THyGA

THyGA

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

THyGA WP4

Workshop "H2NG supply to residential and commercial appliances – standardization and certification" 31/03/2021

Meeting	Workshop WP4
Meeting date & location	31st of March 2021 (Webco)
Document ID	THY_WP4_007_WP4 Workshop main take-aways_02
Author & Company	Kris De Wit, Gas.be

Attendees				
Name	**Company**		**Name**	**Company**
Benoit Charlot	AFG		Nicola Guardigli	Electrolux
Ted Williams	AGA		Jacques Dubost	ENGIE
Wilfried Linke	BDH		Patrick Milin	ENGIE
Andrea Manini	BDR Thermea Group		Stéphane Carpentier	ENGIE
Sebastiano Temperato	BDR Thermea Group		Kris De Wit	Gas.Be
Michel Oldenhof	Bosch		Alexandra Kostereva	GERG
Nourredine Mostefaoui	CETIAT		Robert Judd	GERG
Jean Schweitzer	DGC		Jean-Baptiste Perrin-Terrin	GERG
Hiltrud Schülken	DVGW		Jörg Leicher	GWI
Werner Kinnen	DVGW-CERT		Mark Crowther	Kiwa
Dennis Klein	DVGW-CERT		Mindert van Rij	Kiwa
Krishnaveni Krishnaramanujam	DVGW-EBI		Howard Levinsky	RUG
Regis Anghilante	DVGW-EBI		Martin Bergemann	Siemens
Irma Rustemi	Electrolux		Christoph Schreckenberg	Vaillant
Fabio Spano	Electrolux		Ingo Seliger	Viessmann
Maurizio Beghi	Electrolux		Dave Lander	Dave Lander Consulting

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1 Context and goals of the workshop

A key issue in a transition to common use of relevant shares of hydrogen in natural gas supply is safe operation and reliable functioning of end-use appliances. The lifetime of these end-use appliances is considerable and so new gas appliances put on the market should ideally be compatible with these admixtures as soon as possible. Therefore, appropriate adaptation of certification requirements and related standardization is of utmost importance.

Different initiatives and first experiences exist. **In the framework of its WP4 on standardization and certification the THyGA project team decided to organize a workshop with a number of invited experts** in view of getting better insight into these existing initiatives and experiences and answers on a number of open questions.

On the 31st of March, the Workshop brought together **32 standardisation experts and manufacturers** to discuss and share information on the current certification and standardisation frameworks, in the EU and the USA.

Time	What	Who
13h30	THyGA	
	Welcome	Patrick Milin / Kris De Wit
	THyGA project: general	Patrick Milin
	Current test program: what and why?	Jean Schweitzer
	Certification and standardization: impact of H2 addition	Kris De Wit
14h00	Status of standardization framework	
	Pre-normative project GERG	Robert Judd / Jean Schweitzer
	CEN/TC 238	Nourreddine Mostefaoui
	CEN/TC 109 WG1 AhG H_2	Michel Oldenhof
	CEN/TC58	Martin Bergemann
	Questions	
15h00	BREAK	

Time	What	Who
15h10	Experience with testing and certification with H_2NG	
	KIWA – H_2NG testing prescriptions	Mindert van Rij
	DVGW – H_2NG testing prescriptions	Dennis Klein
	BDR Thermea	Sebastiano Temperato
	Electrolux	Maurizio Beghi
	Questions	
16h00	Other experience with testing and certification with H_2NG	
	KIWA – UK's experience & approach	Mark Crowther
	American Gas Association – US' experience & approach	Ted Williams
	Questions	
16h30	Discussion & conclusions	
17h00	END	

The following notes are the main take-aways identified by the project.

The THyGA project team thanks the experts for their participation, valuable contributions, and acceptance to share their views publicly with all interested stakeholders.

