HyDelta

WP1C – Pipes and indoor installations (components)

D1C.6 question 61 - The development of indoor installation components suitable for 100% hydrogen

Status: final

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Summary

Research is being carried out within the framework of the national HyDelta research programme with the aim of removing barriers to hydrogen projects. Work package 1C of HyDelta deals with main pipelines, connecting pipes, gas meter installations and indoor installations. A range of research questions have been drawn up in order to investigate these topics more in-depth. See Appendix I.

The research question discussed in this report (question 61) is as follows:
How do the developments align for all the components that are suitable for 100% hydrogen in the distribution network (including connections), for indoor installations and for gas burning appliances behind the meter so that the entire chain is coordinated?

Here, the focus is on developments in materials for indoor installations and gas burning appliances.

In order to answer sub-question 61, a questionnaire was compiled for the purposes of conducting interviews, which was coordinated with the Expert and Assessment Group (EAG). These interview questions relate to regulations and the certification process, as well as to manufacturer developments and to experiences gained during pilot projects.

The total number of 26 interviews conducted indicated the following:

At the moment, the components behind the gas meter have not yet been fully adapted for use with 100% hydrogen. However, manufacturers and regulatory bodies are actively working on this issue.

Existing installations cannot be converted one-to-one to 100% hydrogen for the following reasons:

- Existing natural gas appliances are not suitable for hydrogen from a technical and regulatory standpoint.
- Existing flue gas systems may not all be suitable. Suitability must first be demonstrated by a party that is willing and able to take on responsibility for this.
- Existing indoor pipes may not all be suitable[1]. Here too, suitability must first be demonstrated by a party that is willing and able to take on responsibility.

For new installations, the following materials have been or will be used in pilot projects:

- Combi boilers (appliances for both central heating and domestic hot water), field test version; also cooking hobs and fireplaces in the United Kingdom.
- Flue gas systems: with a self-declaration from the manufacturer
- Pipe materials: only with Gastec QA mark for natural gas.

[1] The report “Future-proof gas distribution networks” by Kiwa Technology (2018) mentions the use of gas pipe materials in the application of hydrogen. However, that study only includes materials used for distribution networks. Indoor pipe materials such as PEX, multilayer pipes and the related couplings were not considered in that study.

In the near future, several manufacturers will introduce the following products to the (consumer) market:

- Pipe systems suitable for hydrogen with the Gastec QA mark (from 2022). The QA quality mark will be accompanied by the text: “Hydrogen ready according to AR 214” or in Dutch “Bestand tegen waterstofgas volgens KE 214”
- Combi boilers suitable for hydrogen with CE marking (from 2023)
  These hydrogen appliances are not approved for operation on natural gas, not even for just a few seconds. That means that when switching from natural gas to hydrogen, the last remaining litres of natural gas also have to be removed from the pipeline.
  However, H_2 ready appliances are being developed. These are suitable for natural gas and are easy to convert to hydrogen.

Contents

1. Introduction

1.1 General

This study has been carried out within the framework of the national HyDelta research programme. The programme focuses on the safe integration of hydrogen into the existing gas transport and distribution infrastructure and aims to remove barriers that hamper innovative hydrogen projects. The complete research programme is divided into work packages. For an explanation of the various work packages, please visit www.hydelta.nl.

1.2 Problem definition

The developments for using hydrogen in a built environment are currently focused on the distribution of hydrogen. However, in order to safely introduce hydrogen, it is important for the entire chain starting from distribution up to and including indoor installation and appliances to be coordinated and to be made suitable for 100% hydrogen. For the time being, developments for hydrogen in indoor installations are lagging behind those in the area of distribution.

1.3 Objective

Mapping out developments in various stages of the chain in the built environment and identifying and addressing remaining components[2] and any associated risks.

1.4 Research question 61

This report answers research question 61 from Work Package 1C: Pipes and Indoor Installations.

The research question is as follows:

How do the developments align for all the components that are suitable for 100% hydrogen in the distribution network (incl. connections), for indoor installations and for gas burning appliances behind the meter so that the entire chain is coordinated?

This question concerns developing materials for indoor installations and gas burning appliances so that they are able to be connected to a distribution network operating on 100% hydrogen.

1.5 Procedure

In order to answer question 61, questionnaires were prepared for the purpose of conducting interviews, which were coordinated with the Expert and Assessment Group (EAG). See Appendix IV. These questionnaires deal with regulations and the certification process, with manufacturer developments and with experiences in pilot projects. In the various pilot projects, existing indoor pipe systems and their components, new appliances (only approved for safe use in the pilot projects) and flue gas exhaust systems were used.

To answer these questions, interviews were conducted with representatives of certification bodies, manufacturers and with project initiators of pilot projects in the Netherlands, the United Kingdom (UK) and Italy. Although not all parties working with hydrogen (in the Netherlands and abroad) were

[2] Remaining components: indoor installation components that are not replaced when a residence is switched from natural gas to hydrogen. With regard to risks, see the report as compiled within the context of HyDelta WP1C, D1C.5 sub-question 101; risks in using hydrogen in place of natural gas.

interviewed, the interviews paint a picture of the current situation regarding materials that are suitable and permitted for indoor use with hydrogen.

