THyGA

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

WP4 – certification & standardization framework

D4.2 – overview of relevant existing certification experience and on-going standardization activities in the EU and elsewhere related to gas appliances using H_2NG.

Deliverable:	D4.2
Status:	final, 29th of October 2021
Dissemination level:	PU = Public

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

Document classification

Title	Overview of relevant existing certification experience and on-going standardization activities in the EU and elsewhere related to gas appliances using H_2NG.
Deliverable	D4.2
Reporting Period	M12
Date of Delivery foreseen	M18
Draft delivery date	M20
Validation date	M21

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Work package	WP 4
Dissemination	PU = Public
Nature	Report
Version	Final
Doc ID Code	THY_WP4_D4.2 - overview of relevant existing certification experience and on-going standardization activities in the EU and elsewhere related to gas appliances using H_2NG
Keywords	Hydrogen, H_2, Combustion, Admixture, H_2NG, Certification, Standardization, GAR, EN 437

Document review

Partner	Remark	Version	Date
Gas.be	1st draft	draft 1	26-08-2021
Gas.be	Review after comments from involved THyGA partners.	final	29-10-2021

Document Validation

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Acknowledgement

This document results from the contributions and exchanges during the dedicated workshop on 31st of March 2021 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

AGA	American Gas Association
AhG	Ad-hoc Group (in standardization committees)
AHRI	Air-Conditioning, Heating, and Refrigeration Institute (USA)
CSA Group	Canadian Standards Association Group
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.
EU	European Union
GAR	Gas Appliances Regulation (EU) 2016/426
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 admixture
ISO	International Standardization Organization
NG	Natural Gas
OJEU	Official Journal of the European Union
TC	CEN Technical Committee
TS	Technical Specification
town gas	In the framework of this project the term 'town gas' is limited to manufactured gases made by partial combustion of coal and other combustibles and containing typically around 50 vol% of hydrogen.
vol%	The volume fraction, or the quotient of the volume of a component X and the sum of the volumes of all components of the gas mixture before mixing, all volumes referring to the pressure and the temperature of the gas mixture.

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Scope and objectives

This document gives an overview of relevant existing certification experience, on-going standardization activities and field trials in the EU and elsewhere regarding gas appliances using H_2NG. It concerns **a picture of the today's situation as many of the identified initiatives are ongoing and progressing continuously**.

In the chapter on existing certification experience, it also considers the relevance of the experience with town gas which often contains significant concentrations of hydrogen. It has come in use since the early 19th century and is still present today in some regions.

On the 31st of March, a WP4 workshop[1] was organized bringing together several people with relevant expertise in the field of certification, standardization and field trial activities related to gas appliances and their supply with H_2NG admixtures. This event, besides some individual exchanges, has been a very important source of information for the elaboration of this document.

1. Existing testing & certification experience

1.1 Introduction

The residential and commercial gas appliances in the scope of the THyGA project are all covered by the regulation (EU) 2016/426 (also commonly called GAR) on gas appliances whereas:

- 'appliances' means 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;
- 'burning' means a process in which gaseous fuel reacts with oxygen producing heat or light;
- 'gaseous fuel' means any fuel which is in a gaseous state at a temperature of 15 °C under an absolute pressure of 1 bar.

So, the GAR also covers appliances burning H_2NG or H_2. Considering the lifetime of gas appliances, generally 15 years and more, several manufacturers already prepare their products for these gases contributing to CO_2 emission reduction.

Third party certification is applied within the GAR framework. The conformity assessment procedure is, apart from some specific cases, composed of two steps, i.e., first the examination of conformity of the type/specimen against the relevant legal requirements (so called EU Type-examination — module B), then, determination of the conformity of the manufactured products against the approved EU type.

During the first step an independent notified body checks the conformity to the applicable essential requirements as stated in the GAR. Standards harmonized to the legislation are commonly used to provide presumption of conformity with the essential requirements. Their use however is not mandatory and as no harmonized standards containing test conditions and requirements for gas appliances supplied with H_2NG and/or H_2 exist, manufacturers have the obligation to demonstrate that their products are in conformity with essential requirements using other means of their own choice that provide for the level of safety or protection of other interests required by the applicable legislation. These requirements can be technical specifications such as national standards and

[1] https://thyga-project.eu/wp4-technical-workshop-h2ng-supply-to-residential-and-commercial-appliances-standardization-and-certification/

reference documents, European or international standards which are not harmonized, i.e., not published in the OJEU (yet), or the manufacturer's own specifications.

Some manufacturers and notified bodies already make use of such other technical specifications in anticipation of adoption of related test conditions and requirements in relevant harmonized standards.

1.2 Existing certification experience

1.2.1 European Union

Some GAR notified bodies already offer EU type-examination for supply with H_2NG admixtures and/or H_2. A harmonized methodology for the conformity assessment does not exist yet and privately developed methods are not necessarily publicly available.

As far as GAR compliance in general is concerned the manufacturer's risk analysis is considered a key element in the EU type-examination by the notified body:

- essential requirement 1.2: "The manufacturer must identify and analyze the risks that apply to his appliance. He shall then design and construct it taking into account its risk assessment."
- essential requirement 1.3: "In selecting the most appropriate solutions, the manufacturer shall apply the principles 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."

Some notified bodies rely today mainly upon this manufacturer's risk analysis for the conformity assessment of gas appliances supplied with H_2NG and/or H_2.
The proactive position of these notified bodies is explained by the strategy on hydrogen in United Kingdom with several experimentations starting with H_2NG blends (HyDeploy) and pure H_2 (H21 Leeds, H100 Fife Neighborhood Trial) that imply the on-site use of appliances suited for hydrogen use. Manufacturers and the industry also push for specific requirements linked with hydrogen on space heaters in the Ecodesign review, the proposal of EHI (backed by most actors) is to introduce a pictogram indicating the capability to burn hydrogen on appliances by 2023, to introduce a mandatory requirement for appliances to be able to run on H2NG blends (up to 20%vol H2) by 2025 and from 2029 onwards a requirement on hydrogen readiness (= capability of an appliance to be supplied with unblended hydrogen)[2].

A publicly available reference document defining rules for conducting tests and evaluate conformity of central heating boilers supplied with H_2NG (up to 20 vol% of H_2) only exists in Germany. The method developed and used by DVGW (Germany) is described in

[2] This is still a proposal, the EcoDesign review process should be finalized by the beginning of 2022. Especially, the "hydrogen readiness" concept still has to be defined.

document "*DVGW Zert 2020 - ZP 3100 Ergänzungsprüfungen für Heizkessel für einen Wasserstoffgehalt von bis zu 20 volprozent*" (dd. 7/10/2020).
It has been developed based on DVGW research projects (e.g., G 201205 and G 201615), experiences from the industry and an extensive literature study. It concludes that, in the applied temperature range, elastomer and polymer seals do chemically resist to H_2 presence up to 100%. Also, for metal gas supply components used in boilers it considers that the H_2 presence does not require modifications to the prescriptions of the current EN 15502 standards series applicable to central heating boilers. For assessment of tightness requirements and H_2 concentrations up to 20 vol% it allows testing with air while applying the requirements of §8.2.1 of EN 15502-1:2015.
Besides CH_4 (identified as G20 in EN 437) the ZP 3100 introduces a second reference test gas (cf. ref. gas 2 in table Table 1 – DVGW Zert - ZP 3100 – additional requirements for supply with H2NG up to 20 vol% of H2.composed of 80 vol% CH_4 and 20 vol% H_2. On the condition that it satisfies the essential requirements of the GAR with reference test gas G20, this additional reference gas is considered giving presumption of conformity with those essential requirements with natural gas of group H with an H_2 content which may vary between 0 and 20 vol%. The appliance's settings are not altered for supply with this second reference test gas.
It also defines a new limit test gas for assessing light-back, i.e., a test gas composed of 65 vol% of CH_4 and 35% of H_2 besides the light-back limit test gas G222 for the H-group (cf. EN 437, 77 vol% of CH_4 and 23 vol% of H_2). This new limit test gas corresponds to the G22 limit gas that existed formerly in EN 437.
The ZP 3100 defines the following additional requirements for supply with H_2NG up to 20 vol% of H_2:

§ of EN 15502-1:2015	REQUIREMENTS	TEST CONDITION	COMMENTS	TEST GAS
	Resistance up to 20 vol% H_2 in natural gas. Components and materials.	*Manufacturer's declaration on resistance in connection with risk assessment and safety concept (integration of safety times, see also 8.11.6).*	*Confirmation of conformity of the manufacturer for the selection and evaluation of the compatibility with 20 vol% H_2 in natural gas of metallic and non-metallic materials. The basis can be the standard references from DIN EN 15502-1:2015*	
8.4.1	*Load setting Load measurement*	*Max. Min.*	*Adjustment to G 20 - change to ref. gas 2 and determination of the load range with ref. gas 2.*	*Ref. gas 1 Ref. gas 2*
8.6.2	*Flame stability*	*Ignition*	*Adjustment of Q_{max} with ref. gas 1 - Reduction of the connection pressure to 0,7 x p_n - Change to ref. gas 2 - Testing of the ignition behavior.*	*Ref. gas 2*

§ of EN 15502-1:2015	REQUIREMENTS	TEST CONDITION	COMMENTS	TEST GAS
8.6.2	*Flame stability*	*Ignition*	*Adjustment of Q_{min} with ref. gas 1 - Reduction of the connection pressure to 0,7 x p_n - Change to ref. gas 2 - Testing the ignition behavior.*	*Ref. gas 2*
8.6.2	*Flame stability*	*Ignition/light-back*	*Adjustment of Q_{max} with ref. gas 1 - Reduction of the connection pressure to p_{min} - change to light-back limit gas I - testing of the ignition and light-back behavior.*	*Light-back limit gas*
8.6.2	*Flame stability*	*Ignition/light-back*	*Adjustment of Q_{min} with ref. gas 1 - reduction of the connection pressure to p_{min} - change to light-back limit gas - testing of the ignition and light-back behavior.*	*Light-back limit gas*
8.7	*Throttle gas pressure*		*Adjustment of Qmin with ref. gas 1 - reduction of the connection pressure to 0,7 x p_n - change to ref. gas 2 - reduction of p down to 0 hPa without safety-relevant interference.*	*Ref. gas 2*
8.11.6.2.2	*Safety time*		*Test conditions see DIN EN 15502-1:2015. To be evaluated/measured according to risk analysis/safety concept.*	*Ref. gas 2*
8.11.6.2.5	*Delayed ignition*		*Test conditions see DIN EN 15502-1:2015. To be evaluated/measured according to risk analysis/safety concept.*	*Ref. gas 2*
8.11.7	*Pressure regulator*		*Gas flow should remain within + 5 % / -7,5 %.*	*Ref. gas 2*
8.11.101.2	*Combustion quality*	*Monitoring the air supply or exhaust gas discharge*	*Adjustment of Q_n, Q_{min}, Q_a with ref. gas 1 – switch to ref. gas 2 - covering combustion air supply*	*Ref. gas 2*

§ of EN 15502-1:2015	REQUIREMENTS	TEST CONDITION	COMMENTS	TEST GAS
8.11.101.2	*Combustion quality*	*Monitoring the air supply or exhaust gas discharge*	*Adjustment of Q_n, Q_{min}, Q_a with ref. gas 1 – switch to ref. gas 2 - closure of flue gas outlet*	*Ref. gas 2*
8.11.101.2	*Combustion quality*	*Monitoring the air supply or exhaust gas discharge*	*Adjustment of Q_n, Q_{min}, Q_a with ref. gas 1 – switch to of ref. gas 2 - reduction of fan speed*	*Ref. gas 2*
8.11.101.3.3	*Combustion quality*	*Setting the gas/air ratio*	*Setting Q_n and Q_{min} with ref. gas 1 - switch to ref. gas 2 - checking the CO_2 setting specifications*	*Ref. gas 2*
8.12.2	*Combustion quality*	*Boundary conditions, thermal overload*	*Adjustment according to 8.12.2 a) by increasing the connection pressure to p_{max} (for units without regulator or with gas-air ratio control) or b) of 1,05 Q_n (for units with regulator) with ref. gas 1 – switch to ref. gas 2 - CO measurement*	*Ref. gas 2*
8.12.2.102	*Combustion quality*	*Boiler with gas-air ratio control*	*Adjustment of Q_n at max. CO_2 + 0,5 vol% or by p + 5 Pa at Q_{min} with ref. gas 1 – switch to ref. gas 2 - CO measurement*	*Ref. gas 2*
8.12.3.2	*Combustion quality*	*U=110%*		*Ref. gas 2*
8.12.3.2	*Combustion quality*	*U= 85%*		*Ref. gas 2*

Table 1 – DVGW Zert - ZP 3100 – additional requirements for supply with H_2NG up to 20 vol% of H_2.

DVGW is also developping additional test protocols:

- for gas-fired central heating boilers using 100% hydrogen;
- for fan burners using H_2NG up to 20 Vol-% hydrogen.

1.2.2 United Kingdom

No public document with the requirements for appliances supplied with H_2NG seemed available, but a public guide on hydrogen-fired gas appliances, named PAS[3] 4444, does exist.

PAS 4444:2020

It states that:

- *This PAS gives guidance on the development and construction of hydrogen-fired gas appliances, which are either purpose-built to use hydrogen or are designed to be converted to use hydrogen.*
- *As a guide, this PAS takes the form of guidance and recommendations.*
- *This PAS is intended to prepare the UK gas industry for "hydrogen ready" appliances, including appliances designed to be converted to use hydrogen.*
- *This PAS has been developed on the basis that currently hydrogen limit test gases do not exist and are to be the subject of a wider discussion. Accordingly, other test means have been suggested so as to stress the appliance in excess of that which it is likely to experience in normal service.*
- *The PAS is intended to be used as a supplement to existing standards and generally assumes that any default performance requirements (for example, noise or pressure rating) align with those of an equivalent 2nd family gas appliance unless specifically stated otherwise.*

Although its scope is dedicated to unmixed H_2 supply, it contains relevant information for the THyGA project as it considers the risks inherent to the use of hydrogen in gas appliances and as it applies the same kind of structure as used in EN gas appliance standards. It also provides guidance on aligning with the essential requirements at the time of publication of the PAS of the Gas Appliance Regulation (GAR) for appliances burning hydrogen.

As far as the test gas is concerned, it refers to EN 437:2018 on test gases, test pressures and appliance categories and introduces a 4th gas family[4], a gas group[5] Y and a reference test gas G40.

[3] The PAS (Publicly Available Specifications) process enables a guide to be rapidly developed in order to fulfil an immediate need in industry. A PAS can be considered for further development as a British Standard or constitute part of the UK input into the development of a European or International Standard.

[4] EN 437:2018 defines a gas family as a group of gaseous fuels with similar burning behaviour linked together by a range of Wobbe indices. It specifies 3 families corresponding resp. to town gas, natural gas and LPG.

[5] EN 437:2018 defines a gas group as a specified range of Wobbe index within that of the family concerned (see Table 1); this range is determined on the general principle that appliances utilising 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.