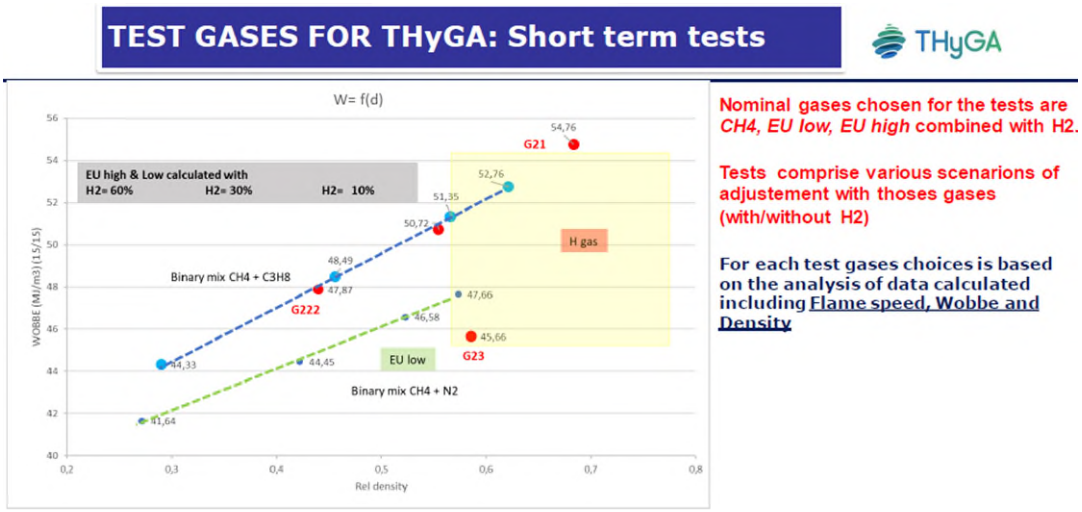
Please note that these exchanges reflect thoughts and leads of the guests on the topic of H2NG and not necessarily official positions of the concerned organizations.

2 THyGA project (P. Milin – Engie, J. Schweitzer – DGC, K. De Wit – Gas.be)

Main goals of the project

- Enable wide adoption of hydrogen in natural gas blends by closing knowledge gaps, identifying adaptation of standards and clarifying the acceptable H2 concentration.

- Test program developed to define the influence of H2 mixed in NG on safety, performances and operation of existing types of residential and commercial appliances.
- Short- and long-term combustion tests using test gases based on Wobbe index of natural gas of type H distributed in EU (47,63 ≤ W_S ≤ 52,78 MJ/m³) and H2 concentrations up to 60%
- Some leakage tests on indoor gas supply systems are also planned.



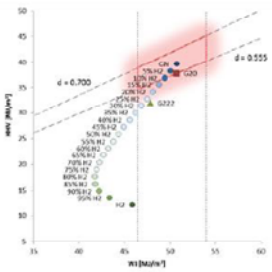
Observations:

- Flash-back could occur after longer burning time → test procedure in current standards may have to be reconsidered → to be confirmed.

- Standardization: new test gases to be defined, but also product standards may have to be updated on tests, test conditions and requirements.
- EN437 → gas family = group of gaseous fuels with similar burning behaviour linked together by a range of Wobbe indices → burning behaviour with H2 significantly different than with CH4 + H2 because blends can lower the initial Wobbe index of NG beyond lower limit of H group (i.e. 45,7 MJ/m³).
- Existing appliances did not have to be designed for H2NG supply → H2NG supply cannot be considered as 'normal use' → no product liability by manufacturer.
- Appropriate H2 concentration ASAP to be adopted in quality specifications for distributed gases (cf. annex II of GAR) for which new appliances need to be designed ?
- The widespread current practice of on-site adjustment of gas appliances may become inappropriate for varying H2 concentrations.

CONSIDERATIONS REGARDING TEST GASES

- defined by **EN 437** elaborated by CEN/TC238
- **gas family** = group of **gaseous fuels** with **similar burning behaviour** linked together by a **range of Wobbe indices**
  - similar burning behaviour → H_2 significantly different from CH_4
  - range of Wobbe indices → H_2 can lower W of NG beyond lower limit of H group (i.e. 45,7 MJ/m³)

