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

D5.3 Mitigation solutions: safety check

Deliverable: D5.3
Status: Final 05/05/2023
Dissemination level: PU = Public

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

Document classification

Title	Mitigation solutions: safety check
Deliverable	D5.3
Reporting Period	M18-M39
Date of Delivery foreseen	M39
Draft delivery date	M39
Validation date	M41

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Work package	WP 5
Dissemination	PU = Public
Nature	Report
Version	V05
Doc ID Code	THY_WP5_0014_D5.3
Keywords	H2NG, existing appliances, used appliances, Mitigation, Safety check

Document History

Partner	Remark	Version	Date
ENGIE	Draft	2	10/03/2023
DVGW-EBI	Amendments (results from gas.be) and remarks from DVGW-EBI	4	
GWI	Amendments on the draft	4.1	17/04/2023
ENGIE	Improvements of the draft bases on GWI remarks	5	
ENGIE	Finalisation	Final	05/05/2023

Document review

Partner	Approval
GWI	Johannes Schaffert, Frank Burmeister, Jörg Leicher
DVGW-EBI	Krishnaveni Krishnaramanujam
ENGIE	Patrick Milin

Executive summary

It is foreseen that, in a near future, natural gas distributed in the gas grids will be progressively replaced by green gases such as biomethane and hydrogen. During the transition period, one of the possibilities to accelerate the greening of the gas is to inject a mix of natural gas and hydrogen (H2NG) in existing networks.

As no member state of the EU have declared natural gas/hydrogen mixtures with up to 20% H_2, no European standard was developed to test the behaviour of gas appliances with H2NG up to 20%H_2 so safe operation could not be guaranteed in all cases.

A major part of the activities of the THyGA project was dedicated to testing typical residential and commercial natural gas appliances in order to have a better view of their behaviour when they are fed with H2NG mixtures. Blending rates of up to 60% H2 were applied. Although most of them performed well, some were subject to malfunctions with high percentage of H2 in H2NG mixtures [1].

One way to mitigate this problem is to ask manufacturers which of their appliances are compatible with H2NG mixtures and which are not and should be replaced. As a complement, for other appliances, the approach of a safety check has been tested by several projects.

From tests carried out in the THyGA project and from data gathered in the literature, it was concluded that major risks that should be covered by a safety check are:

- Gas leakage
- CO emissions
- Adjustment
- Flashback
- Delayed ignition

The following tests were suggested in order to minimize risks identified above:

- Perform a gas leakage test by checking the non-rotation of the domestic gas flowmeter (other methods like pressure drops can be used). If required, correct the problem.
- If required, check that the appliance is clean and correctly maintained.
- If required, adjust appliance to G20 (with a bottled gas)
- Use gas cylinders plugged to the domestic network in order to check safe operation (including CO and flashback) with G20 and with a flashback test gas (ex: G22 or G222) with a hydrogen concentration superior to 20% in order to have some safety margin.

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.

Of course, these tests should only be considered as a work bases and should be refined in the future.

An equilibrium should be established between risks associated to performing these tests and risks of not doing them. For example, in France, for hydrogen admixture rates lower or equal to 2%, no safety check is required. This position should also be considered for hydrogen concentrations such as 5%, 6% or 10%.

List of abbreviations

CO	Carbon monoxide
DAF	Dry Air Free
DSO	Distribution System Operator
EU	European Union
G20Y20	Mixture of G20 gas with 20% hydrogen
H2NG	Hydrogen / Natural Gas blend
H2NG-Y20	Hydrogen/natural gas mixtures up to 20%H2 (vol)
NG	Natural Gas
TCxxx AHG	Technical Committee xxx Ad Hoc Group
WI	Wobbe Index

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Introduction

A major part of the activities of the THyGA project was dedicated to testing the existing appliances in order to have a better view of their behaviour when they are fed with H2NG mixtures. Although most of them performed well [1], some were subject to malfunctions with high percentage of H2 in H2NG mixtures.

In a near future, it is forecast that hydrogen will be injected in existing natural gas networks. On these networks, residential and commercial gas appliances will be a mix of new H2NG-certified appliances and used appliances. As used appliances were not certified to operate with H2NG mixtures, and since it is not possible to know in advance how these used appliances will perform, it will probably be necessary either to change appliances to H2NG certified ones or to perform a safety check in order to avoid any problem. This safety check will also be an opportunity to improve gas safety by checking the tightness of the domestic gas line.

This report explores potential test procedures of a safety check:

- Which tests are necessary?
- Can they easily be performed on the field?
- What problems could encounter?
- Are there potential solutions?

1. The reasons behind the safety check

Ideally, H2NG mixtures would be introduced into a new gas network with gas appliances certified for H2NG. For existing networks, used appliances would be replaced with H2NG compatible ones. However, this option could be expensive as numerous appliances would have to be replaced.

A very simple calculation was made to estimate the proportion of H2NG-certified boiler for future years. It is based on data published in reference [2]:

- 113 million boilers installed.
- 5,2 new boilers sold/year

An additional hypothesis was used: (almost) no H2NG certified boilers would be sold before 2025 (it is based on an EHI position paper asking for a mandatory H2NG marking of boilers in 2025 [3]). Results of the projection of H2NG-certified boilers in Europe are plotted on Figure 1.

It can be seen that, injecting H2NG into the gas grid before 2036 would lead to the need to replace more than 50% of the boilers installed, which would be an expensive operation.

Figure 1: Potential evolution of market share of H2NG boilers in Europe.

Fortunately, tests carried out by several authors [4]–[7] [8] and in the THyGA project [1] indicate that most gas appliances can operate safely with H2NG up to 20% H_2. As a consequence, it can be 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 [9] and in the “Wasserstoff-Insel Öhringen” project in Germany [10].

In the next pages of this document we will examine the risks that need to be covered by this approach and discuss suitable mitigation solutions.

2. Other gas changes: L to H conversion

The gas industry has already dealt with great changes in gas compositions and qualities during its history. The first one was the change from town gases (a manufactured gas, also called 1st gas family), mainly composed of a CO/H_2 mixture to the first natural gases in the late sixties/seventies. As appliances were designed to operate only with 1st family gases, the adjustment method of appliances mainly consisted in drilling lager holes in existing burners [11] or by changing burners [12].

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 [13] and the final conversion of the northern part of the gas network is in progress and will last until 2029 [14]. In

Germany, about 1/3 of the country's gas grid were at some point L-gas grids. The regions currently being supplied with L-gas are in the process of being transitioned to H-gas, a process that is expected to be finished by 2030.

As the introduction of a non-negligible proportion of hydrogen into the gas network can be seen as a change of gas quality. Relevant experience from L to H gas conversion are detailed in the following sections.

2.1 L to H conversion in France

Gas conversion from L to H involves a two-step procedure.

1. Firstly, gas pressure in the domestic network needs to be decreased from 25 mbar down to 20 mbar. This is done by changing the pressure regulator at the DSO delivery point at the inlet of the home gas network.
2. Secondly, gas quality has to be switched from L gas to H gas. This can only be done for large parts of the distribution network, at the scale of one or several towns.

