Testing Hydrogen admixture for Gas Applications

WP4 – certification & standardization framework

D4.3 – considerations on test gases and appliance standards adaptation for H_2NG supply.

Deliverable:	D4.3
Status:	Final, 15th of May 2023
Dissemination level:	PU = Public

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.

Document classification

Title	Considerations on test gases and appliance standards adaptation for H2NG supply.
Deliverable	D4.3
Reporting Period	M18-M39
Date of Delivery foreseen	M39
Draft delivery date	M39
Validation date	M41

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Work package	WP 4
Dissemination	PU = Public
Nature	Report
Version	Final
Doc ID Code	THY_WP4_D4.3 - considerations on test gases and appliance standards adaptation for H2NG supply
Keywords	Hydrogen, H_2, Combustion, Admixture, H_2NG, Certification, Standardization, GAR, EN 437

Document review

Partner	Remark	Version	Date
Gas.be	1st draft with part 1 on test gases	draft 1	16-04-2023
Gas.be	Review after comments from involved THyGA partners	draft 2	03-05-2023
Gas.be	Addition of part 2 on adaptation of appliance standards	draft 3	15-05-2023
Gas.be	Review after comments from involved partners	draft 4	31-05-2023

Document Validation

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Acknowledgement

This document results from the contributions and exchanges during the dedicated workshops on 31st of March 2021 and 8th of March 2023 and interactions with several other people with relevant experience. All THyGA project partners want to thank them explicitly for sharing their knowledge and experience.

List of abbreviations, definitions and references

A_{AS} — An appliance

- not intended for connection to a flue or to a device for evacuating the combustion products to the outside of the room in which the appliance is installed ;
- and fitted with an atmosphere sensing device.

B_{11AS} — An appliance

- intended to be connected to a flue that evacuates the combustion products to the outside of the room containing the appliance. The combustion air is drawn directly from the room ;
- incorporating a draught diverter, marketed without duct systems, intended to be connected to a separately approved and marketed system for discharge of the combustion products ;
- of natural draught type ;
- fitted with an atmosphere sensing device.

B_{11BS} — An appliance

- intended to be connected to a flue that evacuates the combustion products to the outside of the room containing the appliance. The combustion air is drawn directly from the room ;
- incorporating a draught diverter, marketed without duct systems, intended to be connected to a separately approved and marketed system for discharge of the combustion products ;
- of natural draught type ;
- fitted with a clearance monitoring device.

CH_4 — Methane

C_3H_8 — Propane

EN 437 — This European standard specifies the test gases, test pressures and categories of appliances relative to the use of gaseous fuels of the first, second and third families. It serves as a reference document in the specific standards for appliances. The document makes recommendations for the use of the gases and pressures to be applied for the tests of appliances burning gaseous fuels.

EN 15502 — This European Standard specifies, the requirements and test methods concerning, in particular, the construction, safety, fitness for purpose, and rational use of energy, as well as the classification and marking of gas-fired central heating boilers that are fitted with atmospheric burners, fan assisted atmospheric burners or fully premixed burners, and are hereafter referred to as boilers. Where the word boiler is used, it needs to be read as the boiler including its connecting ducts, ducts and terminals, if any. This European Standard covers gas-fired central heating boilers from the types C1 up to C9 and the types B2, B3 and B5: NOTE For further background information on appliance types see CEN/TR 1749:2014.

ER	Essential Requirement as stated in Annex I of Regulation (EU) 2016/426 of the European Parliament and of the Council of 9 March 2016.
EU	European Union
GAR	Gas Appliances Regulation (EU) 2016/426 of the European Parliament and of the Council of 9 March 2016.
group H	Defined by EN 437 as a specified range of Wobbe indices within that of the 2nd family (natural gases) going from 45,7 up to 54,7 MJ:m³ (at 15/15°C and 1.013,25 mbar); this range is determined on the general principle that appliances utilizing this gas group would operate safely when burning all gases within this range without adjustments. Note 1 to entry Adjustment of the appliance may be permitted in accordance with the special national or local conditions that apply in some countries (cf. EN 437 B.4).
H_2	Hydrogen
H_2NG	Hydrogen / Natural Gas mixture/blend
N_2	Nitrogen
TC	CEN Technical Committee

Table of contents

1. Scope and objectives

This document is composed of two parts.

Part I covers considerations regarding test gases for assessing combustion related risks of supply with gaseous fuels of the second family (i.e. natural gases) blended with hydrogen of which the concentration may vary between 0 and a maximum hydrogen concentration X (called “X% H_2NG” throughout this document) to gas appliances within the scope of the Regulation (EU) n°2016/426. If relevant, a specific view is given on 20% H_2NG as this is often put forward as a meaningful limit if hydrogen injection is considered.

As the THyGA project only covers high calorific natural gas (= H gas), considerations in this document are limited to gas groups covering this H gas i.e. gas groups H and E, as defined by EN 437:2021.

The document is mainly intended as input for CEN/TC238 – *Test gases, test pressures, appliance categories and gas appliance types* – in view of the revision of EN 437 for use of the above-mentioned gases.

Part II covers risks to be considered when revising existing gas appliance standards for H_2NG supply.

2. PART I – CONSIDERATIONS ON TEST GASES

2.1 EN 437 approach

The introduction of X% H_2NG or 100% H_2 use does not seem to require a significant change in the approach/philosophy of the current EN437 i.e. the use of

- a reference gas "chosen as to be representative of the gas group and being the gas with which appliances operate under nominal conditions when they are supplied at the corresponding normal pressure ; the appliance is generally factory set for this gas"[1] ;
- limit gases "chosen to help prevent the various kinds of malfunctioning (incomplete combustion, light-back, flame lift, sooting and, only for certain types of appliances (specified in the appliance standards), overheating ; they are representative of the extreme variations in the characteristics of the gases or operating conditions for which appliances have been designed ; tests with limit gases are carried out with the appliance set using the corresponding reference gas ; the tests with limit gases are of short duration, and do not imply a satisfactory functioning when faced with a continual supply of distributed gases with a Wobbe index close to the maximum or to the minimum Wobbe index of the gas group."[1]

It has been confirmed however that a limit gas is not necessarily appropriate for all kinds of burner technologies. This issue is not new, but if distributed gases are going to contain significant hydrogen concentrations, it seems indispensable to differentiate based on the applied burner technology.

Apart from the above, all considerations in this document respect the current EN 437 approach regarding test gases.

2.2 Hydrogen properties

To assess the risk of hydrogen use and more particularly of blends with natural gas, it is important to be aware of the main differences in relevant properties between hydrogen and methane, the main component of natural gas. The following table compares the main relevant properties of hydrogen and methane.

	Unit	CH_4	H_2
Gross Calorific Value[2]	MJ/m^3	37,78	12,1
Net Calorific Value[2]	MJ/m^3	34,02	10,2
Relative density	-	0,56	0,07
Molecular weight	-	28	2

[1] EN437:2021 informative annex D on the "Relationship between the distributed gases and the corresponding test gases".
[2] Dry gas reference conditions of 15°C as combustion reference temperature (if applicable for the concerned property), 15°C as gas reference temperature and 1013,25 mbar as gas reference pressure.

	Unit	CH_4	H_2
Wobbe index[2] (using GCV)	MJ/m³	50,72	45,88
Min. air quantity for complete combustion	mol/mol	9,52	2,38
Laminar flame speed[3]	cm/s	38,6	209,8
Adiabatic flame temperature[3]	°C	1.946	2.101
Flammability range in air	vol%	4,4 - 15	4 - 75
Auto-ignition temperature	°C	595	560
Min. ignition energy	mJ	0,28	0,02
Dewpoint temperature[3]	°C	59	72
Methane number	-	100	0

Table 1 – comparison of main relevant combustion related properties of CH_4 and H_2.

Injecting hydrogen in natural gas will result in different values for the properties of the mixed gas. This has already been illustrated in the THyGA deliverable D2.2 on "Impact of hydrogen admixture on combustion processes – Part I: Theory".

2.3 Gas family and gas group

2.3.1 Gas family

EN 437 divides gases supplied to gas appliances in families and groups. If hydrogen is injected in natural gas, the question is whether the defined gas family and groups still apply or not?

A first distinction is made based on the burning behaviour in function of the Wobbe index of the supplied gas. EN 437 defines a gas family as "a group of gaseous fuels with similar burning behaviour linked together by a range of Wobbe indices". Natural gases constitute the 2nd family covering a range of Wobbe indices from 39,1 up to 54,7 MJ/m³.

Considering the significantly different properties of hydrogen, it is to be considered up to what hydrogen concentration one considers admixtures of natural gas and hydrogen as gaseous fuels with a similar burning behaviour? Based on the THyGA test results, it appears that admixtures with hydrogen concentrations up to 20 vol% may be considered as having similar burning behaviour.

Independent of the Wobbe index of the natural gas, the injection of hydrogen will lead to a decrease in Wobbe index as long as the hydrogen concentration does not exceed about 60 vol%. Further raising the hydrogen concentration will slow down the decrease and from a certain point, depending on the calorific value and relative density of the natural gas, the Wobbe index will start increasing again to end at a value of 45,88 MJ/m³ for 100 % H_2. Figure 1 shows the Wobbe index evolution in function of

[3] At λ = 1.

the hydrogen concentration for the existing reference gas G20 (= methane = CH_4) and the 2 limit gases representing the extremes of possible Wobbe index values for gas group H.