Gas family	Test gases	Designation	Composition by volume	W_i MJ/m³	H_i MJ/m³	W_s MJ/m³	H_s MJ/m³	d
Gases of the fourth family								
Group Y	Reference gas	G40	H_2 = 99.9	**38.67**	10.2	45.88	12.1	0.0696
	Limit gases	To be defined						

Table 2 – PAS 4444 – hydrogen test gas characteristics

Supply pressures are kept identical to those for the H-group natural gases, i.e., 20 mbar as nominal supply pressure with 17 mbar as minimum and 25 mbar as maximum.

Besides the same requirements and test conditions (apart from the use of G40 as reference gas), the PAS 4444 also contains some specific hydrogen related points:

- *Flue gas safety devices:*
  - *The combustion products of hydrogen do not contain significant quantities of substances harmful to health. As such, category I appliances of type A or type B, burning pure hydrogen might not require the fitting of flue gas safety devices. This can be reflected in manufacturers' installation guidance.*
  - *Due to the high water content of flue gases from hydrogen-fired appliances, control of moisture levels in the installed room should be mitigated by adequate ventilation and reference to installation standards.*
- *Alternative to limit gases:*
  Where limit gases are required but not available, the reference gas should be used provided that:
  - *for incomplete combustion gas test, used, the following adjustment is made to the appliance:*
    1) *for appliances with non-aerated burners – a 20% increase of the rated heat input;*
    2) *for appliances with partially pre-mix burners – a 20% increase of the rated heat input with the declared air factor (λ); or*
    3) *for appliances with fully premix burners – a 10% decrease of the declared air factor (λ).*
  - *for flame lift gas test, used, the following adjustment is made to the appliance:*
    1) *for appliances with non-aerated burners – a 20% increase of the rated heat input;*
    2) *for appliances with partially pre-mix burners – a 10% decrease of the lower range of the declared air factor (λ) or a 20% increase of the rated heat input with the declared air factor (λ); or*
    3) *for appliances with fully premix burners – a 10% increase of the higher range of the declared air factor (λ).*
  - *for flame light-back gas test, the following adjustment is made to the appliance:*

1) *for appliances with non-aerated burners – a 20% decrease of the rated heat input;*
2) *for appliances with partially pre-mix burners – a 10% increase of the higher range of the declared air factor (λ) or a 20% decrease of the rated heat input with the declared air factor (λ); or*
3) *for appliances with fully premix burners – a 10% decrease of the lower range of the declared air factor (λ).*

- *Soundness of the gas circuit:*
  - *Soundness of the gas supply circuit for hydrogen-fired appliances should be assured when tested with air at an upstream pressure of 150 mbar and the leakage rate of air does not exceed 0,1 dm^3/h.*
  - *Gas control valve let-by leakage rates for all appliances should be evaluated and minimized within the above allowable leakage rate for the entire gas circuit.*
  - *NOTE It is deemed prudent to use the higher test pressure and lower leakage allowance, negating the need for modified test equipment.*
- *Soundness of the combustion circuit:*

  Type C appliances:

  - *Soundness of the combustion circuit, with respect to the room where the appliance is installed is ensured if, under the specified test conditions, the leakage rate does not exceed the values provided in the applicable standard.*
  - *For appliances firing hydrogen only, a factor of 1.2 can be applied to the maximum air leakage rates, acknowledging that hydrogen firing does not produce significant quantities of harmful combustion products.*

  Soundness testing of gas fires:

  - *Sampling the contents of the hood using the thermo-hygrometer located above the hood damper, any rise above ambient conditions in the enclosed room generating a > 10% RH increase in the measured ambient value over the test period should be defined as unacceptable leakage.*
  - *Alternatively, a dewpoint plate may be used to determine leakage. A dewpoint plate should be located no more than 20 mm above the front top of the gas fire opening. The test should be conducted after 30 min. at nominal heat output. Permanent misting of the dewpoint plate during the test should be defined as unacceptable leakage.*
- *Delayed ignition:*
  - *Any appliance should be constructed so that gas release during ignition, re-ignition and after flame extinction is sufficiently limited by setting the ignition safety time (TSA), or extinction delay time (TIE), to prevent the concentration of gas in the appliance from exceeding the combustion chamber volume of 1%. Alternatively, the appliance should be constructed in such a way that no hazard or damage to the appliance occurs under any conditions including delayed ignition.*
  - *NOTE: If the controls prevent the concentration of gas in the appliance from exceeding the combustion chamber volume of 1%, the delayed ignition test is not required.*
- *Ignition:*

- *The ignition tests should be carried out at 0,7 × p_{min} (12 mbar).*
- *NOTE: The intent of the above ignition test pressure is to stress the appliance in excess of that which it is likely to experience in normal service, this being a reasonably foreseeable condition.*

- *Ignition by variation of the air factor (λ):*
  - *NOTE: This clause does not apply to non-aerated burners.*
  - *For aerated burners, λ can be varied by adjusting the burner setting pressure or by adjusting the combustion air (λ).*
  - *Ignition should be tested with a variation in λ of +/- 10% of the higher and lower air factor range (λ) in accordance with the applicable appliance standards.*
  - *There should be no light-back. Ignition of the main burner should be assured without flame roll-over outside the case.*
- *Flame roll-over:*
  - *Due to visibility issues with hydrogen flames, where flame roll over is considered to be an issue, an additional test using silk paper can be carried out to validate no-flame roll-over in the vicinity of the boundary of the combustion chamber. The silk paper should not ignite.*
- *Extinction delay time:*
  - *The extinction delay should be set such that the gas total volume that flows during the delay is less than 1% of the volume of the appliance.*
- *Delayed ignition within the combustion circuit:*
  - *Any appliance should be constructed to prevent the concentration of gas in the appliance from exceeding 1% of the volume of the combustion chamber.*
  - *Methods for the calculation of appropriate ignition safety times intended for other gas families might not be suitable for hydrogen and should not be used. Typically, ignition safety times for hydrogen are expected to be significantly shorter than those for 2nd and 3rd family gases.*
- *Destructive ignition test – combustion circuit (enclosed zone):*
  - *Due to the nature of hydrogen/air mixtures, an extreme event is suggested so as to test the structural integrity of the appliance. The appliance should be tested with 40% v/v hydrogen/air mixture equivalent to the combustion circuit volume and where relevant, a 3 m flue duct. If a 3 m flue duct is not relevant, manufacturers should provide guidance on a suitable flue duct. Alternative gas/air mixtures may be used based on a justification by the manufacturer for this alternative.*
- *Leakage ignition test case side (ventilated zone):*
  - *NOTE: The intention of this test is to assume a gas leak from a component within a compartment enclosed zone.*
  - *If the design of the appliance is such that no components are located in an enclosed zone, then the test is unnecessary.*
  - *In the event of a hydrogen gas leak within any ventilated zone of the appliance (e.g. within the outer case of a room sealed appliance), upon ignition there should be no hazard to the user. The leakage rate into the ventilated zone of the appliance should be 1 l/h. The ignition test should be carried out after 1 hour and at ambient conditions.*
  - *If gas detection equipment is used in the appliance design, a suggested threshold for hydrogen gas detection is 10 000 ppm (1% by volume).*

