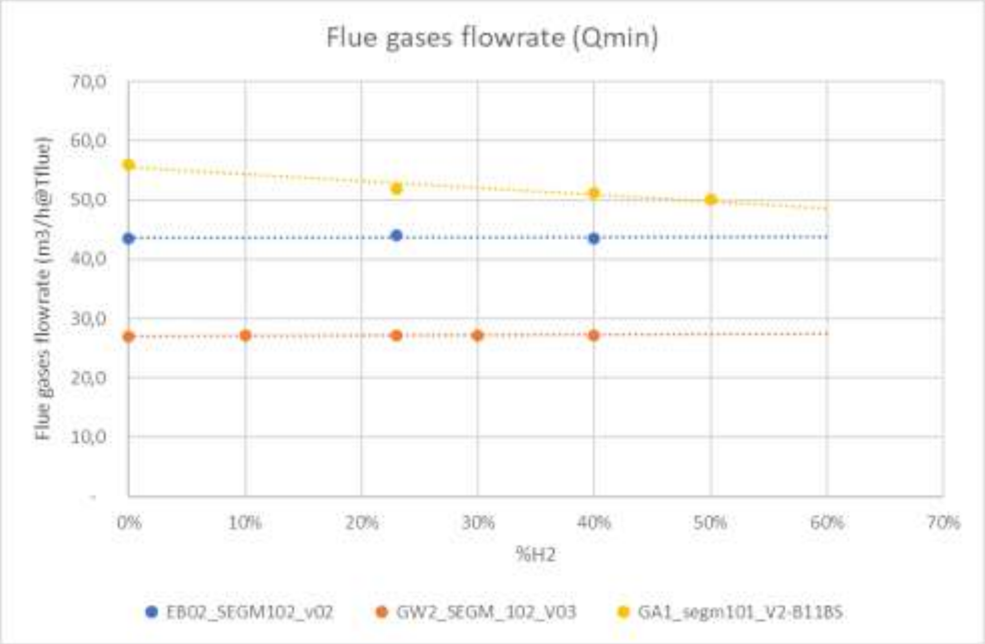
Data treatment

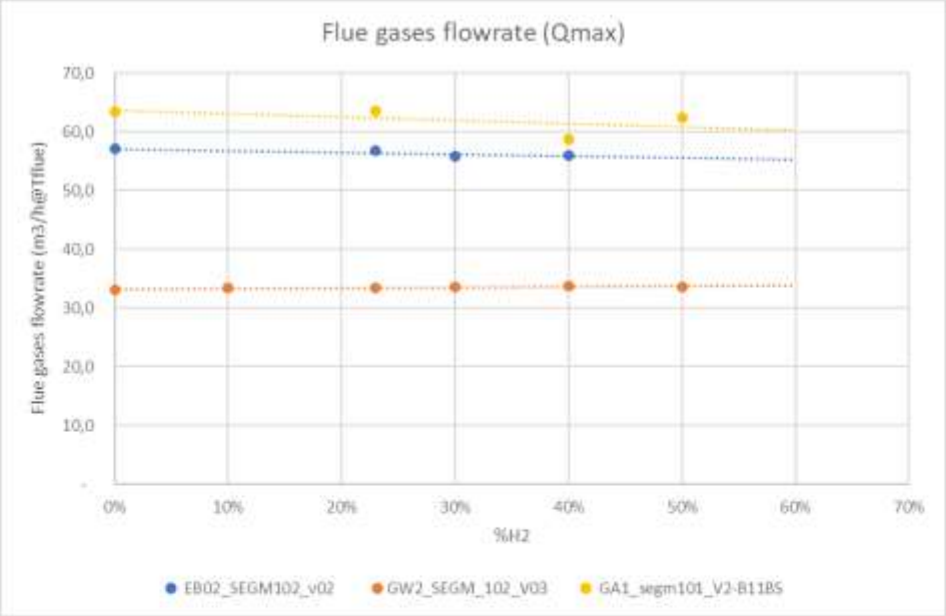
- **Measured during THyGA project:**
  - Boiler inlet: gas flowrate, gas composition
  - Boiler outlet: T flue gases, %CO2, %O2

- **Calculated:**
  - λ (air/fuel equivalence ratio): calculated from %CO2+gas composition and/or %O2
  - Wet flue gas composition: calculated from gas composition and lambda
  - **Flue gases flowrate**: calculated from gas composition, gas flowrate and lambda
  - **Relative density**: calculated from flue gases composition and temperature

WP5 – Natural draught
Flue gases flowrate

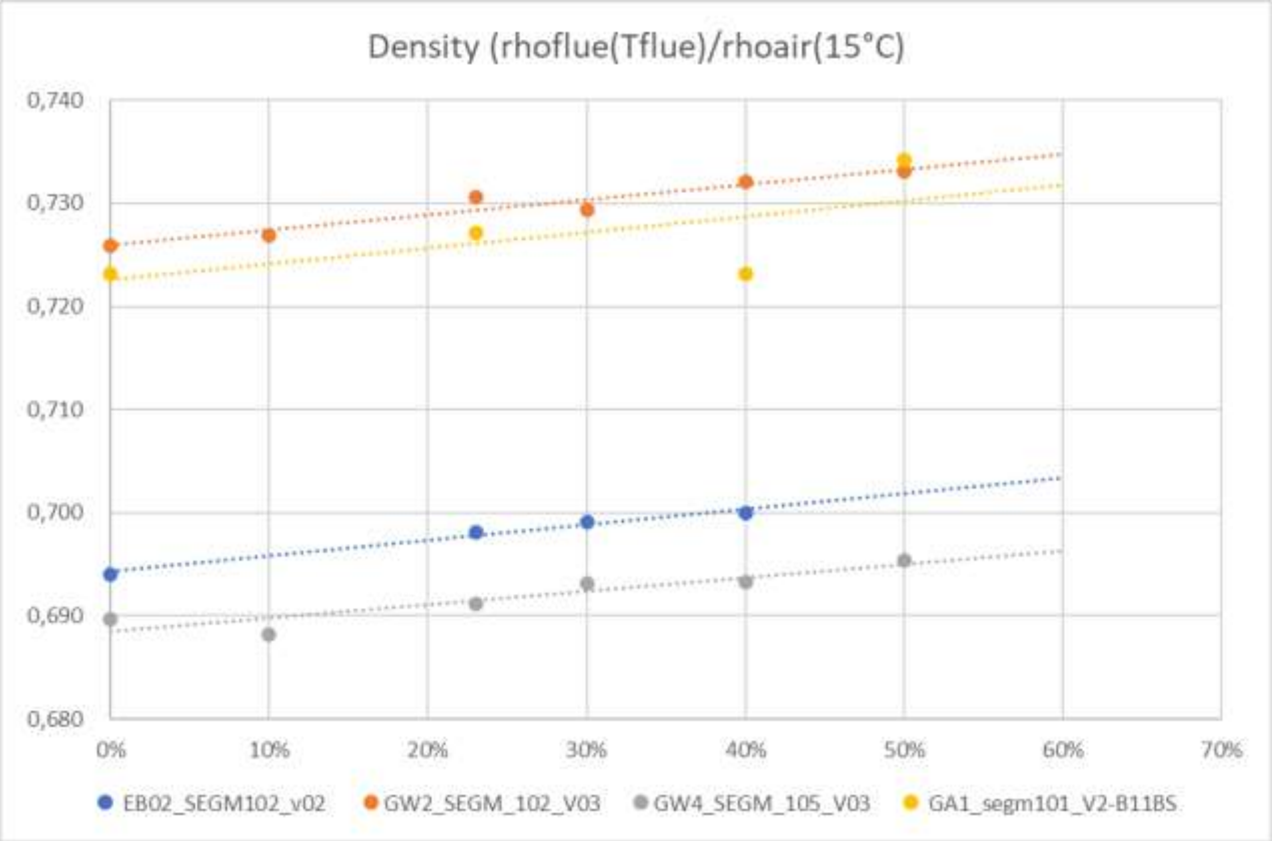
- Flue gases flowrate is stable or decreases with %H2
  - No problems expected