1.6 Reading guide

The findings of the interviews, supplemented with other available information, are contained in chapter 2: Regulations and certification, chapter 3: Manufacturers and chapter 4: Pilot projects. Chapter 5 presents the conclusions.

The overview of references (page 24) is followed by the appendices:
Appendix I contains all of the questions from Work Package 1C of HyDelta. Appendix II names the participants of the Expert and Assessment Group in this study. Appendix III contains a list of all interviewed parties. Appendix IV includes the questionnaire.

2. Regulations and certification

This chapter is based on interviews with Kiwa Gastec UK, Kiwa Italy, Kiwa Netherlands and on the authors' own knowledge

2.1 Gas appliances

Regulations and certification

Hydrogen combustion appliances, just like natural gas appliances, must bear a CE marking according to the European Gas Appliance Regulations (GAR) when they are placed on the market. This means that the following two conditions have to be met as a minimum:

1. A Notified Body appointed by the government has established that the product complies with the GAR (has approved the product).
2. The manufacturer has entered into a certification contract with a Notified Body

Figure 1: CE marking for gas appliance based on the GAR

Because the requirements of the GAR are very general, it is difficult to assess a product solely on the basis of these “regulations”. For this reason, the GAR is associated with a system of standards that are much more concrete in nature. Tests and assessment criteria are defined in these so-called harmonised standards. “Harmonised” means that the Member States have agreed that the standard is a correct interpretation of the GAR. Other methods of assessment are still possible but can be more easily challenged.

One drawback of using harmonised standards is that they often take years to create. Manufacturers who develop innovative appliances must therefore sometimes resort to the GAR, since a relevant standard does not yet exist.

Prior to the final CE marking, the Notified Body may approve a gas appliance for a field test. The appliance complies with all safety requirements but is not yet given the final CE marking. This allows the manufacturer to gain experience with the appliance and to incorporate findings into the final design before entering into mass production.

Standards (current situation)

Standards for hydrogen appliances are not yet available within the scope of this research. Inspections for gas appliances therefore take place based on natural gas standards in combination with a risk inventory in which the properties of hydrogen are explicitly considered. A useful tool in this regard may be the PAS 4444 [1], issued by the British Standards Institute. Although Brexit is now a reality, the method of testing and certification will be based on the same principles as those in the EU for the time being.

There is also a German standard for 0 - 20% admixtures: ZP 3100. This covers the entire range of hydrogen admixtures from 0 to 20% in natural gas.

Development of standards

Within the European Gas Research Group (GERG; www.gerg.eu) European Member States are working on a project with the aim of updating all gas-related EN standards with requirements and test methods for combustion with hydrogen. Eight working groups are now active. Working group 8 is focusing on applications for end users in residential and non-residential buildings. In autumn 2021, this working group will publish a report analysing the knowledge gaps needed to be closed in order to complete these standards. The following steps will involve additional research and, ultimately, modification of the standards.

However, this does not mean that work on hydrogen standardisation will stop until GERG has completed its work. Even now, several committees within the European standardisation umbrella organisation CEN are actively developing supplementary standards. This will be followed by the development of standards for gas composition, central heating appliances and other appliances.

See also the results of HyDelta Work Package 3, as described in the "Development of standards for hydrogen" report.

Gas composition/gas types

NEN-EN 437 [2] is an umbrella standard for ***all*** gas appliances. This standard defines different gas categories, for example the gas category for natural gas with a low Wobbe index or for commercial propane. A nominal gas composition has been defined for each gas category, as well as certain limit gases. These are gases with compositions that are just outside of the normal range, but that still require testing.
At the moment (autumn 2021), hydrogen has not yet been included in NEN-EN 437. However, test gases up to an admixture of 20% have been included in the series of appliance standards NEN-EN 15502 [3] (more on this topic under the heading "Central heating appliances"), in anticipation of the publication in NEN-EN 437.

Central heating appliances

An ad hoc working group from the standards committee[3] for the series of standards NEN-EN 15502 ('Gas-fired central heating boilers') is working on two subjects:

1. Admixtures of up to 20% hydrogen, and
2. 100% hydrogen.

The documents for 20% are nearly ready for submission to CEN[4] (Technical Committee 109 Working Group 1). If CEN approves these documents, they will be issued as a provisional standard (prEN) and a public consultation period will follow before they are published as an EN standard.
The committee is currently (autumn 2021) working on 100% hydrogen.

Cookers

NEN-EN 30 is an important standard for cookers. There have not yet been any significant steps taken towards standardisation for hydrogen-powered cookers.

[3] This is NEN standards committee 349.057
[4] CEN (Comité Européen de Normalisation, www.cenelec.eu)

Sub-conclusion

In theory, it is already possible to market hydrogen-powered central heating appliances under the current regulations (GAR). Both manufacturers and government-appointed inspection bodies can use documents such as the British PAS 4444 to develop and test 100% hydrogen appliances.

For lower concentrations of up to 20%, an initial version of the standard will soon be submitted to the European standardisation body, CEN.

2.2 Flue gas materials

Regulations and certification

The regulation and method of certification for flue gas materials is very similar to that used for gas appliances as described above. Flue gas materials are also subject to the CE-marking system and to European standards. The European regulation generally in force is the CPR (Construction Products Regulations). A flue gas system can also be inspected as an accessory to a specific gas appliance. It then falls under the GAR, just like the gas appliance concerned (see “Regulations and Certification” in section 2.1).