- *Nitrogen oxides:*
  - *Due to the combustion process associated with hydrogen, it is assumed that there are no toxic emissions in respect of CO.*
  - *NOx should be measured dry air-free (daf) - 0% O_2, by:*
    1) *Obtaining the correction factor*
       Fdaf = Vol(λ)/Vol(stoich) - where F = correction factor (daf),
    2) *Vol(λ) = specific volume of dry exhaust gas at the air factor & Vol(stoich) = specific volume of dry exhaust gas at stoichiometric combustion*
    3) *Correcting the measured NO_x (ppm)*
    4) *NO_x (ppm daf) = NO_x (ppm measured) * Fdaf*
    5) *Correcting ppm to mg/kWh*
       *NOx (mg/kWh daf) = NOx (ppm daf) *2.054*
- *Combustion:*
  - *NOTE: Due to combustion properties of hydrogen, sooting tests are unnecessary.*
  - *The combustion measurement for hydrogen-fired appliances should use O_2 and H_2 measurement to confirm correct combustion at condition x, where x is the calculated parameter or λ (air factor), or other.*
  - *The combustion measurement for hydrogen-fired appliances should use O_2 and H_2 measurements on a dry gas basis for the calculation of the air/fuel mass ratio which is required in the thermal efficiency calculation. The hydrogen level of 1.000 ppm is set so that the energy content is negligible in the thermal efficiency determination and is not close to the flammable range at hot flue gas conditions. The equipment used to measure O_2 should measure it directly by either chemical cell, paramagnetic sensors or other suitable means.*
  - *The maximum H_2 content of flue gases should not exceed 0,1% (dry) – 1.000 ppm.*
- *Combustion (indirect) efficiency – gas fires:*
  - *NOTE The equilibrium composition of hydrogen flames shows that if the fuel air equivalence ratio () is < 0,8 (~25% H_2 v/v or ~>5% O_2 in the flue gas on a dry basis), there are insignificant (< 1.000 ppm) levels of H_2 in the flue gases, resulting in a simplified equation to determine the A/F based on dry O_2 in the flue gases. Operation of any appliance with more hydrogen is not allowed as the equilibrium level of H_2 in the flue could be flammable if air leaked in. The requirement to show that H_2 is <1.000ppm is both a safety and thermal efficiency protection measure.*
- *Supplementary markings:*
  - *Hydrogen-fired appliances should have a label affixed to the appliance in a prominent position, indicating that the appliance is hydrogen-fired.*
  - *NOTE: An example of wording that can be used on the label is as follows: "This appliance has been manufactured or converted specifically for hydrogen gas. Read the technical instructions before installing or lighting the appliance and instruct the user to read the user's instructions before lighting the appliance. Appliances converted for use on hydrogen should have the necessary components fitted and adjustments made to enable safe operation."*
- *Packaging:*

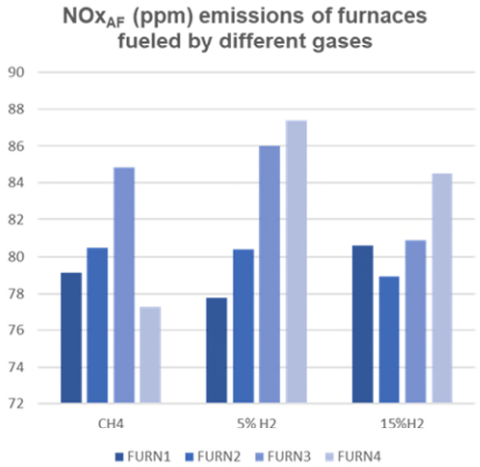
- *Any Category I hydrogen-fired appliances or Category II appliances sold in a hydrogen-burning configuration, should have a label affixed to the packaging in a prominent position indicating that the appliance is adjusted for hydrogen.*

- *Technical instructions:*
  - *Instructions for hydrogen-fired appliances should be specific to the gas type to enable the appliance to be installed, commissioned, and maintained, recognizing that combustion analysis is different from that historically used for natural gas and LPG appliances – namely the use of H_2 or O_2 as the reference for combustion settings.*
  - *As the distributed gas is near dry, wet gas grids within the UK distribution network might have a potential negative impact of on the performance of hydrogen-firing appliances. Appliance manufacturers' instructions for installation should highlight this issue to installers so that an assessment of the local gas distribution network can be provided to the installer by the gas distributor.*
  - *In addition, the instructions should state that only competent persons specifically trained on the use of hydrogen gas should install or maintain appliances.*
- *User instructions:*
  - *User instructions for hydrogen-fired appliances should be specific to the gas type, informing the user of any unusual or distinct qualities of operation using hydrogen.*
  - *In addition, the instructions should state that only competent persons specifically trained on the use of hydrogen gas are to install or maintain appliances.*
- *Appliance conversion risk assessment: Appliance instructions should state that conversion to hydrogen-firing is only to be undertaken by a competent person specifically trained on the use of hydrogen gas and any work undertaken be subject to a risk assessment of the installation and conversion procedure with regard to the intended use and application of the appliance.*

1.2.3 United States of America & Canada

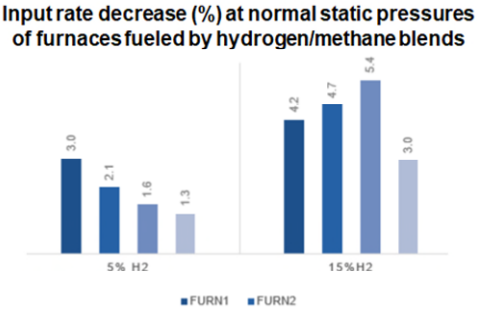
In the US and Canada exploratory testing of residential natural gas appliances' operability on H_2NG admixtures has been carried out. Involved are the AGA, AHRI and CSA Group.
The main findings of the exploratory testing on space heaters (furnaces) with 5 and 15 % of H_2:

- Safety:
  - no operability challenges or critical safety issues were identified;
  - no carbon monoxide (CO) or oxides of nitrogen (NOx, including NO_2) excursions from baseline performance were observed;



- no effects on appliance controls or leakage due to reduced density and other physical characteristics were observed;
- excessive heat exchanger temperatures were not observed;
- stability issue of pilot ignition was observed in one space heater.

- Input effects:
  - consistent reduction in input and useful heat output was observed in all four appliance categories with increasing hydrogen fraction;



  - despite differences in input reduction within and across appliance categories, results were consistent with theoretical predictions;
  - influence of staged and modulated operation was not tested; all results were obtained on maximum load.

1.3 Town gas

Town gas is a general term for manufactured gaseous fuels which have been introduced as a fuel for lighting and cooking in the early 19th century and later it tracked the industrial revolution and urbanization. It was originally used for street lighting, later as fuel for turbines and engines, for heating and for cooking. During the second half of the 20th century, it has in most cases been replaced by natural gas. The term town gas, although it is natural gas or a mixture of natural gas and air today, is still in use in some countries but is obviously not relevant for this THyGA project. In a limited number of countries manufactured town gas is still used today (e.g. China, Hong Kong, Poland, Singapore). Generally, its use is limited to specific cities or areas, but in Singapore it is the main distributed gas and also includes residential use. In Europe town gas for residential use has been replaced everywhere by

natural gas or in cities like Stockholm, Malmö and Göteborg, where it is still called town gas, by a mixture of natural gas with air.

Most often town gas is made by partial combustion of coal (also called coal gas), but more recently also from other combustibles. Coal gas contains a mixture of calorific gases including hydrogen, carbon monoxide, methane, ethylene and volatile hydrocarbons together with small quantities of non-calorific gases such as carbon dioxide and nitrogen. As some town gases contain hydrogen up to concentrations of 50 vol% and more, the experience is obviously relevant for the THyGA project.

The Singapore Standard SS608:2015+A1:2017 annex A contains typical values for composition and different properties of the Singapore town gas. In the following table these values are put next to these of methane (as main component of natural gas) and hydrogen.