Consequently, operations 1 and 2 must be decoupled.

A requirement for being able to convert an appliance is a marking certifying that the appliance is compatible with the future gas H. This is the main difference with the H2NG case: appliances were all tested with reference gases for H group according to EN437 [15], thus **no safety check of appliances was required**.

In order to minimize risks during conversion operation, L gas has to be mixed with H gas during the conversion period, in order to generate a L+ gas whose Wobbe Index is constant and close to the upper limit of contractual L gas specifications.

2.1.1 Lab tests

Years before the start of field conversion of appliances, different conversion procedure were lab-tested in order to study the risks but also how the appliances reacted in the intermediate phase when they had to operate with L gas at 20 mbar. Conversion tests were performed on a selected portfolio of gas appliances representative of the market but with a focus on those which could cause problems.

Appliances selected where:

- Atmospheric burner
- 1st generation of condensing boiler
- Modern premixed condensing boiler
- Water heater
- Some catering equipment

Although appliances were supposed to operate safely with L gas as well as with H gas, the intermediary step of the conversion procedure involved using them at the limit of certification procedure. During a few days between pressure regulator change and the arrival of H gas, some appliances had to operate with L gas at 20 mbar (25 mbar is the usual delivery pressure for L gas in France). Their safe operation in these conditions was checked in lab. As expected, heating power decreased due to pressure decrease, but CO level remained below 1000 ppm and no other problems were observed.

Extra pressure tests as 17 mbar and even at 14 mbar were also performed to take into account extra pressure loss in the domestic network.

Test results (and meetings with manufacturers) led to the dispatching of appliances into five segments covering how the conversion procedure should be performed and what to do with appliances:

- **Segment 1:** No adjustment required on the device.
- **Segment 2:** an adjustment (with or without changing parts) is required and it is carried out upstream of the arrival of the H gas. Sometimes, a second operation is required after arrival of H gas.
- **Segment 3:** the device cannot be adjusted before the arrival of the H gas, and it must be switched off before the arrival of the H gas / switched on after
- **Segment 4:** the device cannot operate with H gas, and it must be replaced before changing the gas.
- **Segment 5:** B11 devices, but non-BS (no safety system to prevent burnt gases from flowing back into the room).

For orphan appliances (where the manufacturer no longer exists), the category of appliance, according to EN gas standards, the publication of the Gas Appliance Directive, as well as the manufacture year, helped choosing the adhoc segment.

2.1.2 Conversion procedure

On the field, the conversion required several visits per customer:

1. all gas appliances needed to be identified (kind of appliance, manufacturer, model, gas category, serial number),
2. if necessary, appliances were converted or stopped between pressure regulator change and H gas injection.
3. Some appliances were checked or put back in operation after H gas injection in the network.
4. For non-compatible appliances, the mitigation measure was to replace them. For appliances that could cause safety issues, such as non-BS B_{11} boilers, CO detectors were installed in order to prevent CO intoxications.

The procedure is illustrated in Figure 2.

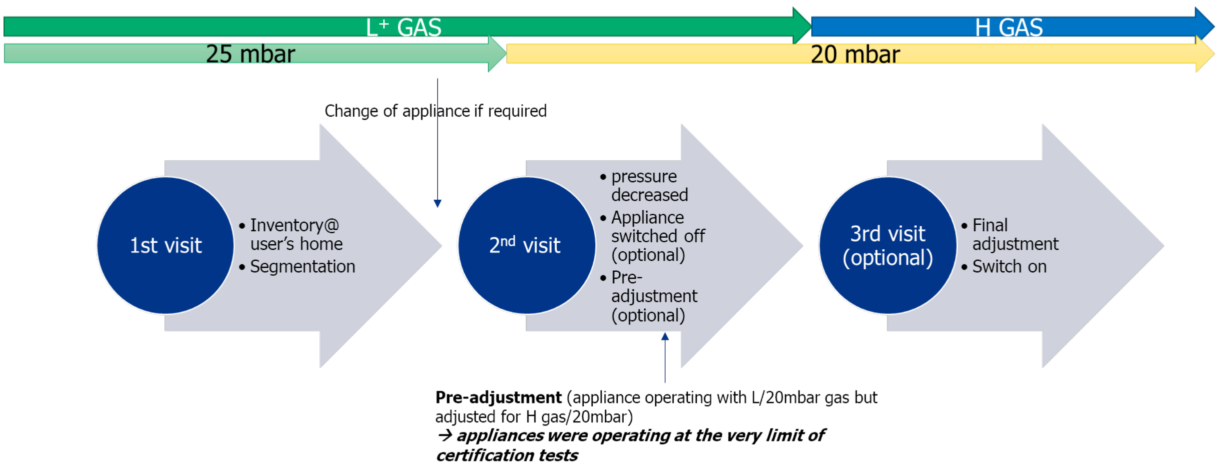

Figure 2: Conversion procedure performed for each home during L→H conversion in France.

Note: nowadays, gas customers can also perform the inventory of their gas appliances by themselves [16]. This helps to reduce the number of visits and the cost of conversion.

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.

2.2 L to H conversion in Belgium

Because of the progressive decrease of production of L gas from Groningen in the Netherland, Belgium is also performing a L to H conversion. The approach, in this country is somehow different. Customers are in charge of contacting their installer in order to check if the appliance is switchable to L gas (of course this required to train properly installers previously). This approach was possible because most of the appliances are of type I2E and are compatible from L to H without the need to replace them.

For H2NG conversion, it is advised that the compatibility of all appliances is evaluated. It could be performed either by installers (like in Belgium) or by dedicated technicians (like in France). But in either case, the DSO must be informed if the installation & appliances are compatible with H2NG.

2.3 L to H conversion in Germany

Germany has also initiated a L to H gas conversion due to the decrease on L gas imports from the Netherlands [17]. The conversion is planned to end by 2030 and begun in 2015. Approximately 5 to 6 million appliances will have to be converted with an annual rate going up to 550 000 gas appliances converted per year.

DVGW has established and published several rules for L to H conversion including documents describing the process of converting and conversion of appliances (DVGW G260(A)). The conversion process also involved an inventory of all gas appliances impacted by conversion resulting in large database of gas appliances was established by DVGW. This database includes the characteristics of gas appliances from 581 producers and 733 brands. In also includes instructions for L to H conversion (nozzle parameters, conversion kits required…) [18].

2.4 Conclusions

Inventory. Before injecting hydrogen in an existing gas network, a list of appliances used on the gas network need to be established. An inventory of all appliances available in homes corresponding the delivery points of the DSO impacted by hydrogen addition should be carried out.

Segmentation. These appliances must be segmented with the help of manufacturers and laboratory tests in order to separate:

- Appliances not compatible with H2NG
- Appliances compatible with H2NG
- Appliances compatible with H2NG but only after specific mandatory actions
  - Specific actions required?
  - Specific safety checks required?