Standards and development of standards

Two different technical CEN committees are currently working on EN standards:

1. An ad hoc working group of TC109 is working on the technical requirements for 20% and 100% hydrogen:
   - The 20% section is at an advanced stage.
   - The 100% section will be addressed soon.
2. TC 166 determines which corrosion class a flue gas exhaust system for hydrogen-powered appliances should fall under.
   Explanation
   A corrosion class indicates which corrosive conditions flue gas exhaust equipment should be suitable for, and therefore under which conditions it should be tested. Class 1 is currently being considered (the lightest class, which also includes normal fossil gases).

Sub-conclusion

Just as with natural gas appliances, it is already possible to place flue gas materials for hydrogen appliances on the market under the current regulations. However, there are no definitive EN standards available as of yet. Nevertheless, there are two committees working on the development of these standards.

2.3 Gas pipe materials and appendages

Regulations and certification

There is no mandatory system for inspecting and certifying gas pipe materials and appendages as there is for gas appliances. However, gas pipes do fall under the European Construction Products Regulations (CPR). This means that as soon as a relevant standard comes into force under the CPR, the material concerned will be required to comply with it. There is, however, no inspection system as with the GAR.

In the Netherlands, gas pipes have to comply with a number of performance requirements that are mentioned in NEN 1078 [4] (new buildings) or NEN 8078 [5] (lower limit quality existing buildings).

The Netherlands has brought these standards in line with the European standards NEN[5]-EN 1775 [6] and NEN-EN 15001 parts 1 and 2. [7].
Although any material may be used in theory, in the Netherlands materials with the Gastec QA mark are commonplace[6]: manufacturers use the quality mark to demonstrate the suitability of their materials, installers in turn use the material to show that their installations are built with suitable components.

Figure 2: Gastec QA mark

Approval requirements

To assess whether a certain type of material or accessory for gas may carry the Gastec QA mark, there is a set of approval requirements (AR); a kind of standard. For example AR 5 for copper pipes or AR 168 for self-closing gas valves. These ARs apply partly to distribution materials and partly to installation materials.

In the past, the approval requirements were established for the application of natural gas. Due to market demands, they have recently been extended to hydrogen. However, not every separate AR has been adapted for this purpose. Instead, an umbrella AR has been developed, AR 214 [8]. This document is an addition to existing approval requirements for natural gas. It is being developed at an accelerated pace. The hydrogen inspections based on AR 214 are subject to an accreditation process and therefore have an equivalent quality level to many other Gastec QA approval requirements.

Initially, this expansion only covered distribution materials, but a new draft version has now been developed that also includes indoor pipe materials. In many cases, the expansion of approval for natural gas to approval for hydrogen can be carried out based on material tables in AR 214. However, there are also additional requirements that have to be examined in the laboratory. These primarily concern:

- Leak tightness (e.g. ball valves may have much lower leakage rate for hydrogen than for natural gas).
- Function of components with moving parts (flow restrictors, pressure regulators etc.)

The Netherlands versus other European countries

Especially when it comes to internal piping materials, the fact that system certificates are widely used in the Netherlands, especially for plastic and multilayer pipes, plays a role. For example, a certificate

[5] In the Netherlands, NEN standards are used. European (EN) standards are therefore published by the Dutch standardisation institute NEN with the prefix NEN. So in this case: NEN-EN 1775.
[6] https://www.kiwa.com/nl/nl/markten/energie-en-energiemanagement/energy/energy-using-products/gasdistributie-materialen/gastecqa-keuringseisen/

for a pipe system where everything is part of the system (pipes, couplings, appendages and assembly tools such as press fitting machine).

In other countries, system certificates are used much less frequently. And plastic in general is also used less extensively. The same EN standards are often used for product approvals for natural gas materials in other Member States as we use in the Netherlands. The current draft of AR 214 [8], which also includes indoor pipe materials, fits in well with this situation. This draft version will first go to certificate holders for review, and then to the panel of experts. It is expected that this draft will be approved at the end of 2021 or the beginning of 2022.

In CEN/TC 234, work is being done to coordinate the activities of the various working groups in order to supplement the European Standards already available for the application of 0-100% hydrogen in pipe systems. For this purpose, a preliminary draft of a technical document has recently been prepared by CEN TC 234 [9]. The voting process on this document among European Member States will continue through December 2021. A positive vote will lead to the work in the various European working groups under CEN/TC 234 “Gas Infrastructure” and eventually to the amendment of the European standards. This process is expected to take several years. Ultimately, this process will also have consequences for the Dutch standards and practical guidelines.

3. Manufacturers

3.1 Gas appliances

Interviewed: Intergas, Remeha and Nefit Bosch, Kiwa NL and Kiwa UK

100% hydrogen

All three of the manufacturers interviewed have developed a working prototype of a combi boiler. In field tests, all three have used a provisional version on a more modest scale (10 to 100).

Nefit Bosch is introducing an H_2 ready appliance based on the existing product line under the name of Worchester. This brand/type will be used primarily in the UK. A field test is currently being conducted.