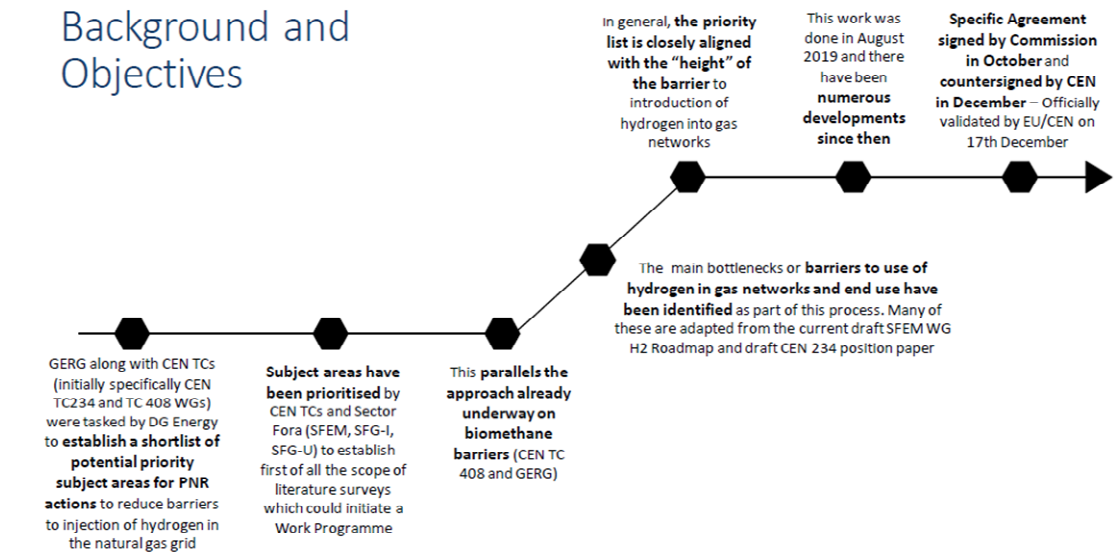


Objective	Name	Composition	W_S	H_2NG
Reference	G20	100 % CH_4	50,72	2nd **reference** gas needed ?
Incomplete combustion + sooting	G21	87 % CH_4 + 13 % C_3H_8	54,69	**no changes** needed ?
Light back	G222	77 % CH_4 + 23 % H_2	47,87	to be adapted to **max. H_2** concentration, but from **worse perspective**
Flame lift	G23	92,5 % CH_4 + 7,5 % N_2	45,66	H_2 lowering risk → **no changes** needed ?
Overheating	G24	68 % CH_4 + 12 % C_3H_8 + 20 % H_2	52,09	H_2 concentration **to be adapted** in function of max. H_2 concentration ?
?	?	?	?	**any new limit gas** to cover any new or impacted risk ?

3 Pre-normative project GERG/CEN (R. Judd – GERG, J. Schweitzer - DGC)

Scope of the project

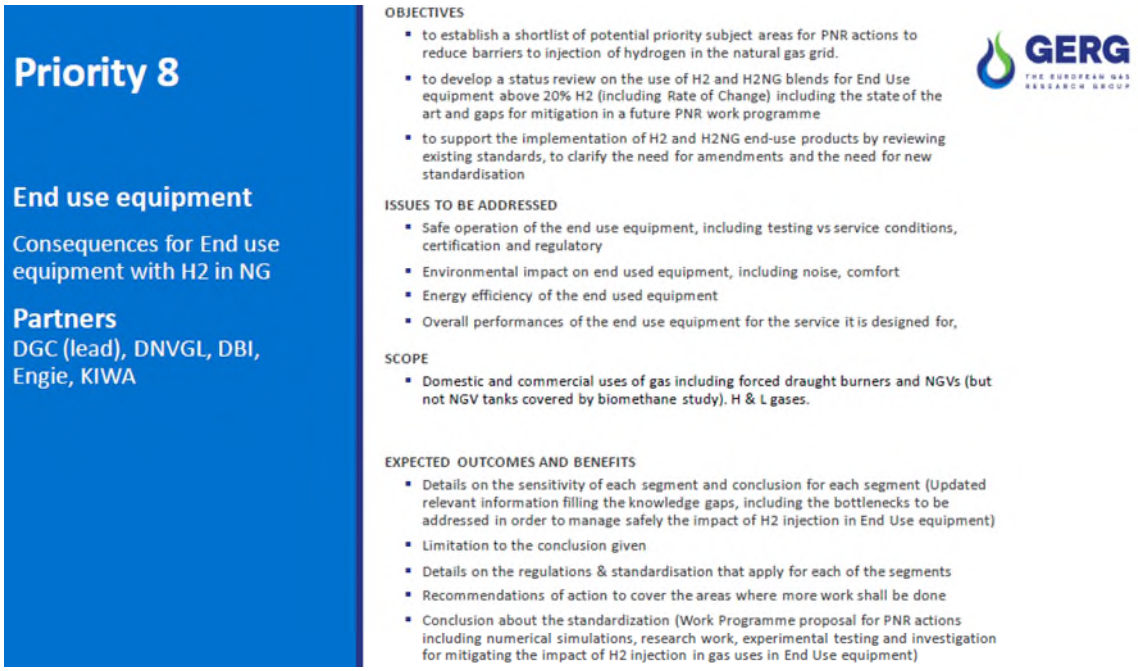
- H2NG gap analysis covering different topics amongst which residential and commercial end-use including draught burners and NGV → topic leader: DGC.
- Tasks: perform detailed knowledge surveys, understand state of the art, understand gaps in knowledge, develop recommendations for pre-normative actions in order to enable the injection of H2 in the grid and development of 100% H2 dedicated grids.
- Planning: project started in Autumn 2020 → final report 30th of Nov 2021