WP5 – Natural draught

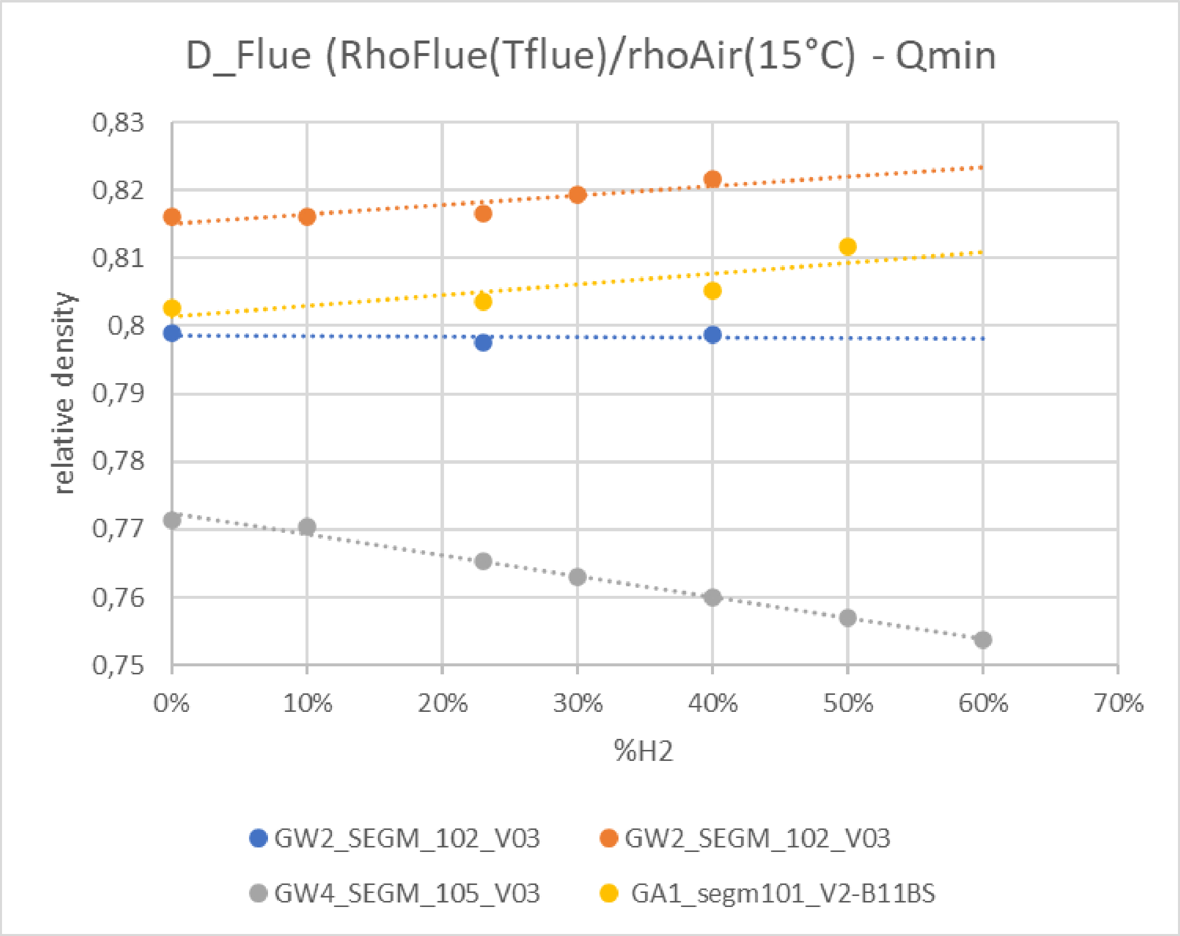
Relative density (**Qmax**)



- Flue gases released in ambiant air → rho(Tflue)/rho_air(15°C)
- **Relative density is low compared to 1** (if relative densities of flue gases and air are identical, there is no draft)
- Small increase of the relative density, but nothing critical
- **@Qmax, no problem with natural draught**

WP5 – Natural draught

Relative density (**Qmin**)



- At Qmin:
  - Flue gases flowrate is lower
  - But relative densities are higher

- Relative densities are stable with a small tendency to increase.