Intergas is introducing a 100% hydrogen appliance based on the current natural gas type Intergas Extreme 30 in terms of its format and aesthetics. The tap water class will be CW3 or CW4. This type has been inspected by Notified Body Kiwa Nederland and approved for demonstration purposes.[7] The device is being used in the "hydrogen tiny house" of the municipality of Hoogeveen. This is a demonstration house for energy coaches and other stakeholders in energy transition.

In addition, Intergas will also be supplying the appliances for a field test in Wagenborgen[8] (Groningen), in a total of approximately 30 housing units of a housing corporation.

Remeha is working towards a situation with four product lines for central heating appliances, based on gas type:

1. Natural gas (as with current appliances)
2. Natural gas, suitable for fluctuating admixtures with 0-20% hydrogen (already available)
3. Hydrogen (100%); one type in mass production from 2023, several types (varying capacities) from 2024.
4. H_2 ready: an appliance suitable for natural gas that can be easily converted to 100% hydrogen by qualified personnel. Target for mass production starting from 2024.

Itho Daalderop

One manufacturer that will **not** be making the switch to hydrogen is **Itho Daalderop**. This company manufactures numerous electrical appliances and has a small market share in gas appliances. On 25 October 2021, "Installatienieuws" published a report that the company is going to stop producing central heating appliances [10] in order to focus entirely on heat pumps.
N.B. Itho Daalderop was not interviewed for this HyDelta project.

Sub-conclusion: 100% hydrogen appliances

The following applies to 100% hydrogen appliances and 100% H_2 ready appliances: The appliance types for the field tests have not yet been released as consumer products, which means they do not yet have a CE marking. There are several reasons for this:

[7] Demonstration: a form of field test used as a preliminary stage for CE marking. You can read about field tests in section 2.1 under "Regulations and certification".
[8] Chapter 4 takes a closer look at a number of pilot projects.

- Some safety-relevant components of a central heating appliance (burner control, safety valve) must themselves bear the CE marking before the appliance as a whole can receive CE marking. The suppliers of these products are nearing completion of this process.
- The results of the field tests are being incorporated into the final appliance design. The final design that is approved for CE may not be subsequently modified, unless a part of the inspection process is repeated.

Temporarily running a hydrogen appliance on natural gas?

To facilitate a smooth conversion of part of the gas distribution network, it would be beneficial if a 100% hydrogen appliance could temporarily run on natural gas for a short or longer period of time. This would allow all the natural gas appliances concerned to be replaced by hydrogen appliances, after which the gas network could be "switched over" to hydrogen without the need for a technician inside the house.
However, none of the manufacturers interviewed has incorporated this feature into the appliance. One manufacturer indicated that this would make the appliance too expensive and therefore unattractive to consumers.

It would also be beneficial if the hydrogen boiler could be safely switched off when the gas network is converted.
The manufacturers stated that although the appliance is not designed and tested for this purpose, that does not necessarily mean that the appliance would not switch off safely. One manufacturer pointed out that the flame would blow out due to the much lower combustion rate of natural gas, causing the appliance to shut down due to flame failure. As the appliances are not designed for this, it is not the intention for the appliances to be supplied with natural gas, not even temporarily.

Technical challenges for a 100% hydrogen appliance as compared to a natural gas appliance include:

Flame supervision:
- Ionisation flame supervision does not work because there are no radicals[9] in the flame to provide conduction.
- Supervision based on light cells does not work because the flame does not emit visible light.

Temperature resistance:
- The base of the flame is hotter. This places a greater demand on the burner material.

Preventing flashback of the flame
- Hydrogen has a higher combustion rate and a lower minimum ignition energy. For this reason, particular attention needs to be focused on the scenario of flashback in the burner (and subsequently in the pipe installation), should air be present in addition to hydrogen.

Training installation personnel.
- Ensuring the timely availability of suitable personnel for conversion operations. Maintaining contact with the training institutes for this purpose.

9 Radicals: atoms or molecules with one or more unpaired electron(s). In the case of ionisation flame supervision, these enable charge (electric current) to be transported between the ionisation probe and the mass of the appliance.

Hydrogen, added to natural gas

Various appliances have already been certified for natural gas with a hydrogen admixture of 20%. Kiwa Nederland alone has certified two manufacturers for this purpose.

Cookers

Interviewed: Atag Keukentechniek

The company intends to develop hydrogen-powered appliances within the "visible horizon", a time frame of five years. At the moment, however, there is still too much uncertainty to proceed: It is not yet clear which gas composition the future sustainable gases will consist of (in particular the concentration of hydrogen admixtures, or whether it will be 100% hydrogen). Nor is the composition of the test gases known. It is unclear whether there will be a sufficient (Dutch) market for hydrogen-powered appliances. Media reports about the need to "do away with gas" have not helped sales. Specifically in the Netherlands, consumers seem more inclined to choose electric cooking options.

Using a mixture with a few dozen percentage points of hydrogen is technically feasible, as it probably does not require many adjustments. The current G24 natural gas limit already contains 20% hydrogen. Earlier studies have shown that an admixture of natural gas with 20 to 25% hydrogen is very feasible.

The design of the burners may have to be modified depending on the admixture. This could include different materials or a different burner configuration.

