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

Roadmap H_2NG for Europe

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Executive summary

The **European countries have different approaches** regarding the injection of H_2 in the grid and for what usages hydrogen shall be used for.

The countries' policies for H_2 are mostly dictated by the current technical national solution to decarbonize the grid (potential share of biomethane), national energy policies (electrification of space heating, etc.) and present end-use market profile (share of domestic-commercial use vs industrial use).

In any case, injecting up to 20% is mostly seen as a first step before getting to 100% H_2 as described in section 3 and some countries even plan to skip this step and go directly from NG to 100% H2. Intermediate levels at 2%H_2 are already acted in some countries and evaluations are being done up to 6%H_2.

The **lack of a regulative framework for blending of H_2 in NG** and unclarities about **liabilities for blending of H_2 in NG** on a grid with appliances only certified for NG are also obstacles to a fast implementation of 20% injection projects.

Current projects with 20% H_2 are still « pilot projects » and there is no standard methodology to implement such projects at a large scale, especially since there is presently **no harmonised certification scheme for X%H_2 ready appliances**. The expected "Standardization Request for Hydrogen" will be a big step forward.

Therefore, for all those reasons the timing of the large scale rollout of 20% H_2 across Europe is very uncertain, but it will need the collaboration between all the stakeholders (Manufacturers of appliances, Certification bodies, CEN TCs, Safety authorities, Gas distributors, European Commission…). Appliances certified for 20%H_2 are already commercialized but the whole roll-out of the European appliances is not expected before 2045/2050, which means that the priority is to tackle the problem of existing appliances.

The THyGA project showed, in summary, that for 20%H_2, taking aside the liability issue for appliances non certified for H_2NG:

- No safety risk identified by the THyGA project for any type of appliance except for delayed ignition with some specific design of appliances (partially premix appliances without fan)
- Adjustment seems to be the main limitation; it only concerns fully-premix appliances without mitigation methodology implemented.

Delayed ignition

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

Based on the first results from the project, it seems recommended

- to reconsider the test method and conditions to take in account reasonably foreseeable worst cases,
- to reassess the delayed ignition risk systematically for appliances not specifically designed for natural gas containing relevant H_2 concentrations, especially when on-site adjustment is allowed/possible.

If any mitigating measures are needed, the next measures may be applied:

- reduce the ignition safety time (by replacing the burner control by one with a shorter safety time),
- avoid (inappropriate) on-site adjustment.

However, the results on delayed ignition and understanding of how it can impact different technologies differently (eg. absence of ventilator) have been brought up at the end of the project. This particular test clearly needs more investigation from the stakeholders.

Adjustment

As discussed extensively throughout the project course, adjustment is the main problem when dealing with H_2NG blends impacts on fully premix appliances.

Several mitigation solutions have been studied in D5.2 (S. Carpentier et al. 2023). Among them, we can underline several technical solutions:

- Appliance adjustment should be based on O_2 values, rather than CO_2 values.
- the authors suggest to only allow adjustment (or re-adjustment) of appliances to G20 if the gas composition or Wobbe is known. A specific procedure to do that would need to be developed.
- Set points for the initial adjustments with G20 could be revised toward lower CO2 or higher O2 at least for the appliances on the market with too close to stoichiometry set points.
- It is preferable to use combustion-controlled boilers that keep the air/fuel ratio constant (via ionization probe or CO sensor), even if more investigation should be performed to clarify if flashback occurs during auto-calibration periods, when the boiler operates for a few seconds in near-stoichiometric conditions.

Moreover, test results show that the CO_2 (or O_2) range of adjustment suggested by manufacturers on some appliances may have to be updated to take into account adjustment from low Wobbe Index and use with high Wobbe Index gases. This is especially required for appliances that operate with a very low air excess.

Liability

As explained in WP4, in reference to the Gas Appliance Regulation, existing appliances did not have to be designed for use of H_2NG; so H_2NG supply cannot be considered as 'normal use' and so **manufacturers would not be liable for any negative impact caused by supply of H_2NG mixtures** (except recent 20%H_2 certified boilers or radiant heaters).

Each country has its own specification for gas quality distribution, installation rules… so the conclusions regarding how to address liability in one country cannot be directly transposed to another. However, the methodology to reach conclusions and the knowledge gathered for that could be shared to favour an efficient high scale implementation of H_2NG blends on the European market.

THyGA's recommendation would be to favour dialogue between gas grid operators and appliance manufacturers: which actions and methodologies to study H_2NG blends' impacts, country per country? Which are the best practices?

- Gas grid operators: how much %H_2 at max ? What are the perspectives? Are there some strategies devised for high scale implementation?
- Manufacturers & manufacturer associations: Which appliances can operate up to x%H_2 Which appliances cannot operate up to x%H_2? Which are the appliances for which more investigations are required?

List of abbreviations

AP	Advisory Panel Group
CDAP	Communication, Dissemination and Awareness Plan
ECH2A	European Clean Hydrogen Alliance
EU	European Union
FCH 2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking
GA	Grant Agreement
GAR	Gas Appliances Regulation
H_2NG	Hydrogen / Natural Gas blend
HE	Hydrogen Embrittlement
KER	Key Exploitable Results
MS	Milestone
NBA-Open	Notified Body Association
PO	Project Officer
SFG-U	Sector Forum Gas - Utilization
TC	Technical Committee
WP	Work Package

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1. Introduction

Gas networks are a vital asset for security of energy supply as they are extensive and help address many of the challenges of energy transmission, distribution and storage, as well as utilization; with the energy transition they will continue to be needed, as they can directly support renewable technologies in many functions such as being the back-up capacity to balance its intermittency (particularly from solar and wind), offering affordable investments and consumer prices, and providing reliable energy.

The decarbonization of gas networks is a challenge that governments and industry need to invest in R&D efforts. As explained in (Ecorys 2022), “with the lack of dedicated hydrogen infrastructure, blending is a useful tool to accelerate hydrogen production while infrastructure is still being built”. However, blending can bring its own challenges mainly because of a lack of common regulation regarding the acceptable volume of hydrogen to be injected (and the trans-border complexity) and the unknown regarding its impacts on the network and the end-users.

2. Context: ambitions of the project in 2019 and evolutions until 2023

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

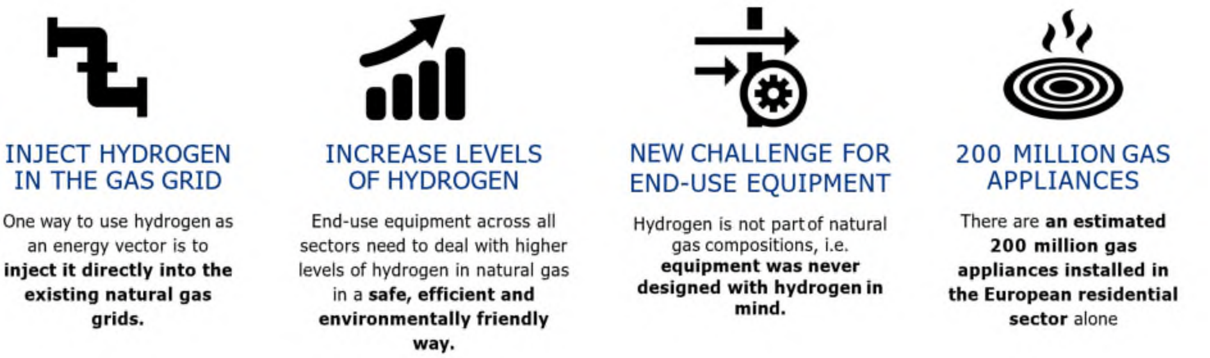

Figure 1: THyGA project's scope of work

At the time, Hydrogen, along with green electricity from wind and solar power, was being discussed as a pathway to decarbonise the European energy systems. By injecting hydrogen into the existing natural gas infrastructure, the CO_2 footprint of gas utilisation would be reduced, contributing to an overall reduction of greenhouse gas emissions. Seeing H_2NG blends as an opportunity to allow for the integration in energy systems based on gas networks, before creation of dedicated hydrogen infrastructures, the FCH 2 JU decided to explore impacts of blends on residential and commercial natural gas appliances with up to 60%H_2 in volume.

Low, medium and high hydrogen concentrations in natural gas should be investigated:

Low = <10% Vol.

Medium = 10-30% Vol.

High = 30-60% Vol.

Figure 2: Extract from the THyGA Grant Agreement (No 874983)l

By the beginning of 2020, when the THyGA project started its activities, the general kno[2]wledge and opinions regarding H_2NG blends had already evolved, with perspectives more focused on lower levels, as illustrated by the results of a live survey with the attendants of the first THyGA Workshop, on the 6th of May 2020[1], 93% of the answers predicted blends lower or equal to 30%H_2.

The same question has been asked during the final Workshop of the project, on the 24th of March 2023[2], with the results quite similar: **focus on blends below 20% in 2030 and transition to pure hydrogen networks in 2050**.

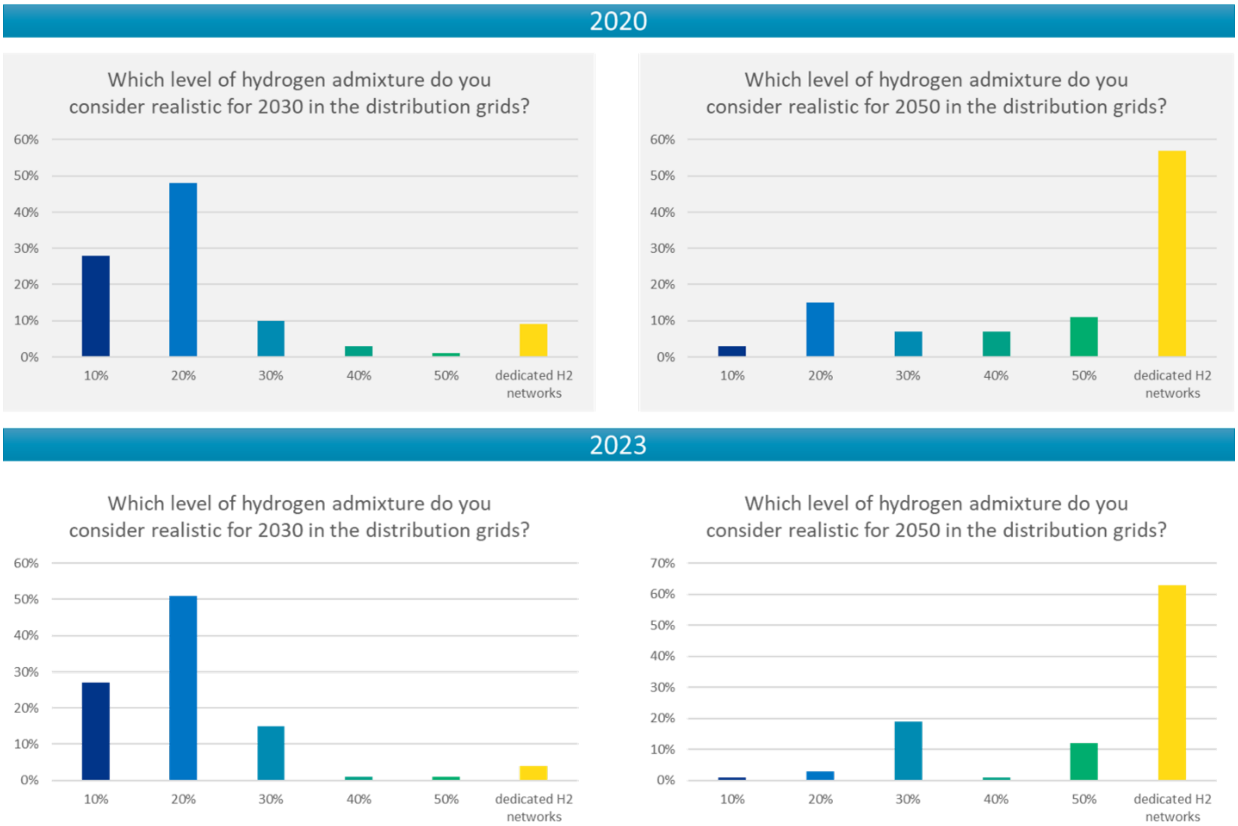

Figure 3: Results from a survey during the first THyGA workshop in 2020 and during the final workshop in 2023.

3. European and National positions regarding H_2NG blends

3.1 Europe

Hydrogen as an energy carrier will play a key role in the EU decarbonisation goals. The European Commission's REPowerEU plan has reinforced objectives on hydrogen, in line with the objective to phase out dependence on imports of natural gas before 2030. The EU's ambition is to produce 10 million tons (Mt) of renewable hydrogen in the EU and to import 10 Mt of renewable hydrogen and its derivatives (e.g., green ammonia) from third countries by 2030. Scaling up the development of

[1] https://thyga-project.eu/1st-workshop-of-the-thyga-project/
[2] https://thyga-project.eu/thyga-final-workshop/

hydrogen infrastructure and supporting hydrogen investments are also identified as key areas to support hydrogen uptake in the EU.

Blending hydrogen into the existing gas networks is a first step to decarbonising natural gas. A 2018 study from the EU Joint Research Centre (JRC 2022) determined that the maximum hydrogen production that can be blended into EU gas systems, with a threshold of 20% by volume, to around 4.5 million tons (almost half of the 10 million tons of hydrogen to be produced according to the EU Hydrogen Strategy).

Currently, there is no harmonised strategy across the EU for hydrogen blending thresholds, as shown in the following figure on blending limits, compiled by the IEA (IEA 2022).

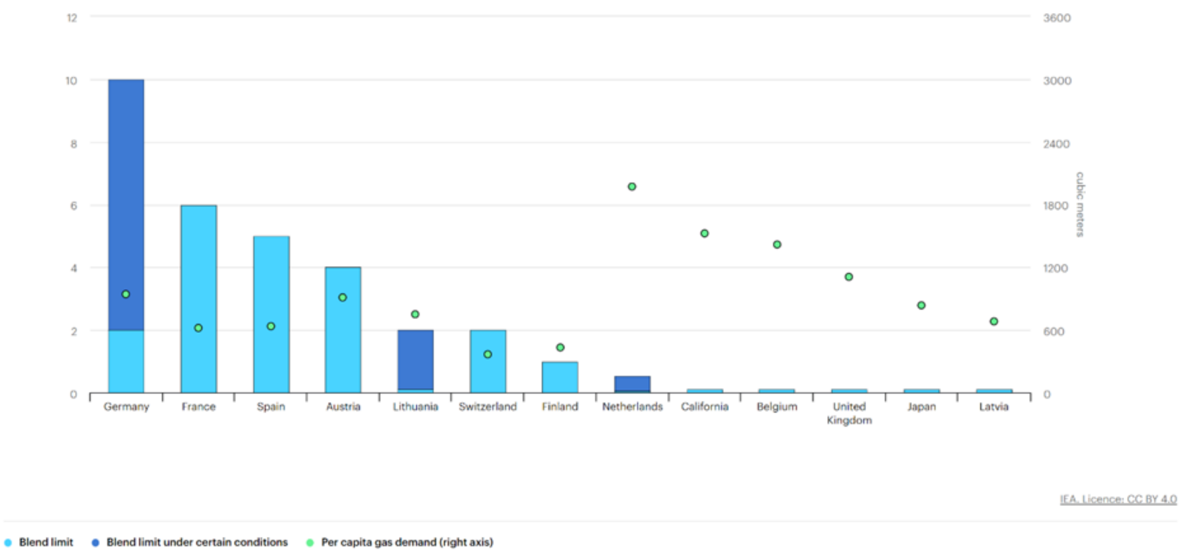

Figure 4: IEA, Current limits on hydrogen blending in natural gas networks and gas demand per capita in selected locations, (IEA 2022)

As shown also in deliverable 4.1 in (K. DeWit et al. 2020), several Member States already have leniency for hydrogen blended in natural gas as long as they remain in the Wobbe index and density ranges. However, National strategies have evolved and almost all Member States initiated works on the allowable percentage of hydrogen which could be blended on their territory, these approaches are summarized in the next chapters and are highly susceptible to changes given the moving regulatory context during the period this report was written.