An example of segmentation could be the following:

Segment number	Compatibility with H2	Actions required to make appliance fully compatible with H2NG
1	No	Change appliance
2	Yes. No action required.	None
3	Yes. Some actions required.	Specific adjustment, change of parts, software update before H2 injection. Requirement for an extra sensor (ex: CO)
4	Yes, under conditions	Specific tests

Table 1: Example of segmentation for H2NG appliances

For example, at the time H2 will be injected, the most recent boilers would be H2NG ready and would fall in segment 2. On the contrary, some very old appliances may fall in segment 1. Depending on appliances, adjustable appliances would probably require to be checked and adjusted before H2 injection and would fall in segment 3. In some cases, it might not be possible to affect a segment to an appliance (ex: in the very first H2NG injection projects, or if the manufacturer has disappeared or cannot provide information about appliance behaviour with H2NG…). In that case appliances are categorized in segment 4 and undergo specific tests.

Appliances database.

1. All appliances installed in homes must be gathered in a database which associates their brand name, model, reference number, years of manufacture, marking and segmentation.
2. All homes concerned by the NG to H2NG conversion must be listed in a database with their appliances.

3. Risk analysis

The introduction of a variable proportion of hydrogen into the gas grid will be a major change for gas appliances and equipment. The safety margin between appliances operating properly and the occurrence of technical problems will be thinner because most gas appliances are not designed and tested to burn H2NG mixtures with up to 20% H2.

3.1 Gas leakage

Intuitively, one of the major risks that should be covered is gas leakage. Hydrogen is a smaller molecule than methane and could diffuse through materials (permeation) or small holes. The British project Hy4Heat has studied extensively gas leakages of pure hydrogen in a large number of configurations [19] and has drawn these final conclusions:

- If a fitting does not leak with methane, it will not leak with hydrogen.
- A leak with methane will result in a leak with hydrogen.
- Leaks derived from accidents such as drilled holes or nail holes are likely to be large leaks with turbulent flow regimes and a volumetric leak ratio of 2.8:1, hydrogen to methane. Leaks from loose and damaged fittings are likely to be small leaks with laminar flow regimes and volumetric leak ratios of 1.2:1 hydrogen to methane.

What is true for pure hydrogen should also be true for H2NG. So, in order to avoid risks of H2NG leakage, **the safety check should assess the tightness of the domestic gas network and appliances**. It's not just a matter of safety. It is also a matter of not having a counter-reference due to a gas leakage started before hydrogen injection.

Tightness of gas components was also studied in the THyGA project [20]. Multiple gas components were tested with CH4 and CH4/H2 mixtures and compared to existing standard requirements. It was concluded that once a gas line is properly installed following natural gas standards at low pressures, it can be expected that it will be tight for the gas blend.

3.2 CO emissions

When gas composition changes, the main risk for people around the appliance is carbon monoxide emission. In modern appliances, this risk is minimized by the conception and certification of appliances:

- All gas appliances are tested with EN 437 limit gases in order to check them [21].
- CO emissions are used as a means to assess the quality of combustion [22] [23] and are kept under certain limit values.

However, as gas specifications will evolve due to the introduction of hydrogen, is it wise to consider that **appliances which will be fed with H2NG,** with H2 proportion above a certain limit (not treated in this document), **should be tested again with limit gases containing hydrogen**.

It has been shown in the Gasqual project [24] that appliances not properly maintained can emit more CO than appliances regularly maintained. The regular cleaning of the burner is required for the boiler to operate on the whole range of the Wobbe Index. If the burner is properly cleaned, it can almost operate on the same Wobbe range as a new burner. Consequently, a **cleaning of the burner is required before testing the appliance with limit gases**. This work could be performed either by the owner (standard cooking appliances) or by an installer (boiler, catering equipment, other).

3.3 Malfunctions due to inadequate adjustment

When an appliance is adjusted when the gas supplied is a mixture of a low Wobbe Index gas and hydrogen, the appliance could emit high amounts of CO when the gas is switched, later, to a high Wobbe Index gas without hydrogen.

Interactions between adjustment and operating problems or CO emissions have been highlighted in previous reports [24] [25] [26]. On the mitigation side, the THyGA report [27] underlines several methods for adjusting a gas appliances both, when the fuel gas composition is known and when it is not known.

Adjustment test reports from projects GASQUAL [24] and THyGA [27] show that adjustment to G20 tends to maximize the Wobbe Index range where the appliance operates safely.

Therefore, adjustment procedure should be corrected to take into account the presence of a variable amount of hydrogen in the gas. Alternatives such as forbidding adjustment or adjusting and appliance back to its factory settings should also be explored.

3.4 Flashback

The occurrence of flashback when hydrogen is added to natural gas is one of the major concerns about hydrogen mixtures.

Although partially premixed appliances are more impacted by this phenomenon than fully premixed appliances, it is not possible to predict which appliances will be impacted more than others.

As a consequence, **a flashback test with specific limit gases (or any other equivalent method) is required during the safety check**.

During flashback check several ignitions (cold and hot) should be performed to detect any occurrence of unusual acoustics such as raised levels of noise of sudden events ("bang" noise).

3.5 Delayed ignition

It is very difficult to determine whether or not the delayed ignition is significantly impacted by H2NG gas mixtures, especially up to 20% H2, as very few test results were reported in the literature. This kind of tests was not included in the safety check of the HyDeploy project but it was reported as being tested in laboratory conditions in [9]. However, no test results were specifically published (as far as we know).

Of course, it is not advisable to perform a delayed ignition test during the safety check, but this point should be investigated.

Within the THyGA project, some appliances were tested and results are published in the final WP3 report [1].

More lab testing of several gas appliances should be carried out with H2NG mixtures at 20% H2, on new and used appliances in order to have a better view on the behaviour of gas appliance regarding this phenomenon.

4. Proposal of a safety check procedure

The purpose of this proposal not to establish a universal safety check procedure. The goal of this work is to dive deeper into concrete actions that would be required in order to foresee technical problems and to estimate the duration time of a safety check.

Obviously, such safety checks would be an expensive option, especially due to personnel requirements. Therefore, prior upstream work with appliance manufacturers, test labs and DSOs must be performed in order to identify appliances that could operate directly with H2NG. Safety check is only seen as last resort option for appliances of unknown behaviour.

4.1 Gas leakage

4.1.1 Gas leakage rates for gas networks

Non rotation of flowmeter test

When commissioning a natural gas installation in France, the "non rotation test" of the flowmeter is performed.

The operator, at first, checks that the flowmeter is fully functional (at least one gas appliance has its shutdown valve open) and checking the gas counter is moving. Then he turns off the shutdown valve of all appliances.

Then, all gas appliances connected to the home gas network are shut down with their inlet valve kept open. It is checked that the flowmeter counter doesn't move. If a flowrate is measured:

- The measurement is carried out over a minimum period of 10 minutes. If the rotating counter shows a flow rate less than or equal to 6 l/h, the operation is complete.
- If the control shows a flow greater than 6 l/h or if the leak is observed without a flow reading, the operation is repeated with appliances control valves closed (last valves, downstream of the fixed piping allowing the gas supply into appliances, integrated or not in the appliance).

If the domestic installation is tight with the device control valves closed, the leak concerns at least one of the appliances. This appliance should be repaired or changed. If the fixed installation is not tight, it should be repaired according to the local regulations.