Technical challenges for a 100% hydrogen cooker include:

- Visibility of the flame
- Burner material
- Flame protection

3.2 Flue gas systems

Interviewed: Muelink & Grol, Kiwa NL, Kiwa Italy

Muelink & Grol (M&G) indicated that they have already submitted their PP material (polypropylene, under the trade name: Burgerhout) to a Notified Body for testing. However, at the moment it is not yet clear whether additional testing will be required on material that already has a quality mark for natural gas. The various standards committees (see section 2.2) are still working on amending the standards.

In anticipation of this, M&G commissioned a limited theoretical analysis by Kiwa Nederland in 2019 to determine the suitability of the material in a PP outlet. Based on the results, the current material for pipes and sealing rings appears to be suitable for condensing appliances ("HE appliances") running on 100% hydrogen [11].

The Dutch and Italian Notified Bodies do not have any further comments on this with regard to developments at manufacturers other than M&G.

Technical challenges for flue gas systems for hydrogen appliances include:

Recirculation via the roof or wall terminal
How much may a roof or wall terminal (combined supply and exhaust construction) resupply (recirculate) flue gas so as not to affect the appliance/combustion? Are roof and wall terminals suitable for natural gas appliances also suitable for hydrogen?

Condensate collection
Hydrogen combustion releases more water vapour than natural gas does. Some of this vapour condenses in the flue system and becomes condensation water. Is the current condensate collection system sufficient to enable it to be drained?

Corrosion resistance
It is possible that condensation water is more corrosive than natural gas.
The service life should be at least equal to that of a flue gas system for natural gas (usually at least 15 years).

Pipe section slope for flue gas system
Because more condensation water is released, there is also the question of whether the current slope requirement for horizontal pipe sections is sufficient for hydrogen.

Connection of pipe sections
The extent to which the connections need to be resistant to the force of an explosive ignition of a hydrogen appliance. Is the material suitable for natural gas appliances also suitable for hydrogen?

Dilution distance
Will the dilution factor 'f' in the Dutch building regulations change? Will this then change the distance between the outlet and the inlet opening for room ventilation? Flue gases from hydrogen appliances contain, among other things, NOx, which is harmful when inhaled.

Visual nuisance
Will the condensate plume at the outlet be more intense? What does this mean in regards to visual nuisance?

3.3 Gas pipe materials and appendages

Interviewed: Aalberts integrated piping systems, Henco, Uponor, Viega

The manufacturers interviewed all have the voluntary quality mark Gastec QA for natural gas on their piping systems, but so far not for hydrogen. This is not possible at the moment, as the Gastec QA-approval requirements have not yet entered into force (see section 2.3). As soon as this is possible, the manufacturers intend to have their products certified for Gastec QA. At a minimum, this concerns the copper and multilayer pipe systems. The systems with single-layer plastic pipes may not be certified for hydrogen as the market for natural gas is already small.

The manufacturers are already doing the following in anticipation of the inspections:

- providing input for approval requirements;

- obtaining information from suppliers on the suitability of the materials used for hydrogen (HDPE, PVDF plus HNBr rubber):
- testing with hydrogen in (foreign) test laboratories (regarding mechanical properties, permeation, leak tightness); and
- participating in pilot projects.

As soon as the approval requirements are finalised, several manufacturers will submit their systems for approval.

4. Pilot projects

For this study, project initiators from two foreign (UK[10]) and four Dutch pilot projects were interviewed. In this chapter, the projects will first be described in brief (section 4.1) and afterwards, the implications this holds for the present study will be considered (sections 4.2 and 4.3).

4.1 Short description of pilot projects

Scotland: H100

Interviewed: Kiwa Gastec UK

Hydrogen source:	Green hydrogen, generated with electricity from a 7 MW offshore wind turbine.
Users:	300 to 1000 residential units
Indoor piping system:	Standard copper piping system as used for natural gas.
Combustion appliances:	Combination heating appliances, cooking hobs, hydrogen fireplaces.
Material suitability assessed:	Based on Kiwa NL report and test work done by Kiwa UK.
Additional mitigating measures compared to natural gas?	Yes[11]

Wales and Northwest: HyNet/Homes

Interviewed: Kiwa Gastec UK

Hydrogen source:	Blue hydrogen, locally produced
Users:	About 2000 residential units
Indoor piping system:	Not yet known, project is still in the formulation phase
Combustion appliances:	Not yet known
Material suitability assessed:	Not yet known
Additional mitigating measures compared to natural gas?	Not yet known

[10] Remarks on the UK projects:
In the project proposal for research question 61 (7 May 2021), the projects Hy4Heat and H21 are mentioned. Unoccupied test sites were used for these programmes. These projects will be described in the WP1A report. A considerable amount of information is already available on the websites of Hy4Heat and H21. The actual pilots in the UK have not yet started and are now summarised here (source: Kiwa Gastec UK).

[11] For the overviews in this section, the only important factor is whether mitigating measures have been applied, as this means that experience still has to be gained in a safe environment. **Which** specific measures are applied are not the subject of research question 61.