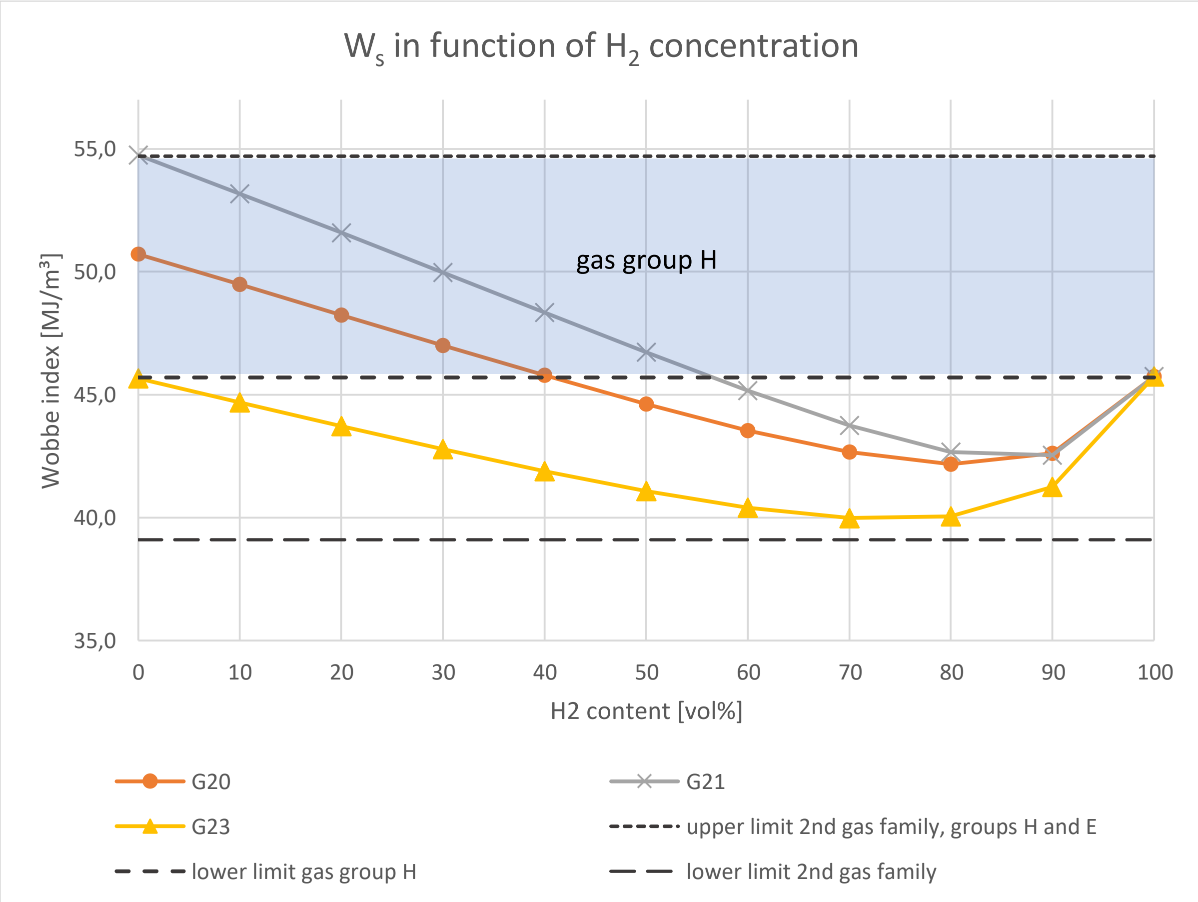

Figure 1 – Wobbe index of test gases in function of hydrogen concentration vs. 2nd gas family and group H limits.

The Wobbe index limits of the 2nd gas family i.e. natural gases are not exceeded due to hydrogen injection in high calorific natural gases.

2.3.2 Gas group

A next level of distinction consists of specified ranges of Wobbe indices within that of the family concerned and is called a gas group. As far as the 2nd family of natural gases is concerned, EN 437 identifies the following main groups:

Gas group	Wobbe index range	
	lower limit [MJ/m³]	upper limit [MJ/m³]
H	45,7	54,7

E	40,9	54,7

Table 2 – main gas groups of the 2nd family as defined by EN437:2021.

According to the definitions of EN 437, these gas group ranges are determined on the general principle that appliances using this gas group operate safely when burning all gases within this range without adjustment (on-site of the factory combustion settings) although adjustment of the appliance may be permitted in accordance with the special national or local conditions that apply in some countries.

The lower Wobbe index limit for the H group may be exceeded due to hydrogen addition and by consequence a decision is to be made. Possible options would be:

- lower the concerned current lower Wobbe index limit, but that would require to change the name of the gas group to avoid not knowing for which H gas group an appliance on the market has been designed;
- limit the hydrogen addition as to respect the current Wobbe index limit;
- raise the natural gas lower Wobbe index limit as to respect the current Wobbe index limit for the concerned hydrogen addition

or a combination of the above options.

For 20% H_2NG and supposing 45,7 MJ/m³ is still considered the appropriate lower Wobbe index limit for natural gases of group H without any relevant hydrogen concentration,

- the lower limit of gas group H would have to be lowered from 45,7 MJ/m³ to 43,7 MJ/m³;
- the hydrogen addition would have to be limited as soon as the Wobbe index of the natural gas drops below about 47,8 MJ/m³;
- the lower Wobbe index limit of high calorific natural gas would have to be about 47,8 MJ/m³.

For information, the lowest Wobbe index of the gases distributed in Europe in 2015-2016 was found to be 47,63 MJ/m³ in a survey executed by the Joint Research Centre of the European Commission in the framework of pre-normative work by a CEN SFGas WG.

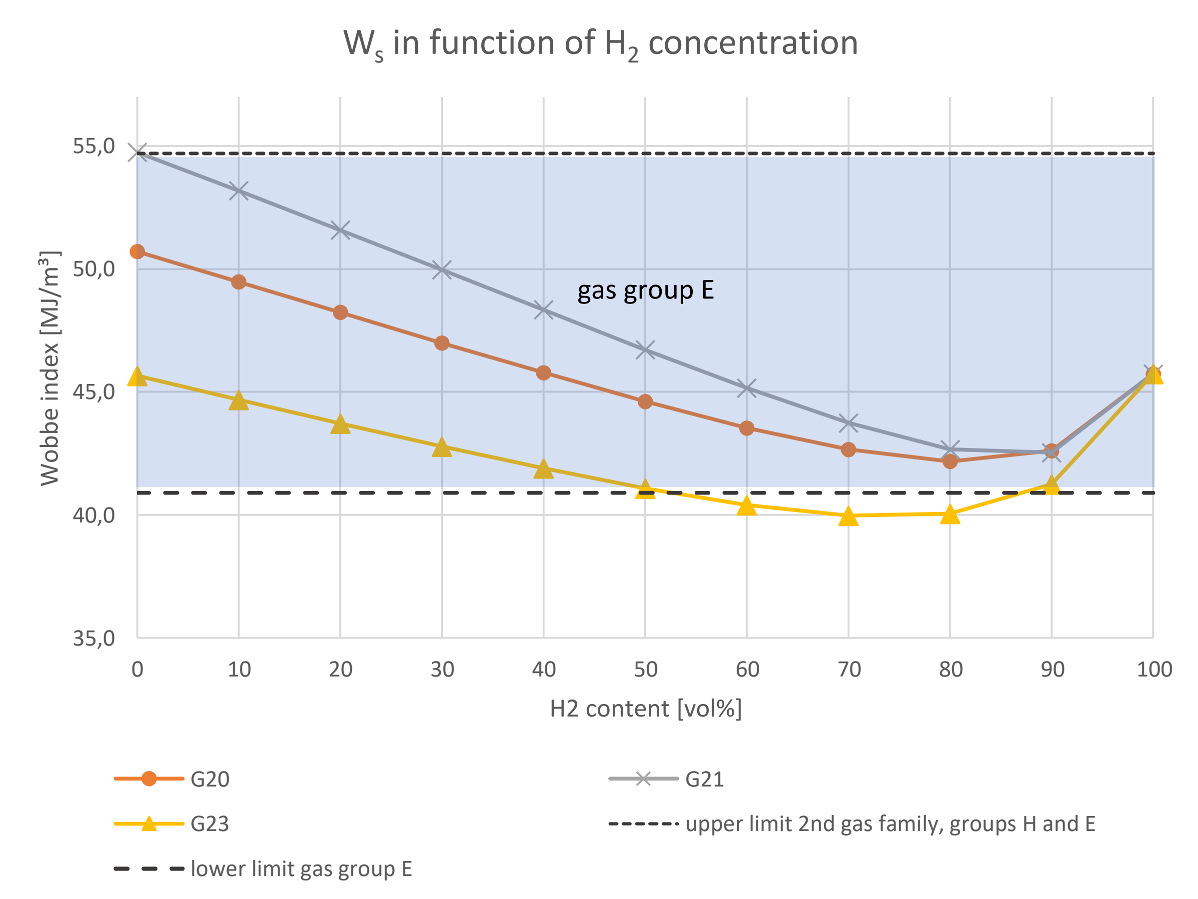

Figure 2 – Wobbe index of test gases in function of hydrogen concentration vs. group E limits.

With a lower limit of 40,9 MJ/m³, gas group E obviously allows for injecting more hydrogen in high calorific natural gas before exceeding this lower limit. Based on G23 up to 50% hydrogen can be added before exceeding the lower limit of gas group E.

2.4 Test gases

Distributed gases are considered to define gas families, gas groups and test gases. These test gases should indeed allow for all gas/combustion related risk assessment for what is defined as 'normal use'[4] of a gas appliance by the Gas Appliances Regulation (EU) 2016/426.

2.4.1 Reference gas

A reference gas is defined as "a test gas with which appliances operate under nominal conditions when they are supplied at the corresponding normal pressure". Generally, an appliance is (pre)set in the production line of the factory to reach the nominal heat output when supplied with this gas. So, appliances are primarily designed based on the reference gas.