- **No natural draught problems are expected for 0-20%H2**

WP5 – Natural draught

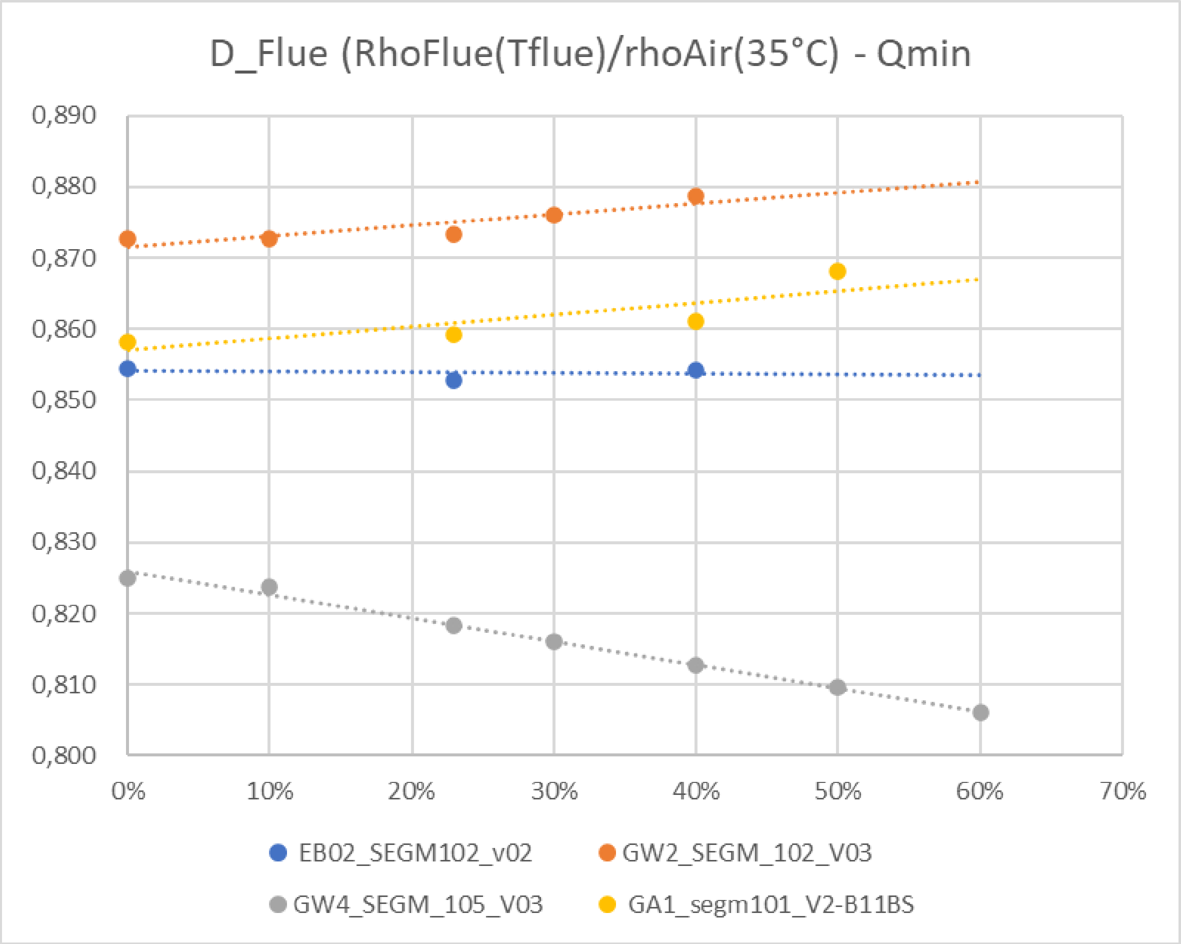
Relative density (Qmin) with **Tair=35°C**

Worst case:

- Summer conditions
- Hot water production

- At Qmin, with an **external temperature of 35°C**, the relative density is still <0.9
- Natural draft is still effective

- **0-20%H2: no problem expected compared to CH4**



WP5 – Natural draught

Conclusions

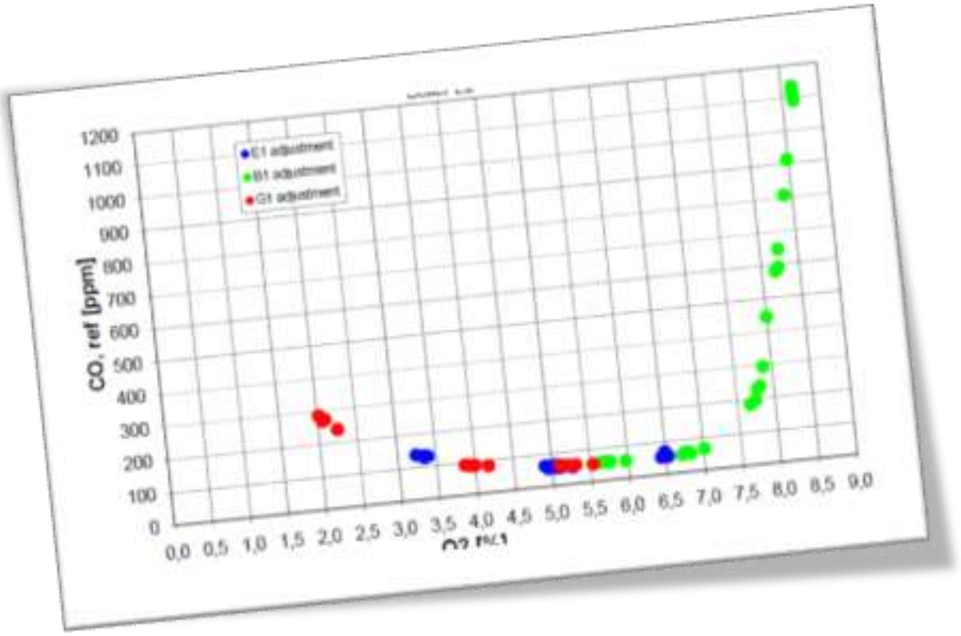
- **A gas mixture with 20%H2 has a very low impact on natural draft and condensation**

- In most cases, flowrate of flue gases remains constant or decreases

- At **Qmin**, in the **worst case**:
  - Relative density of flue gases, increases from 0.816 to 0.822 (@40%H2) – less than 1%
  - Even considering an air temperature of 35°C, relative density of flue gases is still lower than 0.9 (natural draft possible)
  - Difference between Tflue and TDewPoint decreases from 29°C to 25°C (@40%H2).

- In both cases, this evolution remains within safety margin
  - manufacturers/installers should compare these results to their « good practices »
  - **If required, an increase of the heating power at Qmin could solve the problem.**

Adjustment



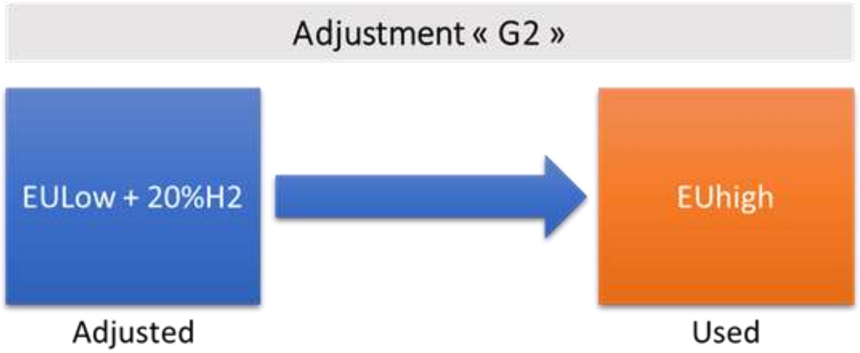
E1 adjustment
B1 adjustment
G1 adjustment
CO, ref [ppm]
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0,0 0,5 1,0 1,5 2,0 2,5 3,0 3,5 4,0 4,5 5,0 5,5 6,0 6,5 7,0 7,5 8,0 8,5 9,0

THyGA
D5.2

WP5 – Adjustment

Reminder: where do the problem occur?