Issues to be addressed for residential and commercial end-use (focus on 20% H2 in NG grids and 100% H2 in dedicated grids):

- Safe operation of the end use equipment, including testing vs service conditions, certification and regulatory.
- Environmental impact on end used equipment, including noise, comfort.
- Energy efficiency of the end used equipment.
- Overall performances of the end use equipment for the service it is designed for.

There clearly are synergies between the GERG project, the THyGA project and ongoing CEN TCs' work.



4 Test gases standard EN 437 – CEN/TC238 (N. Mostefaoui - CETIAT)

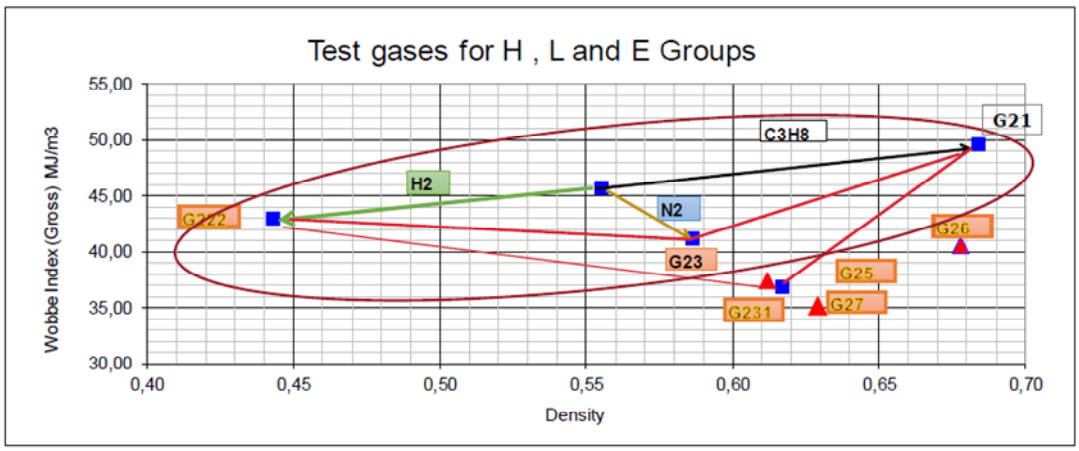
Work regarding H2 in parallel with TC 109 activities.

The activities related to H2NG and H2 have to be launched ASAP after the revised 2021 version of EN 437 is published.

The standard already contains test gases for the use of town gas: they contain between 43 and 59 % of H2, but also between 21 and 32 % of N2. Town gas is still in use in some places in Denmark, Germany, Italy and Sweden.

EN 437

- It defines also for each category the reference and limit gases
  - **Measure the performances and emissions and to check the safety**



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Impact of hydrogen on test gases

- A new revision of NF 437 in 2 steps was adopted by the plenary CEN TC 238 in 2019 and 2020
- Step 1 : mixtures of natural gases and hydrogen to launched as soon as version 2021 is published
  - **The work of CEN TC 238 is done in parallel with CEN TC 109**
- Step 2 : hydrogen to launched as soon as version 2021 is published
- **Work progress will presented by CEN TC 109**

THYGA WORKSHOP _ Mars 2021 STATUS OF STANDARDIZATION - CEN TC 238 7 CETIAT

5 Product standards on central heating boilers – CEN/TC109 WG1 AhG H2 (M. Oldenhof - BOSCH)

The presentation focusses on what has to be changed in terms of tests and corresponding limit gases.

Proposal to introduce:

- new appliance categories (e.g. I2N+, I2H+) for appliances accepting up to 20% H2
- a 4th gas family in EN437 for 100% H2

A draft amendment EN 15502-2-1 for H2NG appliances already exists.

Proposal for marking and limit gases.