A reference gas however is also used as test gas for assessing performance (i.e. nominal heat output, efficiency and emissions) and a number possible risks (like soundness of the gas circuit, surface and component temperatures, delayed ignition, functioning of control and safety devices, etc.) while limit gases are only used for a short duration and only to assess a limited number of specific risks such as light-back, flame lift, incomplete combustion, etc.

Due to the very different properties of hydrogen, injection in natural gas (mainly composed of methane) impacts several risks which today are only assessed with the concerned reference gas. As the hydrogen concentration may vary between 0 and a maximal concentration it seems appropriate to assess specific risks with a 'reference gas' composed of the current reference gas with the maximum hydrogen concentration.

For 20% H_2NG with natural gas of group H, that would mean the creation of a 2^{nd} reference gas consisting of a mixture of methane with 20% H_2 next to the current G20 reference gas (= methane). It coul also be considered not to identify it a 2^{nd} reference gas, but a test gas to be used for assessing relevant specific risks only tested with the existing reference gas today.

The risks relevant to be assessed with such a 2^{nd} reference gas are to be based on the properties of hydrogen which are significantly different from those of methane taking in account that they may also depend on the type of appliance and used combustion technology. More information can be found in part II of this document.

Apart from possible flame visibility issues at high hydrogen concentrations, the THyGA test results did not show any qualitatively new risks created by the injection of hydrogen in natural gas. So, it is only about existing risks impacted by the presence of hydrogen.

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[4] Regulation (EU) 2016/426 on gas appliances considers an appliance to be 'normally used' where the following conditions are met:

a) it is correctly installed and regularly serviced in accordance with the manufacturer's instructions;
b) it is used with a normal variation in the gas quality and a normal fluctuation in the supply pressure as set out by Member States in their communication pursuant to Article 4(1);
c) it is used in accordance with its intended purpose or in a way which can be reasonably foreseen.

If no new risks are introduced by the injection of hydrogen in natural gas, the current limit gases should only be evaluated on their fitness for assessing the concerned risk in case of X% H_2NG supply knowing that the hydrogen concentration may very between 0 and X%.

2.4.2 Limit gases

2.4.2.1. Incomplete combustion and "sooting" limit gas

- current limit gas for gas group H is G21 composed of 87% CH_4 + 13% C_3H_8;
- incomplete combustion and "sooting" are caused by lack of sufficient oxygen and/or a disturbed/interrupted combustion process;
- incomplete combustion leads to higher CO concentrations in the combustion products;
- gases with Wobbe index and relative density higher than methane (i.e. G20 = the gas the appliance is adjusted to), so typically with heavier hydrocarbons, increase these risks ;
- as hydrogen addition reduces the Wobbe index and the relative density, the **current limit gas G21** is **considered appropriate** for assessing this risk in case of supply with X% H_2NG.

2.4.2.2. Flame lift limit gas

- current limit gas for gas group H is G23 composed of 92,5% CH_4 + 7,5% N_2;
- flame lift and flame instability are caused by an imbalance between the gas flow speed out of the burner orifice and the flame speed → with a lower flame speed (which, in itself is dependent on fuel composition, but also local temperatures and the local air excess ratio) the flame front moves away from the burner surface (which is called "flame lift") leading to flame instability;
- flame instability disturbs the combustion process and leads to incomplete combustion causing again higher CO concentrations in the combustion products;
- gases with a Wobbe index lower than the gas the appliance has been adjusted to (within the limits of a gas family/group), lead to a lower gas/air ratio which reduces the flame speed in case of air excess ($\lambda > 1$ → see Figure 3) and by consequence to flame lift;
- so, assessing the risk of flame lift requires a test with the lowest possible Wobbe index;
- injecting hydrogen in high calorific natural gas with the lowest possible Wobbe index, reduces the Wobbe index further which still increases the air excess, but hydrogen has a much higher flame speed than methane which compensates, partially or fully, the impact of the air excess increase ⇒ for X% H_2NG:
  - ➢ if the Wobbe index of the distributed natural gas with the lowest possible Wobbe index + X% hydrogen is equal to or higher than 45,66 MJ/m³ then G23 can be maintained as single flame lift limit gas;
  - ➢ if the Wobbe index of the distributed natural gas with the lowest possible Wobbe index + X% hydrogen is lower than 45,66 MJ/m³ then G23 and a 2nd flame lift limit gas simulating the distributed natural gas with the lowest possible Wobbe index + X% hydrogen, can be used to assess properly the flame lift risk; this 2nd flame lift limit gas could consist of a mixture of CH_4 + N_2 + X% H_2. To be evaluated whether a safety margin is to be included.

2.4.2.3. Light-back limit gas

- current limit gas for gas group H is G222 composed of 77% CH_4 + 23% H_2;
- remark: EN 437 does not define a light-back limit gas containing hydrogen for supply with low calorific gas (= gas group L), the reference gas (i.e. G25 composed of 86% CH4 + 14% N2) is also used for assessing the risk of light-back;
- light-back is caused by an imbalance between the gas flow speed out of the burner orifice and the flame speed → with a higher flame speed the flame front moves to the burner surface and enters ultimately back into the burner where combustion is not intended to take place;
- adding hydrogen to natural gas increases the flame speed at the same gas/air ratio;
- supply with a gas with a different Wobbe index however changes the gas/air ratio in all appliances without appropriate auto-adaptive burner controls and by consequence also impacts the flame speed as shows Figure 3;
- the gas/air ratio shift has an opposite effect depending on whether the air/gas ratio is positioned left or right from the air/gas ratio with the highest flame speed (i.e. generally slightly sub-stoichiometric) and so, it appears appropriate to make a distinction between appliances equipped
    - with a partially premixing burner or with an auto-adaptive burner control keeping λ constant;
    - with a fully premixing burner.

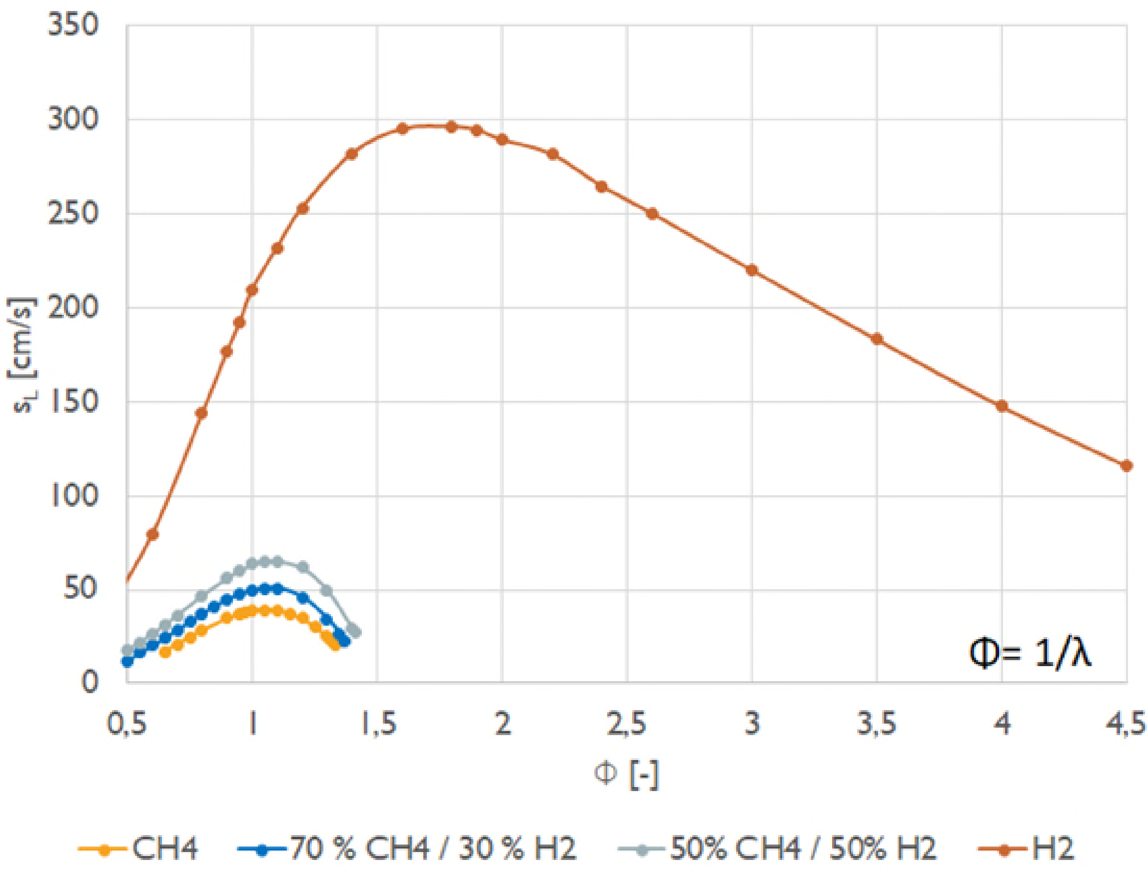

Figure 3 – laminar flame speed of methane, hydrogen and admixtures in function of equivalence ratio Φ (source: GWI, THyGA D2.2 Impact of hydrogen admixture on combustion processes – Part I: Theory)

Appliances equipped with a partially premixing burner or with an auto-adaptive burner control

- when switching from supply of methane to supply of methane + X% hydrogen on appliances equipped with an auto-adaptive burner control (keeping λ constant) the impact on the laminar flame speed will be limited to the difference in flame speed between the two supplied gases (see Figure 4);
- when switching from supply of methane to supply of methane + X% hydrogen on appliances equipped with a partially premixing burner there will be an increased impact on the laminar flame speed due to the decreased gas/air ratio (see Figure 5);
- the rationale behind the hydrogen concentration of 23% of the limit gas G222 has not been found, but if this concentration is considered appropriate to assess the risk of light-back when supplied with high calorific natural gas without any relevant hydrogen concentration then it is obvious that assessing the light-back risk when supplied with X% H2NG needs a limit gas containing more hydrogen;
- for 20% H2NG, a proposal could be to use G22, a former limit gas composed of 65% CH4 + 35% H2;
- it is however recommended to define a light-back limit gas which simulates the worst case(s) i.e. the highest expected flame speed increase based on 'normal use' as defined by GAR;
- the worst case will be defined by the 'worst' gas supply and air supply conditions and so, it the light-back limit gas for these appliances would consist of methane + hydrogen where the hydrogen concentration is defined by
    - ➢ the maximum hydrogen concentration in the supplied gas (i.e. the maximum concentration that will not be exceeded under normal operation)
    - ➢ + a supplementary hydrogen concentration covering the gas/air ratio decrease due to supply with the distributed natural gas with the lowest Wobbe index
    - ➢ + a supplementary hydrogen concentration to cover the flame speed increase caused by the 'worst' air supply condition (i.e. the lowest temperature and the highest atmospheric pressure)
    - ➢ + a safety margin.