- Adjustment problems (**high CO emissions**) occur in the following conditions
  - Adjustment with lowest Wobbe Index gas (EULow+20%H2)
  - Use with the highest Wobbe Index gas (EUHigh)



- The Wobbe Index jump is then 7.24MJ/m3
- More than during certification tests

	Ref gas	Ws	Delta
THYGA	EULow+20%H	45,6	7.24 MJ/m3
	EUHigh	52,8	
Certification	G21	54,7	4 MJ/m3
	G20	50,7	5 MJ/m3
	G23	45,7	

WP5 – Adjustment

Adjustment with CO2: why it is not recommended with H2

$$\%O2 = 21\% - \frac{21\%}{\%CO2_{max}}\ \%CO2$$

λ	Air–fuel equivalence ratio
Va	Volume of air required to burn 1m3 of gas (m3 of air/m3 of gas)
Vf0	Volume of dry burnt gases generated by the combustion of 1 m3 of gas (m3 of flue gases/m3 of gas)
%CO2max	The stoichiometric percentage of CO2

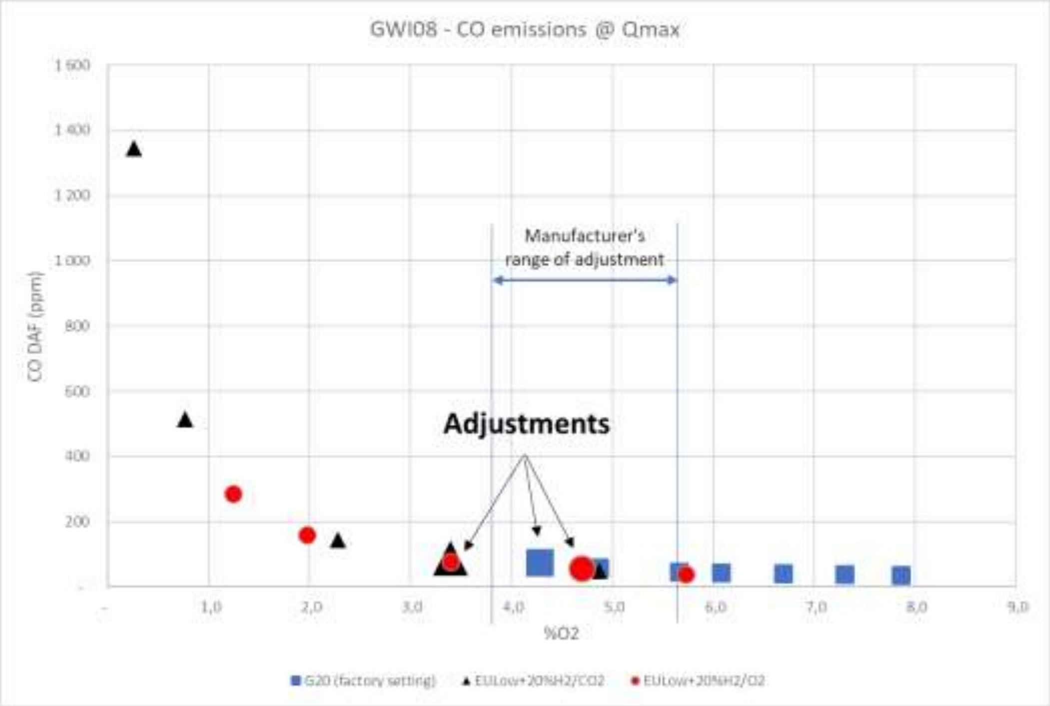
Ref gas	Va	Vf0	Vf0/Va	%CO2max		Lambda (CO2 adj)	Lambda (O2 adj)
G20	9,56	8,56	0,90	0,12		**1,30**	**1,30**
Eulow	9,14	8,23	0,90	0,12		**1,29**	**1,30**
EUHigh	10,52	9,45	0,90	0,12		**1,33**	**1,30**
G20+20%H2	7,79	6,96	0,89	0,11		**1,22**	**1,30**

In the presence of H2:

- CO2 adjustment leads to a richer flame 👎
- O2 adjustment = constant air/fuel equivalence ratio 👍

WP5 – Adjustment

O_2 VS CO_2



- Adjustment based on CO_2 leads to a richer adjument (with $\%H_2$)
- When WI goes up, $\%O_2$ goes down
- It causes CO Emission problems

- **O_2 adjustment is the best way to adjust a boiler close to factory settings**

WP5 – Adjustment

Impact of O2 adjustment: Test results

- High decrease CO emissions @Qmax, but also NOx decrease
- A Qmin, CO and NOx emissions remain constant and very low

Boiler	Qcal	Adjustment	CO DAF (ppm)@Eulow+20%	CO DAF (ppm)@EU High
GWI08	Qmax	CO2	87	1347
GWI08	Qmax	O2	53	285
EN01	Qmax	CO2	93	664
EN01	Qmax	O2	60	288
EN02	Qmax	CO2	9	41
EN02	Qmax	O2	7	22

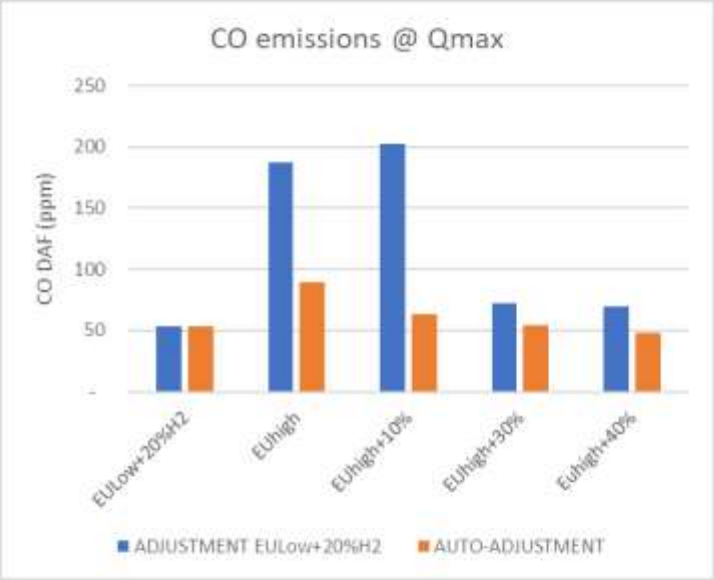
Boiler	Qcal	Adjustment	NOx DAF (ppm)@Eulow+20%	NOx DAF (ppm)@EU High
GWI08	Qmax	CO2	68	147
GWI08	Qmax	O2	32	134
EN01	Qmax	CO2	61	225
EN01	Qmax	O2	39	155
EN02	Qmax	CO2	64	237
EN02	Qmax	O2	39	185