3.2 National context

- **In Germany,** the code of practice G260(2021)[3] explicitly states that at the moment, **no reliable limit for H_2 concentration can be given** (the previous version of G260 from 2013, "recommended" to prepare for H_2 concentrations in the single digit vol.-% range, unless in the vicinity of NG refuelling stations, where the 2% limit from DIN 51624 applied). Still, with a well-developed infrastructure for natural gas and a large number of transmission and distribution operators, the country is developing several experimentations and projects, expecting H_2

[3] DVGW G260 9/2021: "*Gas appliances are, according to the present knowledge, suited for concentrations of up to 10 vol %. Concerning suitability for concentrations of up to 20 vol %, extended studies are being carried out in the context of research project*"

blending in large parts of Germany by 2030 (DVGW Deutscher Verein des Gas- und Wasserfachs e. V. 2022).

- One of the first countries in the EU to deploy a hydrogen plan, **France** does not have a national regulation on blending. In 2018, gas operators identified a limit of **6%** H_2 in natural gas for technical requirements and were projecting an increase to 10% by 2030 (GRT Gaz 2019). However, the agreed threshold has been lowered to **2%** after discussion between gas operators and gas users. The focus is on pure hydrogen networks, and hydrogen producers no longer plan to inject in natural gas grids.

- In **Spain**, the current regulation allows a blending concentration of **5%** by volume of hydrogen into gas pipelines (ENERGIA 2022). Higher percentages are considered achievable with modification of some network equipment and materials, the revision of standards and end-use equipment. In addition, the country has to balance the freshwater requirement for hydrogen production in regions with high water stress; to mitigate this, the production of green hydrogen from desalinated water is under consideration.

- In **the Netherlands**, the current legislation (MR Gas Quality) allows **0.5%** H_2 in DSO grids, **0.5%** H_2 in TSO regional pressure grid and **0.02%** H_2 in TSO high pressure grid. The government indicated they were considering a *blending obligation* to increase demand for green hydrogen (gradual increase up to 10-20%) (Government of Netherlands 2020). However, some industry actors suggest that changes to the current limits are not foreseen, as the main focus of national strategy and pilot projects is on pure hydrogen.

- In **Italy**, a National Decree (Ministry of Ecological Transition 2018) specifies a maximum of **2%** of hydrogen in the natural gas network (provided that Wobbe Index and Density remain in the range fixed to guarantee interchangeability of different gases). The National Gas Committee (CIG) is working to update the applicable standards, and the allowed percentage is expected to increase (5% and 10%).

- In **Denmark**, TSO, DSO and gas authority are waiting for European legislation to be in place before any Danish decision is taken about accepted/defined percentages of H_2NG. The country wants to avoid a similar situation to the regulation on oxygen limits for natural gas, for which neighbouring countries have different limits to Denmark.

- In **the United Kingdom**, the government is set to make a policy decision in 2023 on whether hydrogen blending should be rolled out across the gas transmission and distribution networks. The UK Hydrogen Strategy underlined that strategic decisions on blending hydrogen into the gas grid and hydrogen for heating will have a significant impact on the development of hydrogen networks. The government decision will take into account the safety and integrity evidence provided by pilot projects such as HyDeploy, but also the economic value of introducing a blend.

3.3 Standardization

In March 2023, the European Commission published its "2023 annual Union work programme for European standardization" (European Commission 2023), identifying hydrogen as a priority but rather on the production, transportation and storage axis.

Table 1: Extract from Annex to the Commission Notice

Actions for the development and revision of European standards or European standardisation deliverables supporting the strategic priorities				
Ref	Title	Reference	European standards/European standardisation deliverables	Specific objectives and policies for European standards/European standardisation deliverables
1	Hydrogen technologies and components	COM/2021/804 final - Proposal for a Regulation on the internal markets for renewable and natural gases and for hydrogen COM/2021/557 final - Proposal for a Directive amending Directive (EU) 2018/2001 as regards the promotion of energy from renewable sources	Develop European standards on quality, technology and safety for the production and use of hydrogen.	Improving the development and maintenance of hydrogen infrastructure and technological components in the single market.
2	Transport and storage of hydrogen	Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure COM/2021/803 final - Proposal for a Directive on common rules for the internal markets in renewable and natural gases and in hydrogen	Revise existing standards and develop new European standards for hydrogen quality and safety – relevant for injection into the dedicated hydrogen network, and end uses, including hydrogen-based fuels.	Enabling and promoting the scaling up of transport and storage methods for hydrogen, which will facilitate the replacement of fossil fuels and feedstocks in hard-to-decarbonise sectors.

The European Clean Hydrogen Alliance (ECH2A) gathers representatives from "industry, public authorities, civil society and other stakeholders to support the large-scale deployment of clean hydrogen technologies by 2030". To support the CEN/CENELEC standardization activities, ECH2A created in 2022 a Working Group on hydrogen standardization, to gather the on-going works on standardization, identify gaps and define a development plan on the whole value chain, the "Roadmap on hydrogen standardization" (ECH2A 2023) was published in March 2023.

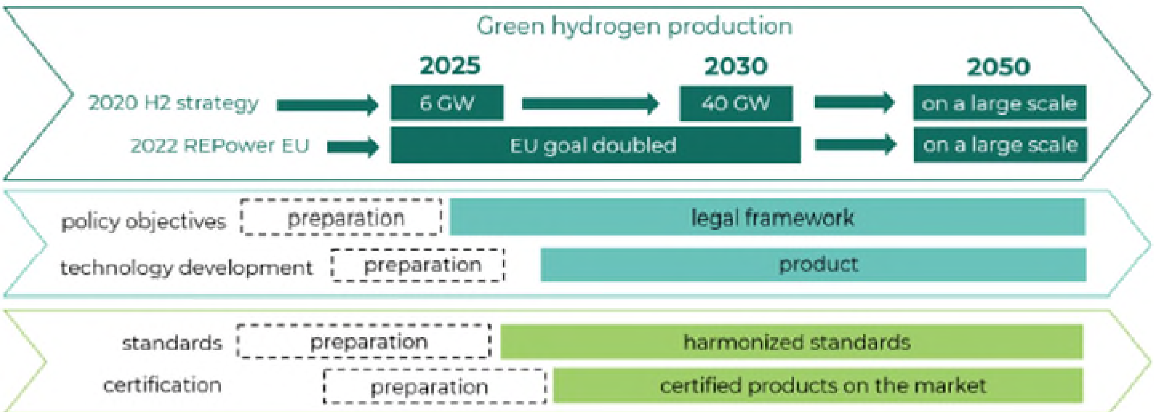

Figure 5: Policy framework in relation to development of hydrogen technologies (ECH2A 2023)

The first task of the working group was to identify the relevant CEN/CENELEC Technical Committees related to hydrogen, as disclosed in Figure 6, those relevant for the THyGA projects are circled in red.

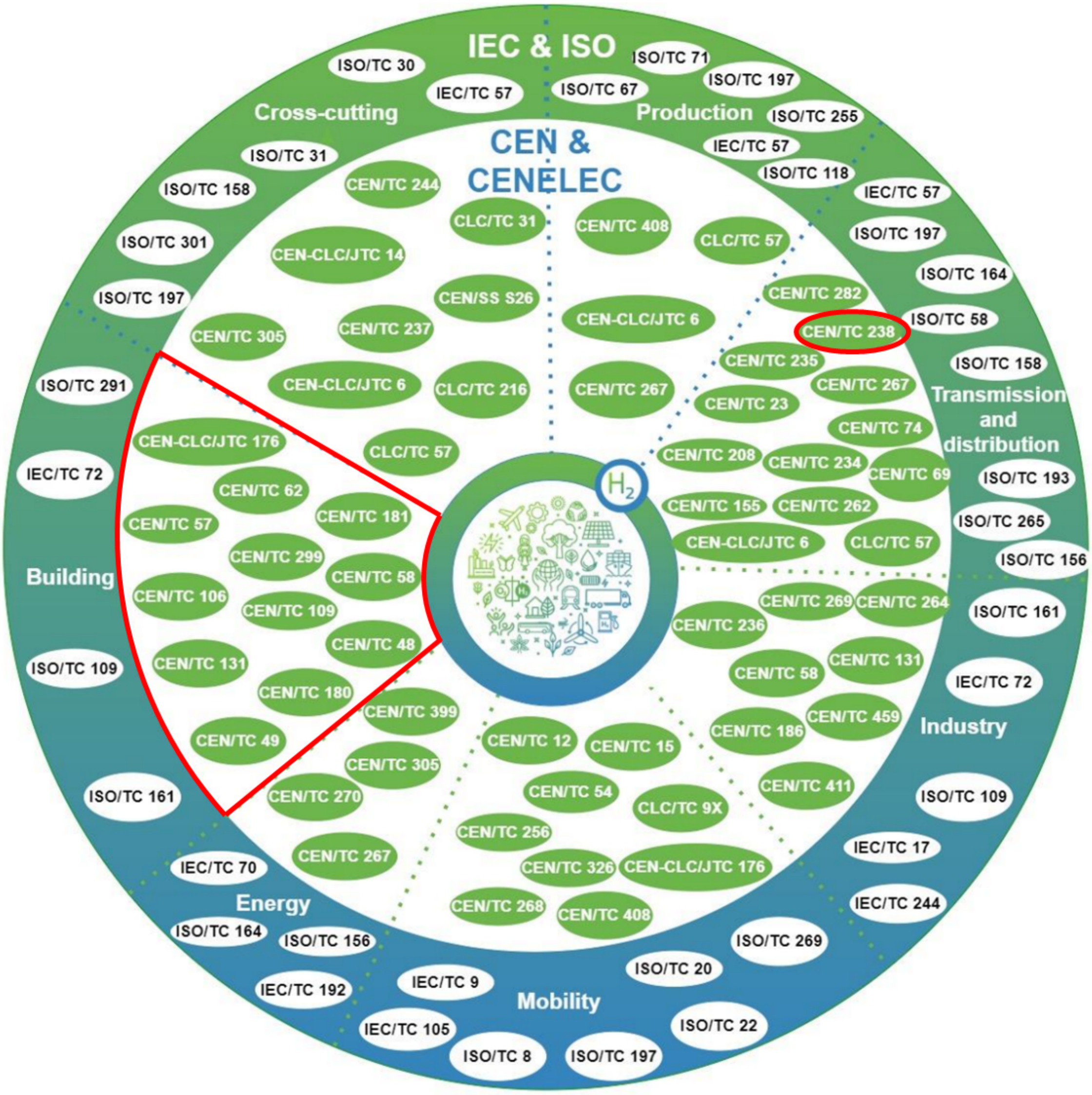

Figure 6: European and international standardisation landscape for hydrogen topics (ECH2A 2023)

This document provides extensive information on regulation framework, initiatives regarding hydrogen as an energy vector (pure hydrogen and H_2NG blends), the main take-over related to our use of H_2NG blends in buildings is summarized from the ECH2EA report's section "6.7 Cluster: Building – Residential application" which de facto also covers commercial applications.

- "There is an urgent need to develop and certify appliances (boilers, hybrids, thermally-driven heat pumps, micro-CHP, etc.) which are able to run with alternative renewable gases such as hydrogen"
- "The relevant CEN Technical Committees are already elaborating and updating the relevant standards for hydrogen use in buildings. The focus is on pure hydrogen and for a transition period for blending with natural gas respectively biomethane" as summarized on Figure 7
- "It is of high priority to update existing standards for the design and testing of applications using 100% hydrogen and H_2 blends regarding e.g. materials, safety, performance, emissions, leakage, product testing, etc. Therefore, common test conditions have to be aligned with the relevant European regulations."

Building - residential application	2023		2030
combustion quality aspects	under development	in place	
components	under development	in place	
installation	under development	in place	
gas quality aspects:			
- blends	under development	in place	
- purity	under development	in place	
- variations	under development	in place	
- gas families/ test gases	under development	in place	
safety aspects:			
- leakage	under development	in place	
- material compatibility	under development	in place	
efficiency	under development	in place	

Figure 7: Cluster building – current status of standardisation (in place: standard published ; under development: the main topic is already identified as a project or in a technical committee) [RefECHEA]

The Commission (DG GROW) and CEN/CENELEC are currently drafting a Standardization Request in support to the Gas Appliances Regulation. Once this work is finalized, the objective is to address the question of a "Standardization Request for Hydrogen" (a draft document has already been established in a CEN-CENELEC process launched in 2016 but was on-hold, in expectation of the "development of the EC hydrogen strategy, the Fit for 55 and RepowerEU initiatives and finally also with the ECHA work on a standardisation roadmap" [RefECHEA]).

Several Notified Bodies and CEN Technical Committees (especially CEN TC58, CEN TC238, CEN TC109, CEN TC 180) have been working on H_2NG certification, the topic has been extensively discussed in Work Package 4 reports (K. DeWit et al. 2020) (K. DeWit et al. 2021) (K. DeWit et al. 2023). Most of the CEN TCs are waiting for the standardization request on hydrogen before starting actively working on the topic.

In 2020, GERG along with CEN TCs (initially specifically CEN TC234 and TC 408 WGs) were tasked by DG Energy to establish a shortlist of potential priority subject areas for PNR actions to reduce barriers to injection of hydrogen in the natural gas grid (GERG Project 'Removing the technical barriers to use of hydrogen in natural gas networks and for (natural) gas end users').

This major gap analysis included a section on end-use. The overall conclusions were that the injection of hydrogen for new appliances designed for this purpose will not be a problem as long as there is a certification scheme adapted to the level of H_2. For existing appliances, a future injection of 20% of H_2 in natural gas grids (H & L gas) seems to be a reasonable hypothesis for the domestic and commercial appliances treated in the study. Some remaining technical grey areas have been clarified in the THyGA project; the liability aspect, using appliances with a gas they were not certified for, was identified as the largest barrier. The results of this GERG-CEN H_2 PNR project [4] will support the Standardisation Request.

CEN/Sector Forum Gas_Utilisation (CEN/SFG_U) has played a significant role around the implementation and coordination with CEN/TCs of THyGA works. Standardization in the field of gas utilization plays an important role to support: the implementation of European legislation, the

[4] https://www.gerg.eu/projects/hydrogen/removing-the-technical-barriers-to-use-of-hydrogen-in-natural-gas-networks-and-for-natural-gas-end-users/

successful integration of the European gas market, and the implementation of the EU's climate and energy targets. So, it was obvious that CEN/SFG_U was to have a role on H_2 field with a special focus on the development of H_2 activities, for instance on compatibility of gas appliances and components with the renewable energies (H_2 blends and 100% H_2). CEN/SFG_U Chairman and Secretary were obviously members to the Steering Committee of THyGA to ensure that mission.