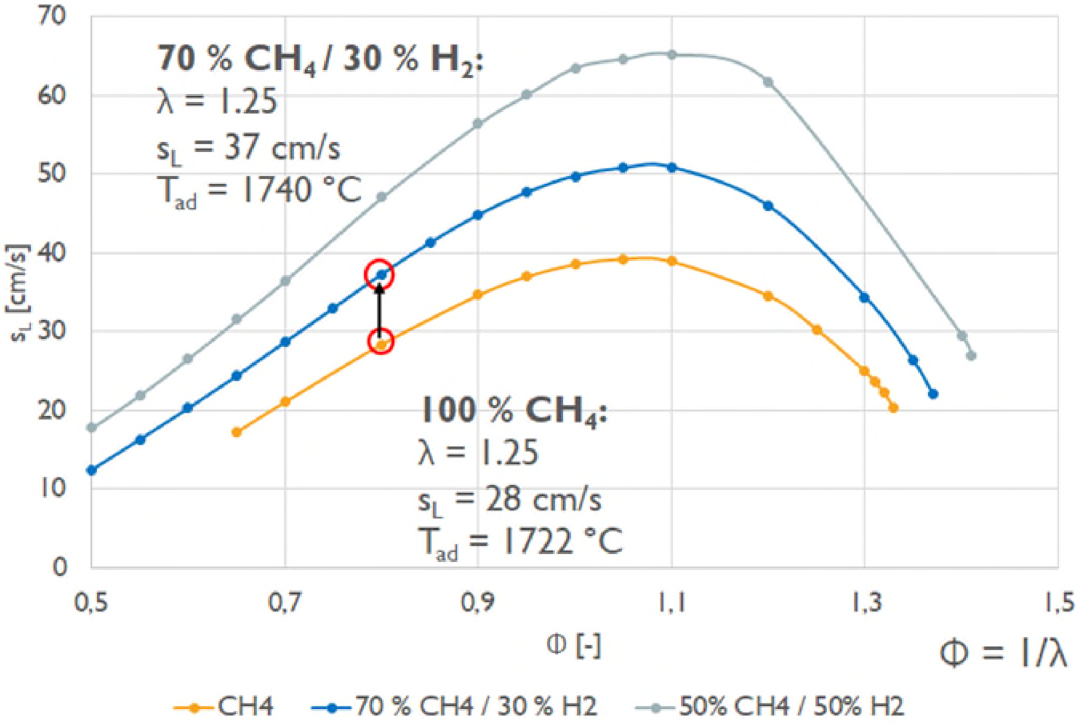

Figure 4 – example showing the impact on the laminar flame speed of switching from methane to a mixture with 30% H2 in an appliance equipped with an auto-adaptive combustion control (source: GWI, presentation of THyGA webinar on hydrogen combustion dd. 30/10/2020).

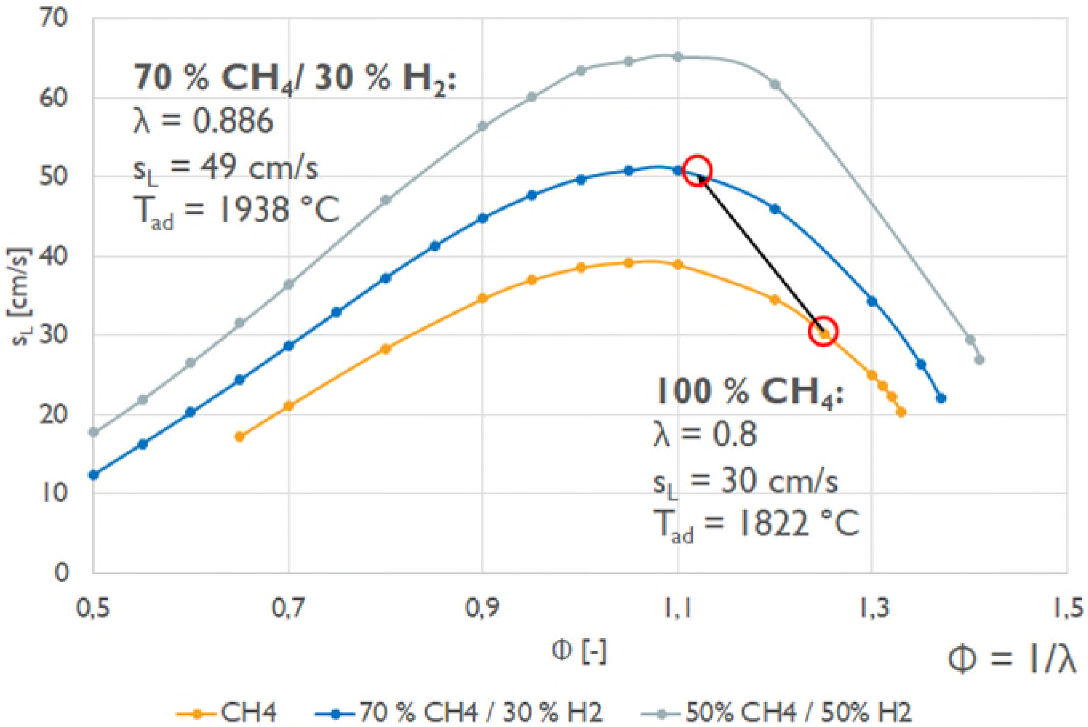

Figure 5 – example showing the increased impact on the laminar flame speed of switching from methane to a mixture with 30% H_2 due to the decreased gas/air ratio in an appliance equipped with a rich premix burner (source: GWI, presentation of THyGA webinar on hydrogen combustion dd. 30/10/2020).

Appliances equipped with a fully premixing burner

- when switching from supply of methane to supply of methane + X% hydrogen on appliances equipped with a fully premixing burner there will be a decreased impact on the laminar flame speed due to the decreased gas/air ratio (see Figure 6);
- independent from changes required for covering X% H2NG supply, it seems appropriate to reconsider the use of G222 as limit gas for assessing the light-back risk for these appliances;
- for assessing the light-back risk for H_2NG use, an appropriate limit gas could consist of a mixture of methane and hydrogen completed with propane to avoid a decrease of the gas/air ratio;
- it is recommended to define a light-back limit gas which simulates the worst case(s) i.e. the highest expected flame speed increase based on 'normal use' as defined by GAR;
- the worst case will be defined by the 'worst' gas supply and air supply conditions and so, the light-back limit gas for these appliances would consist of methane + propane + hydrogen where the hydrogen concentration is defined by
    - ➢ the maximal hydrogen concentration in the supplied gas (i.e. the maximal concentration that will not be exceeded under normal operation)
    - ➢ + a supplementary hydrogen concentration to cover the flame speed increase caused by the 'worst' air supply condition (i.e. the highest temperature and the lowest atmospheric pressure)
    - ➢ + a safety margin;
- the existing 'overheating limit gas' G24 composed of 68% CH_4 + 12% C_3H_8 + 20% H_2 may be considered for assessing the light-back risk for 20% H_2NG supply.

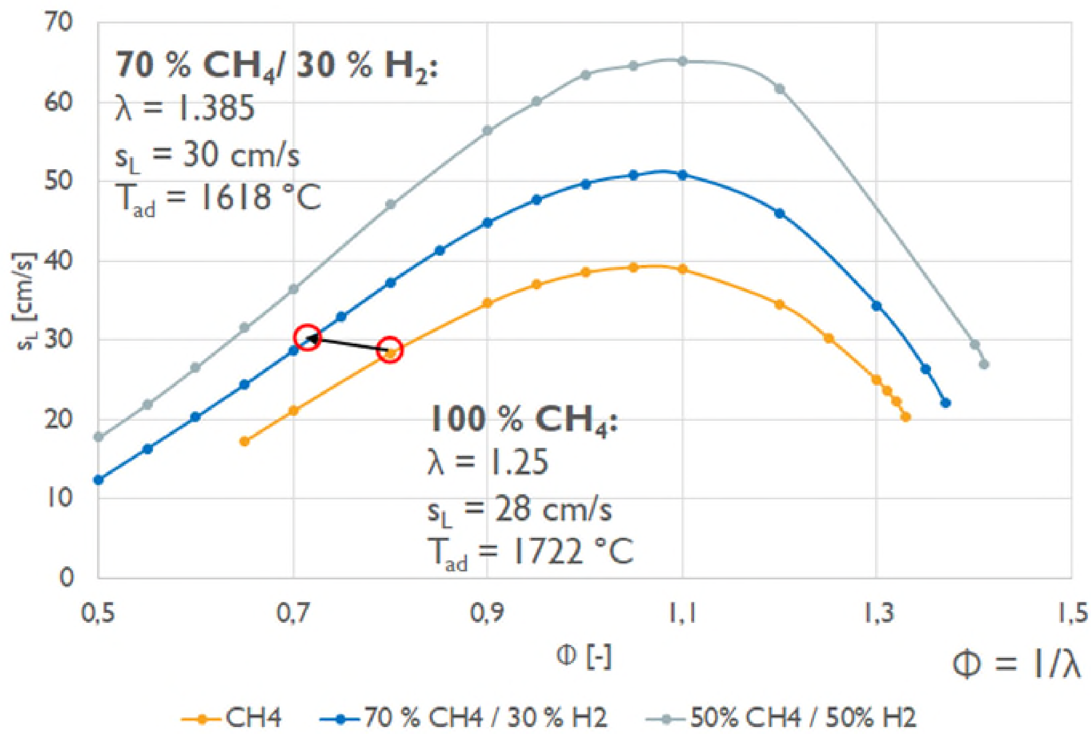

Figure 6 – example showing the reduced impact on the laminar flame speed of switching from methane to a mixture with 30% H_2 due to the decreased gas/air ratio in an appliance equipped with a fully premixing burner (source: GWI, presentation of THyGA webinar on hydrogen combustion dd. 30/10/2020).