Wagenborgen (Groningen): Hybrid heating

Interviewed: Enexis

Hydrogen source:	Green hydrogen, produced by a farmer located a few kilometres away. Distribution to Wagenborgen via new pipeline.
Users:	30 existing terrace houses
Indoor piping system:	Probably multilayer pipes
Combustion appliances:	Peak heating and hot tap water with hybrid hydrogen heat pumps.
Material suitability assessed:	Based on Gastec QA mark according to the revised AR 214
Additional mitigating measures compared to natural gas?	Yes

Uithoorn: Unoccupied residential units with old pipes and new appliances

Interviewed: Stedin

Hydrogen source:	Bottled gas
Users:	14 unoccupied residential units
Indoor piping system:	Existing pipes ranging from 60 years old (from the time of construction) to modern pipes, such as copper, steel and multilayer.
Combustion appliances:	Remeha and Nefit-Bosch appliances (types approved for field tests).
Material suitability assessed:	The materials were assessed during and after the testing period. Pilot assembled in autumn 2020 and dismantled at end of 2020. Approximately 1 week on natural gas, 1 week test on nitrogen, 1 week helium, 1 week hydrogen and the residential units heated on hydrogen for 1 week. Experience: All materials are suitable for hydrogen. When testing with helium, leaky connections were found and repaired (reviewed). The system was then gas-tight for hydrogen. The hydrogen boilers work well.
Additional mitigating measures compared to natural gas?	Yes

Delft: Green Village with WaterstofStraat

Interviewed: gAvilar, Aalberts Hydronic Flow Control

Hydrogen source:	Bottled gas
Users:	Public space for experimentation including three inhabited residential units.
Indoor piping system:	Not yet known
Combustion appliances:	Remeha Hydra appliance.
Material suitability assessed:	Own laboratory tests and general reports.
Additional mitigating measures compared to natural gas?	Yes

Hoogeveen: new and existing residential units

Interviewed:

Hydrogen source:	Grey hydrogen (tube trailers), then Green hydrogen (generated at nearby WWTP), then Green hydrogen (connection to Gasunie main transport network (H_2-backbone))
Users:	First, newly built residential units (2022) and, in a subsequent phase, existing residential units. A total of four phases ultimately comprising 518 residential units (2027)
Indoor piping system:	Based on quality mark
Combustion appliances:	Remeha was chosen for the first instalment
Material suitability assessed:	Based on (preliminary stage of) CE marking (central heating appliance) or via other quality marks (indoor pipes).
Additional mitigating measures compared to natural gas?	Yes

4.2 Evaluation

Many projects are still in preparation or are not yet completed. The following only contains the information that is known to date.

Existing pipelines reused for hydrogen

Existing pipelines have been reused in the projects in Wales and Uithoorn. However, the project in Wales has not yet been carried out, so the results are not yet known. In the Uithoorn project, the indoor pipes were first tested with helium. Three couplings with slight leakage were found. After repairing the leaking couplings, the system was filled with hydrogen for a fortnight. The system proved to be gas-tight to hydrogen.

New gas pipes

New gas pipes will be laid for the project in Wagenborgen and for phase 1 of the project in Hoogeveen. In Wagenborgen, multilayer pipes will most likely be chosen. Both projects are expected to use materials with the Gastec QA hydrogen quality mark (if available).

Gas appliances

In all six projects, new gas appliances designed for 100% hydrogen have been or will be chosen.

Among the UK projects, only the Welsh project is known to be using combination heating appliances, cooking hobs and fireplaces. These will first be tested extensively for safety before being used.

In the Dutch projects, only combination heating appliances will be applied and no other gas appliances. EU regulations apply to these projects, which means that gas appliances need to bear the CE marking (see section 2.1). In the preliminary phase before CE marking, however, use of field test equipment is permitted. The certifying body then gives permission for a certain type of appliance to be used on a limited scale in practice. These appliances are safe to use, but the manufacturer can build in one or more checkpoints in the usage phase so that lessons can be learned before taking the final version into mass production.

At the moment, a handful of combination heating appliance types have been approved for field testing. The appliances that have been or are being used in the pilots mentioned have obtained this type of approval.

The first central heating appliances with CE marking are expected to be available to consumers in 2023.

Mitigating measures

In all pilot projects, additional mitigating measures have been or are being implemented in order to gain experience in an ultra-safe environment.

4.3 Sub-conclusion

Practical experience with existing natural gas pipelines converted to hydrogen is limited to 2 weeks. No defects have occurred that were not already present with natural gas. As of yet, no projects have been carried out that provide long-term findings.

No practical experience has yet been acquired for new pipelines in the Netherlands. In pilot projects, materials with the Gastec QA quality mark based on approval requirement 214 (version including indoor pipe materials, to be completed in early 2022) will be chosen.

For practical tests, field test specimens with approval by the Notified Body will be used in the Netherlands.

5. Conclusions

At present, the components behind the gas meter and the associated regulations have not yet been fully modified for the application of 100% hydrogen. However, manufacturers and regulatory bodies are actively working on this issue. The development of rules and products is more or less the same here.

Interviews with representatives from the certification process, manufacturers and with project initiators of pilot projects in the Netherlands have revealed the following:

Existing installations cannot be converted one-to-one to 100% hydrogen for the following reasons:

- Existing natural gas appliances are not suitable for hydrogen from a technical and regulatory standpoint.
- Existing flue gas systems may not all be suitable. Suitability must first be demonstrated by a party that is willing and able to take on responsibility for this.
- Existing indoor pipes are possibly not all suitable. Here too, suitability must first be demonstrated by a party that is willing and able to take on responsibility.