3.4 Associations

This chapter gathers feedbacks and position from several associations participating to the advisory panel from THyGA, regarding blending, to give insight on stakeholders' views on the topic.

3.4.1 AFECOR

"*One of the major priorities of the association of European control manufacturers for heating systems (Afecor) is to support the European goals in the context of decarbonization and climate neutrality. Since the products of their members (e.g. valves, burner controls, sensors) are key elements of the heating systems and appliances (boiler and burners), it is essential that these components can work safely and efficiently with renewable fuels like pure hydrogen or in blends with natural gas.*

In this context Afecor supports the European regulation developments and is actively involved in hydrogen standardization activities, which lay down the basis for products certifications and CE marking.

Within CEN/TC 58, a Technical Report (CEN/TR 17924:2023) was developed and recently published with the contribution of members of Afecor. This document gives guidance on hydrogen leakage, material, risk assessment and general safety aspects.

Furthermore, Afecor is actively involved in the Clean Hydrogen Alliance, which has just published a roadmap on hydrogen standardization (link) and the Prime Movers' group of ENTSOG (link).

Other statements of the association in relation to hydrogen use are available here."

3.4.2 EHI (European Heating Association)

"*E*HI represents 90% of the European market for heat and hot water generation, heating controls and heat emitters, 75% of the hydronic heat pump market, 80% of the biomass central heating market (pellets, wood) and 70% of the solar thermal market. EHI Members produce advanced technologies for heating in buildings, including: heating systems, burners, boilers, heat pumps, components and system integrators, radiators, surface heating & cooling and renewable energy systems. In doing so, we employ directly more than 125.000 people in Europe and invest more than 1 billion euros a year in energy efficiency.

Current state of play

The installed stock of residential and commercial appliances can already run on biomethane as well as varying degrees of methane-hydrogen blends depending on the age of the boilers. Boilers installed after *the implementation of the Gas Appliance Directive[5] the majority of which being atmospheric boilers have shown in tests that they could handle up to 10% vol. of hydrogen. Nevertheless, because of certification rules, these appliances cannot be re-certified or re-classified as such.*

Since 2005, there are increasing sales of condensing boilers, which are generally able to work with up to 20% vol. hydrogen, but this is currently not a mandatory requirement.

Hydrogen fluctuations in the gas blend do not adversely affect the appliance. The HyDeploy project also confirms this: "The evidence generated showed that UK appliances are capable of operating with a 20% vol. hydrogen blend safely and with good performance and without the need for adjustment".[6] In addition, there are fuel cells on the market today that are already capable of functioning with 100% vol. hydrogen.

The standardisation update to make all heating appliances "100% vol. H_2-ready" enabling them to handle different fluctuations of methane-hydrogen blends is well-underway and will be fully finalised by 2025 at the latest.

In the meantime, as currently installed appliances cannot be re-certified or re-classified for the use of hydrogen in general, a case-by-case approach shall be followed whereby technicians should ensure old appliances are compatible when increasing hydrogen blends in grids.

EHI position

At least 2 years after the review ecodesign and energy labelling regulation for space heating and water heaters enters into force, i.e. 2026–2027:

- *to introduce an optional pictogram on the energy label for the purpose of raising awareness, indicating the capability of appliances to use (Energy labelling space heaters, Annex III; Energy labelling water heaters, Annex III):*
  - *biomethane, e-methane, bio LPG;*
  - *a variable share of hydrogen of up to 20% vol. (in combination with biomethane or natural gas);*
  - *100% vol. hydrogen.*
- *to introduce an ecodesign requirement for the following gas fired appliances to work with a variable share of hydrogen of up to 20% vol. (in combination with biomethane or natural gas) (Ecodesign space heaters, Annex II, Point 4; Ecodesign water heaters, Annex II, Point 1.3):*
  - *all models of heaters (space and combination, including B1 boilers) ≤70 kW*
  - *new models of heaters (space and combination, including B1 boilers) >70 kW;*
  - *new models of water heaters;*

When a technical update is needed after 2026 in view of ecodesign requirements:

- *to introduce an ecodesign requirement for the following gas fired appliances to work with a variable share of hydrogen of up to 20% vol. (in combination with biomethane or natural gas) (Ecodesign space heaters, Annex II, Point 4; Ecodesign water heaters, Annex II, Point 1.3):*
  - *existing models of heaters (space and combination, including B1 boilers) >70 kW;*
  - *existing models of water heaters.*

In 2029:

[5] European Council Directive 90/396/EEC and Directive 93/68/EEC

[6] HyDeploy "Demonstrating non-disruptive carbon savings through hydrogen blending"

- *to introduce an ecodesign requirement for hydrogen readiness, i.e. make sure that the following gas fired appliances are capable of operating safely and efficiently with 100% vol. hydrogen, either after a conversion or without (Ecodesign space heaters, Annex II, Point 4; Ecodesign water heaters, Annex II, Point 1.3):*
    - *all models of heaters (space and combination, excluding B1 boilers) ≤70 kW;*
    - *new models of heaters (space and combination, excluding B1 boilers) >70 kW;*
    - *new models of water heaters; − new models of B1 boilers.*

Change the definition of 'hydrogen ready' to avoid that the hydrogen kit needs to be placed on the market by the manufacturer together with the boiler, this would to material loss in case there will be no conversion or in case of loss by the end-consumer. Instead add the conversion kit to the list of parts that should be made available in the material efficiency requirements (Ecodesign space heaters, Annex I, Point 33; Ecodesign water heaters, Annex I, Point 43; Energy labelling space heaters, Annex, Point 34; Energy labelling water heaters, Annex I, Point 44)."

3.4.3 Marcogaz

"*MARCOGAZ represents the European gas industry on all technical aspects of the gas system's full value chain, including national and European gas associations as well as the individual gas companies' members spread across Europe.*

As a technical association, MARCOGAZ is engaged in monitoring EU energy policy and promoting the best approaches concerning technical regulation, standardisation and certification, while respecting the integrity and safety of gas systems and the rational use of energy.

Undeniably, hydrogen has become a crucial enabler in the EU decarbonization strategy for reaching climate neutrality and the proposed targets by 2050. Hydrogen should allow for storage of intermittent renewable energy and can be used as a fuel for applications which are difficult to electrify.

Marcogaz recognizes the potential of H_2NG blends to reach the European targets and works actively in supporting the industry by several publication on the topic of hydrogen quality (link), detection (link) or impact on the whole value chain (link, Figure 8).

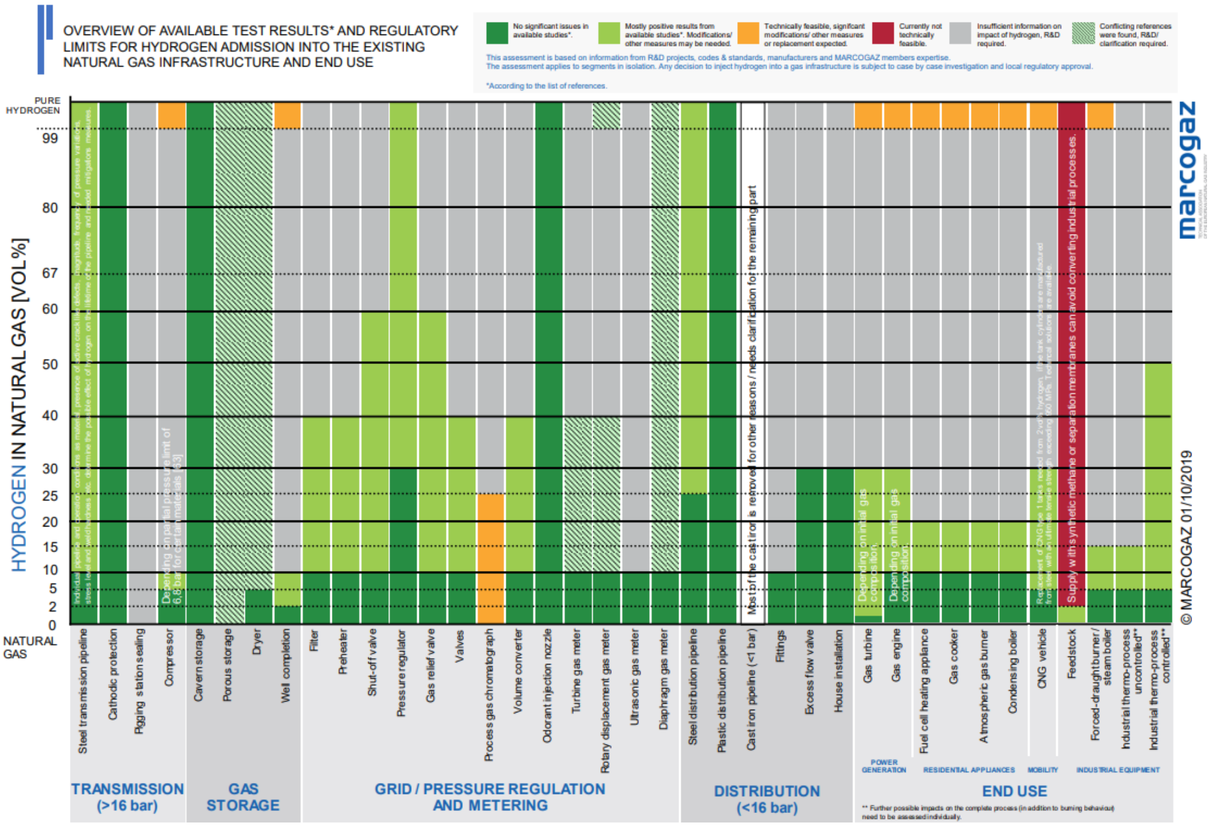

Figure 8: Overview of test results & regulatory limits for hydrogen admission into existing natural gas infrastructure & end use, Marcogaz, 2019

Marcogaz is actively working on several technical reports, to bring more clarity to the actual status of the European gas infrastructure and end-users regarding its hydrogen suitability. In that sense the support of European projects such as THyGA allows to deepen our knowledge and are a real added-value to the high scale implementation of H_2NG blends."

4. Learnings from THyGA

This chapter aims at summarizing the THyGA findings and are literally taken from the different deliverables' results. To sum-up 3 years of work in a few lines obviously implies short-cuts, therefore for a thorough understanding of the project's findings, we encourage reading in details the public reports (see Appendix 1).

4.1 Appliance segmentation

THyGA's Work Package 2 was in charge of establishing the theoretical basis to prepare the studies and tests under WP3, WP4 and WP5. The goal was to gather existing knowledge on gas appliances and the impacts of hydrogen addition to natural gas.

The first task (J. Schaffert et al. 2021) consisted in screening the portfolio of gas technologies installed at the residential and commercial end-user, with the objective to distinguish them according to their energy use (hydronic space heating, air space heating, domestic hot water production, combined heat and power…) and the different available technologies (atmospheric partially premix, fanned partially premix, fully premix burner…) which could be indicators of their suitability up to a certain hydrogen admixture level without causing safety risks, while other technologies may have to be replaced, especially when reaching high hydrogen concentrations.

The research done included a quantitative segmentation of the gas appliance market in terms of appliance population numbers **for each technology segment,** that draws a representative picture of the installed residential and commercial end-use appliances within the European Union in 2020. The THyGA study has been built on available public studies and could present some discrepancies from some studies more dedicated to particular types of appliances.

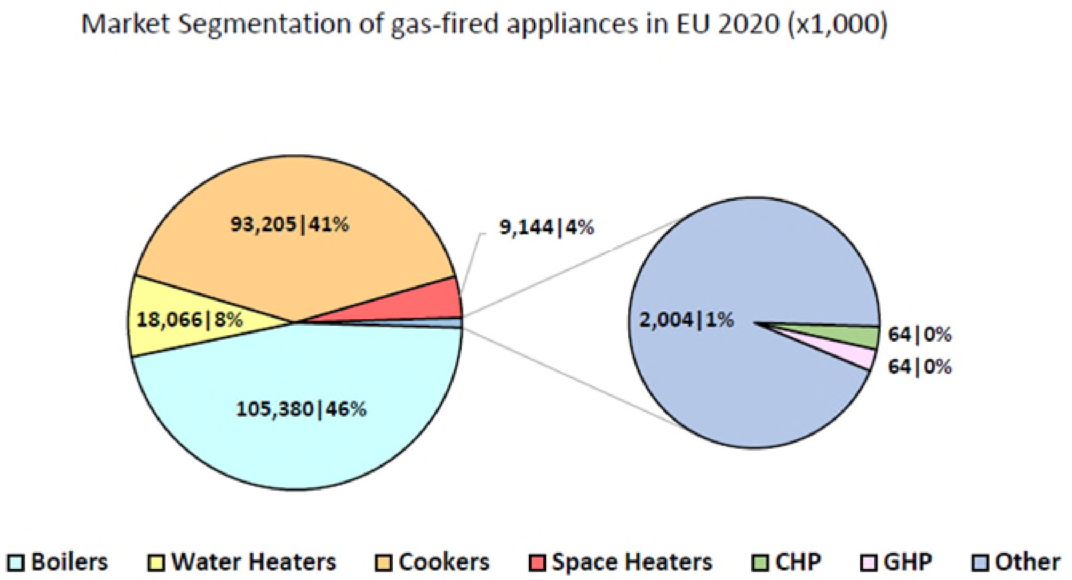

Figure 9: Approximate population of gas-fired appliances in the EU, 2020. Catering equipment not shown due to lack of data (J. Schaffert et al. 2021)

The quantitative assessment of the existing stock of the various gas-fired end-user appliance segments performed was exploited to determine the project test program, but also as the basis for the roadmap described in this document.

4.2 New appliances certified for H_2NG

It is important to distinguish the year of sales of new appliances because as explained in deliverable D4.2 (K. DeWit et al. 2021), several notified bodies and CEN Technical Committees already initiated certification methodologies and Technical Specifications to assess operation of gas appliances with a certain percentage of hydrogen. So far, all initiatives listed agreed on a certification to 20%H_2 in natural gas, especially on boilers and radiant heaters.

This means that these new appliances, already commercialized, are starting to replace the existing appliances, therefore increasing the resilience of the stock to injection below 20%H_2.

Some initiatives are pushing for certified boilers to be sold from 2025 onwards to be certified for 20%H_2 (EHI position paper asking for a mandatory H_2NG marking of boilers in 2025 (EHI 2021) and discussion under the ENER Lot 1 review study as described in 3.4.2).

As discussed in 3.3.1, the industry is expecting a standardization request on hydrogen to strengthen their efforts towards testing and development of dedicated standards.

THyGA's deliverable D4.3 (K. DeWit et al. 2023) is a guideline for standard development, addressed mainly to CEN TC but also manufacturers wishing to prepare for H_2NG developments.

Part I of the report 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") 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.