2.4.2.4. *Overheating limit gas*

- current limit gas for gas group H is G24 composed of 68% CH_4 + 12% C_3H_8 + 20% H_2;
- this limit gas is not systematically used but only when indicated specifically in the concerned appliance standard;
- overheating is caused by a higher flame temperature and overload;
- a flame front closer to the burner surface may also increase specifically the temperature of this burner surface;
- for assessing the overheating risk of supply with 20% H_2NG, the existing G24 is considered still appropriate.

3. PART II - considerations on appliance standards

3.1 Gas appliance standards

Many European standards covering appliances in the scope of the Gas Appliances Regulation exist. The GAR defines ‘appliances’ as “*appliances burning gaseous fuels used for cooking, refrigeration, air-conditioning, space heating, hot water production, lighting or washing, and also forced draught burners and heating bodies to be equipped with such burners*”. They generally specify the requirements and test methods for the appliances’ construction, safety, fitness for purpose, marking and rational use of energy.

Injecting hydrogen in natural gas impacts certain risks and so existing appliance standards need to be assessed on fitness of their requirements and test conditions for H_2NG supply.

This part of the report gives an overview of risks impacted by the presence of hydrogen linked to the corresponding essential requirement stated in annex I of the GAR. It serves as guide for the concerned CEN Technical Committees (see Table 3 below) for assessing the existing appliance standard(s) and/or for elaborating new appliance standards in their scope. It might also be helpful for other technical committees addressing gas combustion (e.g. CEN TC 186 – Industrial thermoprocessing – Safety).

CEN Technical Committee	Committee title
TC 48	Domestic gas-fired water heaters
TC 49	Gas cooking appliances
TC 58	Safety and control devices for burners and appliances burning gaseous or liquid fuels
TC 62	Independent gas-fired space heaters
TC 106	Large kitchen appliances using gaseous fuels
TC 109	Central heating boilers using gaseous fuels
TC 131	Gas burners using fans
TC 180	Decentralized gas heating
TC 238	Test gases, test pressures, appliance categories and gas appliance types
TC 299	Gas-fired sorption appliances, gas-fired endothermic engine heat pumps and domestic gas-fired washing and drying appliances

Table 3 – CEN Technical Committees addressing gas appliances in the scope of the GAR.

Apart from H_2NG supply in general, the specific case of 20% H_2NG is systematically considered when relevant.

This document is not necessarily exhaustive on all possible risks specific to all types and designs of appliances, but tries to gather the main risks expected and/or experienced with H_2NG supply in the THyGA project. Obviously, the respective CEN/TC remains responsible for reviewing the requirements of its concerned standard(s) for assessing all possible risks related to H_2NG supply.

3.2 General overview of risks

Due to the properties of hydrogen being very different from those of methane (cf. Table 1), the main component of natural gas, several risks are impacted.

A distinction can be made between risks related to

- unburned gas,
- combustion,
- combustion products.

Unburned gas-related risks

The basic risk to be considered is an explosion of a mixture of unburned gas with air. The presence of hydrogen in natural gas leads to a more violent explosion.

The flame propagation speed of a hydrogen-air explosion is higher than that of methane-air. The (calculated) maximum pressure decreases with H2, but the intensity of the deflagration increases dramatically (cf. THyGA deliverable D2.2 – "Impact of hydrogen admixture on combustion processes – Part I: Theory", Section 6, Fig. 17 and 18).

Hydrogen may increase the risk of accumulation of unburned gas inside or outside the appliance due to

- *Embrittlement* of some materials, which can lead to material breakage, chemical (in)compatibility and permeability can lead to unburned gas leakage.
  More detailed information material compatibility can be found in THyGA deliverable D2.4 – "Non-combustion related impact of hydrogen admixture - material compatibility".
- Higher *leakage rate*; the volume leakage flow rate, supposed to be laminar, of hydrogen is higher (about 1,26 compared to methane), but for low hydrogen concentrations slightly lower (about 0,99 for 20% H_2NG compared to methane); taking into acount the lower explosion limit, the existing limit values for internal and external leakage rates measured with air are to be reduced by 26% for hydrogen and by 4% for 20% H_2NG; source of the preceding information: CEN/TC 58 leakage rate justification ppt dd. 22/04/2022.
  More detailed information on leakage tests can be found in THyGA deliverable D2.4 – "Testing done on components from different countries including statistics on results obtained for the leakage testing" or D3.7 – "Testing done on components (new and taken from existing installation) from different countries including statistics on results obtained for the leakage testing "

Combustion-related risks

A few combustion-related properties of hydrogen being (very) different from methane lead to a number of possible consequences to be carefully assessed:

- Related to ignition:
  - the *flammability range* of hydrogen in air is a lot wider than of methane (4 to 75 vol% instead of 5 to 15 vol%) which means that also rich gas/air mixtures can still be ignited and burn;

- the *minimum ignition energy* required for lighting a flammable hydrogen-air mixture is only about 7% of the energy required for lighting a methane-air mixture, which means that more possible sources of ignition may occur;
- the *auto-ignition temperature* of hydrogen is slightly lower than the one for methane but most probably not low enough to consider it as an extra risk in gas appliances in the scope of GAR.

The fact that hydrogen presence leads to an 'easier' ignition of the gas/air mixture can have a positive influence on ignition and cross-lighting of the burner, but it depends on the combustion settings. Some cookers have shown issues with cold and/or hot start with higher H_2 concentrations (> 30%), as described in THyGA deliverable D3.8 – "Segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation".

A specific unburned gas related risk is the unburned gas accumulation due to *delayed ignition*. Tests in the THyGA project have shown that there may be issues on appliances

- with a long ignition safety time and a higher gas flow rate (e.g. type C11 glass-fronted individual room heaters) ⇒ the more violent explosion of hydrogen may lead to damage to the appliance and eventually injury of users ;
- equipped with a partially premixing burner (e.g. type B11BS central heating boilers) where the explosion of the cloud may lead to ignition of the gas flowing out of the injector(s) ⇒ take care that, although the result might be the same, the cause doesn't seem to be light-back and so, that risk is to be considered separately.

Safety times may have to be reduced as mitigating measure.

THyGA testing and complementary information provided by manufacturers highlighted that delayed ignition of H_2NG may start to cause issues ≥ 10 % H_2. Further investigation of this particular issue is recommended.

- As indicated in *Figure 1* injecting hydrogen in natural gas lowers the *Wobbe index* and so, without changes to any of the appliance settings and the gas supply conditions, the heat output will decrease as it is defined by

$$P2 = \frac{Wi,2}{Wi,1}.P1$$

For 20% H_2NG however, the decrease in heat output is limited to about 5% for an appliance adjusted to reach the nominal heat output when supplied with G20 (= methane) ⇒ that should have no impact on the fitness for purpose of the majority of appliances. At the same time, it should be noted that the Wobbe index of natural gas will also vary over a certain range around the setpoint and thus, a decrease in the Wobbe index of natural gas is reinforced by a Wobbe index decrease caused by hydrogen injection.

- The *minimum air requirement* for complete combustion of hydrogen is about 4 times lower than the one for methane ⇒ without changes to any of the appliance settings and to the gas and air supply conditions, the air/fuel ratio will increase ; commonly used is λ, the ratio of the actual air/fuel ratio to the stoichiometric air/fuel ratio ; the change in λ (on appliances not equipped with auto-adaptive combustion control keeping λ constant) due to injection of hydrogen can be calculated by using what is called the Combustion Air Requirement Index (CARI) as follows:

$$CARI = \frac{Air_{min}}{\sqrt{d}}$$

$$\lambda_2 = \frac{CARI1}{CARI2} . \lambda_1$$

From a certain point, depending on the technology, an increasing λ will first lead to flames starting to lift off from the burner and become unstable which causes incomplete combustion and by consequence CO concentration increase, before the flame is ultimately extinguished. Appliances however are supposed to shut-off the gas supply before reaching unacceptable CO concentrations in the combustion products.

- At the same λ, the laminar *flame speed* of hydrogen is more than 5 times higher than the one of methane and so, the flame front will move 'upstream',
  - closer to the burner surface leading to higher burner surface temperatures which may
    - on the longer term, be harmful to the burner material;
    - eventually even cause the flame to go out;
  - back into the burner to a location, often up to the injector, which has not been designed for presence of a flame causing material damage and/or incomplete combustion (i.e. high CO levels); this phenomenon generally is called light-back in appliance standards.