	TOWN GAS	HYDROGEN	METHANE
Composition [vol%]			
hydrogen	49,5	100	-
methane	26,7	-	100
ethane	1,3	-	-
propane	0,1	-	-
butane	0,2	-	-
pentane	0,4	-	-
carbon monoxide	3,2	-	-
carbon dioxide	13,2	-	-
nitrogen	4,5	-	-
oxygen	0,9	-	-
Wobbe index [MJ/m³]	23,15 – 26,35	45,88	50,72
Gross Calorific Value [MJ/m³]	18,63 ± 3 %	12,10	37,78
Relative density	0,50 – 0,59	0,07	0,56
Stoichiometric combustion air [vol/vol]	4,4	2,4	10,4
Flammability limits [vol%]	3 - 55	4 – 75	5 - 15
Ignition temperature [°C]	> 400	560	595
Weaver combustion velocity[6]	32-42	100	18,6

Table 3: comparison of the gas characteristics

The supply pressure of town gas is generally lower than of natural gas, typically somewhere between 5 and 15 mbar (resp. 10 and 20 mbar in Singapore) while between 17 and 25 mbar for natural gas of type H.

A harmonized method for certification of gas appliances within the GAR framework for use of town gas exists. Harmonized standard EN 437 defines test gases and test pressures for town gases i.e., the first gas family, as follows:

[6] Weaver flame speed = a dimensionless number defined by the max. laminar combustion velocity divided by the max. laminar combustion velocity of hydrogen.

Gas families and groups	Gross Wobbe index, dry gas at 15 °C and 1 013,25 mbar MJ/m^3	
	Minimum	Maximum
First family — Group a	22,4	24,8

Gas family and Group	Test gases	Designation	Composition by volume % [c]	W_i MJ/m^3	H_i MJ/m^3	W_s MJ/m^3	H_s MJ/m^3	d
Gases of the first family [b]								
Group a	Reference gas Incomplete combustion, flame lift and sooting limit gas	G 110	CH_4 = 26 H_2 = 50 N_2 = 24	21,76	13,95	24,75	15,87	0,411
	Light back limit gas	G 112	CH_4 = 17 H_2 = 59 N_2 = 24	19,48	11,81	22,36	13,56	0,367

Gas family		Nature of gas	Designation	Com-position by volume %	W_i MJ/m^3	H_i MJ/m^3	W_s MJ/m^3	H_s MJ/m^3	d	Test pressure mbar	Country code
Gases linked to the first family	Group c	Reference (propane-air)	G 130	C_3H_8 = 26,9 air [a] = 73,1	22,14	23,66	24,07	25,72	1,142	FR: p_n = 8 p_{min} = 6 p_{max} = 15 PL: p_n = 20 p_{min} = 16 p_{max} = 23	FR, PL
		Light back limit	G 132	C_3H_8 = 13,8 C_3H_6 = 13,8 air [a] = 72,4	22,10	23,56	23,84	25,41	1,136		
	Group e	Reference Incomplete combustion (methane-air)	G 150.1	CH_4 = 57 air [a] = 43	22,44	19,39	24,92	21,53	0,746	p_n = 8 p_{min} = 6 p_{max} = 15	DK, SE
		Light back limit	G 152	CH_4 = 40 air [a] = 54 C_3H_6 = 6	19,03	17,26	21,07	19,10	0,822		
	Group Lm	Reference	G 1.250	CH_4 = 54 N_2 = 46	21,27	18,36	23,64	20,40	0,745	PL: p_n = 8 p_{min} = 6 p_{max} = 11	PL
		Incomplete combustion	G 1.251 [c]	CH_4 = 58 N_2 = 42	23,12	19,73	25,68	21,31	0,728		
		Light back limit Flame lift limit	G 1.252	CH_4 = 50 N_2 = 50	19,48	17,00	21,65	18,89	0,761		

Table 4: Extracts from EN 437

EN 437 tables B.2 and B.5 stipulate that:

- in Denmark, Italy and Sweden appliances for the use of town gas of group 'a' of the 1st gas family are still put on the market;

- in France and Poland, appliances for the use of town gas of group 'c' of the 1st gas family are still put on the market;
- in Denmark and Sweden, appliances for the use of town gas of group 'e' of the 1st gas family are still put on the market;
- in Poland, appliances for the use of town gas of group 'Lm' of the 1st gas family are still put on the market.

Although all belong to the family of the town gases, only group 'a' is relevant for the THyGA project as the other gases do not contain any significant concentrations of H_2, but it appears that none of the mentioned countries really do still use that kind of town gas. E.g. Stockholm was the last Swedish city that has been converted to town gas of group e. Since 2011 it is supplied with a mixture of natural gas and air.

EN 437 defines test pressures for group 'a' town gases as follows: 8 mbar as nominal test pressure with min. and max. test pressures of resp. 6 and 15 mbar.

In Singapore where town gas is the main distributed gas, the "SINGAPORE CONSUMER PROTECTION (SAFETY REQUIREMENTS) REGISTRATION SCHEME[7]" imposes specifically for town gas appliances:

Test pressure of town gas for gas appliances	*All gas appliances must be tested up to 31 mbar for town gas.*
Gas appliances tested to EN 30-1-1: 1998/2008	*Testing to sub-clause 6.1.6 (Temperature of the LPG cylinder and its compartment) and sub-clause 6.2.1 (Ignition, cross-lighting and flame stability) must be carried out.* *To use G112 gas as a limit gas for test clause 7.3.2.1.3 third test group to check for occurrence of light back, under performance clause 6.2.1.1.*
Flame failure device (FFD) incorporated in gas appliances	*Component testing* *Supplier can choose to test to one of the following:* *a) Test report/certificate showing that the FFD complied with EN 126: 1995 or EN 125: 1991 for gas appliance tested to EN 30-1-1 at component level must be provided.* *b) Test report/certificate showing that FFD complied with AG 204: 1984 for gas appliance tested to AG 101 at*

[7] SINGAPORE CONSUMER PROTECTION (SAFETY REQUIREMENTS) REGISTRATION SCHEME by Enterprise Singapore, first published on 1st of April 2002 and last updated 23rd of November 2020.

	component level must be provided. (Valid till 30/03/2021). *c) Test report/certificate showing that FFD complied with AS 4620 – Thermoelectric flame safeguards for gas appliance tested to AS 5263.0:2017 or AS 5263.1.1:2016 at component level must be provided.* *Set testing* *Supplier can choose to test to one of the following:* *d) Testing to sub-clause 6.1.3 of EN 30-1-1 at set level must be carried out.* *e) Testing to sub-clause 3.6.13 of AG 101at set level must be carried out. (Valid till 30/03/2021).* *f) Testing to sub-clauses of 3.6.1.15 of AS 5263.0:2017 at set level must be carried out.*
Gas oven	*It is compulsory for all gas ovens to be fitted with flame failure device.*
Toughened glass gas hob	*a) A brochure, entitled 'Toughened Glass – A Shattering Experience?' must be included for each toughened glass gas hob put up for sale. (Order for the brochure can be placed with the Safety Authority).* *b) Toughened glass gas hob tested to EN 30-1-1 would require any of the following testing and compliance:* • *sub-clauses 2.1.15, 2.1.16, 2.1.18, 2.10.9.5, 2.11.2.2 & 5.7.5 of AG101: 1998/AS 4551: 1998 (Valid till 30/03/2021)* • *sub-clauses 2.1.16(a), 2.1.17, 2.1.19, 2.10.9(e), 2.11.2.2 & 5.7.5 of AG 101: 2000/AS 4551: 2000 (Valid till 30/03/2021)* • *sub-clauses 2.1.16(a), 2.1.17, 2.1.19, 2.10.8.3(e), 2.11.3(g) & 5.8.4 of AS 4551: 2008*