Note: checking if the leakage rate is 1 l/h would require 6x the time previously mentioned (one hour required). In order to check leaks of less than 6 l/h, another method will be required.

Pressure test

When commissioning a gas installation in the Netherland or UK, it is not the gas flowing through the flowmeter that is used to detect leaks. The criteria adopted is still a volumetric flowrate, but it is measured thanks to an air pressure drop. The volume of the gas network is estimated in order to calculate the flowrate from the pressure drop measured.

A distinction is made between new and existing pipes. The requirement for new connecting pipes is more stringent than the requirement for existing pipes (leakage rates at MOP (maximum operating pressure): max. 0.2 dm_3/h for new pipes vs max. 1 dm_3/h for existing ones) [28]. It is considered that a new pipeline may not leak as a result of installation errors or material faults. On the contrary, it is considered allowable that, for an existing pipe, a minor but non-dangerous leakage may occur due to ageing.

Notes about Hy4Heat lab leakage tests

In the project Hy4Heat [19], large number of equipment used on domestic gas network were leak tested with hydrogen and methane. They found out that many of the leaks observed on intentionally damaged fittings resulted in small leak flows of less than 1 l/hr with both gases (close to the boundary between passing and failing the British gas tight tests in domestic system and light commercial systems). For non-damaged fittings the leakage rates observed were of order of 1 ml/hr.

4.1.2 Gas leakage allowed for appliances

For European appliances, tightness test is performed with air at a pressure above the MOP. Test pressures and maximum leakage rates are summed up in Table 2. For the 4 categories of appliances considered, a maximum leakage rate of 0.1-.14 l/h is considered acceptable.

Appliance	Standard	Test pressure for natural gas	Maximum leakage rate
Boilers	EN 15502-1:2012+A1:2015	50 mbar (150 mbar for LPG)	0.14 dm3/h
Cookers	EN 30-1-1:2021	150 mbar for NG and LPG	0.10 dm3/h

Catering	EN 203-1:2021	150 mbar for NG and LPG	0.14 dm3/h
Independent gas-fired convection heaters	EN 613:2000	50 mbar (150 mbar for LPG)	0.10 dm3/h

Table 2: Soundness test conditions for European gas appliances.

Notes:

- The flowrate is approximately proportional to $\sqrt{\Delta P}$ and the operational pressure of a natural gas appliance is 20 mbar.
- At low pressure, it can be considered that leakages are laminar. So, for the same fitting, the ratio of leakage rate for methane and air is 1.65 (which is the ratio of dynamic viscosity of air over methane).

As a consequence, tests performed with air at 50 mbar would lead to the same leakage flowrate at 20 mbar with CH4.

It can be considered that leakage rates for new appliances is 0.14 l/h which is quite lower than what is allowed for gas piping.

4.1.3 Conclusions concerning maximum allowable leakage rate

Maximum allowed leakage rates have been summarised in Table 3. Tests for appliances are more stringent than tests for piping and cannot be used as a limit. For piping, the range is wide between countries, so no generic limit values can be established. However, from the literature mentioned above, it can be concluded that:

- if a leak is found and if the leakage rate is less than 1l/h, no action is required.
- If the leakage is superior to 6l/h, the leakage must be repaired.
- Between these two values, more investigations should be performed to find out where the leak comes from (close appliances valves in order to check if the leak comes from the network or one of the appliances, use a leak detector spray...). Corrective actions should be encouraged.

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

Table 3: leakage rate limits for domestic gas network.

4.1.4 Materials compatibility

For gas transport, it is well known that several grades of steel are not compatible with hydrogen because of embrittlement at high pressure.

Such problems do not occur at domestic pressures, but the long-term compatibility of material is not clearly known for the time being.

Current gas standard does not forbid certain materials for H2NG just because they have not been reworked for H2NG mixtures. So, in the future, attention should be paid to the nature of materials used in gas appliances and domestic networks.

Germany

In the absence of a European standard covering extra tests for H2NG appliances, German DVGW CERT TP 3100.20 for boilers [29] and DVGW CERT ZP 3502 for forced-draught burners [30] were written to introduce supplementary tests required for the certification of domestic gas appliances for H2NG up to 20% hydrogen admixture. ZP 3502 specifies that the elastomeric or polymeric (PTFE, fibre gasket/adhesive gasket materials) sealing materials for their respective temperature application ranges do not show any chemical incompatibility with hydrogen, even when used with 100 % hydrogen. As a consequence, they do not require specific tests. Test procedures and associated maximum leakage rates described in products standards (EN 15502-1 is mentioned) can be used with H2NG.

UK

Technical specification PAS 4444 published in the UK for hydrogen appliances only specifies that "Any materials in contact with hydrogen gas or flue gases should be defined as suitable for the intended purpose. Evidence that the materials conform to the applicable standards should be provided in the product.".

As a consequence, no specific check of materials is recommended for the moment, but attention should be paid to the evolution of material specifications in standards updates.

4.1.5 Test procedure

In order to test the whole safety check procedure, we have arbitrarily chosen one of the leakage tests.

The simplest approach to testing the soundness of a domestic gas network is to use the "French approach" described in see section 6.1.1, as no modification of the installation is required. This is the one tested when assessing the whole procedure.

4.2 Appliance preparation / paperwork

In the report [24], the GASQUAL project mentioned that if no cleaning of the burner is performed regularly, the CO emissions of an appliance increases, especially with high or low Wobbe Index gases.

This phenomenon is illustrated on Figure 3. 8 where appliances were investigated, and it was shown that the initial CO emissions increased with burner fouling. A cleaning brough back CO emissions almost at initial level for 6out of 8 appliances and made CO emission decrease for the 2 others.