  This flame speed however is also impacted by a λ shift (see *Figure 3*, *Figure 4*, *Figure 5* and *Figure 6*) which does occur by injecting hydrogen in natural gas supplied to appliances not equipped with an auto-adaptive combustion control. For fully premixing, uncontrolled appliances, the flame speed increase is compensated partially or fully by the λ increase (see *Figure 6*) while for partially premixing appliances the λ shift may reinforce the flame speed increase (see *Figure 5*) which increases the risk on light-back. It should be noted that the measurements indicate that commonly used combustion control technologies found in today's residential appliances are often unable to maintain a constant air excess ratio if hydrogen is admixed, especially when running at full load.

  More investigation is needed on appliances equipped with auto-adaptive burner controls to clarify if light-back possibly occurs during auto-calibration periods (when the boiler operates for a few seconds in near-stoichiometric conditions).

- At the same λ, the adiabatic *flame temperature* of hydrogen is significantly higher than the one of methane (see Figure 7) and so, this may cause
  - material surface temperatures to be higher and so, appropriate material use is required ;
  - higher thermal NO_X formation.

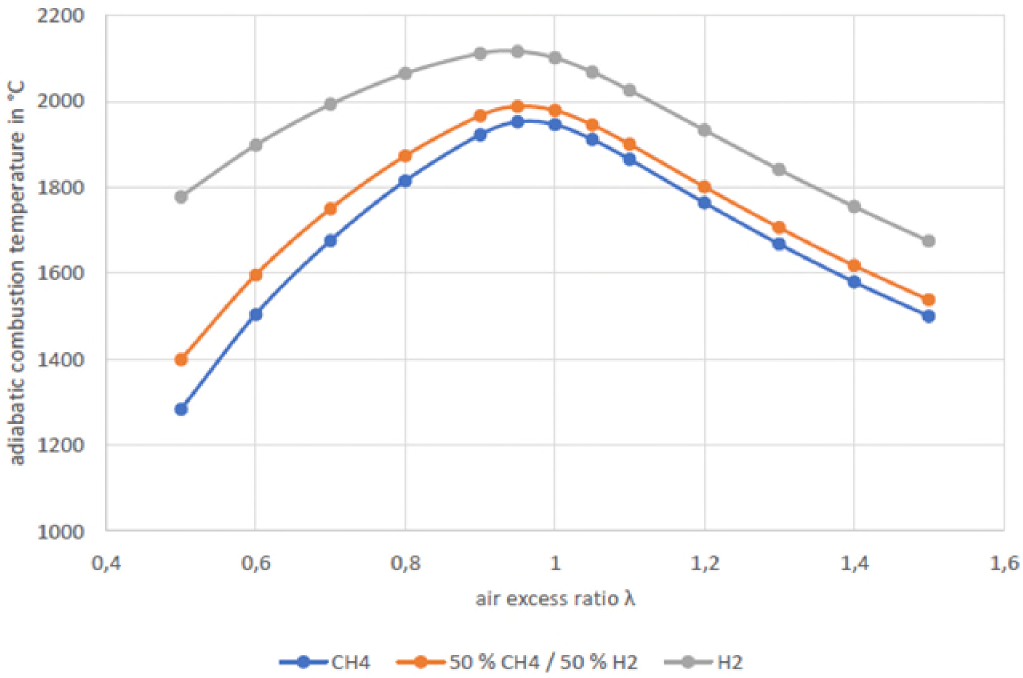

Figure 7 - Adiabatic combustion temperatures of CH4, 50 % CH4 / 50 % H2 and H2 as functions of the air excess ratio, with air as oxidizer. T_{fuel} = 15 °C, T_{air} = 15 °C, p = 1 atm. (source: THyGA D2.2 - Impact of hydrogen admixture on combustion processes – Part I: Theory)

The flame temperature is also impacted by a λ shift which does occur by injecting hydrogen in natural gas supplied to appliances not equipped with an auto-adaptive combustion control. For fully premixing appliances, the λ increase compensates the flame temperature increase and even can lead to lower NO_X emissions. while for partially premixing appliances the λ shift reinforces the flame temperature increase.

When λ stays constant, i.e. for burners equipped with an auto-adaptive combustion control and for non-premixing burners, thermal NO_X formation increases. For 20% H_2NG the adiabatic flame temperature increase at the same λ is rather limited though, i.e. about 10 to 20°C.

NO_X formation however is a complex mechanism as also other factors can interfere with these trends. For example, increased heat loss (=> lower flame temperatures) due to the flame moving closer to the burner, can cause NO_X emissions to decrease, despite constant λ. More relevant information on NO_X formation can be found in THyGA deliverables

- D2.2 – "Impact of hydrogen admixture on combustion processes – Part I: Theory" in chapter 5 ;
- D2.3 – "Impact of hydrogen admixture on combustion processes – Part II: Practice" in chapter 3.2.3 ;
- D3.8 – "Report on the impact of H_2 concentrations on safety, efficiency, emissions and correct operation for different segments of appliances" in the different chapters related to the different segments.

- While the flame temperature is higher, the *radiant heat* of a hydrogen flame is significantly lower than the one of a methane flame due to the absence of carbon and the presence of heat absorbing water vapor created by the combustion.

- The *flame visibility* and *colour* are often food for discussion, but it is a fact that visible emissions from hydrogen-air flames are considerably weaker than those from comparable hydrocarbon flames (like from natural gas). They are visible though, but often only at reduced light emission levels.
  The detailed flame spectra in Figure 8 show flame emission bands in the ultraviolet, visible and infrared regions of the spectrum. The reddish emission bands due to water and a blue continuum result in a visible hydrogen flame which is illustrated in Figure 9 for a laminar premixed hydrogen-air flame with increasing λ. The reddish colour disappears which would be due to temperature sensitivity.

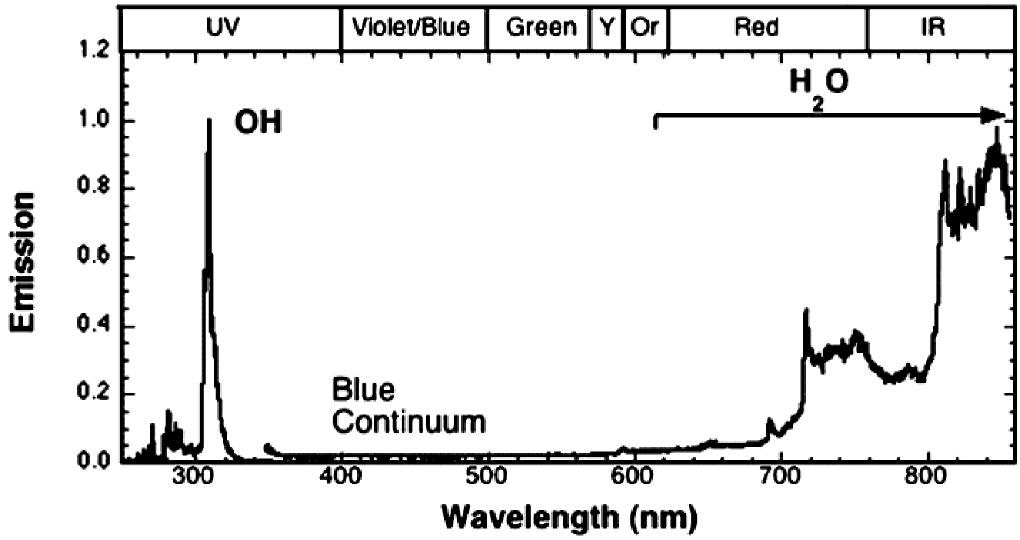

Figure 8 - Emission spectra in a typical premixed H2–air jet flame showing measured spectral peaks from ultraviolet to near infrared; Note that the visible spectra extending from 350 nm to 850 nm in (a) was scaled by a factor of 6.5 with respect to the OH spectra in the ultraviolet. (source: R.W. Schefer et al. / Combustion and Flame 156 (2009) 1234–1241)

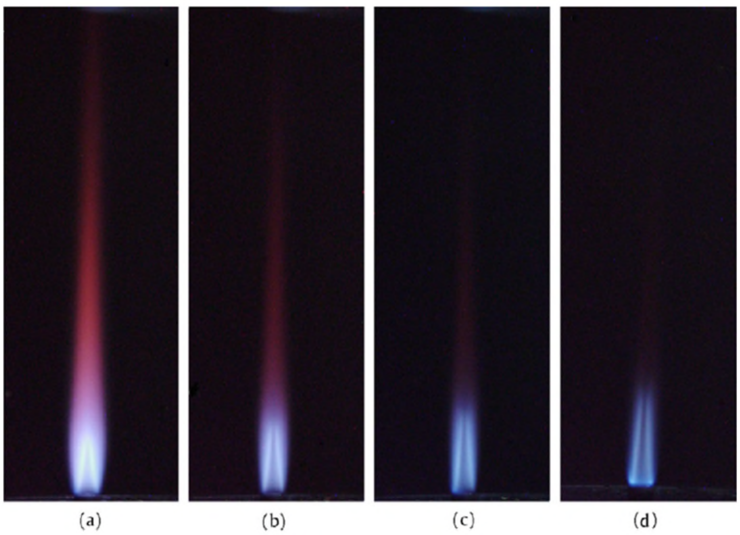

Figure 9 - Flame luminescence photographs of laminar, premixed H2–air jet. (a) λ = 1.0, (b) λ = 1,25, (c) λ = 1,43, (d) λ = 1,61. Images taken at f /2.4 aperture with 4-s exposure time. Jet velocity is 33 m/s. Reynolds number = 580 (source: R.W. Schefer et al. / Combustion and Flame 156 (2009) 1234–1241)

- A specific issue related to combustion is the *adjustment* of burner settings *on-site*. Adjusting burner settings on-site is widespread practice, especially on appliances with non-premixing or fully premixing burners, but if not done properly (i.e. without taking into account the actual Wobbe index value, the local Wobbe index range and the actual air supply conditions) it can reduce performance and/or safety of gas appliances especially when the Wobbe index range of the locally distributed gas is wider. So, it is not an exclusive issue for H_2NG supply, but it is to be recognized that injecting hydrogen widens an existing local Wobbe index range.
  Several mitigating measures can be taken to improve the current practice, especially, but not exclusively, for H_2NG supply:
    - base adjustment on O_2 values instead of CO_2 values;
    - (re)assess the current recommended O_2 values;
    - not allow on-site adjustment;
    - equip appliances with auto-adaptive controls that keep λ constant with H_2 present in the supplied natural gas.