For new installations, the following materials have been used in pilot projects:

- Combination heating appliances (field test version)
- Flue gas systems: with a self-declaration from the manufacturer
- Pipe materials: only with Gastec QA mark for natural gas.

In the near future, several manufacturers will introduce the following products to the (consumer) market:

- Pipe systems suitable for hydrogen with the Gastec QA mark (from 2022). The QA quality mark will be accompanied by the text: “Hydrogen ready according to AR 214” or in Dutch “Bestand tegen waterstofgas volgens KE 214”
- Combination heating appliances suitable for hydrogen with CE marking (from 2023).
  These hydrogen appliances are not approved to be powered by natural gas, not even for a few seconds. That means that when switching from natural gas to hydrogen, the last remaining litres of natural gas also have to be removed from the pipeline.
  However, hydrogen-ready devices are being developed. These are suitable for natural gas and are easy to convert to hydrogen.

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I List of questions HyDelta WP1C

The following questions are addressed in this work package.

- Question number HyDelta 187: Research into the safe commissioning and decommissioning of pipeline sections in hydrogen distribution during the conversion to a hydrogen network and the associated costs.
- Question number HyDelta 124: Research into the performance of strength and density tests.
- Question number HyDelta 135: What is the effect of the existing gas network on the quality of hydrogen in distribution and transport?
- Question number HyDelta 185: Home pressure regulator: What are the risks if it is not modified?
- Question number HyDelta 101: Investigation of risks related to existing gas installations (at the customers) when converting from natural gas to 100% hydrogen.
- Question number HyDelta 61: How is it ensured that the developments of all components suitable for 100% hydrogen are integrated - in the distribution network (incl. connections), in the indoor installation and in the gas consumption appliances in homes and businesses - so that the entire chain is compatible?
- Question number HyDelta 55: What will a conversion to a hydrogen network look

II List of participants Expert- and Assessment Group (EAG) question 124

Table 1. Composition Expert- and Assessment Group (EAG)

Name	**Employer**
D. Nieuwenhuizen	Stedin
H. Smit	Enexis
W. Koppenol	Enexis
W.R. Nispeling	Alliander
R. den Hartog	Westland Infra
J. Jonkman	RENDO
R. Scholten	RENDO
C.H. Hermsen	Hermsen Installatiegroep
F. van Gijtenbeek	Henco
D. Vroman	Henco
F. Vos	Techniek NL
R. van den Tempel	Remeha
V.M.A. Barendregt	HSF
S.L.M. Lueb	Kiwa Technology
H.J.M. Rijpkema	Kiwa Technology
H. Salomons	Kiwa Technology

III Interviewed parties and persons

Table 2. Interviewed parties and persons

Subject		Name	Employer
Testing and certification	Appliances	J. Meuleman	Kiwa Nederland
	Gas pipe materials and appendages	F. van Halem	Kiwa Nederland
	Gas pipe materials and appendages	W. Blumink	Kiwa Nederland
	Flue gas systems	M. Breda	Kiwa Italy
	Appliances UK	A. Pittaway /G. Kaval	Kiwa Gastec UK
	Appliances UK	S. Faderani/B. Higinbotham	Kiwa Gastec UK
	Appliances UK	M. Crowther	Kiwa Gastec UK
	Appliances UK	Ph. Brain	Kiwa Gastec UK
	Appliances UK	I. Summerfield	Kiwa Gastec UK
	Appliances UK	P. McLaughlin	Kiwa Gastec UK
Involved in pilots	Wales (HyNet Homes)	I. Summerfield	Kiwa Gastec UK
	Schotland (H100)	P. McLaughlin	Kiwa Gastec UK
	Uithoorn	F. van Alphen	Stedin
	Wagenborgen	W. Koppenol	Enexis,
	Hoogeveen	B. Meijer	N-Tra
	Delft, H2@Home	L. Mostert	gAvilar
	Delft, H2@Home	B. Mureau	Aalberts Hydronic Flow Control
Production	Cooking appliances	M. van Bruggen	Atag Keukentechniek
	Flue gas systems	H. Bruining	Muelink en Grol
	Piping systems	F.van Gijtenbeek/D.Vroman	Henco
	Piping systems	P. Broest	Aalberts Integrated Pipe Systems
	Piping systems	C. Verlinden	Viega
	Piping systems	M. Bohl	Uponor
	Gas appliances	R. van den Tempel	Remeha
	Gas appliances	H. Wierenga	Nefit Bosch
	Gas appliances	G. Zijlstra	Intergas Verwarming

IV Applied questionnaire

Questionnaire

This questionnaire is part of HyDelta Work Package 1C piping and indoor installations and relates to research question 61.

The colored columns indicate which category applies to which interviewed.

Kiwa Netherlands:	Departments for testing and certifying equipment, piping systems and flue gas discharge systems.
Kiwa UK & H21 UK	Departments involved in testing and certifying equipment and the departments involved in projects defined under Hy4heat in the UK. DNV-GL involved in projects defined under H21 in the UK, as far as internal installations are concerned.
Pilot projects	Parties involved in pilot projects
Manufacturers:	Manufacturers of gas appliances, piping systems and flue gas discharge systems, these terms are abbreviated in the tables on pages 2 and 3.

