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PILOT PROJECT ON HYDROGEN INJECTION IN NATURAL GAS ON ISLAND OF AMELAND IN THE NETHERLANDS

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ABSTRACT

The Netherlands, as many other countries, strive for a more sustainable energy mix and efficient energy consumption. Hydrogen, which is one of the energy carriers of the future, plays an important role in this respect. The use of hydrogen, when produced in a sustainable way on a large scale (for instance by means of wind and solar energy) considerably reduces the CO_2 emissions, compared to fossil fuels. Injection of hydrogen in natural gas is one of the possibilities on the route to sustainable gases.

The aim of the injection of hydrogen into natural gas in this pilot project was to obtain knowledge regarding the electrolysis, the mixing process and the behaviour of the gas grid and gas appliances. Different types of mains, joints, service governors, gas meters, boilers and cooking devices were tested. The experiences and the opinion of the end-users were an important part of the pilot project since successful energy transition requires a broad social basis.

This pilot project is part of progamme “Sustainable Ameland”. The project was executed by Joulz, together with Kiwa Gas Technology as subcontractor, on behalf of GasTerra and Stedin. It was the first time that the influence of the injection of hydrogen in the natural gas supply was tested in an actual situation in the Netherlands. This took place in a small scale natural gas grid which supplies the apartment complex “Noorderlicht” in the town of Nes on Wadden Sea island Ameland, of the northern coast of the Netherlands. Apartment complex “Noorderlicht” houses 14 families. Each apartment has its own gas meter and heating system. Gas boilers and cooking appliances have never before been exposed to a hydrogen-natural gas mixture for such a long time. The duration of this project was four years.

Hydrogen was mixed in the natural gas supply from 5% to 20% (volume), increasing the hydrogen content in steps of 5%. After assembling the housing for the electrolyser, the hydrogen supply was switched from hydrogen bottles to on-site production by electrolysis. The electricity needed for generating the hydrogen was produced by solar panels on the nearby new building of the “knowledge and innovation centre”. Thus, the hydrogen used came from a fully sustainable source.

For pipeline materials testing a reference grid and a test grid were added to the existing natural gas grid. These similar grids were constructed especially for this project. The grids were made of components originating from the same batch. The grid contained different pipeline materials for mains, joints, service governors and gas meters. The selected pipeline materials and accessories are commonly used in the Dutch gas network.

The boilers and cooking appliances were selected based on burner principle. These selected appliances are also commonly used in the Netherlands and were not adjusted for hydrogen enriched natural gas. Beforehand all gas appliances were tested by means of test gases containing 30% of hydrogen. This 10% safety margin over 20% was applied to overcome dynamic behaviour (overshoot) of the mixing unit.

The initial state of service governors, gas meters, boilers, cooking devices and opinion of end-users were saved in a baseline measurement. The test data was compared to the baseline data. In case of mains and joints the test measurements of the test grid were compared to the test measurements of the reference grid. In this paper the influence of the injection of hydrogen in the natural gas supply on the gas grid and gas appliances has been evaluated.

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1. Introduction

The Netherlands, as many other countries, strive for a more sustainable energy mix and efficient energy consumption. Hydrogen, which is one of the energy carriers of the future, plays an important role in this respect. The use of hydrogen, when produced in a sustainable way on a large scale (for instance by means of wind and solar energy), considerably reduces the CO_2 emissions compared to fossil fuels. Injection of hydrogen in natural gas is one of the possibilities on the route to sustainable gases.

From 2002 until 2006 the European Commission co-financed the Sixth Framework Project Naturalhy to contribute to the preparation for the hydrogen economy by identifying and removing the potential barriers inhibiting the development of hydrogen as an energy carrier, using the existing natural gas system as a catalyst for change. The Naturalhy project states that the addition of hydrogen to natural gas can make a significant reduction in total greenhouse gas emissions and is an effective means of "greening" natural gas so that the mixture is used directly in existing appliances for heat production and electricity generation. With regard to pipeline durability, Naturalhy results show that effects on pipe materials used in the natural gas grids, caused by hydrogen, can be mitigated by appropriate measures. Modifications to maintain a safe and reliable supply to customers of natural gas / hydrogen mixtures will mainly be necessary for the transportation pipelines made of steel, but importantly, no "show stoppers" have been identified.
For domestic appliances, personal health and home safety are at stake and millions of appliances are involved, that’s why it is important to note that the maximum hydrogen concentration for the domestic market is determined by the safe operation of properly adjusted conventional domestic appliances as well as by the local conditions of natural gas quality (range and current value of Wobbe index). For properly adjusted appliances and favourable conditions of natural gas quality, conventional domestic appliances can accommodate up to 20% of hydrogen.