  More detailed information on the issue of, and mitigating measures for on-site adjustment, can be found in THyGA deliverable D5.2 "Test report on mitigation solutions for residential natural gas appliances not designed for hydrogen admixture" – chapter 1.

More detailed information on combustion and combustion related risks can be found in THyGA deliverables D2.2 – 'Impact of hydrogen admixture on combustion processes – Part I: Theory' and D2.3 – 'Impact of hydrogen admixture on combustion processes – Part II: Practice'.

<u>Combustion products related risks</u>

Apart from the NO_X and CO concentrations already treated above, H_2NG combustion impacts the combustion products also on some other aspects involving certain risks:

- The increase of the proportion of *water vapour* in the combustion products could cause problems of condensation at locations not designed for it (e.g. in certain combustion products evacuation systems).
  For 20% H_2NG, extra condensation is not expected to appear for non-condensing appliances, as several physical effects compensate each other. The main risk occurs at minimum heat input in which case the flue gas temperature is lower.
  A specific issue appeared during the THyGA testing on cookers. In our experiments a cooking pot filled with cold water was positioned on a top burner. Condensate was formed on the bottom of the cold pot, leading to droplets falling on the burner and into the flame.
  The *acidity* of *condensate* generally decreases (i.e. pH increases) with increasing hydrogen concentrations in the fuel gas, but that is mainly caused by the decreasing NO_X concentration in the combustion products. If NO_X concentration increases, (e.g. on appliances equipped with auto-adaptive burner controls keeping λ constant), the acidity of condensate may also increase.
  More detailed information on the topic of condensates can be found in THyGA deliverables D5.1 "Review on other projects related to mitigation and identification of usable sensors in existing appliances" – chapter 6.2 and D5.2 "Test report on mitigation solutions for residential natural gas appliances not designed for hydrogen admixture" – chapters 4 and 5.

- Adding hydrogen to natural gas decreases *flue gas flowrate* which could eventually have an impact on appropriate location of combustion products evacuation discharge safety systems (e.g. TTB) or earlier condensation in the flue gas system. For 20% H_2NG the chance on issues seems very low though.
  More detailed information on the topic of flue gas flow rate can be found in THyGA deliverables D5.1 "Review on other projects related to mitigation and identification of usable sensors in existing appliances" – chapter 6.1.1 and D5.2 "Test report on mitigation solutions for residential natural gas appliances not designed for hydrogen admixture" – chapter 3.3.3.

- *Natural draught* is not expected to be an issue on most appliances and certainly not for 20% H_2NG. Preliminary calculations show that increasing the proportion of H_2 decreases the volume of flue gases and its density (at constant temperature). However, increasing the proportion of hydrogen also increases the air excess, and thus, can also decrease flue gases temperature. As lower flue gas temperature means reduced natural draught, this must be investigated further, mainly in extreme conditions, when a boiler is at the limit of a malfunction (e.g. partially blocked flue gas evacuation).
  More detailed information on the topic of natural draught can be found in THyGA deliverable D5.1 "Review on other projects related to mitigation and identification of usable sensors in existing appliances" – chapter 6.1 and in D5.2 "Test report on mitigation solutions for residential natural gas appliances not designed for hydrogen admixture" – chapter 3.

<u>Control and safety devices</u>

To manage risks, appliances are equipped with control and safety devices like a burner control connected to e.g. flame supervision devices, limit temperature devices, oxygen depletion sensors, combustion products discharge safety system, … Obviously these systems also need to stay fit for purpose when supplied with H_2NG.

Risks to be assessed due to H_2NG supply include (i.e. non-exhaustive)

- Auto-adaptive control that is able of keeping λ constant with H_2 present in the supplied natural gas:
  - Is the determining parameter still appropriate?
  - Is the applied measurement system (incl. its location) of the determining parameter still appropriate?
  - More investigation is needed to clarify if light-back possibly occurs during auto-calibration periods (when the boiler operates for a few seconds in near-stoichiometric conditions).

  More detailed information on the topic of sensors for (auto-adaptive) controls, can be found in THyGA deliverable D5.1 "Review on other projects related to mitigation and identification of usable sensors in existing appliances" – chapter 5 and in D5.2 "Test report on mitigation solutions for residential natural gas appliances not designed for hydrogen admixture" – chapter 2.

- Combustion control:
  - are safety times still appropriate? Cf. delayed ignition with a more violent explosion of accumulated H_2NG.

- Combustion products discharge safety system:
    - thermal products discharge safety device (sometimes still called 'TTB') on B_{11BS} type appliances : position and shut-off temperature still appropriate?
    - oxygen depletion device (also called atmosphere sensing device = device that reacts to the lack of oxygen in the surrounding atmosphere) on A_{AS} and B_{11AS} type appliances: no issues expected.

- Flame supervision device:
    - thermocouple: seems to work well;
    - ionization current: seems to work well up to high H_2 concentrations and certainly for 20% H_2NG;
    - UV-cell: seems to work well.

- Gas valve:
    - tightness: is gas supply shut-off still correctly assured? Are leakage rates limits still appropriate?

- Limit temperature device:
    - is the chosen limit temperature still appropriate?

CEN/TC 58 – "Safety and control devices for burners and appliances burning gaseous or liquid fuels" may be consulted as it has already made a lot of work in assessing and dealing with risks related to these components which are integrated in many types of appliances.

And finally, for the overall assessment of risks and review of existing appliance standards related to H_2NG supply to gas appliances, it is useful to consult:

- the work done by CEN/TC 109 – "Central heating boilers using gaseous fuels" related to the review of the existing standards for supply with H_2NG and H_2 ;
- the test results of the THyGA project described in deliverables D3.8 – "Report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation" and D3.9 – "Long term effect of H2 on appliances tested".

3.3 Essential requirements impacted by H2NG supply

3.3.1 General requirements

> ER 1.1 – Appliances shall be so designed and constructed as to operate safely and present no danger to persons, domestic animals or property, when normally used.
> Fittings shall be so designed and constructed as to fulfil correctly their intended purpose when incorporated into an appliance or assembled to constitute an appliance.

This ER is **impacted** by H_2NG supply, including 20% H_2NG, but is often satisfied by satisfying all other applicable ERs.

> ER 1.2 – The manufacturer is under an obligation to analyse the risks in order to identify those which apply to his appliance or fitting. He shall then design and construct it taking into account its risk assessment.

The risk analysis is obviously **impacted** by H_2NG supply including 20% H_2NG. The risks listed under part II chapter 2 and any other risks specific to the installation and use of the concerned appliance are to be considered.

> ER 1.3 – In selecting the most appropriate solutions, the manufacturer shall apply the principles set out below, in the following order:
> (a) eliminate or reduce risks as far as possible (inherently safe design and construction);
> (b) take the necessary protection measures in relation to risks that cannot be eliminated;
> (c) inform users of the residual risks due to any shortcomings of the protection measures adopted and indicate whether any particular precautions are required.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply and certainly not for 20% H_2NG.

> ER 1.4 – When designing and constructing the appliance, and when drafting the instructions, the manufacturer shall envisage not only the intended use of the appliance, but also the reasonably foreseeable uses.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

> ER 1.5 – All appliances shall:
> (a) be accompanied by instructions for installation intended for the installer;
> (b) be accompanied by instructions for use and servicing, intended for the user;
> (c) bear appropriate warning notices, which shall also appear on the packaging.

Apart from the **appropriate appliance category** and **corresponding data**, **no particular changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 1.6.1 – The instructions for installation intended for the installer shall contain all the instructions for installation, adjustment and servicing required to ensure that those operations are correctly performed so that the appliance may be used safely.
The instructions for installation intended for the installer shall include also information on the technical specifications of the interface between the appliance and its installation environment allowing its correct connection to the gas supply network, the supply of auxiliary energy, the combustion air supply and the flue gas evacuation system.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 1.6.2 – The instructions for use and servicing intended for the user shall contain all the information required for safe use and in particular shall draw the user's attention to any restrictions on use.
The manufacturers shall note in the instructions where additional care is needed or where it would be advisable that any of the above work be carried out by a professional. This shall be without prejudice to national requirements to that effect.
The manufacturer of the appliance shall include in the instructions accompanying the appliance all necessary information for adjustment, operation and maintenance of the fittings as part of the finished appliance, as appropriate.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 1.6.3 – The warning notices on the appliance and its packaging shall clearly state the type of gas to be used, the gas supply pressure, the appliance category and any restrictions on use, in particular the restriction whereby the appliance shall be installed only in areas where there is sufficient ventilation so as to ensure that the risks presented by it are minimised.

The **type of gas** and **appliance category** as will be defined **for H_2NG** are to be stated on the warning notices on the appliance and its packaging.
Stating the restriction whereby the appliance shall be installed only in areas where there is sufficient ventilation so as to ensure that the risks presented by it are minimised, is always of importance when using combustible gases and by consequence also for H_2NG supply. Care should be taken to **minimum ventilation requirements** as to be **appropriate for** the concerned **H_2NG supply**.