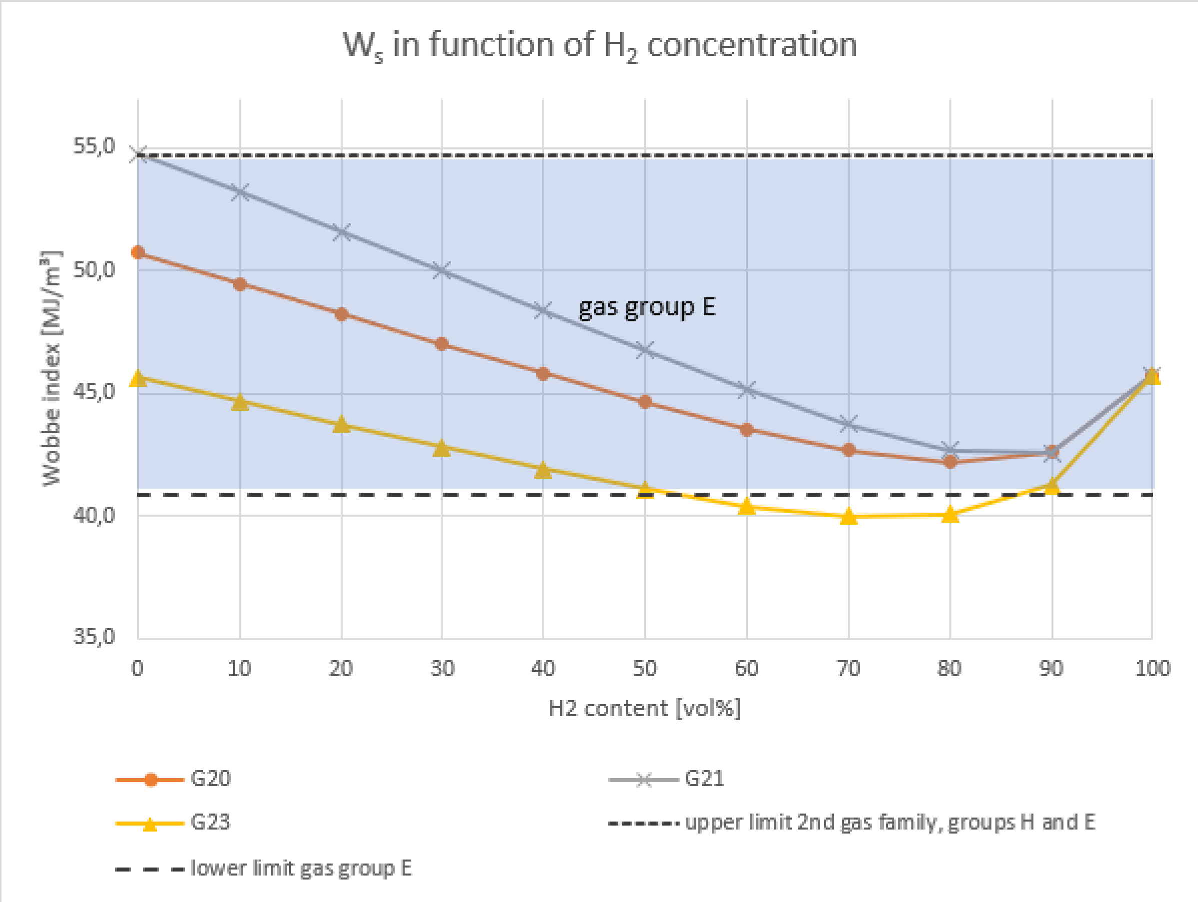

Figure 10. Wobbe index of test gases in function of hydrogen concentration vs. group E limits, D4.3

This chapter 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. It provides views and recommendation regarding reference gases and limit gases for the following tests:

- Incomplete combustion and "sooting" limit gas
- Flame lift limit gas
- Light-back limit gas
- Overheating limit gas

Part II covers risks to be considered when revising existing gas appliance standards for H_2NG supply. It 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 2 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 2 : CEN Technical Committees addressing gas appliances in the scope of the GAR.

Due to the properties of hydrogen being very different from those of methane, the main component of natural gas, several risks are impacted. A distinction can be made between 3 main risks being discussed in detail in the report (calculation, references to other THyGA or CEN/TCs reports):

- unburned gas,
- combustion,
- combustion products.

Then, each of the requirement from the GAR is analyzed in regard to H_2NG as shown on the example below.

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.

Figure 11: example of analysis of the impact of H_2NG on general requirements from the GAR

4.3 Test results on end-use appliances, for residential and commercial

The strong point of the THyGA project is the extensive test campaign on almost all segments of appliances identified in Task 2.1 (see (J. Schaffert et al. 2021) (J. Schaffert et al. 2021) for more details).

- Short-term tests were carried out to observe how appliances react during a small duration (few minutes to few hours) on different H_2NG mixtures.
- long-term tests were designed to evaluate behaviour over several weeks, on 5 boilers and 3 domestic cookers (J. Schweitzer et al. 2023).

The results show that observations and analyses from the literature (Tasks 2.2 and 2.3) are confirmed:

- Atmospheric burners are more sensitive to flashback with the addition of H_2 in natural gas.
- Premix burners can cope with higher % of H_2, but appliances that have an adjustable air/gas ratio and that are not equipped with a combustion control (typically premix) present potentially higher risk (CO emissions).

4.3.1 Short-term tests

The analysis summarized below is based on the test of 102 appliances (burners) and is taken integrally from deliverable D3.8 (J. Schweitzer et al. 2023).

When looking at the overall results table and when ranking the issues as a function of an increasing rate of admissible hydrogen %, we can observe that:

- The first issue observed is a limited number of appliances whose design makes them sensitive to delayed ignition. This will happen from 15% H_2 and maybe already at 10% H_2 for some segments. There is probably no better solution than replacing those appliances or changing some components (retrofit). Adjustment of appliances could worsen the delayed ignition issue.
- The second issue that may happen starting from 20% or maybe below, is high CO production with premix appliances that can be adjusted on-site. The most critical case is when they are adjusted at a time when there is H_2 in the blend and used with a rich gas without H_2 later. Luckily, this issue or at least part of it can easily be solved with adjusting with O2 instead of CO2 or through other proposals listed in THyGA deliverable D5.2.
- The third issue is Flashback. It generally occurs for 30% H_2 or more, appearing first on partially premix appliances when increasing the H_2 %.
- There are specific issues that are linked to specific technologies, like CO emissions for the fuel cells but only one test was done so it is difficult to conclude.

Apart from the specific case of adjustment, if the appliances are used as delivered (adjusted in factory on G20) and untouched after installation even when the gas is changing, CO is generally not an issue.

In general CO is decreasing with H_2, but this is not the case for all appliances.

Ionisation systems used for the **flame surveillance** are working well even with high % of H_2 (tested with up to 60% H_2).

Issues with operation ("fit for purpose") where hydrogen may impact the operation of appliances, so they become unsuitable for the purpose they were intended for, are mostly observed for higher % of H_2. For example, decorative heaters may not give the same flame aspect that the customer is used to have with natural gas. For cookers, heating time will be longer due to the reduction of maximum heat delivered when adding H_2 to NG. Finally, for Instantaneous water heaters the power may decrease in such a way that it would impact the comfort of the user. However, safety issues will generally appear before these operational issues.

Performances & emissions

The impact on NOx emissions is positive for the vast majority of the tested appliances (decrease of measured emissions). Note that this conclusion only applies to the test done under conditions simulating a real domestic or commercial installation, where no changes are made on appliances when the gas quality changes.

The CH_4 emissions **(unburnt hydrocarbon, during start and stop mainly)** are reduced when H_2% is increasing, but since there is less CH_4 in the fuel, this could be expected**. The counterpart** of H_2NG blends is that unburnt H_2 emissions would appear. H_2 emissions have not been tested on many appliances (test is not as simple as for NOx), and therefore it is difficult to conclude.

The impact on appliance efficiency is generally very modest and can be either positive or negative (several competing phenomena, decrease of Wobbe Index, of heat input, more condensation in some cases…).

Discussion on the limitations of our conclusions

As any study, the conclusion made on the work done will have natural limitations and uncertainties.

A first factor of uncertainty is the correct evaluation of the safety by the different laboratories. Although we believe this should not be a problem for this project, it is a factor worth mentioning. It can play a role in some cases where a conclusion shall be based on an observation that is not "black or white" or on a phenomenon that is not necessarily visible for all appliances due to their construction (e.g. Flashback). Also, laboratories have experience with testing with natural gas, but testing with hydrogen is a new activity and there are no standards yet describing how to test or observe some results. The project was based on our own testing protocol including also uncertainties related to the methods adopted.

One of the other important limitations is the number of appliances tested: 100 appliances were tested when more than 200M are installed. Even if the number is high and allows for many conclusions, such a testing campaign will never be exhaustive enough to cover all technologies or design specificities, especially for older appliances still in use.

- The set of tested appliances was chosen with regard to their representativity of the market and their availability. We have used a weighting method (deliverable D2.5) to focus testing on the more representative appliances (larger share of installed appliances in boilers and domestic, cookers).
- We also assumed a homogeneous behaviour within each segment of each type described in deliverable D2.1 (and Appendix 1). However, variations of technical features for a single segment of installed appliances are important and a project testing "only" 100 appliances cannot really guarantee that the conclusions and observation made will fully apply to the other appliances in the same segment.
- Moreover, it can happen that two appliances of the same model will not behave exactly the same way due to some aspects in the production line, tolerance rules, etc.
- Also, it shall be noted that for some segments we have only tested one single appliance (for example GHP, PEMFC, SOFC, etc.) which impedes general conclusions.

Therefore, to take into account the listed limitations, the worst-case approach was chosen to conclude segment by segment. This means that if only one appliance does not perform safely for a given operation condition and H_2%, the whole segment will be considered as not performing safely with this H_2% (even if the other tested appliances did perform well).

Aging is another source of uncertainty. Most of the appliances tested were new (provided willingly by manufacturers). We presumed that a used appliance cannot work better than a comparable new one. This includes the fact that new appliances are generally set by the manufacturers to work under optimal conditions before leaving the factory. The impact of the maintenance (or no maintenance) on installed appliances was not studied either.

There are also several factors that were not explored sufficiently to conclude, due to the difficulties of testing and budget limitations. Delayed ignition is probably the most important of those.

All in all, we can say that we have some natural limitation to the conclusion made for the reasons explained above, but we have tried to compensate for those with our "worst-case" approach.

4.3.2 Long-term tests

The analysis summarized below is based on the test of 7 appliances (5 boilers and 2 cookers), with around 3000 operating hours each, and is taken integrally from deliverable D3.9 (J. Schweitzer et al. 2023).

The tests carried out with a blend of natural gas with 30% hydrogen under the test conditions and duration given have not shown any particular impact on the performances and operation of the appliances.

The signs of wear and tear that were observed for boilers would have also been observed using pure natural gas and there is no visible additional impact due to the presence of hydrogen.

For one of the cookers tested – probably due to a higher temperature – the appearance of the burner surface did change but without impacting the performance. The quality of the material / alloys used for the burner is certainly playing an important role.

Those results are positive but cannot be extrapolated to the Millions of appliances on the market due to obvious limitations of our test campaign which most importantly are:

- The high diversity of appliance types, and materials used for the > 200 millions of appliances installed in the EU.
- The shorter testing time compared to the appliance's normal lifetime.

4.4 The appliance in its environment of installation

The results regarding the safe and operational behaviour of the appliances were quite positive, especially below 20%H_2. However, the project wished from the beginning to widen the field of research by looking into impacts of H_2NG blends on the installation of the boiler, especially for existing appliances; specific research was then implemented on the gas alimentation to the appliance (indoor gas line), the condensates exiting the appliance, and the exhaust fumes evacuated through dedicated ducts for type B and type C appliances (according to EN437).

4.4.1 Leakage tests

The project aimed at evaluating the tightness of the components located on domestic and commercial gas lines from the gas meter to the end user appliance, in presence of a mixture 40%H_2+60%CH_4 at 35 mbar. The objective of the test is to be able to conclude on being as close as possible to the service condition - for that reason we tested with a "safety margin" (so 35 mbar instead of 20 and 40% H_2

instead of 20%), the test protocol and results are extensively discussed in deliverable D3.7. The components were taken from installations being used currently in Germany, Denmark, Belgium and France.

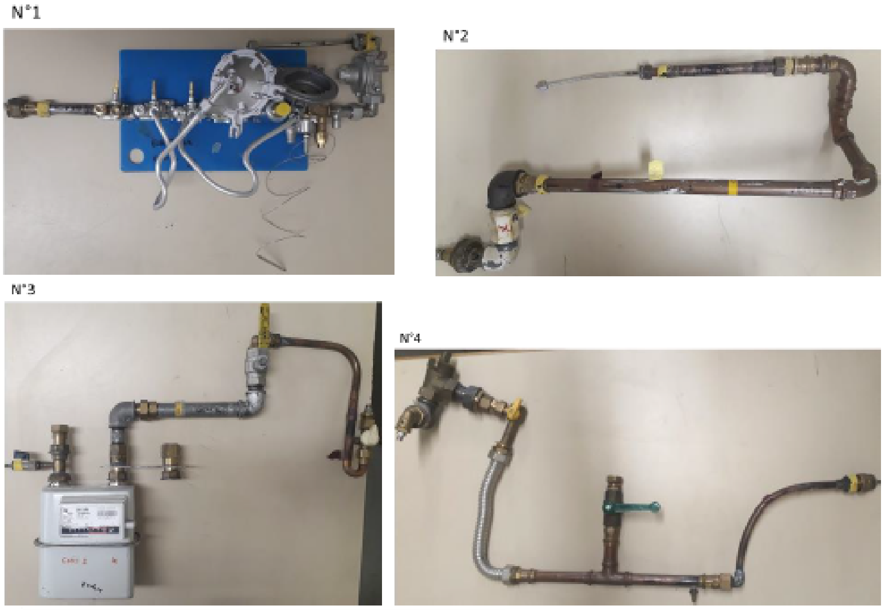

Figure 12: Example of components taken from existing installations

The current standard methods to evaluate natural gas distribution tightness propose a testing duration of several minutes. In this work (L. Blanchard et al. 2022), the components tightness was first evaluated using such standard methods before carrying out tests on a longer period of time and evaluating the potential influence of time. The results were compared to the current admissible leakage rates for natural gas in the gas distribution network: 1 $l.h^{-1}$ according to the NEN 7244-7 standard and in appliances: 0.1 $l.h^{-1}$ according to the EN 30-1-1:2021 standard for cooking appliances burning gas.

Generally, none of the leakage rates obtained on the short- and long-term tests were above the admissible leakage rates of the NEN 7244-7, and EN 30-1-1:2021 standards.

Hence, once a gas line is properly installed, following natural gas standards at low pressures (35 mbar), **it can be expected that it will be tight for the gas blend**. Furthermore, the review and comparison of other projects results addressing tightness of gas distribution network/components in 100%H_2 was added, enabling the formulation of recommendations on testing methods.

4.4.2 Condensates

Concerning condensates, hydrogen can have two kinds of impacts (S. Carpentier et al. 2023) : it could cause an increase of the condensate flowrate (more water in flue gases, increase of heat exchanger efficiency, …) but it can also, potentially, change the acidity of condensates which could have an impact on the lifetime of heat exchangers.

It is known that hydrogen has higher adiabatic flame temperature than natural gas. Flame temperature has an impact on the production of thermal NOx. NOx tend to dissolve in condensed water of condensing appliances and form nitric acid and cause the acidity of the condensates. As a consequence, the impact of hydrogen on condensates was experimentally investigated.