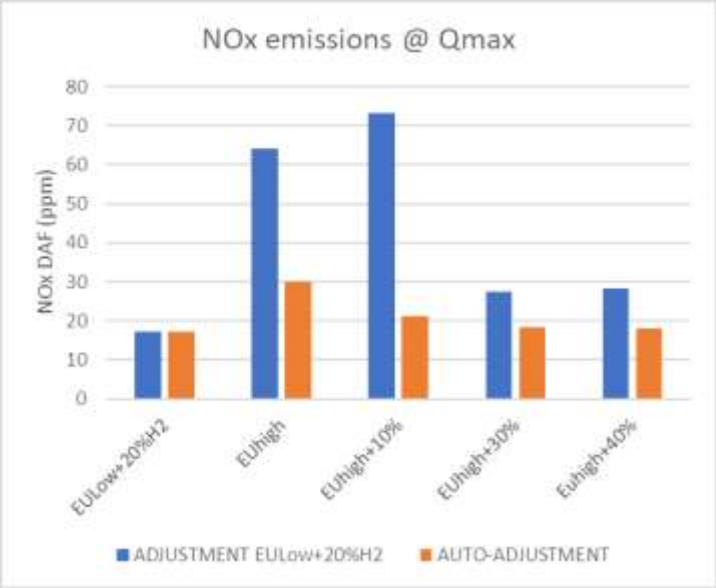
Boiler	Qcal	Adjustment	CO DAF (ppm)@Eulow+20%	CO DAF (ppm)@EU High
GWI08	Qmin	CO2	64	45
GWI08	Qmin	O2	62	43
EN01	Qmin	CO2	5	5
EN01	Qmin	O2	7	9
EN02	Qmin	CO2	14	2
EN02	Qmin	O2	18	6

Boiler	Qcal	Adjustment	NOx DAF (ppm)@Eulow+20%	NOx DAF (ppm)@EU High
GWI08	Qmin	CO2	12	25
GWI08	Qmin	O2	11	27
EN01	Qmin	CO2	16	56
EN01	Qmin	O2	21	69
EN02	Qmin	CO2	42	36
EN02	Qmin	O2	12	30

WP5 – Adjustment
Combustion control (CO sensor)

- CO sensor in flue gases
- Qmax: Pollutant emissions are lower than a CO_2 adjustment
- Qmin: CO and NOx concentration are close for auto-adjustment / CO_2 adjustment





WP5 – Adjustment

Alternative methods

Alternative adjustment methods could help **if no O2 analyser is at hand** or if the installer can have information about the %H2 of the gas

- No O2 analyser
  - **Forbid adjustment** (boiler adjusted to G20 behave well when factory settings are kept → GASQUAL, THyGA) 👍
  - **Factory adjustment to G20+10%H2**. Bad idea. Richer combustion leads to higher CO, NOx and flame velocities. 👎
- **If %H2 of the fuel gas is known**: update %O2 adjustment value according to %H2 👍
- **Limit the Wobbe range** of delivered gases
  - Difficult in the current Ukrainian war context → increase of Wobbe range (bioCH4 to LNG) 👎
  - Fine if only bioCH4+H2 mixtures are used. 👍
- **Boiler auto-adjustment**
  - **Ionization probe**: WI fluctuations of NG compensed by the probe, not %H2 → low emissions and safe behaviour regarding flashback (λ increase with %H2) 👍
  - **CO sensor**: low pollutant emissions compared to CO2 adjustment. No flashback during tests. Data still need to be processed. 🤔
  - **O2 sensors** are also an option to consider

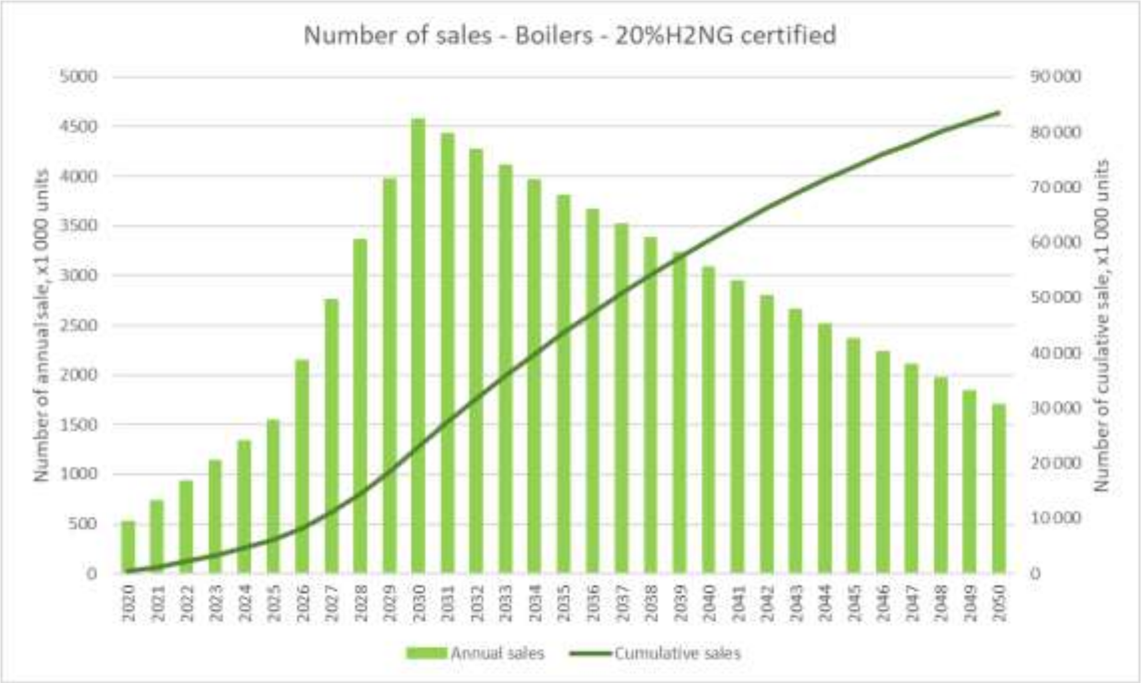
THyGA

Gas conversion strategies

WP5 – Gas conversion strategies

Situation 2030/2050

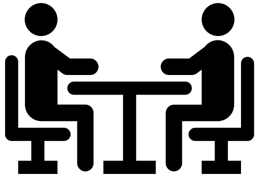
Potential evolution of market share of H2NG boilers in Europe.



- Mitigation approaches (1st thoughts):
  - Wait untill all appliances are H2-ready → too long
  - Replace all non H2-ready appliances → costly 💰
  - Check compatibility of all non H2-ready appliances → costly 💰
- An alternative solution must be found
  - How to be sure that non H2-ready appliances operate well and safely with H2NG mixtures ?