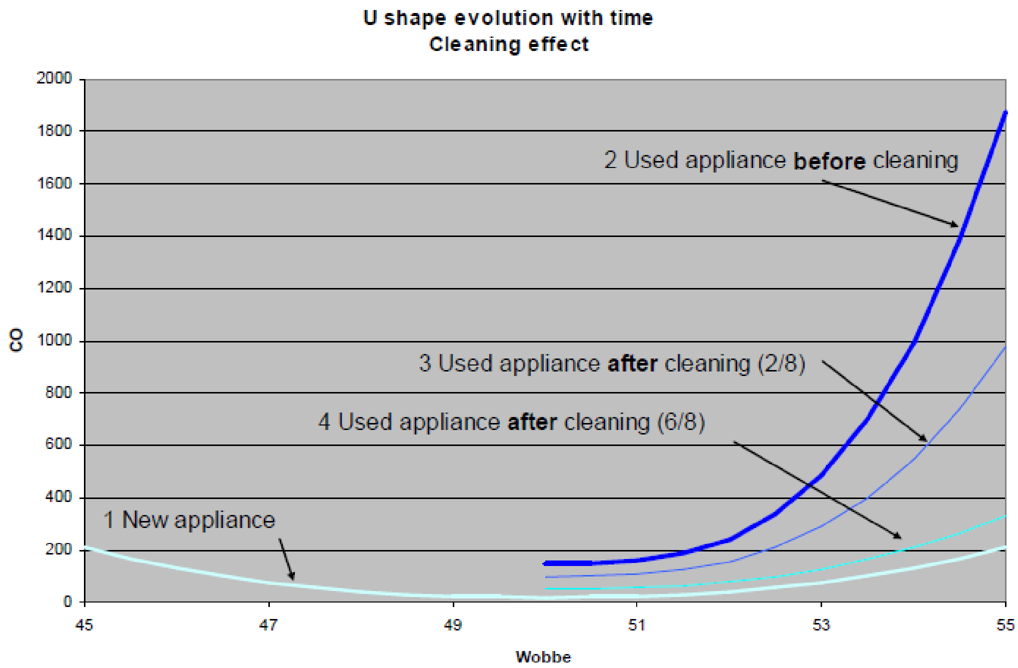

Figure 3: Evolution of CO emissions of a burner in new/used not cleaned/used cleaned conditions. (Source:[24]). For 6 appliances over 8, the impact of cleaning was to decrease CO emissions back to their initial values for high Wobbe Index gases. For two appliances over eight, no conclusion was drawn.

As a consequence, prior to any manipulation or measurement on a gas appliance, it is advised to ensure that the appliance has been cleaned either by the owner (for cookers) or by an installer (for boiler, water heater…) thanks to a maintenance certificate of less than a year.

The safety check operation must be performed by a qualified person (with relevant education, training, knowledge and experience to enable him or her to perceive risks and to avoid danger which is related to gas appliances and H2NG mixtures).

This leads to the following initial procedure:

- At first, the qualified person must inform the customer on why this test procedure is necessary, what are the benefits for him (his gas installation will be safer, both for natural gas and H2NG), and what is the test procedure. Afterwards, he will ask for maintenance certificates of appliances, if necessary.
- Then the qualified person will check how many gas appliances are present in the building and turn them off except one (to check the rotation of the flowmeter later). He will also check visually the cleanness of appliances before the tests as well as the data plates (conformity to the country of destination?).

4.3 Adjustment

The question of adjustment has been raised numerous times during the THyGA project: as the Wobbe Index range of delivered gases will increase due to the presence of hydrogen, adjustment to gases close to the Wobbe index limits could be a problem.

In the GASQUAL project [24], it has been shown that an appliance adjusted to G20 can cover more easily the Wobbe Index range of delivered gases than an appliance adjusted to the local composition of the natural gas delivered site at the time of commissioning. However, no tests were carried out with gas of low Wobbe Index containing 20% H2 during the GASQUAL project.

As hydrogen proportions could vary from 0% to 20% in the gas, the idea of adjusting appliances with G20 + 10% H_2 or G20 + 20% H_2 has been discussed within the THyGA project.

It has been shown in report [27] that adjusting a gas appliance with a mixture of NG and H_2 (low WI) can cause problems regarding to CO emissions when the appliance is subsequently fed with a gas of high WI: for fully premixed appliances, an increase of the WI reduces the air excess. Depending on the WI of the gas used for adjustment, on the step of WI, on the percentage of hydrogen in the gas at that moment and on the %CO_2 prescription of the manufacturer, CO emissions can increase above the limit of 1000 ppm used for appliance certification.

On the contrary, factory adjustment did not lead to excessive emissions of CO. These effects are, however, also very dependent on the initial air excess ratio the appliances was adjusted to.

Consequently, adjusting gas appliances to G20 before any injection of H_2 in the gas network seems preferable. To do that, the qualified person has to bring a G20 bottle.

The adjustment procedure must be carried out as specified in the appliance documentation. The location where the bottled gas is plugged in is described below.

4.4 Gas cylinders connection

Two connection options can be considered.

The first one is to plug the bottles directly to the appliance. This might be the best solution if only a cooking appliance is concerned.

The second one is to plug the gas cylinders just downstream of the gas flowmeter, at the inlet of the gas domestic network (Figure 4). The valve just upstream of the flowmeter is used to separate the domestic network from the gas grid. Then the flowmeter can be unplugged. Gas cylinders are then plugged to the domestic network.

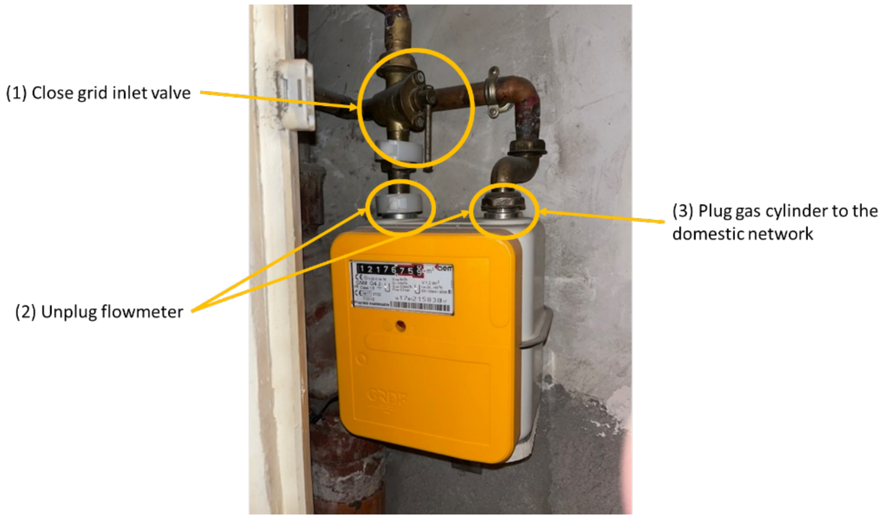

Figure 4: how to plug gas cylinders on the domestic network.

As some air can enter the pipe during the connection, a purge of the pipe is required to evacuate the air bubble and the natural gas of the gas network. This can be done at the level of the appliance or by using a dedicated burner (Bunsen-like burner). Depending on the gas network, this operation could last at least 5 minutes.

The risk involved with the connection operation is to introduce air in the gas domestic network which could increase the risk of flashback. This is the reason why the gas cylinder must be connected through a manifold/collector. When switching from G20 (the first test gas) to G22 or G24, no additional risk of perturbation due to the presence of air will then be possible. On the contrary, during the first minutes of use of G20, the flame (ideally a cooker flame) must be monitored (increased risk of extinction/flashback).

When unplugging the bottles, the same operation must be also performed.

Gas consumption – Bottle size

The volume of gas required to test an appliance can be estimated from its heating power and test duration:

- G20: 20 min @ Qmax
- G22 (or G24): 10 min@Qmax / 10 min@Qmin

Four appliances were considered: one cooktop appliance widely used in homes, one cooking range representing the high end of cooking appliances, and two boilers of different heating power. The expected volume of gas consumed is listed in Table 4.

Volume of gas consumed (m^3)	20 min G20	G22: 10 min@Qmax, 10min@Qmin)
Cooktop 4 burners (10kW)	0,35	0,30
Gas range+oven (6 burners, 2 ovens, 1 grill)	0,78	0,68
Boiler (16kW)	0,56	0,42
Boiler (24kW)	0,85	0,63

Table 4: Order of magnitude of the volume of gas consumed by a safety check.