Appendix: Questionnaire per category interviewed

Question number	Survey question 61 questionnaire	Interviewed category								
		Kiwa NL			UK			Manufac-turers		
		Kiwa NL Appliances	Kiwa NL Piping Syst.	Kiwa NL Flue Syst.	Kiwa UK	H21	Pilot projects H2	Manufact. Appliances	Manufact Piping Syst.	Manufact. Flue Syst.
	Questions about testing and certification									
1	What standards and testing requirements are currently available for the approval of **gas appliances** in relation to hydrogen? For example, is hydrogen included in EN 437 (standard for test gases)?	V			V	V				
2	What standards and testing requirements are currently available for the approval of **gas piping materials and components** related to hydrogen?		V		V	V				
3	What standards and testing requirements are currently available for the approval of **flue gas discharge systems**?			V	V	V				
4	What specific equipment/components are these standards and test requirements applicable to?	V	V	V	V	V				
5	What standards and testing requirements are being developed for certification in relation to hydrogen?	V	V	V	V	V				
6	Which manufacturers have already appliances/components had tested on hydrogen? Which components does it concern?	V	V	V	V	V		V	V	V
7	Are hydrogen-tested appliances also tested for **short-term** (hours) operation on natural gas? If so, to what percentages of natural gas in hydrogen can such an appliance operate? *Explanation: This can be useful when converting a house from natural gas to hydrogen, when there is still some natural gas in the gas piping.*	V			V	V		V		
8	Is the possibility of using natural gas for a long period of time (days/weeks/years) taken into account in the case of testing? *Explanation: This can be useful when converting (parts of) streets, neighborhoods etc. This allows the appliances to be switched first and then connected to hydrogen (possibly after a small adaptation to the appliance).*	V			V	V		V		
9	Are hydrogen-tested devices also tested for safe **shutdown** when natural gas is offered? If so, at what percentage of natural gas?	V			V	V		V		
	Questions about the manufacture of products and/or the placing on the market									
10	Are your components currently suitable for 100% hydrogen?							V	V	V
11	Are your components currently suitable for mixtures of natural gas and hydrogen? What mixing ratios?							V	V	V
12	Can answers [10] and [11] be proven with test reports?							V	V	V
13	Can answers [10] and [11] be proven with own tests or practical experiences?							V	V	V
14	Are you developing components specific to hydrogen or natural gas/hydrogen mixtures?							V	V	V
15	Are your components suitable for short-term (hours) operation on natural gas and then on hydrogen?							V	V	V
16	Are your components suitable for day/week/month operation on natural gas and then on hydrogen?							V	V	V
17	Are gas fireplaces suitable for hydrogen developed?	V			V	V	V	V		
18	Are gas cooktop plates suitable for hydrogen developed?	V			V	V	V	V		
19	Are other types of household appliances developed?	V			V	V	V	V		
20	Are products developed that, for example, allow the flushing, blow-off or flaring of natural gas from the inner plant to be safely possible?	V	V		V	V	V	V	V	

Question number	Survey question 61 questionnaire	Interviewed category								
		Kiwa NL			UK			fabric ten		
		Kiwa NL Appliances	Kiwa NL Piping Syst.	Kiwa NL Flue Syst.	Kiwa UK	H21	Pilot projects H2	Manufact. Appliances	Manufact Piping Syst.	Manufact. Flue Syst.
	Questions on pilot projects									
21	What is the purpose of this pilot project?				V	V	V			
22	How is the project set up?				V	V	V			
23	What part of the chain does the project include? *The chain roughly consists of:* *Generation → transport → pressure regulation and measurement → Gas distribution → house pressure regulator → gas meter → gas piping → appliances → flue gas discharge → terminal.*				V	V	V			
24	What is the source of the hydrogen gas? *Gas cylinders, local production, ….?*				V	V	V	-		
25	Which hydrogen appliance users are involved in the project? *For example: Consumers, utilities, … etc*				V	V	V			
26	Is the gas odorized? If so, what type of odorant has been used?				V	V	V			
27	What types of gas appliances have been used in the pilot with 100% H_2? *For example: central heating boilers, boilers, combi boilers, hot plates, decorative fireplaces, ……)*				V	V	V			
28	What equipment has been used for: (Material, brand and type)				V	V	V			
28a	- Gas piping materials and connections (couplings, etc.)				V	V	V			
28b	- Pipe fittings				V	V	V			
28c	- Gas appliances				V	V	V			
28d	- Flue gas discharge systems				V	V	V			
28e	- Reducing system (gas pressure regulator, safety devices, etc).									
29	How has it been demonstrated in advance that these materials are suitable? (test reports), examination reports, etc.				V	V	V			
30	What are the practical experiences with all these materials?				V	V	V			
31	What has been tried, but did not work in practice? And why not? What alternatives have been tried (experiences?)				V	V	V			
32	What turned out to be working well?				V	V	V			
33	What extra mitigation measures have been taken compared to a regular natural installation?				V	V	V			