Draft amendment EN15502-2-1 for H2NG appliances:

Main adaptations:

- Marking of H2NG appliance with a "Y" following by a number to indicate the %H2 in the gas:
  - E.g. 2EY20 for 80% CH4 and 20% H2.
- Amendment written for max. 20% H2 volume in the distribution gas, which means a range of 0-20% H2 is covered.
- Nominal heat input = heat input with reference gas (0% H2).
  - Max ± 5%/ 500W heat input tolerance allowed.
- Reduced heat input = heat input with hydrogen blend (20% H2)
  - No max. heat input tolerance.
- Risk analysis to be extended for materials in contact with hydrogen.
- Delayed ignition (to be done with NG&H2NG).
- Combustion measurements/calc. based on O2 instead of CO2.
- Light back to be done with higher %H2 test gas (see next page).
- (Mal)-adjustment of the boiler taking into account adjustment at both 0% and 20% H2.

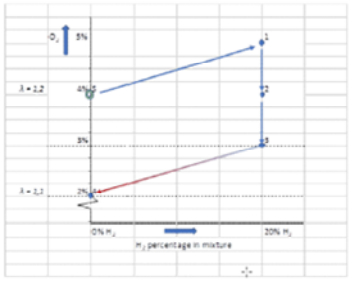

Figure 100: Illustration to show (mal)-adjustment of the boiler in combination with up to 20% Hydrogen volume in the distribution gas.

5 TT-RH/ENG1-Dev | 2021-03-23

BOSCH

Limit gases for H2NG appliances for fully pre-mix appliances:

-2 proposals:

- "classic" proposal in line with current EN437, but for light back gas for 2EY20/2HY20 the test gas G22 is chosen (35% H2).

Gas category without H2 (EN437)		Gas category with Hydrogen blend (new, future adaptation in EN437)					
Gas category	Reference gas	Gas category	Reference gas	Declared heat input for 20% in the distribution gas	Incomplete combustion gas	Light Back gas	Flame lift limit gas
2_E	G20	2_{EY20}	G20	$G20_{Y20}$	G21	G22	G231
2_H	G20	2_{HY20}	G20	$G20_{Y20}$	G21	G22	G23

- Alternative for 20% H2 in the distribution gas a lambda variation of +/- 10% can be chosen (in line with the PAS4444 for 100% H2). A similar approach can be done for higher % H2 in the gas.

Gas category without H2 (EN437)		Gas category with Hydrogen blend (new, future adaptation in EN437)					
Gas category	Reference gas	Gas category	Reference gas	Declared heat input for 20% in the distribution gas	Incomplete combustion gas	Light Back gas	Flame lift limit gas
2_E	G20	2_{EY20}	G20	$G20_{Y20}$	0,9* λ	0,9* λ	1,1* λ
2_H	G20	2_{HY20}	G20	$G20_{Y20}$	0,9* λ	0,9* λ	1,1* λ

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BOSCH

6 Product standards on safety and control devices – CEN/TC58 – AFECOR (M. Bergemann - SIEMENS)

Main points:

- For safety and controls devices, a lot of parameters are relevant and need to be considered.
- 4 project groups within CEN/TC58: Leakage rates and breather holes, Combustion safety, Sensors and Electronics, Materials.
    - Leak-tightness: no significant differences with NG.
    - Breather holes: in case of diaphragm failure higher flow rates through breather holes have been measured for H2 → risk assessment needed.
    - Combustion safety: avoid unburned gas accumulation, procedures needed for parts replacement.
    - Sensors and electronics: limits of ionization sensors, difference in spectral range for optical sensors, safety times to be adapted, moisture.
    - Materials: H2 embrittlement, operating temperature classes to be introduced

CEN/TC 58 Hydrogen Activities
Project Group 2: Combustion Safety

afecor
European Controls Manufacturers Association

Assessment parameters
- High temperature exposure of parts
- NOx emissions

To be investigated
- Accumulation of leakage rates, avoid ATEX zones
- Avoid deflagration
- Purging procedure
- Procedure for components only temporarily supplied with hydrogen
- Procedure for part replacement (filters, valves, actuators)
- Detection of incomplete combustion, hydrogen emission measurement
- Factors compromising product lifetime

CEN/TC 58 Hydrogen Activities
Project Group 3: Sensors and Electronics

afecor
European Controls Manufacturers Association

Assessment parameters
- Flame detection signal strength
- Safety times of burner controls

To be investigated
- Focus on EN 298 (burner controls), EN 12067-2 (electronic fuel/air ratio controls) and EN 16340 (combustion product sensors)
- What are the limits of ionization sensors for increasing hydrogen content, can the method still be used for adaptive systems?
- Will the difference of the spectral range of natural gas and hydrogen flames cause any problems for optical sensors?
- Higher ignition energy needed for hydrogen, flame detection time may need to be adjusted
- Moisture becomes a factor to be considered especially for combustion product sensors

31 March 2021 Martin Bergemann 5

7 Gas Appliances Regulation (EU) 2016/426 (GAR) (M. van Rij - KIWA)

Main points.