WP5 – Gas conversion strategies

“Best practice” methodology (based on experience)



- **Dialog between gas operators and appliances manufacturers**:
  - *What is/was done for L to H conversion projects*
  - *What is being done country per country (France, Italy,…)*
  - Gas operators
    - how much %H2 at max ? (ex: France = 2%/2023)
  - Manufacturers & manufacturer associations:
    - Which appliances can operate up to x%H2
    - Which appliances can’t operate up to x%H2
    - Appliances for which more investigations are required

- Build together **a common (European) database of appliances compatibility**

Some appliances won’t be in the list. Can a safety check solve the problem ?

WP5 – Gas conversion strategies

Example of safety check: HyDeploy

Safety check of used appliances **was firstly introduced in the HyDeploy** project for **ALL used appliances**
It is also used in the the "Wasserstoff-Insel Öhringen" project, but for **some appliances** only

Project phase 1

Lab test of representative appliances

- Fireplaces, hobs and boilers
- Test gas ≈30% H2

Progressive increase of hydrogen by steps of 5% H2

Project phase 2: used appliances

Safety check

- Gas appliances and network → safe with current gas
- Test with a reference gas (G20)
- Tests with 2 H2NG at different concentrations

Installation of a CO detector

WP5 – Gas conversion strategies

Example of safety check : Risk analysis

Risks identified

- Gas leakage
  - No significant risk increase compared to NG, but a safety check can't be done without this verification
- CO emissions
  - Appliance must perform safely before any %H2 injection
  - Appliance must perfom safely with H2NG mixture
- Malfunctions due to inadequate adjustment
  - Avoid excessive CO emissions, overheat,…
- Flashback
  - No flashback should occur with H2NG mixtures
- Delayed ignition
  - Ignition should be fast enough to avoid big volumes of unburnt H2NG to ignite
- Material compatibility

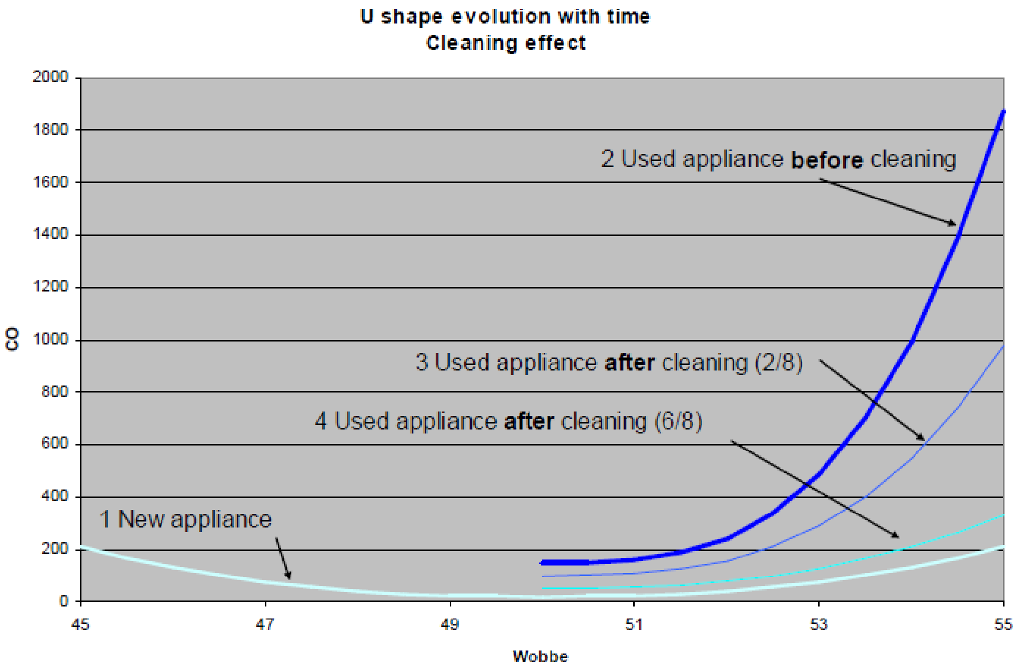
WP5 – Gas conversion strategies

Example of safety check : in practice (1/2)

Gas leakage: two test options

- Pressure drop
- Non rotating of the flowmeter
- A limit value have to be established

Maximum leakage flowrate (dm3/h)	-	0,14	0,20	1,00	6,00	Over 6.0
NL New						
Project "Wasserstoff-Insel Öhringen"						
NL Existing						
France						
Recommandation						



Appliance preparation / paperwork

- Appliances are clean
- Appliances are maintained (certificate)

 Source: GASQUAL project

WP5 – Gas conversion strategies

Example of safety check: in practice (2/2)

From which %H2 should we implement it?

Gas composition must be under control: 2 gas cylinder used

- G20 (current status)
- G22 (limit gas)

G20 is also used for adjustment to factory settings

G22 is recommended instead of G222 because of the limited time available on site

Gas cylinder can be connected at the flowmeter

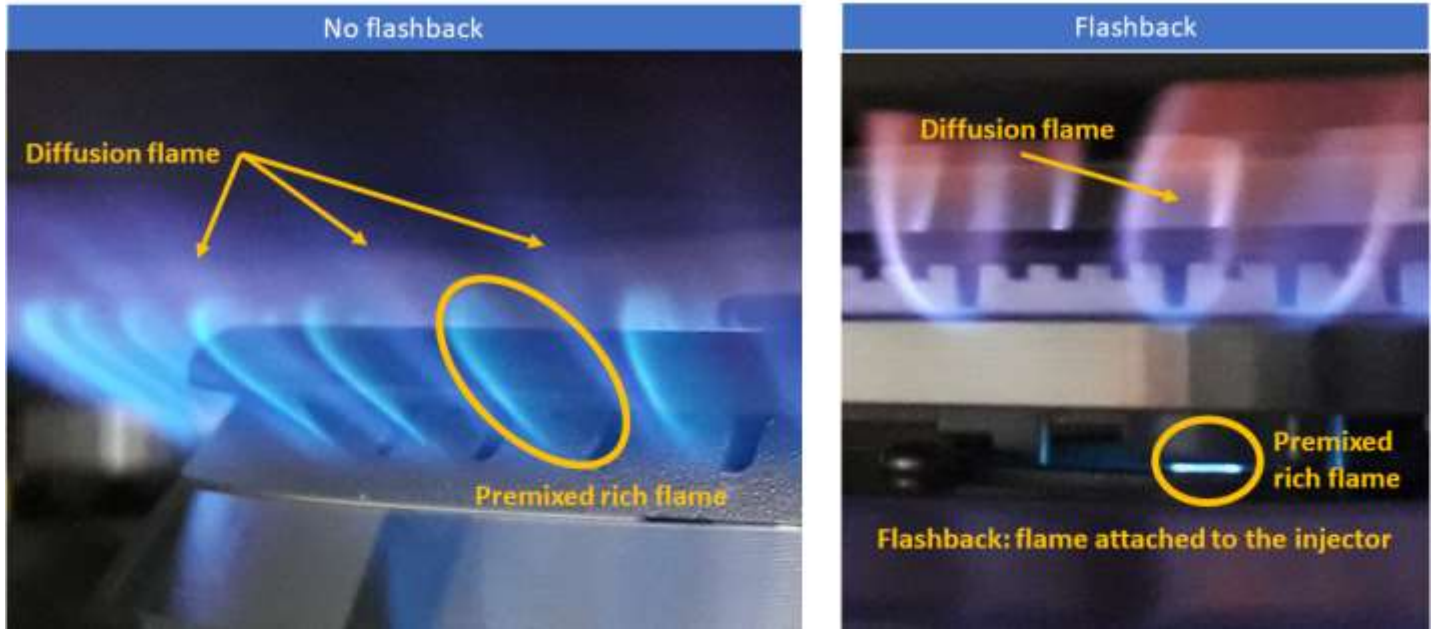
Gas cylinder weight and capacity is an issue:

- M20 (4 m3 but 35 kg)
- S11 (2.3 m3 11 kg)

WP5 – Gas conversion strategies

Example of safety check: Flashback detection

- **Flashback detection might not be so easy**
- Sound when premixed H2NG/air mixture is ignited → needs constant attention
- Visually: the premix part of the flame disappears. Only the diffusion flame is visible (reddish)
- Premix appliances: flame not always visible but flame detector should shut down the appliance (→ to be checked on more appliances)



WP5 – Gas conversion strategies

Example of safety check: estimated duration

Total safety check duration	Duration (min)	Option duration (min)	remarks
Test description to the customer	5		
Visual check of appliances/get mainainance certificate	5		
Leak detection			
Check rotating flowmeter	5		
switch off all appliances	2		
Check non rotation of flowmeter	10		
rotating flowmeter (leak identification)		15	
Plug bottles	10		
Switch to G20			
Purge gas network from air	5		
Boiler check emissions (CO before adjustment) - adjustment		20	
Check CO emissions G20 - Boiler	10	10	10 more minutes if >1000ppm
Check CO emissions G20 - Cooker	10	10	
Switch to flashback gas			
Check/CO & flashback Qmax - Boiler	10		
Check/CO & flashback Qmin - Boiler	10		
Check/CO & flashback Qmax - Cooker	10		
Check/CO & flashback Qmin - Cooker	10		
Unplug bottles + check tightness	10		
TOTAL CHECK TIME	112	55	

- 2 hours long (for one cooker and one boiler)
- More time required if adjusment / extra leak detection is required
- Requires well trained technicians
- Weight vs capacity of bottled gas could be a problem

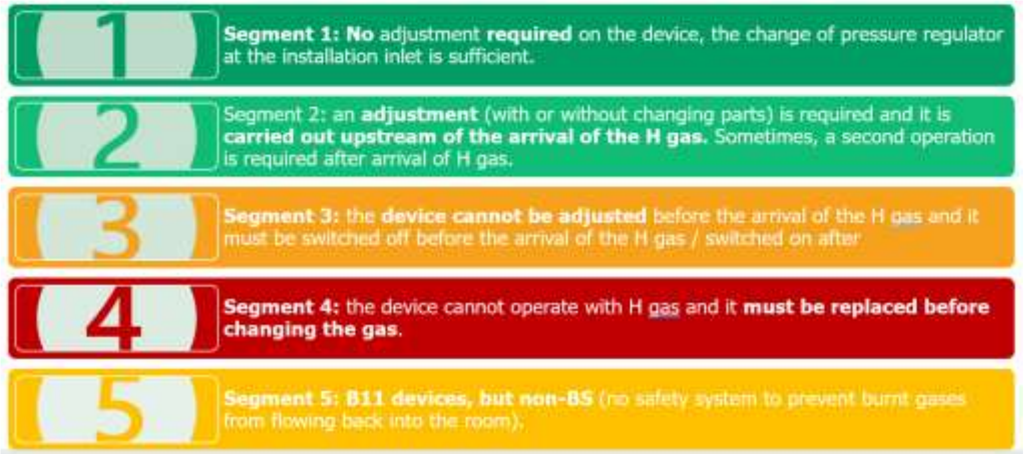
- Optimization is required
- Cost evaluation: safety check vs replacement must be done

- Note: duration checked within the THyGA project but not presented here

WP5 – Gas conversion strategies

Conclusions

- Make a list of appliances: OK, not OK, or in between
  →importance of the segmentation
- Build experience for NG → H2NG conversion
- Minimize the number of safety checks to be performed
- Safety check:
  - About 2h
  - Bottled gas plugged donwstream of gas meter
  - Ref. gas + H2NG limit gas



Segmentation used in L to H convertion project (France)

- **Conclusion: more investigations are needed in order to facilitate the arrival of H2NG mixtures**

Conclusions and take-away

Modified slide taking into account late delayed ignition test results

Conclusions and take-away

Project conclusions « in a nutshell »

Gas is an energy vector needed for the transition to reach carbon neutrality. In that sense, it is really important to work on every option such as blending to multiply the available pathways.

The main strength and characteristic of THyGA is the very extensive test campaign, on around 100 different appliances, with a great variety of systems… but even there, we are touching a part of the whole range of installed appliances !

Only the fraction of the results have been shown and will be provided in the technical reports, projects members will do their best to go on using the results to support the industry's projects

Our conclusions are that blending up to 20%H2 is technically feasible but implementation would need a collaboration with DSO, energy provider, Member states… Especially, 3 topics should be adressed by all stakeholders: delayed ignition on some appliances, liability and adjustment !

Liability

Conclusions and take-away

Liability with H2NG

THyGA showed that the majority of installed appliances technically cope with 20%H2 for end-use but there are liability issues doing that

As explained in WP4, in reference to the Gas Appliance Regulation, existing appliances did not have to be designed for use of H2NG; so H2NG supply cannot be considered as 'normal use' and so **manufacturers would not be liable for any negative impact caused by supply of H2NG mixtures** (except recent 20%H2 certified boilers or radiant heaters)