Different sizes of gas bottle are available in the industry. The order of magnitude of their gas capacity, size and weight are given on **Gas cylinder size**. Large bottles have a capacity of 10 m^3 but their weight (70 kg) make them unsuitable. Depending on national occupational health and safety guidelines, different maximal tolerable weights may apply that restrict the use of specific gas cylinders. These guidelines may also differ concerning age and sex of the qualified person. The smaller sized bottles S05 weight only 10 kg, but their gas capacity of 1 m^3 would limit their use to one home only, unless small appliances have to be tested.

Between these two extremes, small S11 or medium M20 bottles could be used for safety checks in several homes. As gas consumptions between tests with G20 and tests with G22 is not very different (Table 4), the same gas cylinders could be used. However, as some extra G20 could be needed for adjustment, M20 cylinders could be chosen preferably, if health and safety guidelines allow.

Gas cylinder type	Gas capacity @200bar (m3)	Height (m)	Weight (kg)
Large - L50	10,0	1,60	**70**
Medium - M20	4,0	1,00	**35**
Small - S11	2,3	0,76	11
Small - S05	**1,0**	0,62	10

Table 5: Gas cylinder characteristics.

Whatever the cylinders choice, they should be transported on a trolley, both for handling and safety reasons.

A long flexible pipe might also be necessary when the trolley cannot be put close to the gas flowmeter, as in the case of Figure 5 (stairs).

Figure 5: Example of a gas flowmeter (in yellow) with a difficult access.

It should be noted that an appliance of 80 kW consumes 4 m^3 of gas in about 20 min. As a consequence, boilers for collective heating could not be tested with a M20 bottle. Instead, an alternative method like gas bundles (collection of bottles) or bigger bottles are needed.

4.5 Flashback & CO Emissions

During certification tests, the limit value for CO DAF[1] emissions used is usually 1000 ppm. This is the limit chosen in this document. However, depending on the laws in force in each country, the evolution of environmental regulations or the variability of gas quality, a lower limit value could be used.

Once the appliance has been properly cleaned and adjusted (if required), CO emissions are measured:

[1] Dry, air free (DAF) values provide a standardised way of comparing emissions.

1. With G20 to check the behaviour of the appliance with a gas representative of natural gases. If CO emissions are above 1000 ppm, corrective actions must be taken.
2. The appliance is operated using a test gas for flashback (e.g. G22 or G222). No flashback, malfunction or high CO emissions should occur.

As a complement to appliance check, people participating to the demonstration project HyDeploy were given a CO detector as a safety measure [31].

Limit gas for flashback

According to the current version of EN 437 [21], flashback limit gas for natural gases of the H category is G222. This gas is a mixture of CH_4 with 23% of hydrogen (by volume).

Flashback test gases mentioned in the HyDeploy project [32] were composed of G24 which has a high Wobbe Number (51.9 MJ/m^3) and a hydrogen content of 20 % mol/mol, a propane content of 12 % and 68 % CH4. In the project "Wasserstoff-Insel Öhringen", G222 is used for 20% H2 admixtures in gas and G22 for 30% admixtures.

During current work in several standardization committees, G22 (CH4+35%H2) has been mentioned as a flashback limit gas for H2NG up to 20%H2 because it corresponds closely to a mixture of 80% of G222 and 20% of H2H2 (which makes CH4+36%H2).

For boilers and gas premixed appliances, TC109 AHGH2 has put G21 (CH4+13%C3H8) on top of its flashback limit list (as well as G24). It is well known that, for premixed appliances, the addition of hydrogen to natural gas does not increase flame velocity because the increase of the fundamental flame velocity is counterbalanced by the increase of air excess. On the contrary, adding propane increases flame velocity and decreases air excess. So G21 or G24 with, respectively 13% and 12% of propane are considered as adequate gases to test flashback for premixed appliances. According to EN 437, gas appliances of categories H and E have already been tested with G21. As a consequence, it does not seem to be required to test them for flashback for H2NG.

Concerning the occurrence of flashback, it has been observed during the THyGA project, that flashback can occur after a long period of operation time (1h). Of course, it is not possible to make such long-term tests during a safety check. An alternative to a long-term test can be to use a gas with a higher hydrogen content than 20% H_2. This safety margin was, in a certain manner, taken into account when G222 was chosen as a limit gas for a reference gas G20.

Test gas	Composition	Application	Purpose
G20	CH4	Certification (normal use of gas appliances)	CO emissions in normal conditions
G222	77%CH4/23%H2	Certification (Flashback limit gas)	Test absence of flashback for natural gas
G22	65%CH4+35%H2	This gas was used as a flashback limit gas before G222	Flashback test gas (composition close to G222+20%H2)
G21	87%CH4/13%C3H8	TC109/AHGH2	May be used as a flashback limit gas for fully premixed boilers for certification (Work in Progress)
G24+20%H2	68%CH4/12%C3H8/20%H2	Hydeploy (mixture of a high Wobbe Index gas + 20%H2)	Flashback test gas

Table 6: Example of gases used to test NG/H2NG appliances.

As a consequence, a test with **G22** (the test gas close to a mixture of G222 plus 20% H2 for safety margin) seems to be the **best option to guarantee absence of flashback** during a 5 min test.

Test procedure

Flashback has the highest probability to occur during transitions periods (turning on, heating up of the burner…), so the test procedure should involve the following procedure:

- Turn on the appliance (cold start)
- Heat up at Qmax (5 min)
- Turn appliance off, turning appliance on (hot start 01)
- Go down to Qmin (5 min)
- Turn appliance off, turning appliance on (hot start 02)
- Switch off appliance.

If a gas cooker has to be tested, all burners are turned on as simultaneously as possible.

After all the work on gas appliances (tests, adjustment…) has been performed, gas cylinders are unplugged, a new gas seal is installed, leakages at the connection are checked with a leak detection fluid, the system is restored to its initial state and the correct operation of all the appliances is checked.

Test duration

For boilers, standard EN 15502-1 [22] does not impose a test duration. It is only mentioned that "*A sample of the combustion products is taken <u>when the boiler has reached thermal equilibrium</u>*".

Standards for cookers are more explicit. For domestic cookers, combustion products are measured after 20 min [23]. For catering equipment, automatic control has to be taken into account. Combustion products are generally measured between 15 and 20 min after ignition: "*Combustion is checked 15 min after ignition or before a thermostatic control reduces the burner rate, unless the burners have plates, for which the test is carried out 20 min after ignition or before the thermostatic control reduces the burner rate*".

So, it is estimated that the combustion (CO + flashback) test duration for combustion is about 40 min: 20 min with G20 and 20min with the flashback gas. To this duration, 10-15 min should be added to plug/unplug bottles and check that, when installation is plugged back to the gas network, no gas leak appears.

Alternative method

An alternative method for testing flashback has been introduced by PAS 4444 [33] for pure hydrogen. As it is not possible to add a new gas to hydrogen in order to increase flame velocity, it has been stated that the limit gas for flashback is replaced by an increase/decrease (depending on stoichiometry) of the air factor.