ER 1.7 – The instructions for incorporation of the fitting into an appliance or its assembly in order to constitute an appliance and for its adjustment, operation and maintenance shall be provided with the fittings concerned as part of the EU declaration of conformity.

Some particular points of attention have been elaborated by CEN/TC 58 – Safety and control devices for burners and appliances burning gaseous or liquid fuels like

- "It is recommended to refer in the instructions to a minimum air exchange rate in case of a diaphragm fracture or a fracture of non-metallic parts as possible failure mode."
- "It is recommended to refer in the instructions of the control to its leakage rate measured with air in case of diaphragm fracture or fracture of non-metallic parts." (source: ppt on justification of leakage rate values for hydrogen and 20% hydrogen admixtures dd. 14/04/2022)

3.3.2 Materials

> ER 2 – Materials for appliances or fittings shall be appropriate for their intended purpose and shall withstand the mechanical, chemical and thermal conditions to which they will foreseeably be subjected.

Main possible risks related to H_2NG supply are

- embrittlement, chemical incompatibility and permeability;
- higher flame temperature at same λ, but lower radiant heat.

For 20% H_2NG at the low pressures used in gas appliances the chance of issues seems low.

3.3.3 Design and construction

3.3.3.1. General

> ER 3.1.1 – Appliances shall be so designed and constructed that, when normally used, no instability, distortion, breakage or wear likely to impair their safety may occur.

Main possible risks related to H_2NG supply are

- delayed ignition;
- inappropriate on-site adjustment of burner settings;
- light-back → especially for
  - appliances equipped with partially premixing burners;
  - appliances equipped with auto-adaptive burner controls where light-back possibly might occur during auto-calibration periods (when the boiler operates for a few seconds in near-stoichiometric conditions).

> ER 3.1.2 – Condensation produced at the start-up and/or during use shall not affect the safety of appliances.

Main possible risks related to H_2NG supply are

- more condensation due to higher H_2O content in the combustion products;
- eventual condensation at locations not designed for it (on non-condensing appliances or their combustion products evacuation system). Mainly at risk at Q_{min} with lowest flue gas temperatures.

For 20% H_2NG the chance on issues is low though.

ER 3.1.3 – Appliances shall be so designed and constructed as to minimise the risk of explosion in the event of a fire of external origin.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.4 – Appliances shall be so designed and constructed that water and inappropriate air penetration into the gas circuit does not occur.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.5 – In the event of a normal fluctuation of auxiliary energy, appliances shall continue to operate safely.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.6 – Abnormal fluctuation or failure of auxiliary energy or its restoration shall not lead to an unsafe situation.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply. Attention is to be paid, however, to appropriate safety times in case of restoration.

ER 3.1.7 – Appliances shall be so designed and constructed as to obviate any gas-related risks due to hazards of electrical origin. As far as relevant, the results of the conformity assessment in relation to the safety requirements of Directive 2014/53/EU of the European Parliament and of the Council (1) or the safety objectives of Directive 2014/35/EU of the European Parliament and of the Council (2) shall be taken into account.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply. Attention is to be taken, however, to any possible uncontrolled sources of ignition knowing that the minimum ignition energy of hydrogen is lower.

For 20% H_2NG the chance on issues is low though.

ER 3.1.8 – Appliances shall be so designed and constructed as to obviate any gas-related risks due to hazards originating from electromagnetic phenomena. As far as relevant, the results of the conformity assessment in relation to the electromagnetic compatibility requirements of Directive 2014/53/EU or Directive 2014/30/EU of the European Parliament and of the Council (3) shall be taken into account.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply. Attention is to be taken, however, to any possible uncontrolled sources of ignition knowing that the minimum ignition energy of hydrogen is lower.

For 20% H_2NG the chance on issues is low though.

ER 3.1.9 – All pressurised parts of an appliance shall withstand the mechanical and thermal stresses to which they are subjected without any deformation affecting safety.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.10 – Appliances shall be so designed and constructed that failure of a safety, controlling or regulating device may not lead to an unsafe situation.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.11 – If an appliance is equipped with safety and controlling devices, the functioning of the safety devices shall not be overruled by that of the controlling devices.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.12 – All parts of appliances which are set or adjusted at the stage of manufacture and which should not be manipulated by the user or the installer shall be appropriately protected.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.1.13 – Levers and other controlling and setting devices shall be clearly marked and give appropriate instructions so as to prevent any error in operation/use. Their design shall be such as to preclude accidental operation.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

3.3.3.2. Unburned gas release

ER 3.2.1 – Appliances shall be so designed and constructed that the gas leakage rate is not dangerous.

Main possible risk related to H_2NG supply is

- higher leakage rate.

For 20% H_2NG the chance on issues is very low though.

ER 3.2.2 – Appliances shall be so designed and constructed that gas release at any state of operation is limited in order to avoid a dangerous accumulation of unburned gas in the appliance.

Main possible risks related to H_2NG supply are

- higher leakage rate → for 20% H_2NG the chance on issues is low though;
- more violent explosion of unburned gas requiring appropriate safety times to avoid possible issues.

ER 3.2.3 – Appliances intended to be used in indoor spaces and rooms shall be so designed and constructed as to prevent the release of unburned gas in all situations which could lead to a dangerous accumulation of unburned gas in such spaces and rooms.

Main possible risk related to H_2NG supply is

- higher gas leakage rate.

For 20% H_2NG the risk is comparable to natural gas.

ER 3.2.4 – Appliances designed and constructed to burn gas containing carbon monoxide or other toxic components shall not present a danger to the health of persons and domestic animals exposed.

Hydrogen is not poisonous nor toxic, but like for all gases, apart from oxygen, an accumulation can cause asphyxiation (i.e. the state or process of being deprived of oxygen, which can result in unconsciousness or death).
It does not seem like any supplementary precautions are required for supply with H_2NG and certainly not for 20% H_2NG.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

3.3.3.3. Ignition

ER 3.3 – Appliances shall be so designed and constructed that, when normally used, ignition and re-ignition is smooth and cross-lighting is assured.

Main possible risk related to H_2NG supply is

- delayed ignition.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration for the delayed ignition test, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

3.3.3.4. Combustion

ER 3.4.1 – Appliances shall be so designed and constructed that, when normally used, the combustion process is stable and combustion products do not contain unacceptable concentrations of substances harmful to health.

Main possible risks related to H_2NG supply are

- CO concentration too high ;
- NO_X concentration too high ;
- light-back.

As expected, THyGA tests have demonstrated that CO concentrations decrease with hydrogen added to natural gas as far as the λ increase does not lead to any excessive flame instability/flame lift-off which can also cause 'incomplete combustion' and by consequence lead to higher CO concentrations.

Attention is to be paid however to **inappropriate (on-site) adjustment of combustion settings** (which is not exclusive to H_2NG supply). Besides the use of appropriate test gases (cf. part I of this document) it **might be considered to adopt** such **testing in appliance standards**.

With hardly any exceptions, appliances tested in the THyGA project emitted lower NO_x emissions when supplied with H_2NG and certainly for 20% H_2NG. **Apart from considering** the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

As far as **light-back** is concerned, besides the use of an **appropriate limit gas** (cf. part I of this document) a **longer testing time** may have **to be considered** for appropriately assessing this risk, as THyGA tests have shown that it is not excluded that light-back only happens after a longer time (was found on one cooker after 50 minutes).

ER 3.4.2 – Appliances shall be so designed and constructed that, when normally used, there will be no accidental release of combustion products.

Apart from considering the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.4.3 – Appliances connected to a flue for the dispersal of combustion products shall be so designed and constructed that in abnormal draught conditions there is no release of combustion products in a dangerous quantity into the indoor spaces or rooms concerned.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.4.4 – Appliances shall be so designed and constructed that, when normally used, they do not cause a concentration of carbon monoxide or other substances harmful to health, such as they would be likely to present a danger to the health of persons and domestic animals exposed.

Besides the use of **appropriate test gases**, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

3.3.3.5. Rational use of energy

ER 3.5 – Appliances shall be so designed and constructed as to ensure rational use of energy, reflecting the state of the art and taking into account safety aspects.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply

3.3.3.6. Temperature

ER 3.6.1 – Parts of appliances which are intended to be installed or placed in close proximity to surfaces shall not reach temperatures which present a danger.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.6.2 – The surface temperature of parts of appliances intended to be handled during normal use shall not present a danger to the user.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

ER 3.6.3 – The surface temperatures of external parts of appliances, with the exception of surfaces or parts which are associated with the transmission of heat, shall not under operating conditions present a danger to the health and safety of persons exposed and in particular to children and elderly people, for whom an appropriate reaction time shall be taken into account.

Apart from the use of a **2nd reference gas** consisting of methane + the maximum H_2 concentration, **no changes** to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

3.3.3.7. Contact with food and water intended for human consumption

ER 3.7 – Without prejudice to Regulations (EC) No 1935/2004 (1) and (EU) No 305/2011 (2) of the European Parliament and of the Council, materials and parts used in the construction of an appliance which may come into contact with food or water intended for human consumption as defined in Article 2 of Council Directive 98/83/EC (3), shall not impair quality of the food or water.

No changes to the corresponding requirements of existing appliance standards seem required for H_2NG supply.

References

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4. Standard prEN 15502-2-1 of CEN/TC109 – Central heating boilers using gaseous fuels.
5. PAS 4444:2020 on “Hydrogen-fired gas appliances – Guide” of BSI.
6. Input of THyGA WP4 expert workshops on 31/03/2021 and 08/03/2023.
7. HyDeploy project.
8. KIWA 2023 – “De kwaliteit van waterstof - Wat zijn de Eisen en hoe wordt dit gecontroleerd?”.

List of Illustrations

List of tables