Although the results cannot be directly extrapolated to all condensing gas appliances, it is believed that, for all condensing appliances for which the air/fuel ratio increases with %H_2 (=most domestic appliances), NOx concentration in flue gases will decrease (decrease of flame temperature by air dilution → less thermal NOx). **The consequence is that condensate pH will increase or remain stable so no mitigation measure will be required.**

4.4.3 Exhaust gas

The first THyGA report (D2.3 (J. Schaffert et al. 2021), D5.1 (S. Carpentier et al. 2022)) mentioned a **grey area concerning natural draught for exhaust gases, especially for existing appliances**: the increase of air excess caused by the introduction of hydrogen could lower flue gases temperature, thus causing draught problems on appliances with no fan. The topic was extensively studied in WP5 (mitigation), based on test results from WP3 (Experimental work) and is described in deliverable D5.2 (S. Carpentier et al. 2023).

Up to 20%H_2, natural draught is almost not impacted by H_2 admixture. In most cases, the flowrate of the flue gases was reduced or remained constant when hydrogen was added. Relative density of flue gases at maximum heating power is higher than at minimum heating power and will not cause any trouble. Relative density of flue gases ($\varrho_{flue}/\varrho_{air}$(15°C) at Qmin is always below 0.83 up to 40%H_2. Its variation is lower than 1% between 0%H_2 and 40%H_2. **As a consequence, no natural draught problems are expected in the range 0-40%H_2.**

Also, the increase of the proportion of water vapour in the flue gases could cause problems of **condensation in flue pipes not designed for** was studied. The impact of this phenomena was checked experimentally to investigate if mitigation measures are required.

Up to 20%H_2, extra condensation is not expected to appear for non-condensing boilers, as several physical effects compensate each other. The most difficult configuration occurs at minimum heating power where flue gas temperature is lower. Even with 40%H_2, the minimum temperature difference between flue gas temperature and dew point temperature was 28.8°C, thus leaving some safety margin.

4.5 In summary

Table 3 provides a synthetic view of the test results of the THyGA projects, several points are important to note

- Adjustment is a major problem starting from 10%H_2 but there are solutions, as explained in section 5.2.1
- These results don't tackle the liability issue, described more precisely in section 5.2.2
- Delayed ignition is a real concrete problem not taken into account in this table since it only concerns some specific designs of appliances within some of the segments. However, this is probably the major issue at low levels of H_2 and some thoughts are given in 5.2.3

Table 3: Synthetic result for all segments tested in the THyGA test campaign

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

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

5. Perspectives for H_2NG blends

The **European countries have different approaches** regarding the injection of H_2 in the grid and for what usages hydrogen shall be used for.

The countries policies for H_2 are mostly mostly driven by the current technical national solution to decarbonize the grid (potential share of biomethane), national energy policies and present end-use market profile (share of domestic-commercial use vs industrial use).

In any case, injecting up to 20% is mostly seen as a first step before getting to 100% H_2 and some countries even plan to skip this step and go directly from NG to 100% H_2. Intermediate levels at 2%H_2 are already acted in some countries (Italy, France soon) and evaluations are being done up to 6%H_2 (Italy).

The revised regulation of the third Energy package for gas could possibly add a new element in this game, if a cross border value for % of H_2 is included, recent discussions decreased from 10% to 5% (Ecorys 2022) and some also talk about 2 to 3%.

The **lack of a regulative framework for blending of H_2 in NG** and unclarities about **liabilities for blending of H_2 in NG** on a grid with appliances only certified for NG are also obstacles to a fast implementation of 20% injection projects.

Current projects with 20% H_2 are still « pilot projects » and there is no standard methodology to implement such projects at large scale, especially since there is presently **no harmonised certification scheme for X%H_2 ready appliances**. The expected "Standardization Request for Hydrogen" will be a big step forward.

Therefore, for all those reasons the timing of the large scale roll out of 20% H_2 across Europe is very uncertain, but it will need the collaboration between all the stakeholders (Manufacturers of appliances, Certification bodies, CEN TCs, Safety authorities, Gas distributors, European Commission….), especially regarding 2 topics developed below in section 5.2, liability and adjustment.

5.1 Market vision with blends

5.1.1 Perspectives on the stock and sales

Most of European and National policies are more and more supporting thermodynamic systems such as heat pumps (electric, hybrid) to logically increase energy efficiency in buildings: concretely it means a strong shift in the sale of appliances from gas boilers to electrical heat pump, even if some gas appliances such as hybrid heat pumps, Gas Heat Pumps or CHP still have good perspectives.

The objective of the THyGA project is not to provide a prospective vision on the evolution of the stock of appliances on the market, especially given the complexity of the regulatory framework during the period when this report is being written (reviews of ENER LOT 1, 2, 20, 22, 23 of the Ecodesign and Labelling directives, final steps for the reviews of REDII and EPBD…). In spite of biomethane production increase, pressure on gas appliances is felt, and some even talk about a "gas boiler ban".

The THyGA project members deemed important to finalize the project by giving perspectives on the evolution of the stock of residential and commercial appliances compatible with blends of hydrogen in the coming years because it provides perspectives regarding the efforts needed to support injection of hydrogen in gas grids from the end-users' perspectives.

Several hypotheses have been made to give a vision of the evolution of the European gas appliances stock. The trajectory could be deemed as optimistic by many, the main reason being that its construction is "regulatory evolution – agnostic": most of the relevant regulation being in process, there was not much value in spending too much time in projecting their impact on the appliances population. Therefore, the projection used in the next chapters is based on the only public available source, the review studies for Ecodesign: the main hypotheses used for stock and sales are available in Appendix 2.

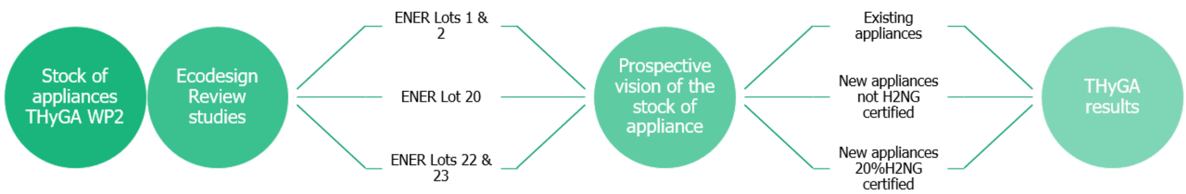

Figure 13: THyGA Roadmap methodology

5.1.2 Evolution of the stock of appliances and suitability for H_2NG

Given the perspectives from the industry summarized in section 3 and feedbacks from the THyGA workshops (section 2), it is most reasonable to expect H_2NG blends being limited to 20%H_2, accompanying a transition to biomethane, and the development of pure hydrogen networks in 2050.

The results below focus on results with up to 20%H_2 but some more details are available in appendix 3 or in deliverable D3.10 (J. Schweitzer et al. 2023).

Figure 14 and Figure 15 provide the expectation on the stock of appliances, integrating the growing market share of appliances certified for 20%H_2: with our hypothesis, it seems that the stock will not be fully ready for 20%H_2 before 2047 (due to the high lifetime of some appliances, and the hypothesis of an obligation of certification to 20%H_2 to some appliances starting in 2035).

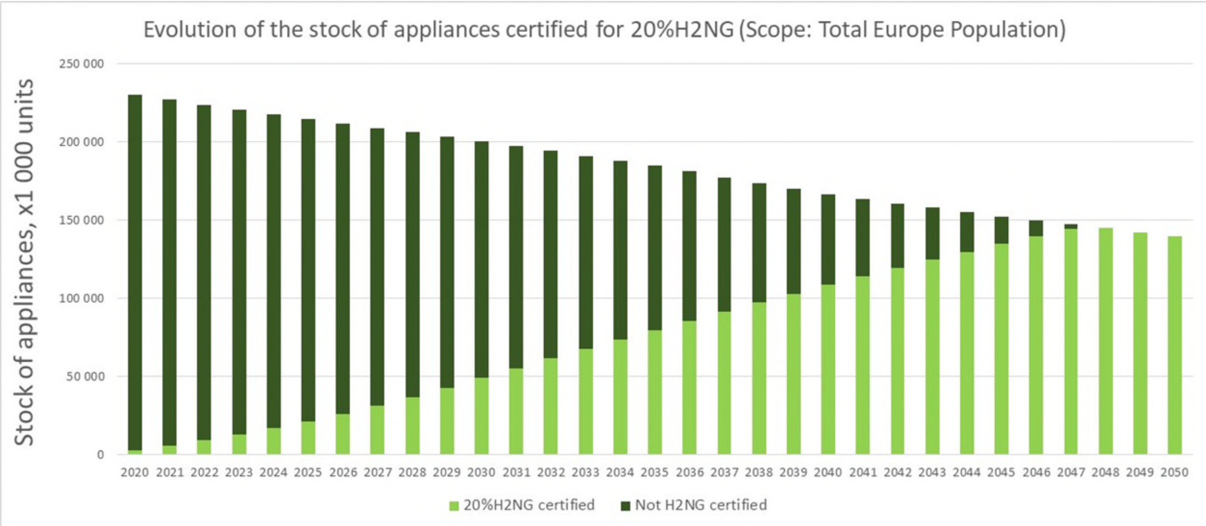

Figure 14: Perspectives on the stock of appliances in Europe

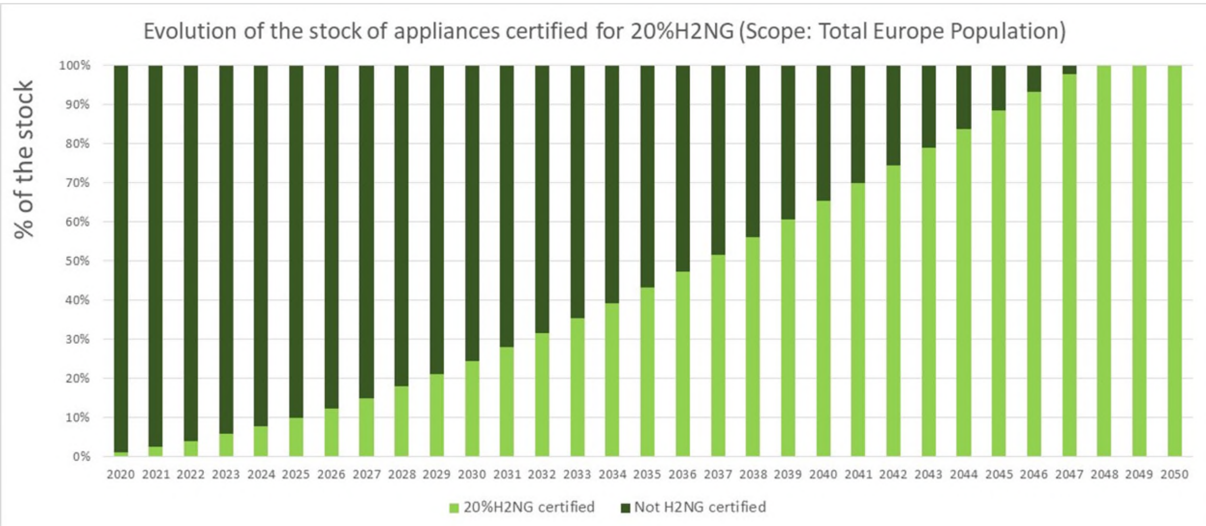

Figure 15: Evolution of the percentage of the stock of appliances certified for 20%H_2 in Europe

This emphasizes the need to work on the existing appliances' suitability to accept H_2NG blends to prepare for high scale implementation, at short or mid-term.

THyGA showed, in summary, that for 20%H_2, taking aside the liability issue for appliances non certified for H_2NG (section 5.2.2):

- No safety risk identified by the THyGA project for any type of appliance except for delayed ignition with some specific design of appliances (partially premix appliances without fan)
- Adjustment seems to be the main limitation, it only concerns fully-premix appliances without mitigation methodology implemented. Some leads are also provided in section 5.2.1, it accounts for almost one third of the stock of appliances in Europe (Figure 16).

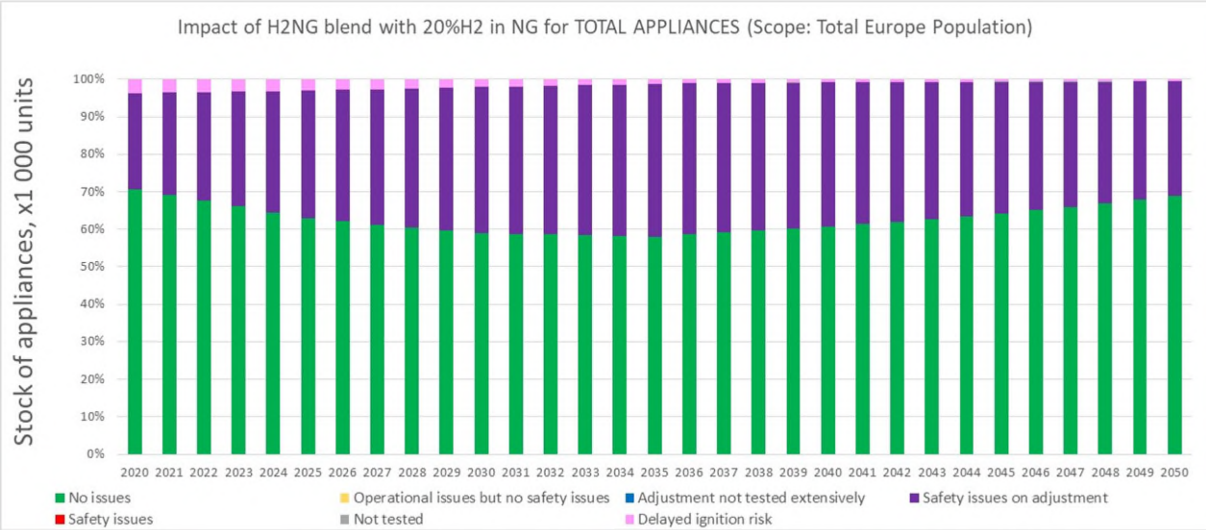

Figure 16: ThyGA results projected on the evolution of the stock of appliances

With a different scale, and with the hypothesis that adjustment issue is solved, around 3.5% of the existing appliances could suffer a safety issue, due to delayed ignition. This percentage decreases with time since most boilers and water heaters are being replaced with recent technologies with fans. However, there is still a doubt about some space heaters (but could technically be solved for new appliances).