At the time this report is being written, TC109/WG1 and TC109 AHGH2 are discussing the opportunity of an alternative method which implies changing the air excess to test flashback. This could be an interesting alternative compared to the use of bottled gases for flashback safety checks.

There is a lack of feedback on this method, and it has not already been validated by a standardization committee, so it is too early to consider it as an alternative method for limit gas tests, but it has to be mentioned in this report for future investigations.

What is flashback – How to detect it?

Flashback occurs when the flame velocity becomes superior to the exit velocity of fresh gases at the flame port of the burner. Under these conditions, the flame can enter inside the burner and stabilizes at the level of the gas injector.

Detecting flashback requires to stay relatively close and alert near to the appliance. This is because the first consequence of flashback will be an abnormal sound, usually a "bang". Usually, the bigger the volume of air/gas ignited, the louder the sound. This sound has to be detected by the qualified person performing the test. At the same time, the person must stay in a safe position, a few meters away e.g. in case the boiler housing flies off.[2]

For partially premixed flame observed at cooking appliances, the second parameter that changes when flashback occurs is the colour of the flame. Usually, a partially premixed flame is composed by a central intense-blue premixed flame surrounded by a diffusion flame which is less intense Figure 6.

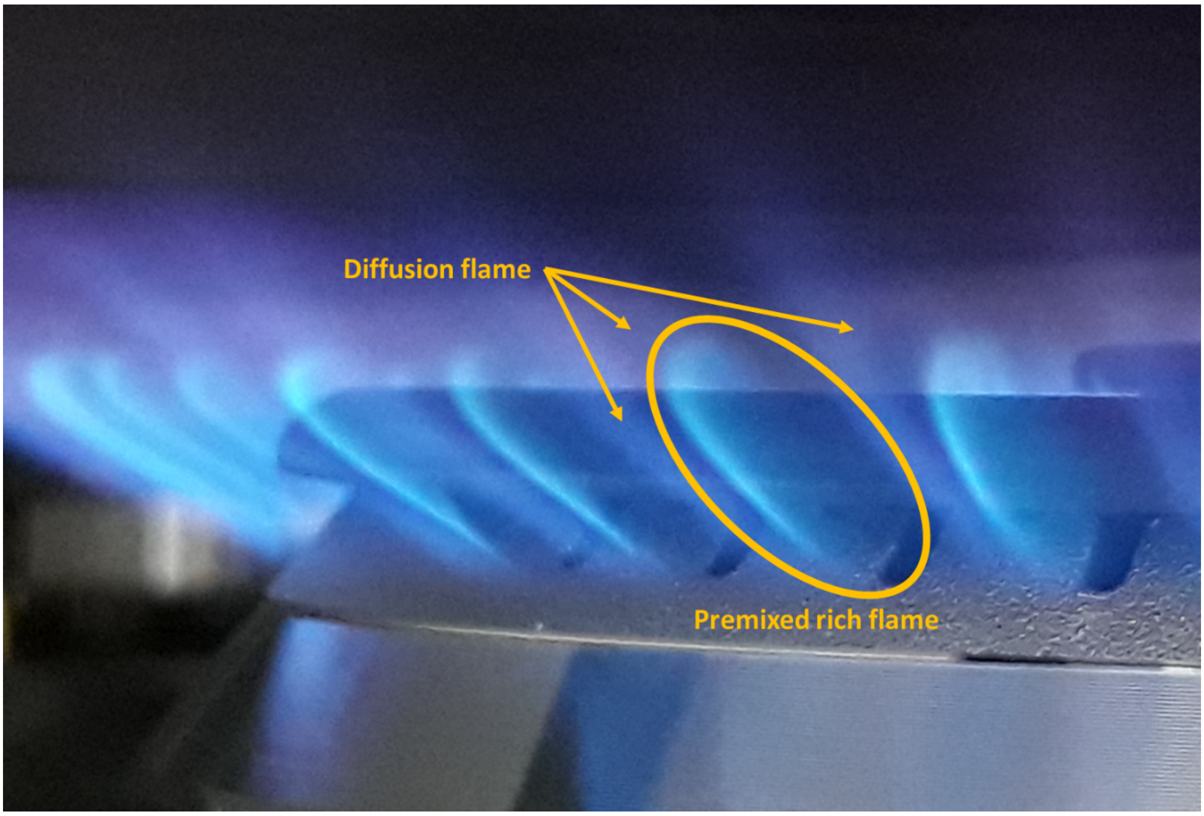

Figure 6: Structure of a partially premixed flame.

When flashback occurs, the premixed rich flame is attached to the injector inside the burner. Thus, at the flame port, only the diffusion flame remains, but without the intense blue cone (Figure 8).

Note: the colour of the flame is not a good indicator of a flashback because flames of H2NG tend to have an orange/reddish colour naturally.

[2] In the THyGA laboratories, technicians and researchers performed the measurements from a neighbouring room or neighbouring test box.

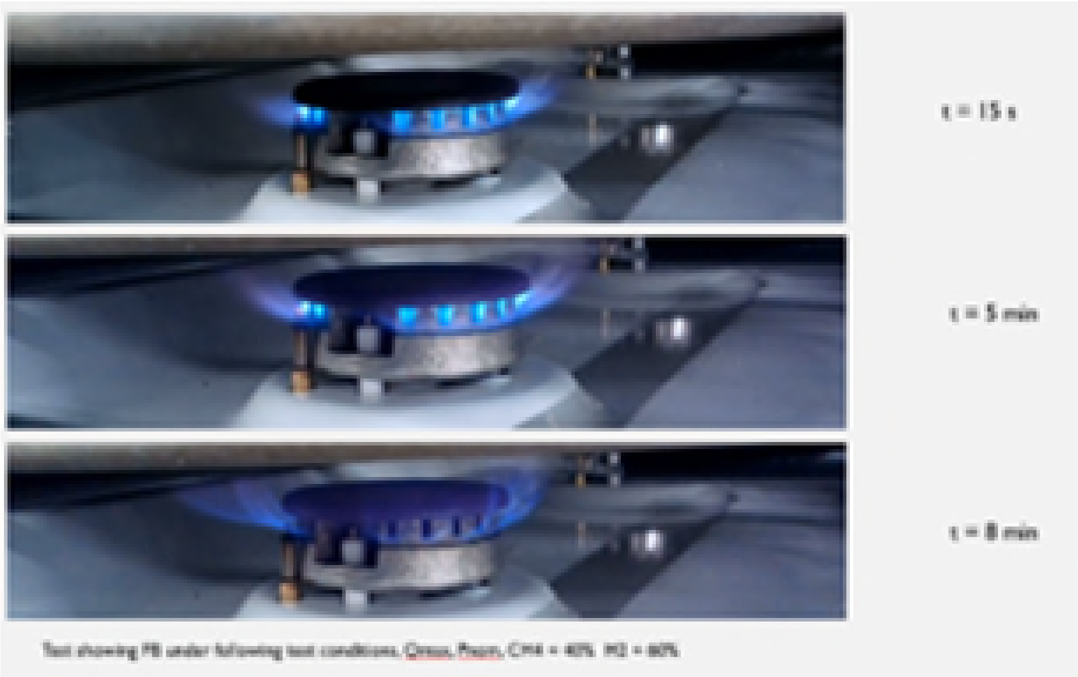

Figure 7: Flashback on a cooking burner (bottom photography)

For fully premixed flames, it is expected that, in case of flashback, the flame enters the burner and stabilizes at the injector but, as no flame develops outside the burner, the flame detection device (e.g. the ionization probe) cuts the fuel gas feed, and the appliance operation stops. However, on recent airtight boilers, the flame is not always visible (boilers are less and less equipped with a small window that enable to see the flame). So, it is not always possible to check the flame visually after the flashback “bang” or to visually detect flashback if the “bang” was not heard.