- Risk analysis of H2NG use by gas appliances: risks on fan location, ionization current, delayed ignition, surface temperature of the burner and its surroundings.
- Proposal to indicate the Wobbe index bandwidth of natural gas (without hydrogen) an appliance is designed for in warnings, instructions and design documentation with a Z value Zzz (e.g. Z20 = appliance designed for a Wobbe index bandwidth of 2,0 MJ/m³)
- Proposal to indicate the max. H2 concentration an appliance is designed for in warnings, instructions and design documentation with a Y value Yyy (e.g. Y20 = appliance designed for a max. H2 concentration of 20 vol%)
- On-site adjustment becomes more critical if current way of doing is not adapted → proposal to test with adjustments for the 2 most extreme reasonably foreseeable adjustments using the actual distribution gas.
- Use of O2 instead of CO2 concentration in flue gases for on-site adjustment.
- Safety margins between test gases and distributed gases to be evaluated → current test gases with H2 do consider distributed gases not containing H2.

Conclusion:

- The instructions must be clear on the gasses the appliance is designed for (The Y and the Z are a option for this).
- The manufacturer must provide a risk analysis (RA) using the gasses the appliance is designed for.
- For H2NG evidence must be given that the ER's of the GAR and the risks form the RA are covered to the same extend as for NG-only appliances.
  - Key issues indicated by the ER's: On site adjustment of the appliance, Ignition and combustion stability, Materials suitable for H2 .
  - Some key issues form the RA: Fan location, Delayed ignition , Ionization current, Surface temperatures of the burner and its surroundings.

12 Kiwa Nederland B.V.

Recommendation for the future of H2NG

- Introduction of H2NG is supported if:
  - The actual accurate information on the Wobbe index of the NG-only gas and the H2 content are available on a city by city basis to the public and the installers. (This is not the case today !)
  - This may require modifications of the National legislation on DSO and TSO in each member state that considers introducing H2NG.
  - If national legislation is in place to provide this information, the adjustment instructions of the manufacturer may assume that this information is available to the installer and use this information as the basis for the installation instructions. (Today it is not reasonable to assume that this information is available for the installer)

13 Kiwa Nederland B.V.

8 Testing prescriptions in Germany (D. Klein – DVGW)

Increasing demand for approval with H2 in NG up to 20% → test protocol and requirements needed until standards are available → DVGW ZP 3100 is an additional testing protocol for gas-fired central heating boilers using H2NG up to 20 vol% H2

It uses a 2nd reference gas besides G20 (i.e. 100% CH4): 80% CH4 + 20% H2 + new limit gas for flash-back: G22 (i.e. 65% CH4 + 35% H2).

ZP 3100 – the testing protocol

A Testing protocol for appliances that can use 0-20% hydrogen admixture

- Based on the EN 15502-2-1
- Additional tests which are affected by hydrogen admixtures
- Tested with a second reference gas (80-20) and a new limit gas for flame lift (G 22)
- Components, parts and materials need a manufacturer declaration that they are suitable

Structure of the ZP:

Clause in EN 15502-2-1	Requirement	Test condition	Comment	Test Gas

DVGW

ZP 3100 – Basis for standardization

- The Testing protocol was developed by german experts of testing laboratories, manufacturers and notified bodies
- It was used to support the amendment for hydrogen of EN 15502-2-1 in CEN/TC 109/WG 1 AHG hydrogen
- The new test gases are also used to support the revision of EN 437 in CEN/TC 238/WG 1
- ZP 3100 is published and available for free under:

https://www.dvgw-cert.com/de/produkte-gas/pruefgrundlagen/zertifizierungsprogramm-zp.html

DVGW

9 Manufacturers' views and experiences – part 1 (S. Temperato – BDR Thermea)

The group already disposes of a certified full H2 boiler. 100% H2 appliances should prevent:

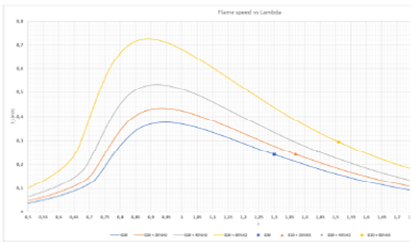
- any explosion outside the combustion chamber because of gas leakage ;
- any ignition of the gas/air mixture before the burner ;
- any flash-back also in case a wrong lambda is used.