The “Sustainable Ameland” project was initiated to demonstrate the injection of hydrogen up to 20% into low calorific Groningen natural gas (G25) in practice in order to contribute to the energy transition. Moreover the project enabled the accumulation of experience with the electrolysis, the mixing process and the influence of hydrogen mixture on the behaviour of the Dutch gas grid and conventional gas appliances. It gave the public the possibility to become acquainted with hydrogen mixtures.

2. Aim of the Project and Parties involved

The aim of the injection of hydrogen into natural gas in this pilot project was to obtain knowledge regarding the electrolysis, the mixing process and the behaviour of the gas grid and gas appliances. Different types of mains, joints, service governors, gas meters, boilers and cooking devices were tested. The experiences and the opinion of the end-users were an important part of the pilot project since successful energy transition requires a broad social basis.

This project demonstrates the prospects of the injection of hydrogen up to 20% into the natural gas grid. The project sponsors GasTerra and Stedin both have their own interest to support the project. The project was executed by Joulz, together with Kiwa Gas Technology as subcontractor. Table 1 gives an overview of all participating companies and their principal role.

Party	Role in the Project
Council of Ameland,	Power of decision
GasTerra	Project sponsor (international gas trading company)
Stedin (an Eneco company)	Project sponsor (distribution service operator)
Joulz (an Eneco company)	Project leader (contractor for energy infrastructures)
Kiwa Gas Technology	Subcontractor (supplier of technology)
Nefit, Remeha and Vaillant	Suppliers (manufacturers of gas boilers)
Atag, Etna and Pelgrim	Suppliers (manufacturers of cooking appliances)

Table 1: Participating Parties and their Principal Role in the Project

The council of Ameland is the authority in charge to grant the permit for the project. The Wadden Sea island of Ameland has a beautiful countryside (the Wadden Sea is a world heritage site) and the council of Ameland wants to keep it that way for her community and the over half a million tourists that visit it each year. In line herewith the council stimulates the application of sustainable energy and wants to act as an example for other authorities.

GasTerra is an international trading company operating in natural gas. The company operates in the European energy market and makes a significant contribution to the supply of gas in the Netherlands. GasTerra believes it is important that the profit factor is in balance with social and ecological interests. This position is the basis for the strategy and activities at GasTerra. The economic value of natural gas and its importance to society as a source of energy give GasTerra a significant role in the utilisation of domestic gas stocks. GasTerra promotes the safe and efficient use of natural gas and is active in the development of clean and economical applications. GasTerra recognises the huge importance of the transition to a sustainable energy supply and initiates projects in this area.

Stedin is responsible for the gas infrastructure in the Dutch regions Randstad and Friesland. This distribution service operator enables the gas grid to meet the gas demand of today and anticipates to the changing gas demand of tomorrow. Therefore Stedin continuously invests in modernisation, replacement, expansion and maintenance of the gas grid. Furthermore it initiates projects for sustainable energy. The injection of hydrogen might provides opportunities for the gas distribution grid in future. Stedin is an Eneco company.

Joulz is a contractor in the Dutch market for energy infrastructures. As project leader in this project Joulz carried out the project management, coordination of activities and has been responsible for the realization of the project. Joulz installed the hydrogen supply, blender and gas grid and gas appliances on Ameland. Next to that Joulz executed an extensive risk inventory and evaluation, a maintenance and inspection programme, and a full time fault-clearing service to ensure safety. Joulz is an Eneco company.

Kiwa Gas Technology is a provider of gas technology services for gases such as natural gas, LPG, hydrogen gas and biogas. Kiwa Gas Technology performed the design of the hydrogen supply, blender and test gas grid. Furthermore they selected and tested the gas appliances. Moreover they carried out the initial and final laboratory measurements on the pipeline system and gas appliances.

3. Project Approach for Hydrogen Injection on Ameland

Figure 1: The Hydrogen Supply, Blender and Apartment Complex “Noorderlicht” on Ameland

Location
The project was located on the island of Ameland for several reasons. First of all Stedin is the gas distribution service operator on Ameland. Second, the council of Ameland owns the apartment complex were the project took place. Third the apartments, housing 14 families, all have an individual gas meter, cooking appliance and gas boiler. Fourth the apartments are located on the periphery of the town enabling controlled isolation of the gas grid and providing space for the hydrogen supply and blender. And last but not least the residents of apartment complex “Noorderlicht” were committed to the project. A picture of the project location is given in figure 1.

Safety
The council of Ameland permitted the injection of hydrogen in natural gas for this specific location. The permit ensured among others compliance with standards for gas regulator stations, low voltage installations, explosion safety, zoning, ventilation, lightning and fire-resistance. A fully fail-safe installation was build. Besides, the blender installation, gas grid and domestic gas installation were subjected to an extensive maintenance and inspection programme. The apartments were equipped with safety sensors for detection of gas leakages and carbon monoxide. Furthermore employees, residents and the local fire brigade were trained in the properties and control of hydrogen.