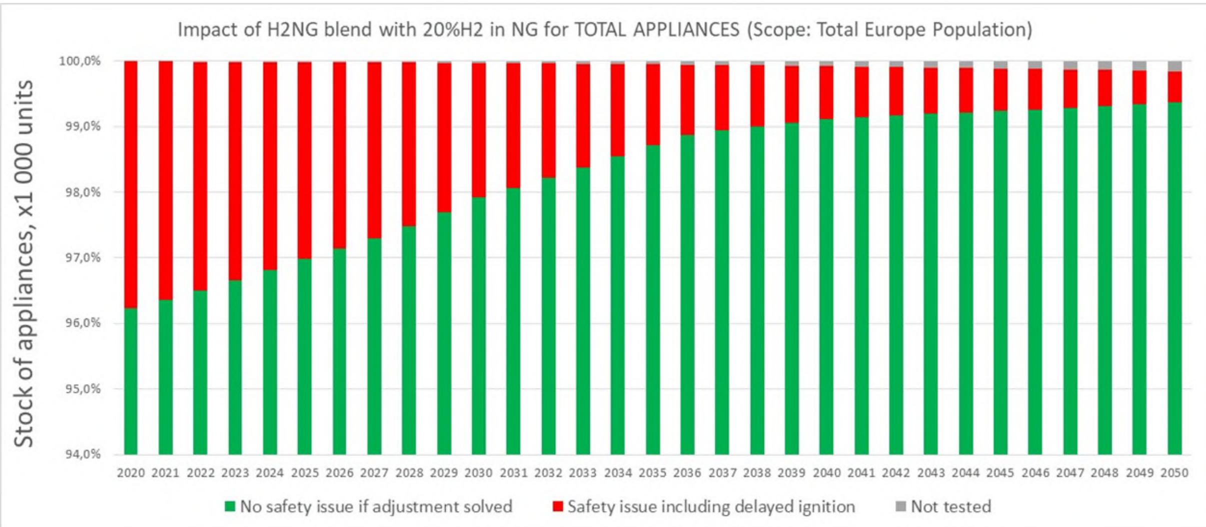

Figure 17 : ThyGA results projected on the evolution of the stock of appliances, considering asjustment is solved

5.2 Mitigation actions are not technical but organisational

5.2.1 Adjustments

As discussed extensively throughout the project course, adjustment is the main problem when dealing with H_2NG blends impacts on fully premix appliances. The topic has been discussed in D2.2 (J. Schaffert et al. 2021), D2.3 (J. Schaffert et al. 2021), D3.8 (J. Schweitzer et al. 2023) and D5.2 (S. Carpentier et al. 2023) in particular, and it is also important to note that the adjustment issue is linked to changes of gas quality during a period of time, therefore is not directly related to H_2NG blends, it already impacts installed appliances on the field, viewing variations of the gas quality according to their origin (LNG with high Wobbe Index gases, varying piping Natural gas quality according to its origin) and this phenomena will increase in the transition to green gases (biomethanes with generally lower Wobbe Index, H_2 injection also decreases the Wobbe Index).

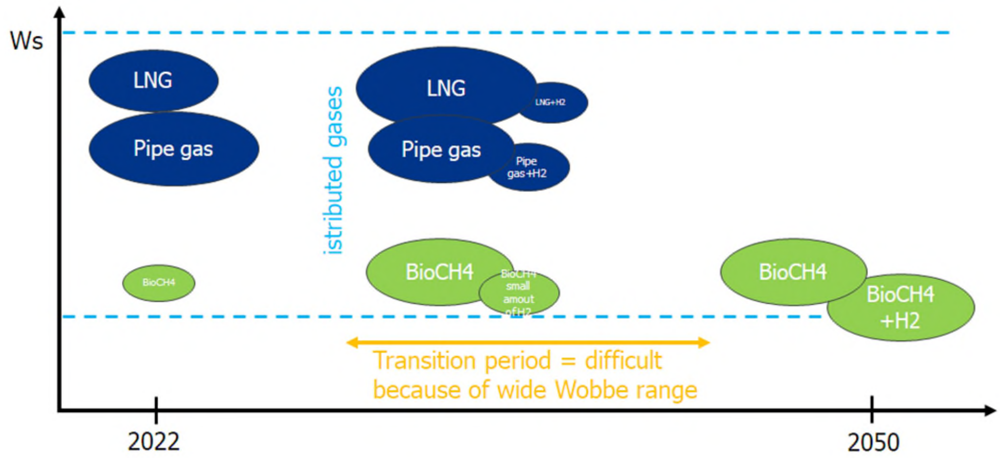

Figure 18: Probable evolution of the natural gas origin

As shown on Figure 19, some end-users already live with quite high variations of the gas quality, the addition of hydrogen would add to this daily variation.

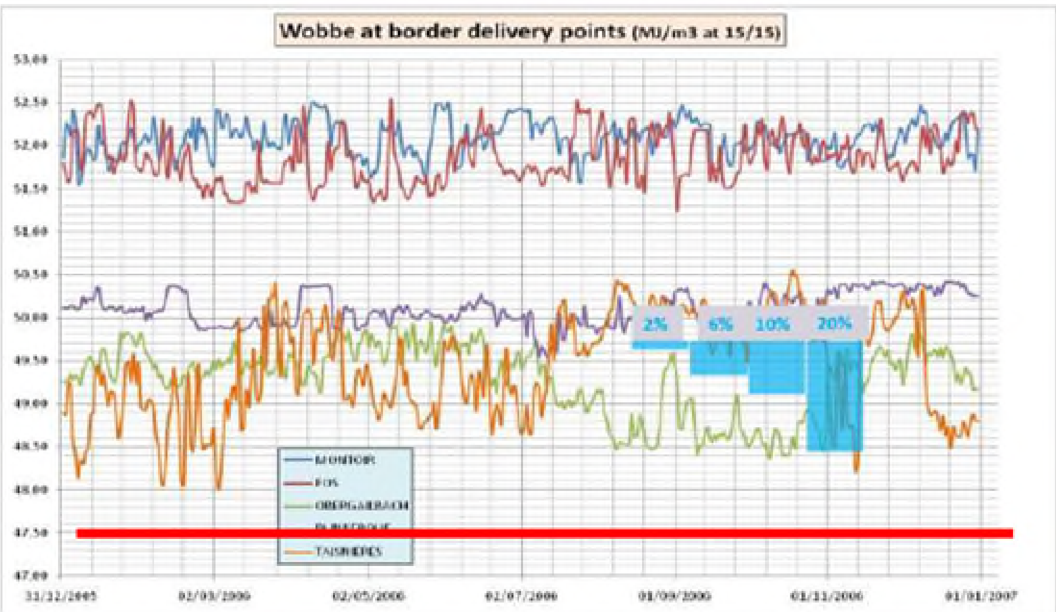

Figure 19:Example of variation of the Wobbe Index on several locations in France, and the relative impact that addition of H_2 would add (Source: ENGIE)

The appliance field adjustment of air/gas ratio is carried out according to possible national regulations and to manufacturers' instructions. It typically consists of adjusting the air/gas ratio to reach the CO_2 or O_2 concentration in the combustion products specified by the manufacturer. Thus, the final air/gas ratio adjustment will depend on the distributed gas quality and the ambient conditions on the moment of adjustment. Furthermore, to our knowledge, there is no harmonised requirements regarding the minimum metrological requirements and accuracy of the instruments used by installers to control the CO_2 or O_2 concentrations. This may also influence the final adjustment.

The project described 4 potential adjustments (D2.5, D3.8) implying variations from Low Wobbe Index with/without H_2 to High Wobbe Index with/without H_2. The adjustment G (EUlow+20%H_2 → EUhigh) was identified as the most critical, and leads to the higher CO emissions.

<u>THyGA Recommendations</u>

Adjustment is an important aspect to consider for blending, especially since solving it would decrease greatly the problematic cases as highlighted in Figure 17. THyGA showed promising solutions but it is important to pay attention to national or local regulation which could impede implementation.

Several mitigation solutions have been studied in D5.2 (S. Carpentier et al. 2023). Among them, we can underline several technical solutions:

- Appliance adjustment should be based on O_2 values, rather than CO_2 values.
- the authors suggest to only allow adjustment (or re-adjustment) of appliances to G20 if the gas composition or Wobbe is known. A specific procedure to do that would need to be developed.
- Set points for the initial adjustments with G20 could be revised toward lower CO_2 or higher O_2 at least for the appliances on the market with too close to stoichiometry set points.
- It is preferable to use combustion-controlled boilers that keep the air/fuel ratio constant (via ionization probe or CO sensor), even if more investigation should be performed to clarify if flashback occurs during auto-calibration periods, when the boiler operates for a few seconds in near-stoichiometric conditions.

Moreover, test results show that the CO_2 (or O_2) range of adjustment suggested by manufacturers on some appliances may have to be updated to take into account adjustment from low Wobbe Index and use with high Wobbe Index gases. This is especially required for appliances that operate with a very low air excess.

Another option would be to forbid on-site adjustment (boiler adjusted to G20 behave well when factory settings are kept → GASQUAL, THyGA) but it would imply to define another approach for maintenance actions.

5.2.2 Liability for existing appliances

As explained in WP4, in reference to the Gas Appliance Regulation, existing appliances did not have to be designed for use of H_2NG; so H_2NG supply cannot be considered as 'normal use' and so **manufacturers would not be liable for any negative impact caused by supply of H_2NG mixtures** (except recent 20%H_2 certified boilers or radiant heaters).

The objective of THyGA's WP3 was to understand how appliances would behave with H_2 injection, especially for the safety aspects but also the operational aspects (efficiency, heat input, emissions, flame aspects…). As discussed in section 4.3, the results were rather positive and we expect no issues with operation below 20%H_2, except for some appliances with specific design and subject to potential delayed ignition issues. However, since not all appliance types or models could be tested by THyGA, the results cannot simply prove the safe operation of all appliances on the market.

High scale conversion of gas quality is not new

The gas industry has already dealt with great changes in gas qualities during its history, deliverable D5.1 and D5.3 provide some description on the cause and organisation behind.

- The first one was the change from town gases (sometimes also called syngas, or 1st family gases), mainly composed by a CO/H_2 mixture to the first natural gases.
- Recently, massive changes of gas quality in natural gases occurred concerning mainly the change from L gas to H gas. In France for example, the first gas changes were started in the 70's and the final conversion of the northern part of the gas network is in progress and will last until 2029.

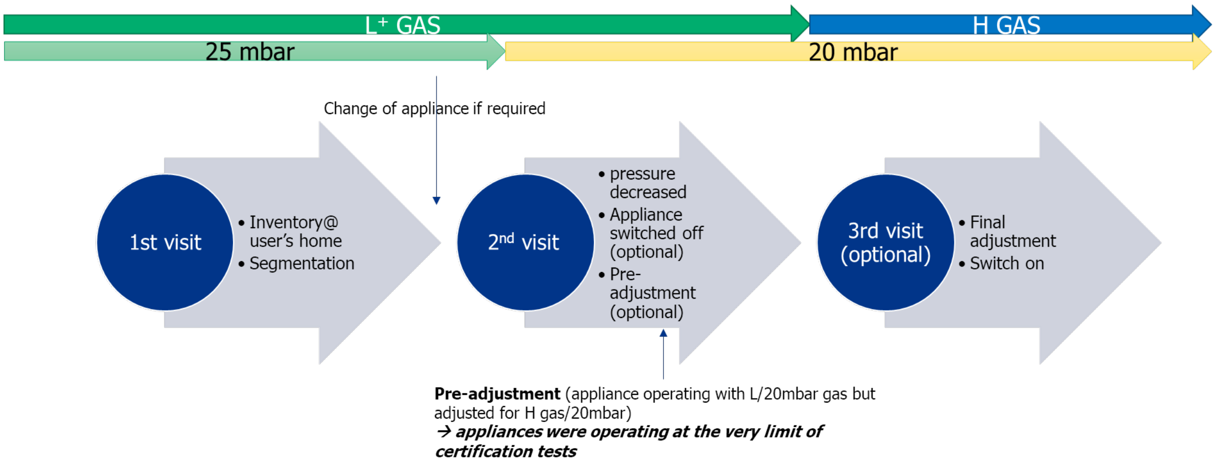

Figure 20: Conversion procedure performed for each home during L→H conversion in France

Although the described procedure is quite interesting and could prefigure some kind of NG to H_2NG conversion, the situation of L to H conversion is quite different from the injection of H_2 into gas networks since gas appliances are certified for L and H groups.

Safety check

Since it is not possible to know a priori how the used appliances will perform, it will probably be necessary either to change appliances to H_2NG certified ones or to perform a safety check in order to avoid any problem. The THyGA project showed in D3.8 that most gas appliances can operate safely with H_2NG up to 20%H_2. Therefore, it is conceivable to use existing appliances in an existing gas network, provided that they have passed a safety check. This is what was done in the HyDeploy project in UK and in the "Wasserstoff-Insel Öhringen" project in Germany.

A proposed protocol, based on HyDeploy methodology, is described in deliverable D5.3. It was estimated that in a home equipped with gas cooker and boiler, the safety/test operations should be carried out in about 2h. If a problem is encountered (gas leak) or a specific operation is required (adjustment), then the estimated time of operation is about 3h.

Concertation approach

Safety check is an option but it is complicated and costly. It will probably prove necessary for older appliances (no feedback on operation with H_2NG, manufacturer disappeared…) but one way to mitigate this problem is to ask manufacturers which of their appliances are compatible with H_2NG mixtures and which are not and should be replaced. This is a common process in many Member States, a concertation with associations and manufacturers discusses the potential impacts of H_2NG and reaches an agreement on the safe operation of the existing appliances under their scope. This process has been implemented in Italy and France recently to reach a first-step agreement for 2%H_2 injection in the natural gas grid. It means that for %H_2 lower or equal to 2%, no safety check is required. This position should also be considered for %H_2 values such as 5%, 6% or 10%. At least for some appliances.

Each country has its own specification for gas quality distribution, installation rules… so conclusions from a country cannot be directly transposed (if an appliance from manufacturer A has been deemed suitable for use with H_2NG in country A, it does not mean that it is suitable for country B). However, the methodology to reach conclusions and the knowledge gathered for that could be shared to favour an efficient large scale implementation of H_2NG blends on the European market.

THyGA recommendation

The objective is to favour dialogue between gas grid operators and appliance manufacturers: which actions and methodologies to study H_2NG blends' impacts, country per country? Which are the best practices?

- Gas grid operators: how much %H_2 at maximum? What are the perspectives? Are there some strategies devised for large scale implementation?
- Manufacturers & manufacturer associations: Which appliances can operate up to x%H_2 Which appliances cannot operate up to x%H_2? Which are the appliances for which more investigations are required?

5.2.3 Delayed ignition

Delayed ignition tests have been performed on 3 appliances (2 boilers, 1 fire), at the manufacturers' facilities (a representative of the THyGA test labs was present for the first 2 tests). They were carried out according to the corresponding test conditions and requirements as stated in the concerned product standard(s). Therefore, only limited results are available, and appliances were only tested at 20%H_2 so these conclusions are not extendable to all segments and ranges of hydrogen (J. Schweitzer et al. 2023).

- **For concentrations up to 20% H_2, the impact has proven not to be detrimental or dangerous on the tested appliances equipped with a fan in the combustion circuit**, but…
- **… inappropriate onsite adjustment, if possible, may increase the risk on an unacceptable impact** (material deterioration and/or user hazard) of delayed ignition due to accumulation of a flammable mixture with a higher energy content.

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

Impacted segments:

- 101: open flued boiler (former EN 297) - partial premix/conv. **without fan**
- 102: open flued boiler (former EN 297) - partial premix **without fan** – low NOx version
- 104: room sealed boiler (former EN 483) - partial premix/conv. **without fan**
- 105: room sealed boiler (former EN 483) - partial premix/conv. **without fan** – low NOx version
- 201: open flued instantaneous water heater (former EN 26) - partial premix/atm. **without fan**
- 203: open flued accumulation water heater (former EN 89) - partial premix/atm. **without fan**
- 500: fires without fan are also likely to present problems**, without fan**

Note: According to our best knowledge, the products identified with segments 104 and 105 are probably non-existing or very rare on the market. However, both are covered/foreseen in the EN 1749 standard and not excluded by the EN15502-2-1 standard.

THyGA recommendation

Based on the above findings the authors recommend:

- to reconsider the test methods and conditions to take in account reasonably foreseeable worst cases,
- to reassess the delayed ignition risk systematically for appliances not specifically designed for natural gas containing relevant H_2 concentrations, especially when on-site adjustment is allowed/possible.

If any mitigating measures are needed, the next measures may be applied:

- reduce the ignition safety time (by replacing the burner control by one with a shorter safety time),
- avoid (inappropriate) on-site adjustment (S. Carpentier et al. 2023).