	• *sub-clauses of 5.7.101(a), 5.12.101, 5.12.5, 2.14.2.2(d), 2.15.3.101 & 5.7.104 of AS 5263.1.1:2016*
Gasket for elbow joint of gas cooker.	*Installation instruction must mention about the fixing of gasket for the elbow joint, if applicable. (Appendix R)*
Glass-ceramic gas hob with enclosed covered burner (simulated gas explosion test).	*The gas hob must be subject to 'simulated gas explosion' test. The hob is filled with an explosive mixture of gas and detonated with a source of ignition.*
Material of gas hob cook top.	*Different material requires separate certification and registration. E.g. stainless steel, enamel, stone, toughened-glass, ceramic-glass.*
Installation manual or installation instructions for gas cookers.	*All registered gas cookers shall be supplied with installation manual or installation instructions within the operating manual, user's manual, user's guide, etc. which shall also include safety instructions for use of the gas cooker.*

Table 5: Requirements for town gas in Singapore

The Singapore consumer protection registration scheme refers to European material and product standards including some test gases defined in EN 437 for the 1st family (town gas).

Although composition, supply pressure, characteristics and combustion properties are to a lesser or greater extent different, the experience with town gas would obviously be relevant when considering risks of the use of H_2NG admixtures. However, since town gas is not applied for residential use in Europe has not been using town gases for decades (with a few exceptions in Scandinavia like Stockholm until 2011) and since the limited Asian information obtained didn't bring any new elements, it is concluded that further efforts to investigate this experience will not bring added value to the project.

2. Existing and on-going standardization activities

Looking to the use of H_2NG admixtures in residential and commercial end-use applications, relevant standardization activities take place on national and international level.

2.1 Global

ISO/TC 197 – Hydrogen technologies

Within ISO, TC 197 'hydrogen technologies' works on standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen. The standards relevant for the scope of the THyGA project are:

Reference	Title	Year	Status
ISO 14687	Hydrogen Fuel Quality – product specification *This document specifies the minimum quality characteristics of hydrogen fuel as distributed for utilization in vehicular and stationary applications.*	2019	Under revision
ISO/TR 15916	Basic considerations for the safety of hydrogen systems *This document provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards.*	2015	Under revision

Table 6: Relevant standards and reports from TC 197

Some relevant points of its business plan[8]:

BUSINESS ENVIRONMENT

2.1.1 Hydrogen has the potential to become a key component of a renewable, sustainable energy system of the future. The benefits of hydrogen make it a versatile energy carrier and a fuel that could be extensively used in the near future. Indeed, hydrogen can be produced using a variety of primary energy sources (sunlight, wind power, hydroelectric power, nuclear power) from water or directly from hydrocarbons (like biomass and fossil fuels), transported, stored and used in a number of energy applications (power generation, distributed as residential CHP, transportation).

[8] ISO/TC 197 Business Plan dd. 07-11-2005 draft #7

2.1.3 ISO/TC 197 was created to promote the safe use of hydrogen as an energy carrier and fuel and accompany the development of these new technologies. At present, the only significant use of hydrogen in the energy field is in the space programs. Liquid hydrogen and liquid oxygen are combined as propulsion fuel for the space shuttle and other rockets. Hydrogen is also fed to the fuel cells on board the space shuttle providing heat, electricity and drinking water for the astronauts.

2.1.5 On the other hand, hydrogen is currently widely used in the industrial sector. The current major uses of hydrogen are the petrochemical and chemical industries. Hydrogen is produced and used in refineries, and it is widely used for the synthesis of chemical raw materials (production of ammonia, ethylene and methanol). Hydrogen plays a fundamental role in chip industries and therefore in electronics. Hydrogen is also used in smaller quantities in steel and glass making and food hydrogenation.

2.1.6 These existing industrial applications are already covered by a number of regulations. They should not be neglected by ISO/TC 197, but they should be worked on "on an as-needed" basis. With regard to the energy applications, hydrogen is likely to play its first important role as a fuel for distributed power generation and as an electricity storage medium for renewable energy. Hydrogen powered fuel cells and internal combustion engines could be used to provide on-site electricity, home and office heating and even drinking water. In the longer term, hydrogen could be produced from renewable primary sources such as hydropower, sunlight and wind power but also by biological processes from biomasses. Hydrogen produced from solar and wind power would then be stored and reconverted to electricity when these intermittent renewable sources are not generating power. As an electricity storage medium, hydrogen could also lower the cost of peak electricity. Hydrogen produced from off-peak or surplus power could be used to store energy.

2.1.10 Since safety is a key factor for the acceptability of hydrogen, the development of hydrogen technologies may be accompanied by the development of means to detect hydrogen leaks. Electronic detectors are the options to be considered or recombiners to remove hydrogen to prevent its accumulation to hazardous levels.

2.1.11 With regard to the technologies that will facilitate the progression towards a hydrogen-based energy system, fuel cells, internal combustion engines and hydrogen burners are being looked at. However, fuel cells are unquestionably the hydrogen utilization technology that can potentially achieve the highest energy efficiency and provide the biggest environmental benefits to society.

2.2 European Union

CEN/CLC/JTC 6 – Hydrogen in energy systems

CEN has 1 existing technical committee which scope is focused directly on hydrogen, i.e. CEN/CLC/JTC 6 on hydrogen in energy systems. Its scope:

> Standardization in the field of systems, devices and connections for the production, storage, transport and distribution, measurement and use of hydrogen from renewable energy sources and other sources, in the context of the European strategy for the development and acceptance of the hydrogen market. The scope includes cross cutting items such as:

terminology, Guarantee of Origin, interfaces, operational management, relevant hydrogen safety issues, training and education. Excluded are:

- Storage and transport of liquid hydrogen which is covered in the scope of CEN/TC 268.
- Storage and transport of compressed hydrogen which is covered in the scope of CEN/TC 23.
- Vehicle refuelling stations and associated equipment and procedures as related to the standardization Request M/533.
- The injection of hydrogen and the mixture of hydrogen with natural gas (H_2NG) in the gas infrastructure, which is covered in the scope of CEN/TC 234.
- The use of mixtures of natural gas with hydrogen (H_2NG).

The committee has 3 WG's: WG1 on terms and definitions, WG2 on guarantees of origin and WG3 on hydrogen safety. The standards most relevant for the scope of the THyGA project are:

Reference	Title	Year	Status
prEN ISO 24078	Hydrogen in energy systems – vocabulary	Expected by end of 2021	Under elaboration
EN reference to be defined (WI=JT006002)	Safe use of hydrogen in built constructions	No information	Under elaboration

Table 7: Relevant standards and reports from CEN/CLC/JTC6

Besides the above committee the work of most of the many technical committees on natural gas infrastructure and utilization is impacted when the use of H_2NG admixtures is considered. As far as end-use is concerned that includes the following technical committees:

CEN/TC238 - Test gases, test pressures, appliance categories and gas appliance types

This technical committee has the following scope:

> *Standardization of test gases, test pressures, appliance categories and gas appliance types as a reference standard to serve as the basis for the elaboration of standards for gas appliances, including mirroring the activity work of ISO/TC 193 'Natural gas'.*

The committee has 3 WG's: WG1 on EN 437, WG2 on emission measurements and WG3 on CEN/TR 1749 conversion into EN. The standards relevant for the scope of the THyGA project are:

Reference	Title	Year	Status
EN 437	Test gases - Test pressures - Appliance categories	2021	Published
CR 1404	Determination of emissions from appliances burning gaseous fuels during type-testing	1994	Published

Table 8: Relevant standards and reports from TC 238

EN 437 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. Procedures for tests are given in the corresponding appliance standards. The test gases and the test pressures specified in this

standard are in principle intended to be used with all types of appliances. However, the use of some test gases and test pressures may not be appropriate in some well-defined cases for which the specific appliance standards may specify other test conditions in order to establish compliance with their requirements.