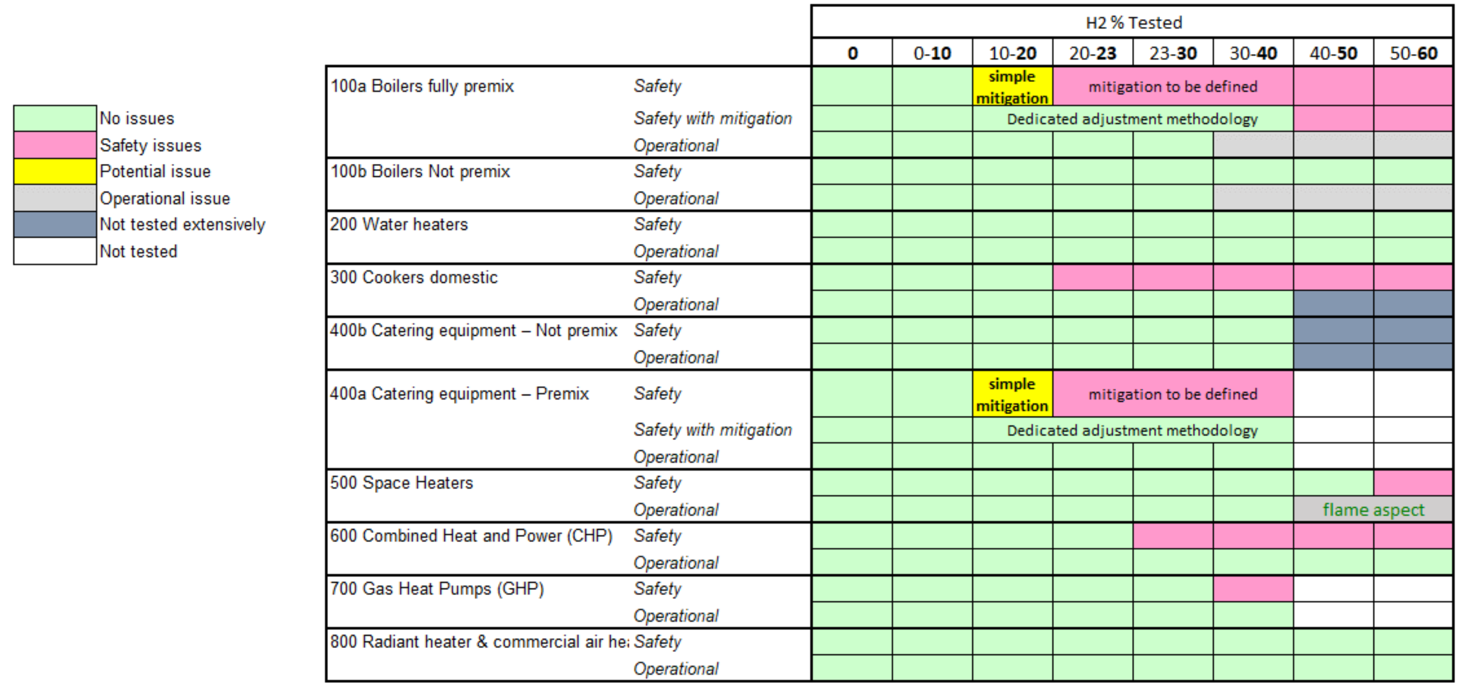
Member States are working on methodologies and concertation to evaluate the percentage of hydrogen that can be injected within their distributed natural gas. A harmonization of these methodologies and sharing of the results would greatly favor the implementation of blending.

THyGA recommandation N°1: to favor knowledge sharing between Member States and gather all stakeholders (manufacturers, gas distributors, safety authorities…) to discuss how H2NG should be dealt with for existing appliances

Adjustment

Conclusions and take-away

Adjustment



Adjustement is an important parameter to consider for blending. THyGA showed promising solutions (O2 adjustment, forbid adjustment…) but it is important to pay attention to National or Local regulation which could impede implementation

<u>**THyGA recommandation N°2**</u>: stakeholders should discuss how to solve this in practice

New slide taking into account late delayed ignition test results

Delayed ignition

New slide taking into account late delayed ignition test results

THyGA

Conclusions and take-away

Delayed ignition

Appliances equipped with specific partially premixing burners without a fan in the combustion circuit (i.e. appliance type B11BS) used in certain types of boilers and water heaters seem to be sensitive to delayed ignition. No light-back occurs, but the unburned gas accumulates also downstream of the burner. When this accumulated unburned gas is lighted it creates a flame at the injector.

Few of these appliances are actually on the market, but according to outfindings it seems recommended to reconsider the test method and conditions to take in account reasonably foreseeable worst cases, to reassess the delayed ignition risk systematically for appliances not specifically designed for natural gas containing relevant H2 concentrations, especially when on-site adjustment is allowed/possible.

THyGA recommandation N°3: more extensive testing is needed to completely assess the delayed ignition risk and work on mitigation measures (reduce the ignition safety time, avoir inappropriate on-site adjustment…)

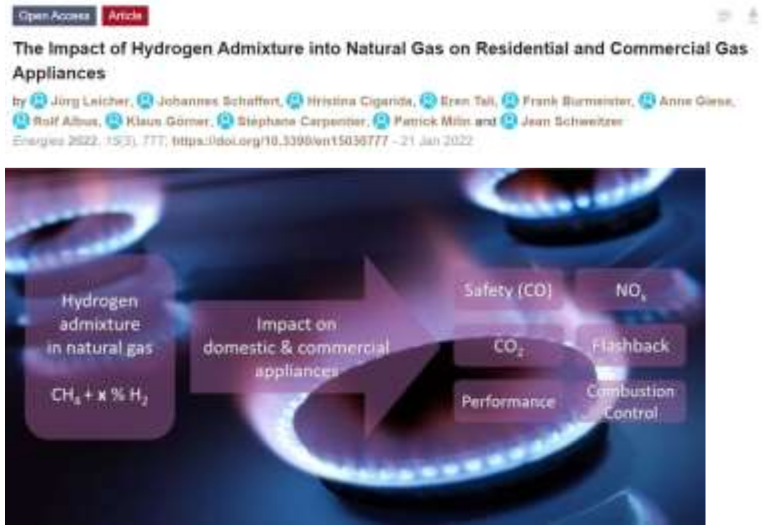
THyGA

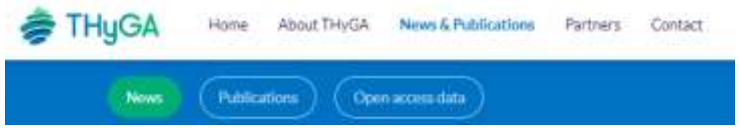
Final steps for the project

Final steps for the project

A wealth of information on the project website

- **Reports, articles, newsletters & replays of several workshops**





Industry Choice Award

Final steps for the project

Exploitation of the results

- **22 Public deliverables (6 to come early April)**
- Open Data (Project test protocol, Reporting test sheet, Agregated test results, Roadmap tool)
- THyGA results will be disseminated to CEN TCs and members can support presentations in technical meetings

VISIT THE THyGA WEBSITE

All public presentations and deliverables of the project will be available on the project website

thyga-project.eu

CONTACT EMAIL

Do not hesitate to contact us by email at contact_thyga@engie.com

Thank you !

To all partners
to the Clean Hydrogen Partnership and the European Commission
to the advisory panel members and the manufacturers

THyGA will go on in conferences and technical events! See you soon !!

Find Us Online

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For regular updates, you can also follow the GERG LinkedIn page and website

GERG
THE EUROPEAN GAS RESEARCH GROUP

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Thank you for your attention

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