5.2.4 Recommendations for future testing

Within the limits of the testing program from the THyGA project (test protocol, limited number of tests), we estimate that we have been conclusive on many aspects. Late discovery or low volumetry of results led to a need for additional testing, which would be necessary to be more conclusive.

Of course, increasing the numbers of tested appliances is recommended, and especially widening the scope (while we tested lots of boilers and domestic cookers, the representativity is lower in other segments and of course many specific technologies have not been assessed).

- The results on delayed ignition and understanding of how it can impact different technologies differently (eg. absence of ventilator) has been brought up at the end of the project. This particular test clearly needs more investigation from the stakeholders.
- While we have now a correct idea on the decreasing trend for unburnt hydrocarbons with increasing H_2 injection, only one Lab was equipped with suitable sensor for unburnt hydrogen detection, and could test it on limited numbers of appliances. The hydrogen emissions also need to be understood better.

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Appendix 1: THyGA public deliverables and workshops

	Reference	Deliverable title	Link
WP2	D2.1	Market segmentation of domestic and commercial natural gas appliances	Report
	D2.2	Impact of hydrogen admixture on combustion processes – Part 1: Theory	Report
	D2.3	Impact of hydrogen admixture on combustion processes – Part 2: Practice	Report
	D2.4	Non-combustion related impact of hydrogen admixture - material compatibility	Report
	D2.5	Testing programme for hydrogen tolerance tests of domestic and commercial natural gas appliances	Report
WP3	D3.5	Intermediate segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation	Report
	D3.6	Intermediate long-term effect of H2 on appliances tested	Report
	D3.7	Testing done on components (new and taken from existing installation) from different countries including statistics on results obtained for the leakage testing	Report
	D3.8	Segment of technologies by segment report on the impact of the different H2 concentrations on safety, efficiency, emissions and correct operation	Report
	D3.9	Long term effect of H2 on appliances tested	Report
	D3.10	Compiling of results from all tasks and development of further statistics at EU and country level	Report
WP4	D4.1	Overview of the current EU certification/standardization framework and description of the identified issues	Report
	D4.2	Overview of relevant existing testing/certification experience	Report
	D4.3	Recommendation on test gases and guide for assessment of gas appliance standards for H2NG.	Report
WP5	D5.1	Review on other projects related to mitigation and identification of usable sensors in existing appliances	Report
	D5.2	Test report of the identified mitigation solution on problematic appliances	Report
	D5.3	Preconisation on measures to adapt existing appliances	Report
WP6	D6.5	"Green Hydrogen" for Europe roadmap	Report

	Reference	Deliverable title	Link
WP2	Article	The Impact of Hydrogen Admixture into Natural Gas on Residential and Commercial Gas Appliances	Link
	Webinar	Impact of hydrogen admixture on residential and commercial combustion processes insights from combustion science	Replay
	Webinar	Materials science – impacts of hydrogen blends	Replay
WP3	D3.6	THyGA Workshop on interim test results – December 2021 (D6.2)	Link
WP4	Workshop	Technical workshop "H2NG supply to residential and commercial appliances – standardization and certification".	Replay
WP6	Workshop	First workshop of the THyGA project	Replay
	D6.3	Workshop on standardization (D6.3)	Replay
	D6.4	Final public workshop (D6.4)	Replay
		Newsletter #1	Link
		Newsletter #2 – June 2021	Link

	Newsletter #3 – November 22	Link
Conference	THyGA at World Gas Conference 2022	Link
Article	THyGA in the Global Voice of Gas	Link

Appendix 2: references for the stock and sales of appliances' evolution scenario

<u>Review study of Commission Regulation (EU) No. 813/2013 [Ecodesign] and Commission Delegated Regulation No. (EU) No. 811/2013 (Energy Label) (space and combination heaters), review study Task 7 "scenarios", VHK, Delft (NL), for the European Commission, DG ENER C.3, July 2019</u>

VHK ENER Lot 1 review study, task 7, Table 7 EU-28 sales per base case in thousands of units, for the ECO-scenario (including new proposed measures)

											Figures used in THyGA report D6.5					
SALES ECO, 000 units	**1990**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020 / 2025**	**2025 / 2030**	**2030 / 2035**	**2035 / 2040**	**2040 / 2045**	**2045 / 2050**
Gas non-cond	3 852	1 995	1 480	452	258	87	60	37	22	9	-43%	-66%	-31%	-38%	-41%	-59%
Gas cond	129	3 466	4 048	5 276	4 724	4 153	3 351	2 555	1 698	857	-10%	-11%	-17%	-19%	-23%	-27%
Jet non-cond	1 130	350	118	40	30	22	16	10	6	3	-4%	-6%	-10%	-15%	-23%	-41%
Jet cond	0	117	196	274	270	261	239	208	161	96						
Elec Joule	42	67	64	70	65	60	55	50	45	40						
Hybrid	1	3	10	22	294	566	860	1 154	1 451	1 747						
Elec HP	20	285	346	589	1 124	1 658	2 236	2 814	3 446	4 077						
Gas HP	1	3	8	18	95	173	260	347	435	524	428%	82%	50%	33%	25%	20%
mCHP	2	3	8	15	32	49	66	84	102	121	113%	53%	35%	27%	21%	19%
Solar combi (16 m2)	19	33	39	38	46	54	65	76	87	99						
Boiler >400 kW	30	30	30	30	30	30	30	30	30	30						
Total Central Heating boiler, Space Heating	**5 226**	**6 354**	**6 348**	**6 825**	**6 969**	**7 112**	**7 238**	**7 365**	**7 484**	**7 603**						

Hybrid sales included in condensing boiler sales

VHK ENER Lot 1 review study, task 7, Table 8 EU-28 stock per base case in thousands of units, for the ECO-scenario (including new proposed measures)

											Figures used in THyGA report D6.5					
SALES ECO, 000 units	**1990**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020 / 2025**	**2025 / 2030**	**2030 / 2035**	**2035 / 2040**	**2040 / 2045**	**2045 / 2050**
Gas non-cond	47 237	68 112	56 841	38 517	20 752	10 635	4 314	2 232	1 077	634	-46%	-49%	-59%	-48%	-52%	-41%
Gas cond	643	27 317	43 291	64 405	80 444	86 045	82 502	69 148	55 730	41 058	25%	7%	-4%	-15%	-17%	-20%
Jet non-cond	25 845	22 141	17 708	12 962	8 346	3 962	1 467	703	449	307	-21%	-25%	-20%	-8%	-9%	-14%
Jet cond	0	521	1 302	2 505	3 858	5 134	5 848	6 035	5 663	4 923						
Elec Joule	729	942	1 035	1 177	1 255	1 218	1 168	1 054	963	873						
Hybrid	17	25	52	133	1 054	3 327	6 994	11 904	17 092	22 391						
Elec HP	349	2 506	3 836	5 863	9 693	15 379	23 561	33 209	43 559	54 369						
Gas HP	5	25	48	112	428	1 123	2 210	3 637	5 161	6 731	282%	162%	97%	65%	42%	30%
mCHP	11	39	59	113	228	422	676	972	1 288	1 613	102%	85%	60%	44%	33%	25%
Solar combi (16 m2)	270	437	529	616	710	802	896	1 045	1 229	1 429						
Boiler >400 kW	524	545	552	558	564	565	554	543	543	543						
Total Central Heating boiler, Space Heating	**75 630**	**122 611**	**125 252**	**126 960**	**127 330**	**128 612**	**130 189**	**130 481**	**132 752**	**134 871**						

Hybrid stock included in condensing boiler stock

Review study of Commission Regulation (EU) No. 814/2013 [Ecodesign] and Commission Delegated Regulation No. (EU) No. 812/2013 (Energy Label) (hot water production), review study Task 7 "scenarios", VHK, Delft (NL), for the European Commission, DG ENER C.3, July 2019

VHK ENER Lot 2 review study, task 7, Table 9. EU-28 sales per base case in thousands of units, for the ECO-scenario (including new proposed measures)

SALES ECO, 000 units	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050	Figures used in THyGA report D6.5					
											2020 / 2025	2025 / 2030	2030 / 2035	2035 / 2040	2040 / 2045	2045 / 2050
EIWH < 12 kW (2nd)	253	368	406	448	448	448	448	448	448	448						
EIWH ≥ 12 kW	729	618	609	635	702	769	837	904	971	1 039						
EIWHS Shower (2nd)	1 039	1 344	1 320	1 298	1 379	1 460	1 540	1 621	1 702	1 783						
ESWH ≤ 30 L (2nd)	1 635	1 815	1 827	1 907	2 039	2 170	2 301	2 433	2 564	2 696						
ESWH > 30 L	3 586	4 181	3 839	4 007	4 284	4 560	4 836	5 112	5 388	5 664						
GIWH < 13 L/min (2nd)	1 689	1 129	914	927	914	901	888	875	862	849	-1%	-1%	-1%	-1%	-1%	-2%
GIWH ≥ 13 L/min	274	250	208	211	209	206	203	200	197	194						
GSWH, Condensing	0	7	10	12	14	17	19	21	24	26	-7%	-8%	-8%	-9%	-8%	-11%
GSWH, Non-condensing	285	162	117	73	65	56	48	40	32	24						
Dedicated WH Heat Pump	0	46	129	185	281	377	473	569	665	762						
Dedicated WH Solar	159	575	582	473	491	509	526	544	562	580						
Subtotal Dedicated WH	**9 649**	**10 495**	**9 961**	**10 176**	**10 824**	**11 472**	**12 119**	**12 767**	**13 414**	**14 062**						

VHK ENER Lot 2 review study, task 7, Table 10. EU-28 stock per base case in thousands of units, for the ECO-scenario (including new proposed measures)

SALES ECO, 000 units	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050	Figures used in THyGA report D6.5					
											2020 / 2025	2025 / 2030	2030 / 2035	2035 / 2040	2040 / 2045	2045 / 2050
EIWH < 12 kW (2nd)	3 552	4 544	5 099	5 858	6 491	6 792	6 892	6 892	6 892	6 892						
EIWH ≥ 12 kW	12 071	11 090	8 484	7 874	7 816	7 871	7 817	7 756	7 694	7 632						
EIWHS Shower (2nd)	14 241	19 777	20 561	20 019	19 517	19 414	19 348	19 271	19 194	19 118						
ESWH ≤ 30 L (2nd)	22 956	28 577	28 594	28 485	28 717	29 209	29 372	29 372	29 372	29 372						
ESWH > 30 L	49 158	64 716	65 767	67 412	66 343	64 827	63 646	61 416	59 149	56 881						
GIWH < 13 L/min (2nd)	23 714	23 508	19 871	16 469	14 404	13 737	13 057	12 276	11 496	10 716	-13%	-4%	-5%	-6%	-6%	-7%
GIWH ≥ 13 L/min	3 842	4 367	4 037	3 711	3 225	3 137	2 986	2 813	2 639	2 466						
GSWH, Condensing	-	33	77	132	170	196	212	229	247	264	-26%	-22%	-19%	-14%	-17%	-20%
GSWH, Non-condensing	4 001	3 719	2 957	2 166	1 523	1 117	854	683	512	340						
Dedicated WH Heat Pump	-	267	711	1 449	2 650	4 302	6 345	8 588	10 831	13 073						
Dedicated WH Solar	873	6 490	8 425	9 205	10 054	11 052	13 047	16 328	19 723	23 117						
Subtotal Dedicated WH	**134 407**	**167 087**	**164 581**	**162 781**	**160 911**	**161 654**	**163 576**	**165 625**	**167 748**	**169 872**						

Review study on Local Space Heaters, Final report, Viegand Maagøe and Danish Technical Institute, May 2019

Extract from chapter 2.1 Sales

2.1.1 Sales split and market shares

The sales are based on the impact assessment and updated based on stakeholder inputs. The current assumption for sales is shown in Table 19. In general, it is difficult to fit sales numbers from GfK, PRODCOM or other sources to the categories in the regulation as some of the categories are very broad while others are very specific. Furthermore, the categories from the regulation and the categories from the impact assessment are not aligned. The sales from the impact assessment[82] is fitted to categories in the regulation[83] and presented to stakeholders for validation of the numbers. Based on consultation with stakeholders the following is assumed:

- The sales of electric fixed space heaters from the impact assessment are assumed to be correct. However, the future sales of electric space heaters are very difficult to predict, and different stakeholders have suggested both and increase and decrease in future sales. Hence, the sales are assumed to be stable from 2016 towards 2030.
- No sales data is available on radiant heaters (the current legal definition), because no products exists that fit this definition according to manufacturers.
- The sales of domestic gas appliances are too high in the impact assessment as the market has been declining for years. So, the current sales of domestic gas appliances are corrected and based on sales from the UK and the Netherlands[84] assuming that these two countries are responsible for 80 % of the total market. For domestic gas appliances the future sales are expected to decrease with 30 % towards 2030. After 2030 the sales are assumed to be stable.

Regarding liquid heaters no stakeholders have supplied any information, so the sales are in principle unknown. However, the sales are estimated to be roughly 10 % of the sales of gas heaters and follows the same trend.

The average growth rate for the different products are presented in Table 18.

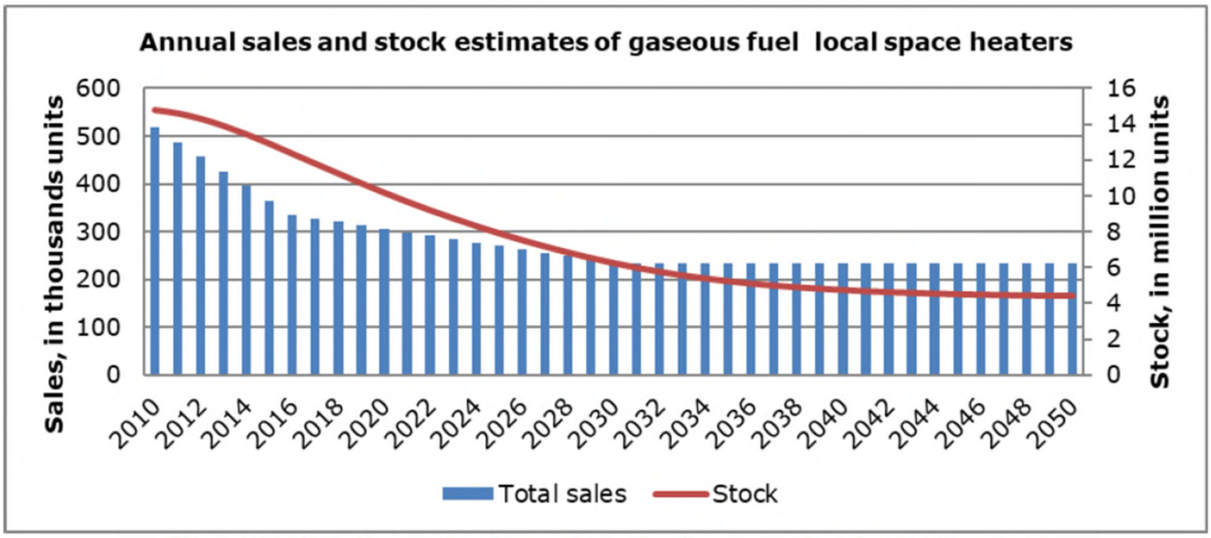


Figure 11: Total annual sales and stock of gaseous local space heaters

Preparatory study of ecodesign and energy labelling measures for domestic cooking appliances, Final report, JRC, October 2022[7]

The final review study from the JRC has been published in October 2022 after several draft version, in 2019 and 2021.