Related to hydrogen, a revision of EN 437 in 2 parallel steps has been adopted by the plenary CEN/TC 238 in 2019 and 2020:

1. H_2NG admixtures integration work to be launched as soon as version 2021 is published; work to be done in collaboration with CEN/TC 109 already having related activities.
2. H_2 integration work to be launched as soon as version 2021 is published.

EN gas appliance standards

All the following CEN/TC's on different types of residential and commercial gas appliances will have to assess the impact of H_2NG use on their standard(s):

CEN/CLC/JTC 17	Gas Appliances with Combined Heat and Power
CEN/TC 48	Domestic gas-fired water heaters
CEN/TC 49	Gas cooking appliances
CEN/TC 57	Central heating boilers
CEN/TC 58	Safety and control devices for burners and appliances burning gaseous or liquid fuels
CEN/TC 62	Independent gas-fired space heaters
CEN/TC 106	Large kitchen appliances using gaseous fuels
CEN/TC 108	Sealing materials and lubricants for gas appliances and gas equipment
CEN/TC 109	Central heating boilers using gaseous fuels
CEN/TC 131	Gas burners using fans
CEN/TC 180	Decentralized gas heating
CEN/TC 181	Appliances and leisure vehicle installations using liquefied petroleum gas and appliances using natural gas for outdoor use
CEN/TC 299	Gas-fired sorption appliances, indirect fired sorption appliances, gas-fired endothermic engine heat pumps and domestic gas-fired washing and drying appliances.
CEN/TC 399	Gas Turbines applications - Safety

Table 9: Relevant CEN Technical Committees

Several TCs already started discussing the topic, but the status of the related work of 2 TCs is of particular interest for the THyGA project:

CEN/TC 58 - Safety and control devices for burners and appliances burning gaseous or liquid fuels

As the safety and control devices in the scope of this CEN/TC are incorporated in all types of residential and commercial gas appliances its relevance is obvious. CEN/TC 58's scope:

> *Safety and control devices for equipment burning gaseous or liquid fuels, ranging from small domestic appliances to large industrial burners, excluding the following: - mechanical controls other than gas controls - devices for transmission and distribution equipment.*

4 project groups tackle the topic of H_2 and H_2NG: group 1 on leakage rates and specifically breather holes, group 2 on combustion related risks, group 3 on sensors and electronics and group 4 on materials.

During the WP4 workshop on the 31st of March 2021 the status in each of the groups was presented. An overview:

Group 1: leakage rates and specifically breather holes

Assessment parameters

- minimum ventilation rate requirements;
- lower explosion limit (LEL) of hydrogen.

Leak-tightness test results for controls

- tests done by several manufacturers;
- test gases: methane, air, helium, hydrogen → no significant difference;
- leakage rates below the limits given by the applicable standards EN 13611 – *Safety and control devices for burners and appliances burning gaseous and/or liquid fuels - General requirements* and EN 126 – *Multifunctional controls for gas burning appliances*;
- insignificant temperature dependence.

Breather holes

- for the case of a diaphragm failure higher flow rates through breather holes have been measured for hydrogen than for methane;
- risk assessment is needed.

Group 2: combustion related risks

Assessment parameters

- exposure to higher temperatures;
- NO_x emissions.

To be further investigated

- accumulation of unburned gas → avoid ATEX zones → avoid deflagration;
- adequate purging procedure;
- procedure for components only temporarily supplied with hydrogen;
- procedure for spare part replacement (like filters, valves, actuators);
- detection of incomplete combustion → unburned hydrogen emission measurement;
- factors compromising product lifetime.

Group 3: sensors and electronics

Assessment parameters

- flame detection signal strength;
- safety times of burner controls.

To be further investigated

- focus on EN 298 – *Automatic burner control systems for burners and appliances burning gaseous or liquid fuels*, EN 12067-2 – *Gas/air ratio controls for gas burners and gas burning appliances - Part 2: Electronic types* and EN 16340 – *Safety and*

control devices for burners and appliances burning gaseous or liquid fuels - Combustion product sensing devices;

- what are the limits of ionization sensors for increasing hydrogen content and 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?
- lower 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.

Group 4: Materials

Assessment parameters

- temperatures;
- pressures.

To be further investigated

- gas temperature is not a factor considered in today's standards → high temperature effects can be excluded for gas temperatures below 178°C;
- operating temperature classes to be added to the standard EN 13611;
- H_2 embrittlement to be considered for metals, even for temperatures below 0°C;
- springs not made from austenitic steel need to be qualified by endurance tests.

Further process in CEN/TC 58 related to $_{H2}$ and H_2NG use:

- the parts of EN 13611 needing to be checked and probably have been marked;
- the investigation results are to be compiled within 1 year in a publicly available document to be published in anticipation to adapted standard(s);
- a formal new Work Item proposal for a CEN Technical Report has been submitted to CEN/TC 58: "Safety and control devices for burners and appliances burning gaseous and/or liquid fuels – Guidance on hydrogen specific aspects" → once approved a new Working Group is to be established within CEN/TC 58.

CEN/TC109 - Central heating boilers using gaseous fuels

CEN/TC 109 has set up an AhG specifically covering H_2NG and H_2 in an early stage and so, has produced important work of relevance for CEN/TC 238, but also for CEN/TC's working on other types of gas appliances as most of the risks are similar.

CEN/TC 109's scope:

> All the gas-fired central heating boilers, including the boilers of the condensing type, with or without integrated domestic hot water production, of all types and all nominal inputs, i.e. :
> - the boilers fitted with atmospheric burners or premixed burners (fan-assisted or not),
> - the units composed of a boiler body and its fan-assisted burner, constituting an indissociable entity,
> - the assembling of a boiler body (according to the requirements prescribed by the CEN/TC 57) and a fan-assisted burner (according to the requirements prescribed by the CEN/TC 131), but only for the specific characteristics suited to the utilization of gaseous fuels.

The committee has 5 active WG's: WG1 on domestic central heating boilers using gaseous fuels, WG3 on assembly of boiler bodies and forced draught burners, WG4 on hot water production of central heating boilers for domestic use, WG5 being the steering group ECOTEST and WG6 on material efficiency.

The AhG was set up under WG1 in November 2019 and identified 3 'job tickets':

1. Investigate what H_2 concentration the current appliances (from e.g., 2005 onwards) can handle when supplied with H_2NG including what must be changed in terms of tests and corresponding limit gases.
2. Develop a proposal for a new appliance category to be introduced based on 20 vol% H_2 and examine what must be changed in terms of tests, test conditions and more specifically for limit test gases.
3. The same tasks for 100 vol% H_2 supplied via dedicated infrastructure.

Subsequently standards of EN 15502 series will have to be adapted accordingly.