H2NG blends:

- Not new → town gas used since many years and still today in several countries.
- Components often are already approved for use of town gases.
- 20% H2 recommended as maximum mainly due to possible variation of the H2 concentration.
- Main risks:
  - wrong onsite adjustment of burner settings
  - delayed ignition
  - heat output & comfort reduction (about 5%)
- λ most important parameter to consider for evaluating the operating margin.
- Some auto-adaptive combustion controls based on ionization current don't seem to react to the Wobbe index change in case of H2 presence ® could be positive to avoid onsite adjustment.
- Boilers with very high modulation ratio at min. power: high burner temperature and higher risk on flash-back
- Approval for existing appliances on the market remains an open point ® liability to be defined → min. manufacturer's declaration + safety instructions.

BDR Thermea experience: NG+H2 blend

- **Lambda is the most important parameter to consider for the evaluation of the operating margin**
  Flashback is never an issue when the boiler is set to operate with NG. Also at 60%H2 the flame speed remains low because of the reduction of the Ws and the increase of the lambda.
  Flashback could be an issue, increasing the %H2, only if it associated to a reduction of lambda.



- **Some Electronic Combustion controls based on ionisation current don't seem to react to the Ws change in case of presence of H2 in the blend**. This behaviour could be positive because it avoids any risk of adjustment in the field by service people and the boiler operates always in safe conditions.
- **Boilers with very high modulation ratio operating at min power could meet problems:** high burner temperature and flashback could happen more likely.

BDR THERMEA GROUP 5

BDR Thermea experience: NG+H2 blend

Some considerations:

- BDRT/BAXI SpA is directly participating on several Working Groups connected with H2:
  THYGA, Hy4heat, TC109 ad hoc WG for H2, Assotermica Green Gas Group, UNI mirror Group, Notified Body.
- The risks associated to the use of the NG+H2 blends, as described in the previous slides, are not in our opinion an obstacle for the introduction of H2 in the NG grid.
- Use of a limit gas, to verify the operating margin for the flashback (e.g. G22 used for max 20%H2 blend), is consistent with the approach used today on EN15502 standards.
- Ecodesign / Energy labelling should not be impacted by the NG+H2 blend adoption for limited H2 content (up to 20%). Same approach should be used also for other applicable legislations.

10 Manufacturers' views and experiences – part 2 (M. Beghi – Electrolux)

Main points

- Product certification is not possible without modification also in the legislation (cf. GAR and ECO-design/energy labelling) for gas appliances.
- It is important to define and evaluate the meaning and content of "H2Ready" and "H2NG compatible" product ranges to achieve tangible CO2 emission reductions.
- Different scenarios in relation to how appliances would need to be adapted or retrofitted:
    - simple factory pre-setting
    - on-site adjustment
    - H2 Ready with conversion kit, part replacement
    - specific design
- Could different max. H2 concentrations in countries create barriers?
- Importance of variations of H2 concentration ® to be taken in account when defining test conditions.
- What about H2 quality considering different ways production (e.g. steam reforming, electrolysis)?
- How to deal with the existing appliances on the market

Technical items

- Hydrogen blends:
    - how much? 2%, 5%, 10%, 20%, ...
    - Could different national approaches be a barrier with hydrogen blends % variations country by country?
    - Percentage variability over time or compatibility with NG100%? Limit gas must include this variability
    - Are all H2 the same (CH4 reforming vs hydrolisys)?
- Appliances already on the market: which strategy for them?
    - Support sells for (x%) Hydrogen ready appliances in order to prepare transition (labeling?)
    - Retrofit kit? Is it to be defined a backwards time limit with incentives?
- CEN TC 49: showed interest in WP8 (end uses) for the pre-normative requirements «PNR H2NG/H2 IN NG SYSTEMS» lead by CEN TC 234; no specific activity running so far

Other items

- The need for Certification, Homologation or backward compatibility could drive the business model for adaptation: uncertaintanty about H2 introduction and impacts could lead consumer towards electric appliances
- Supplier competence and component readiness?
    - Alignment with potential impacts and development schedules
    - Component readiness for H2NG vs Town Gas?
- Testing activities to be updated:
    - unburnt H2 → any limit?
    - unburnt HCN → any limit?
    - NOx → any limit?
    - Gas leakage tests: criteria for limit flow Rates and test pressure; test with air comparison
    - Shall test instruments and requirements be adapted to H2 flows?