Uninterruptible Gas Supply
The fully fail-safe installation ensured uninterruptible gas supply. In case of an electricity breakdown, or failure in the hydrogen supply, the hydrogen injection stopped while the natural gas injection kept going. The hydrogen supply, blender and test grid could be disconnected by means of a valve in case of an emergency.

Mixing Process and Hydrogen Supply
Hydrogen was mixed in the natural gas supply from 5% to 20%, increasing the hydrogen content in steps of 5%. The injection started in December 2007.

After installing the housing for the electrolyser, the hydrogen supply was switched from hydrogen bottles to on-site production by electrolysis in December 2008. The electricity needed for generating the hydrogen was produced by solar panels on the nearby new building of the “knowledge and innovation centre”. Thus, the hydrogen used came from a fully sustainable source. The project was finished April 2011.

The blender (mixing unit) injected hydrogen by means of two mass flow controllers (low and large capacity) actuated on the gas consumption and hydrogen percentage set point. The mass flow controllers were connected in a parallel circuit to meet the needs of the dynamic gas demand by optimising the range of control. A gas analyzer was installed to monitor the gas quality and intervene when necessary.

Figure 2: Blender feed with Hydrogen from Bottles

Figure 3: Blender feed with Hydrogen from Electrolysis

Gas Distribution Pipelines and Accessories
A reference grid and test grid were added to the existing natural gas grid. These similar grids were constructed only for the sake of this project. The grids were made of components of the same batch. The grids contained different materials for mains, joints, service governors and gas meters for testing, see figure 4. The selected components are commonly used in Dutch gas grids.

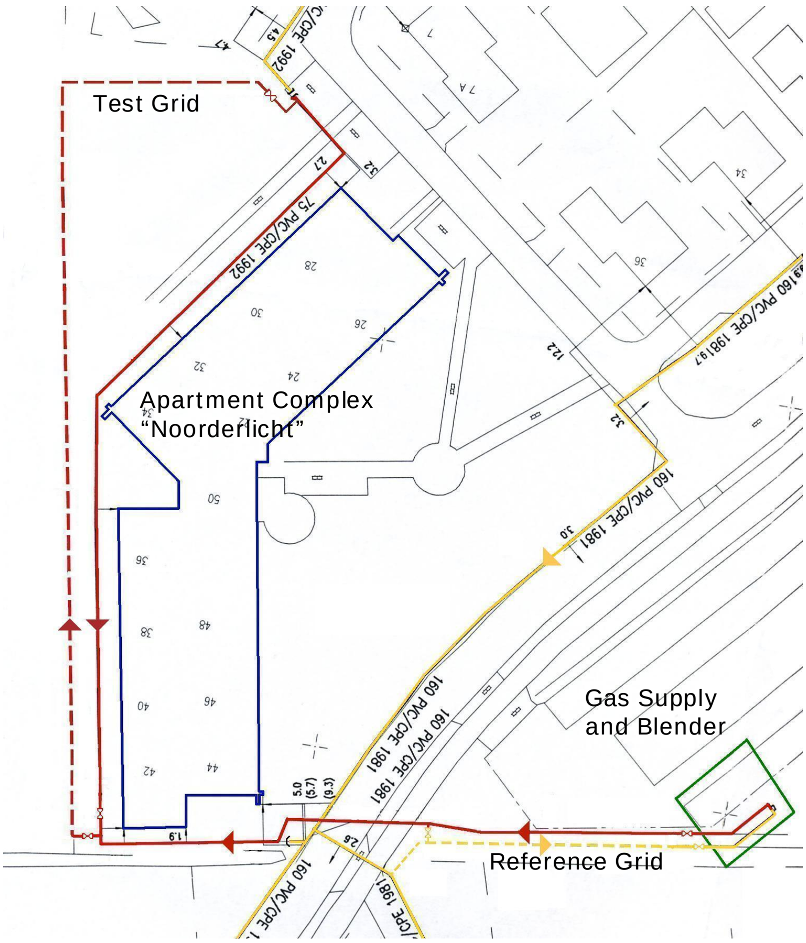


Figure 4: Map of Apartment Complex "Noorderlicht", the Gas Supply, Blender and the Gas Grid (Yellow: Natural gas; Red: Hydrogen enriched Natural Gas; Dotted Yellow: Reference Grid; Dotted Red: Test Grid)

Cooking Appliances and Boilers
The boilers and cooking appliances were selected based on burner principle and are commonly used in the Netherlands, which has gas with a narrow Wobbe index bandwidth. The appliances were not adjusted for hydrogen enriched natural gas. Beforehand all gas appliances were tested for safety by means of test gases containing 30% of hydrogen. This 10% safety margin was applied to overcome dynamic behaviour (overshoot) of the blender. New cooking appliances and boilers were installed because the existing appliances were almost at the end of lifespan.