During the WP4 workshop on 31st of March, the status and proposals (although still to be confirmed within the AhG) related to these job tickets were presented:

> Job ticket 1
>
> The AhG focused on job tickets 2 and 3 as the THyGA project covering job ticket 1 started shortly afterwards.
>
> Job ticket 2
>
> Draft amendment EN15502-2-1 - *Gas-fired central heating boilers - Part 2-1: Specific standard for type C appliances and type B2, B3 and B5 appliances of a nominal heat input not exceeding 1 000 kW* for supply with H_2NG with max. 20 vol% of H_2 has been elaborated. Its final review has been done in 2021, and the TC109 finally decided to support the document as a Technical Specification (TS) rather than an amendment.
>
> It contains proposals of appropriate test gases and appliance categories and will be introduced as Technical Specification (TS) related to EN 15502-2-1 until the EN 437 standard is adapted accordingly.

Job ticket 3

The similar work for 100 vol% H_2 started in October 2021.

Depending on the required changes, this will be written as an amendment to the EN15502-2-1 – *Gas-fired central heating boilers – Part 2-1: Specific standard for type C appliances and type B_2, B_3 and B_5 appliances of a nominal heat input not exceeding 1 000 kW* or probably, also as a TS.

Main adaptations to the draft amendment of EN15502-2-1 – *Gas-fired central heating boilers – Part 2-1: Specific standard for type C appliances and type B_2, B_3 and B_5 appliances of a nominal heat input not exceeding 1 000 kW* for H_2NG (with max. 20 vol% of H_2) supplied appliances:

- The current review takes in account a max. H_2 concentration of 20 vol% in the distributed natural gas. Appliances designed for such H_2NG supply are assumed to satisfy the essential requirements of GAR when supplied with gases corresponding to the concerned appliance category containing an H_2 concentration which may vary between 0 and 20 vol% of H_2.
- The appliance category is followed by a "Y" followed by a number indicating the max. H_2 concentration in natural gas for which the appliance has been designed.
- E.g. 2EY20 stands for an appliance of category I2E which may be supplied with an H_2NG admixture containing up to 20 % H_2.
- Nominal heat input = heat input with reference gas (0 vol% H_2) while reduced heat input = heat input with hydrogen admixture (20 vol% H_2). Both to be indicated on the appliance and in its manual.
- Risk analysis to be extended for materials in contact with hydrogen.
- Delayed ignition to be done with reference gas and reference gas containing 20 vol% of H_2.
- Combustion measurements and calculations use O_2 instead of CO_2 concentration.
- Light-back risk to be checked with limit test gas containing more H_2 dan current light-back limit test gas except for appliances equipped with full premix burners; for this type of burners the appropriate assessment method will be defined separately.
- Adjustment to both 0 vol% and 20 vol% H_2 taken in account for safety assessment.

Limit gases for full pre-mix H_2NG appliances: 2 possibilities

- A "classic" proposal in line with the current EN 437 standard, but for light-back assessment the limit test gas G21 is chosen for fully premixed appliances for fully premixed appliances of cat. 2EY20 and 2HY20:

Appliance category without H_2 *(EN437)*		**Gas category with hydrogen blend (new, future adaptation in EN437)**					
Appliance category	Reference gas	Appliance category	Reference gas	Declared heat input for 20% H_2 in the distributed gas	Incomplete combustion limit gas	Light-back limit gas	Flame lift limit gas
2_E	G20	2_{EY20}	G20	$G20_{Y20}$	G21	G21	G231
2_H	G20	2_{HY20}	G20	$G20_{Y20}$	G21	G21	G23

Table 10: First proposal of tests gases from TC109

G21 (i.e. CH4 + 13 vol% C_3H_8 instead of 23 vol% H_2 for the currently used light-back limit test gas G222) has been identified as the appropriate limit gas for testing light-back of appliances equipped with fully premixed burners as the increased flame velocity, causing the risk on light-back, due to the H_2 presence is compensated by the increase of the air excess which lowers the flame velocity again.

- As alternative for assessing 20 vol% H_2 in the distributed natural gas, a lambda variation of +/- 10 % can be chosen (corresponding to the PAS 4444 approach for 100% H_2):

Appliance category without H_2 *(EN437)*		**Gas category with hydrogen blend (new, future adaptation in EN437)**					
Appliance category	Reference gas	Appliance category	Reference gas	Declared heat input for 20% H_2 in the distributed gas	Incomplete combustion limit gas	Light-back limit 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

Table 11: Second proposal of tests gases from TC109

Besides the above CEN activities related to H_2NG use, a lot of new related activities have been launched or will soon be launched. A non-exhaustive overview:

Very relevant within the framework of the THyGA project, is also the CEN/GERG pre-normative project called "H_2NG Gap analysis 2020". To reduce barriers to injection of hydrogen in the natural gas grid, GERG together with a few CEN TCs were asked by DG Energy to establish a shortlist of potential priority topics/areas requiring pre-normative research. One of the priority topics/areas defined is domestic and commercial end-use. As the planned work includes:

- details on the sensitivity of each of the appliance segments and related conclusions,
- details on the regulations & standardization that apply for each of the segments,
- recommendations for actions to cover the areas where more work needs to be done,
- and conclusions about the standardization (Work Program proposal for PNR actions including numerical simulations, research work, experimental testing and investigation for mitigating the impact of H_2 injection in gas used in end-use equipment),

it obviously is closely related to the THyGA project.

2.3 United States of America & Canada

In the United States and Canada, the standardization work on H_2NG admixtures did not start yet, but probably the first aim will be to define appropriate test gases in the ANSI/CSA Z21 and Z83 series of standards containing combustion performance requirements e.g. the ANSI Z21.47-2016/CSA 2.3-2016 on gas-fired central furnaces.

2.4 Japan

Based on an exchange with the Japanese Gas Association it seems that activities regarding H_2 injection in natural gas today are limited to some private testing on hydrogen concentrations that could be accepted by the different appliance types. Regarding hydrogen today's focus is rather on distribution of

- synthetic methane, with an objective of 1% by 2030, via the existing grid;
- hydrogen with a first project of supply to the Olympic village (after the 2021 games).

2.5 Other

Contact has been taken with gas companies and/or standardization organizations in Australia, Canada and Korea but no relevant information has been obtained.

3. CONCLUSIONS

Based on consultations and received information, it seems that, apart from Europe, standardization and certification activities for use of H_2NG mixtures is limited with only some first interest popping up in the USA and in Japan.

In Europe, standardization activity for H_2NG use has started in 2020 and is strongly increasing. Many CEN technical committees started considering including H_2NG supply to their appliances in the product standards in their scope. CEN TC109 on central heating boilers, TC 58 on safety and control devices and TC 238 on test gases, test pressures and appliance categories seem most advanced in this exercise today. T**he developments are obviously of interest for the THyGA project and by consequence a structural liaison has been put in place and has led to a proposal of reorienting the further WP4 work on certification and standardization to the elaboration of a guide for review of existing product standards for H_2NG use**.

In Europe certification of gas appliances for H_2NG use, generally limited to 20 % H_2, already started. The general framework and essential requirements are defined in the existing Gas Appliances Regulation (EU) 2016/426 (also called GAR), but due to the lack of requirements for H_2NG use in standards, current certification does not take place on a harmonized basis.

Manufactured town gas finally, widely distributed and used since the early 19th century and still in use in some Asian countries, contains typically around 50 % of hydrogen and is therefore considered useful experience to develop a framework for H_2NG use. Residential use of this town gas however is no longer exiting in Europe since a few decades, apart from some Scandinavian cities like Stockholm where town gas only has been replaced by a mixture of natural gas and air in 2011 (this mixture is also called town gas but is irrelevant for the THyGA project as it doesn't contain hydrogen). Despite the obvious interest in the lessons learned from residential use of manufactured town gas, it turned out to be very difficult to gather useful information and the few received information did not bring any new elements. So further effort to investigate town gas use seems not to have much added value.