11 HyDeploy project (M. Crowther – KIWA Gastec)

As demonstration project of hydrogen in homes, HyDeploy aims to prove that blending up to 20% volume of hydrogen with natural gas is a safe and greener alternative to the gas we use now.

- It is providing evidence on how customers don't have to change their cooking or heating appliances to take the blend.
- Laboratory tests carried out before starting live trial on a closed network at the Keele site → used limit gas for flash-back composed of 71,6% CH4 and 28,4% H2 resulting in a Wobbe index equal to the lower Wobbe index limit of the GSMR.
- Safety issues limited to the functioning of oxygen depletion sensors (ODS) and some minor issues with flame detectors based on the ionization current → ODS is a safety device which is used on some gas appliances with open fires installed in living areas (e.g. decorative fuel effect appliances and type A water heaters) → further investigation is recommended.
- Majority of test data indicates no deterioration in public safety when using 20% H2 in NG.

Safe domestic and commercial 20%v/v hydrogen use

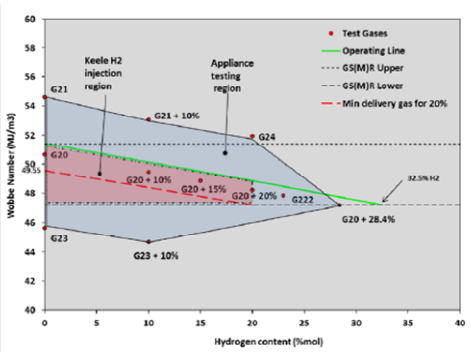


Figure 1 Test Gases Used to Assess Appliance Operation

Safe domestic and commercial 20%v/v hydrogen use

Table 6 Laboratory Test Results

Test Assessment	General Test Result	Variation Within Test Result	Comments
CO Production	No change or a reduction in CO production with increasing hydrogen concentration compared to that of natural gas: compliance demonstrated against BS 7967-2015	Appliances displayed similar behaviour albeit at different absolute levels due to predicted differences in combustion style [5]	Deviation from specification is not significant except in extreme conditions.
Combustion Behaviour including ignition efficiency, cross lighting and assessment of light back	No evidence of deterioration in combustion performance, no ignition failings and no occurrence of light back [5]	None	No significant change in appliance performance.
Combustion behaviour (100% Hydrogen)	Light back at concentrations greater than 80 % mol/mol hydrogen. Below 80 % mol/mol, no ignition issues or occurrences of flame failure. [5]	At ~ 90% mol/mol hydrogen ignition issues observed	Suggests an upper fractional limit of 80% mol / mol hydrogen is present.
Function of Oxygen Depletion Sensor (ODS)	Out of four live flame effect fires showed a compliance against ODS specification with O2O but failed the safety criteria when hydrogen was added.	The fire with oxy pilot ODS trialled against the various test gases failed to provide ODS function with sufficient safety factor to be acceptable. Further studies into ODS design and function is recommended.	Inset live flame effect fires contain an oxygen depletion sensor (ODS) to guard against flue blockage. BS EN 7977-1 requires that the ODS shuts off the gas supply before the CO concentration reaches 200 ppm in the test chamber
Flame Failure Devices (Ionisation Probe)	Up to 90 % mol/mol hydrogen the measured ionisation current in the Worcester Bosch boiler showed a reduction in ionisation current with increasing hydrogen concentration. No false flame out events occurred.	Ionisation current is used as a control mechanism by a number of boiler manufactures. None of these appliance types are present on the O3 network at Keele University and therefore this aspect has not been considered as part of the HyDeploy test programme.	It is a well-established consensus that there is limited ionisation current in hydrogen flames; the trials reaffirmed this consensus.
Energy Efficiency	Minimal effect of hydrogen on the efficiency of the appliances. [5]		The Wobbe Number of the delivered gas was kept within GSMR limit.

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

12 Status in USA (T. Williams – AGA)

Blends using NG as a carrier gas for delivering H2: 5 to 15% H2 appears to be viable without significantly increasing risks → report: NREL – Blending H2 into NG pipeline networks - 2013

AGA, AHRI and CSA group did exploratory testing of residential NG appliances operability on methane/H2 mixtures → final reports soon available:

- Stability issue of pilot ignition observed in 1 space heater.

Issues raised for AGA consideration:

- Influence of "real natural gas" in NG/H2 blends
- Focus on diffusion flame burner appliances → certification testing vs. field performance
- Potential standards actions → test gas in Z21/Z83-CSA standards