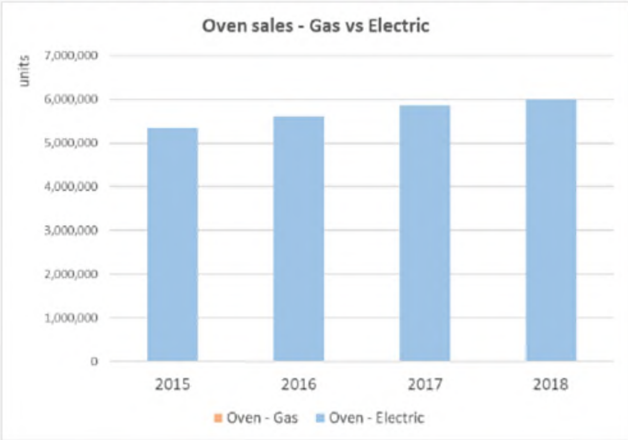
Some extracts used in the THyGA scenario are given below, it is important to not that within the JRC report "gas appliance" means appliances which can work with different kind of gases: natural gases, liquefied petroleum gases (mainly propane and butane) and manufactured gases. Therefore, THyGA adapted the trends given for all gas appliances to natural gas appliances stock, based on deliverable D2.1 (J. Schaffert et al. 2021).

Extract from chapter 2.2.3 Sales of domestic cooking appliances

[7] https://publications.jrc.ec.europa.eu/repository/handle/JRC130716

2.2.3.1 Ovens

Over the period 2015-2018, oven sales grew steadily, from nearly 5.5 million units sold in 2015 to slightly over 6 million units in 2018 (Figure 18). The vast majority of ovens sold over that period were electrically heated (sales of gas ovens are so small that they are not visible in the graph).

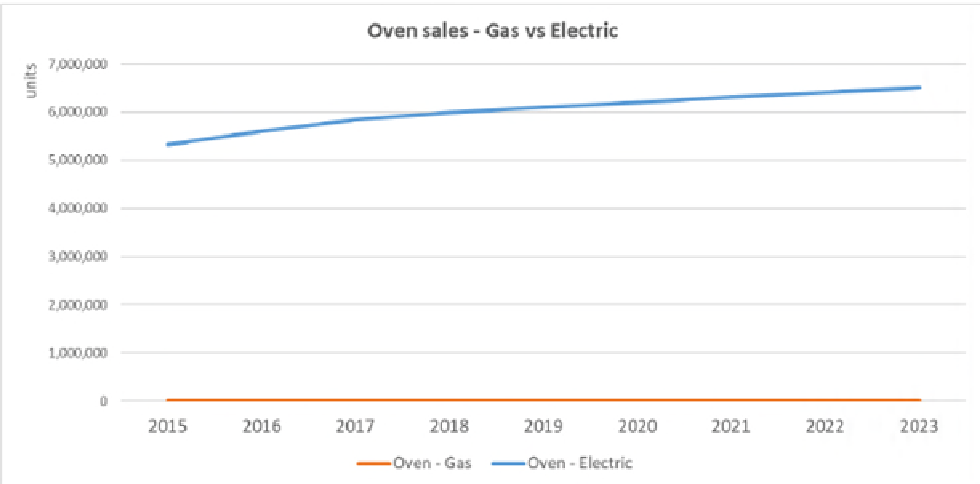


Euromonitor (2019)

Figure 18. Oven sales in 2015-2018 in the EU

Ovens in the market are currently being offered with a wide variety of modes, including steam-assisted and microwave-assisted heating functions. In Figure 19 data is shown for five representative EU countries. As can be seen, steam-assisted ovens tend to be growing over recent years, reaching 200 000 units in these five countries in 2018, with microwave-assisted ovens relatively stable at around 30 000 units. If these numbers are compared with the total market of ovens in those countries, it can be observed that these functions still represent a very low percentage of the market.

Looking specifically at technology trends for the different product groups (Figure 45), it can be seen in the first instance that electric ovens are expected to continue to dominate the market over the coming years (sales of gas ovens are so small that the red line appears almost flat on the graph).

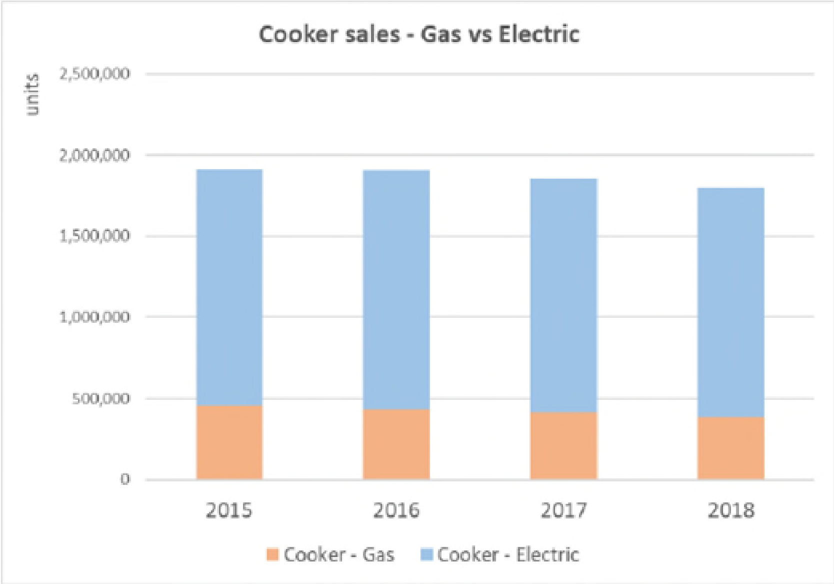


Euromonitor (2019)

Figure 45. Oven heat source trends

2.2.3.2 Cookers

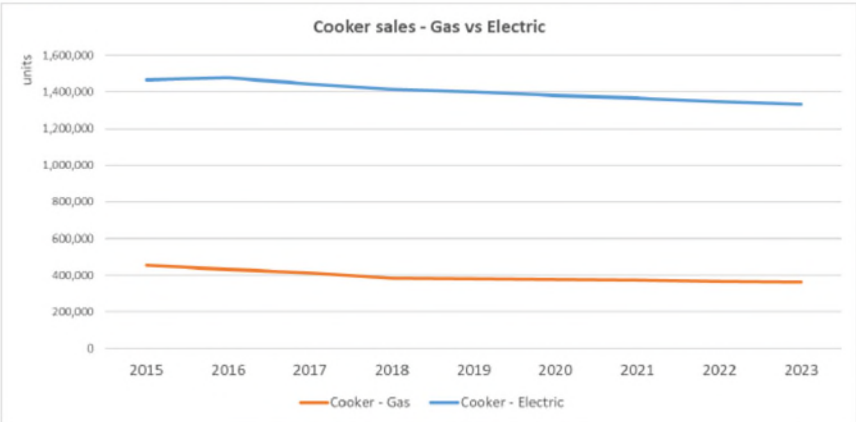
In terms of cookers, sales decreased slightly over the period 2015-2018, with approximately 1.8 million units sold in 2018 (Figure 21). In contrast with ovens, the proportion of gas-heated cookers is 21%, with electricity still being the most popular choice.



GfK (2019)

Figure 21. Cooker sales in EU2015-2018 in the EU

In terms of cookers (Figure 46), energy sources are distributed differently, with approximately 25% of the sales being gas and 75% electric. In both cases, sales are expected to slowly decrease over the period 2018-2023.

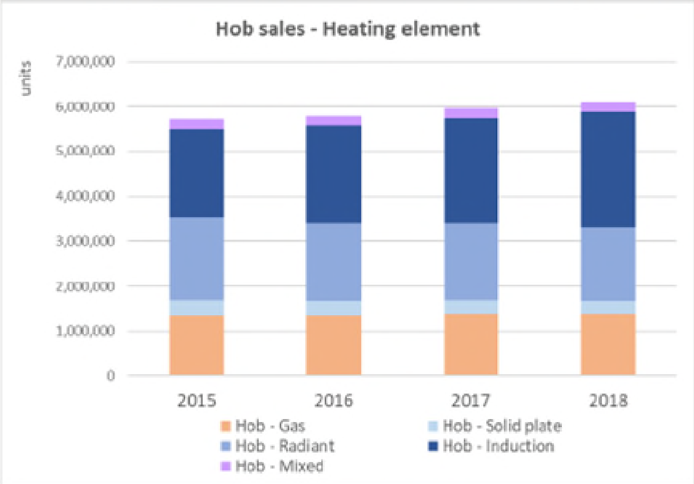


Euromonitor (2019)

Figure 46. Cooker heat source trends

2.2.3.3 Hobs

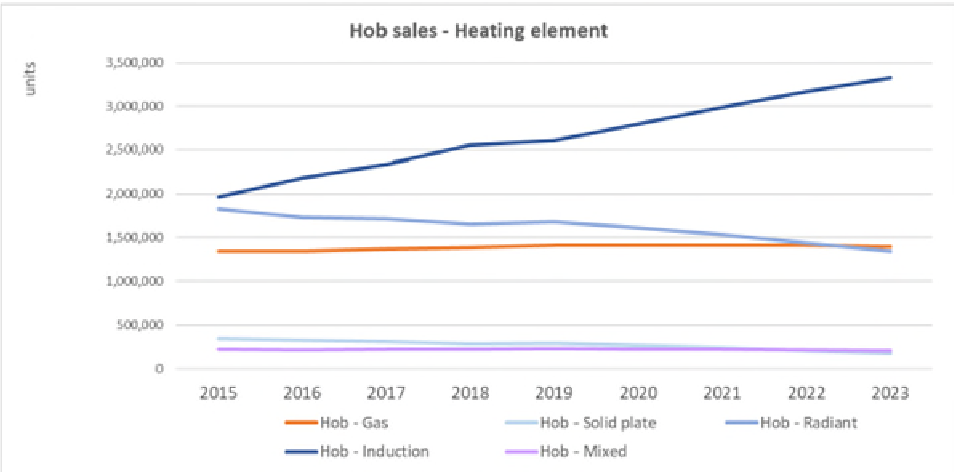
In terms of hobs, sales grew slowly over the period 2015-2018, from 5.8 million to 6.1 million in 2018. The technology that grew the most was induction: 41% of units sold in 2018 were induction.



GfK (2019)

Figure 22. Hob sales in EU2015-2018 in the EU

For hobs (Figure 47), induction technologies are expected to see a significant growth over the coming years. Gas hob sales are expected to grow at a very slow rate, with radiant and solid plate technologies decreasing gradually.



Euromonitor (2019)

Figure 47. Hob heat source trends

Extract from chapter 2.2.6 Stock of domestic cooking appliances

As can be seen in Figure 50, the total stock of ovens is estimated to increase in 2019-2040 from 122 million to 154 million approximately.

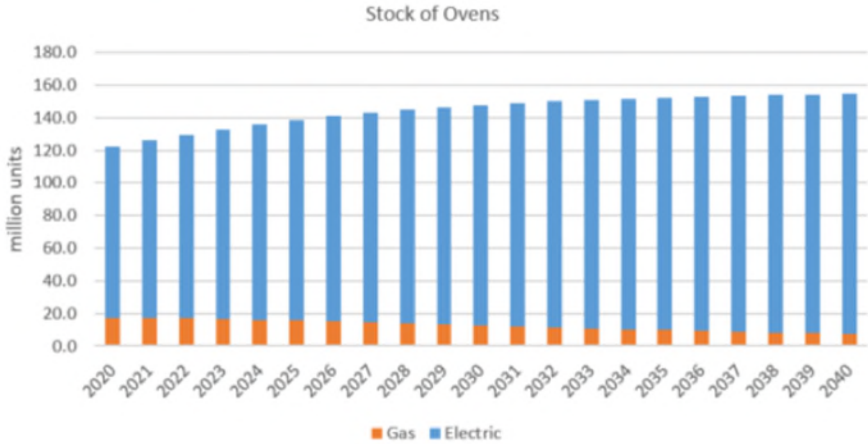


Figure 50. Estimated oven stock in 2020-2040

In Figure 51, the total stock of hobs is presented.

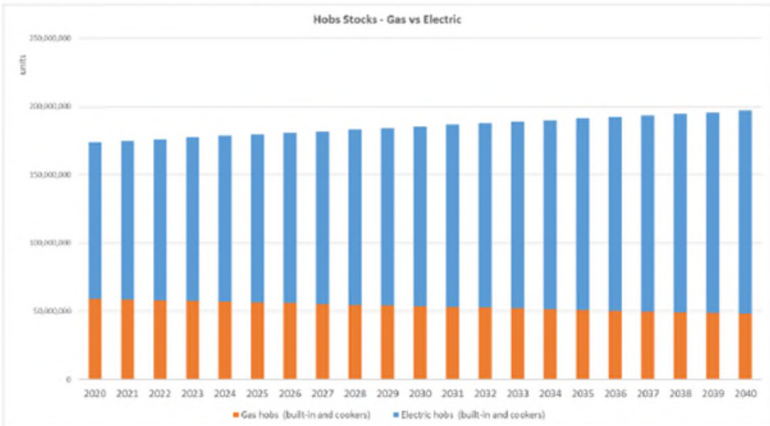


Figure 51. Estimated hob stock in 2020-2040

According to the sales data, induction will grow significantly, becoming the most common technology in the coming years. (Figure 52).

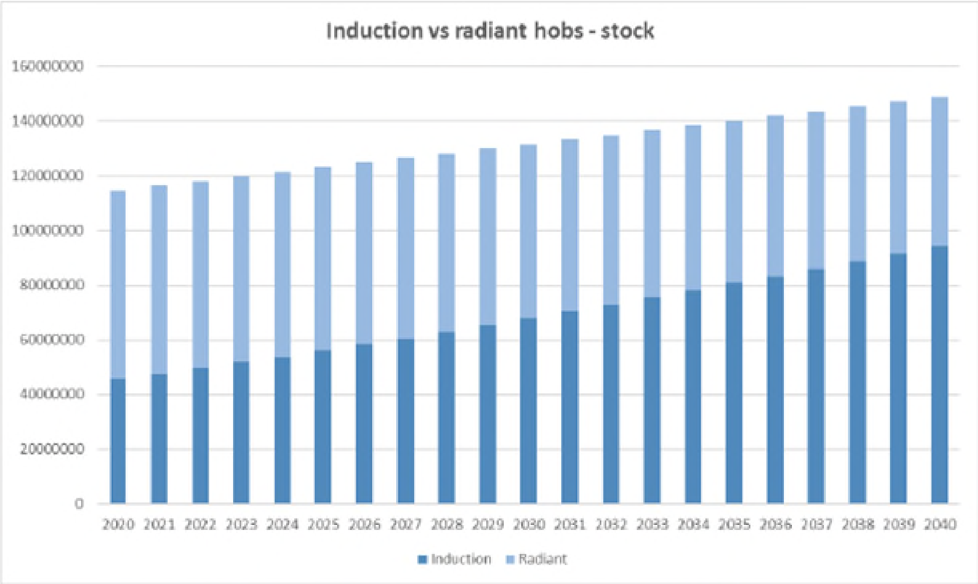


Figure 52 Estimated induction / radiant hob stock in 2020-2040