For partially premixed appliances, the qualified persons must be trained to detect flashback (visual and sound alert).

For full premixed appliances it might not be enough as the flame is not visible to confirm the occurrence of flashback:

- More investigations on flashback behaviour for full premixed appliances may be required in order to verify that they all shut off in case of flashback,
- A sound detector might be developed to help detect the flashback sound.

4.6 Delayed ignition

Delayed ignition has been identified as a risk when hydrogen is combined to natural gas. However, it is obvious that it cannot be tested directly in customer’s home, because special measurement equipment is necessary, which makes it only suitable for laboratory tests.

More knowledge is required about this phenomenon. Very few appliances were tested within the THyGA project (one boiler and one space decorative fire). No safety problem was underlined by these tests at 20%H2 with a delayed ignition of 5s, but the statistical robustness of the result is not sufficient, given the extremely small sample size. Clearly, more tests with more appliances are required in order to have an overview of the situation.

4.7 Can all appliances be tested?

Is it always possible to measure CO, to check flashback?

Flashback

In order to check flashback, the operator needs to have a view on the flame. For cookers, most catering equipment and decorative fires, the flame is visible, although it is not always possible to see the whole flame in some cases.

Older boilers/water heater used to have a small window to check the presence and the colour of the flame during operation.

On the other side, modern airtight premixed boilers, water heaters and some catering equipment are not designed so that the user can see the flame. This makes the detection of flashback harder because it is only possible to rely on sound and not on sound plus visual observation of the flame.

A specific flashback test approach will be required for full premix appliances where the flame is not visible.

CO measurements

In the French project GRHyD, some emission measurements were performed on gas cookers. The measurement was made with a method similar to the one defined in standard EN 30 [23] with a standard pot and measurement lid (sampling device). In the case of a safety check, the qualified person cannot bring with him as many pots and sampling lids as necessary (some gas ranges tested in the THyGA project have up to 6 open burners). Therefore, CO detection can only be performed by moving a combustion analyser above the cooker in order to detect burner malfunctions.

On the side of space heaters/boilers, it may not always be possible to have access to combustion gases at the level of the appliance. A specific procedure could involve drilling a hole in the flue duct to measure flue gas composition may have to be developed.

4.8 Total safety check duration

The hypothesis used for the calculation of the safety check duration is that the qualified person has to check two appliances: one cooker and one boiler.

As it is currently described, the total duration of the safety check ranges between 2h and 3h depending on the number of appliances and operations to perform on the installation.

Total safety check duration	Duration (min)	Option duration (min)	remarks
Test description to the customer/get maintainance certificate	15		
Visual check of appliances/shut down all but one	10	10	
Leak detection			
Check rotating flowmeter	5		
switch off all appliances	2		
Check non rotation of flowmeter	10		
rotating flowmeter (leak identification)		15	
Plug bottles	10	10	
Move bottles form place A to B		10	
Switch to G20			
Purge gas network from air	5	5	
Boiler check emissions (CO before adjustment) - adjustment		20	
Check CO emissions G20 - Boiler	10	0	10 more minutes if >1000ppm
Check CO emissions G20 - Cooker	10	0	10 more minutes if >1000ppm
Switch to flashback gas			
Check/CO & flashback Qmax/Qmin - Boiler	10		
Check/CO & flashback Qmax/Qmin - Boiler	10		
Unplug bottles + restore connections + check tightness + check applia	15	15	
TOTAL CHECK TIME	112	85	

Table 7: Estimation of the total duration of the safety check for one cooker and one boiler.

The 2h test is in line with the duration of the safety check announced by the HyDeploy project [31]. Numerous tests are planned during this check. Maybe with more lab tests and experience gathered on the field, the amount or duration of tests could be reduced.

5. Conclusions

It is foreseen that, in a near future, natural gas flowing the gas grids will be replaced progressively by green gases such as biomethane and hydrogen. During the transition period, one of the possibilities to accelerate the greening of the gas is to inject a mix of natural gas with hydrogen in existing networks.

Currently, no member state of the EU has declared to EU H2NG mixtures. Only natural gases were declared [34]. As a consequence, no European standard was specifically developed to test the behaviour of gas appliances with H2NG. So safe operation could not be guaranteed for existing appliances.

One way to mitigate this problem is to ask manufacturers which of their appliances are compatible with H2NG mixtures and which are not and should be replaced. As a complement, for other appliances, the approach of a safety check has been tested by several projects.

From tests carried out in the THyGA project and from data gathered in the literature, it was concluded that major risks that should be covered by a safety check are:

- Gas leakage
- CO emissions
- (Mis-)Adjustment in the field
- Flashback

- Delayed ignition

The following tests were suggested in order to minimize risks identified above:

- Perform a gas leakage test by checking the non-rotation of the domestic gas flowmeter (other methods like pressure drops can be used). If required, correct the problem.
- Check that the appliance is clean and correctly maintained.
- If required, adjust appliance to G20 (with a bottled gas)
- Use gas cylinders plugged to the domestic network in order to check safe operation (including CO and flashback) with G20 and with a flashback test gas with a hydrogen concentration superior to the hydrogen concentration planned for blending into the local gas distribution grid in order to have a safety margin.

It was estimated that, for a home equipped with a gas cooker and a boiler, all operations could be carried out by one person in 2h if no problem is encountered or 3h otherwise (gas leak search, appliance adjustment…).

Of course, tests suggested here should only be considered as a work basis and should be refined in the future.

An equilibrium should be established between risks associated to performing these tests and risks of not doing them. For example, in France, for hydrogen admixture rates lower or equal to 2%, no safety check is required. This position should also be considered for hydrogen concentrations such as 5%, 6% or 10%.

Although we have a more precise idea of what should be done during a safety check as well as its duration, there are many questions still left unanswered as, for example, the following ones:

- Can all installers perform this check (with an additional training as in L/H)?
- Gas cylinders:
    - How to perform safely the transport of gas cylinders?
    - Is it safe to introduce gas cylinders within a home? What about apartments (gas cylinders in a lift?)
    - Could the use of gas cylinders cause extra safety problems?
- What to do if there is no technical information of the device?
- How to check combustion for built-in appliances (decorative fires) or if appliance has no specific connection point?

6. List of Illustrations

7. List of tables

8. List of references

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