Opinion of the End-users
The experiences and the opinion of the end-users were an important part of the pilot project since successful energy transition requires a broad social basis. Questionnaires were spread among the residents of apartment complex "Noorderlicht" periodically. The website http://www.duurzaamameland.nl/ was developed to inform society nationwide. Primary school and high school kids have been informed on the importance of hydrogen economy by television programme Green Dream District on National Geographic Channel.

4. Results

In general the project participants look back upon a successful injection of hydrogen in natural gas on Wadden Sea island Ameland. No safety problems have occurred and the natural gas supply has not been interrupted.

Mixing Process and Hydrogen Supply
The injection started in December 2007. The first year the hydrogen was supplied by bottles. This created the opportunity to examine and get accustomed to the blender (most safety critical element) independent of the on-site hydrogen production. The hydrogen supply was switched from hydrogen bottles to on-site production by electrolysis in December 2008. The project was finished April 2011. The percentage of injected hydrogen during the project is presented in figure 5 and table 2.

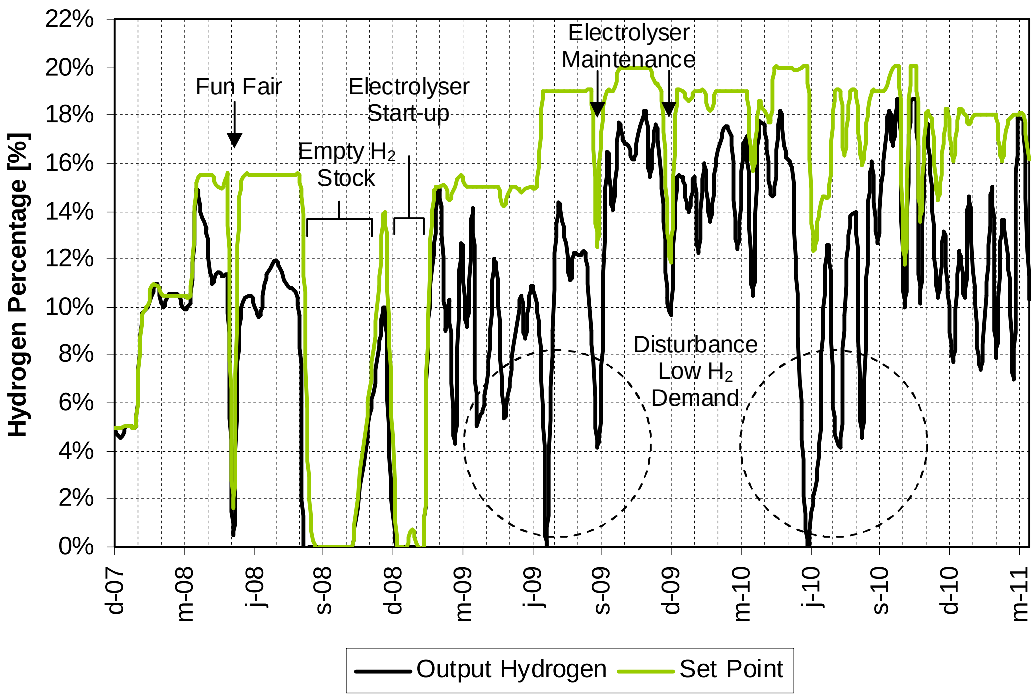


Figure 5: Hydrogen Injection [%weekly averaged]

Year	Hydrogen [% yearly averaged]
2008	6%
2009	9%
2010	12%
2011	10%
Total	9%

Table 2: Injected Gas Mixture, Natural Gas and Hydrogen

The injection of hydrogen was interrupted a few times during the project. In the strong winter of 2010 and 2011 the capacity of the electrolyser was inadequate to meet the extremely high gas demand resulting in a lower injection percentage than the desired set point. The interruptions of hydrogen injection were caused by disturbances and maintenance. Most disturbances were caused by breakdown of the electrolyser in times of low gas demand during the summer period. Low gas demand results in a lower gas system pressures and low flow changes the conductivity of the water for hydrogen production. Furthermore, a fitting became a source of leakage because of the cold temperatures in the winter of 2010 and 2011. For safety reasons the hydrogen supply was temporarily shut down during those periods. Dealing with these disturbances were the most important learning opportunities regarding mixing process and hydrogen supply.

Gas Distribution Pipelines and Accessories
Before large scale introduction of hydrogen enriched natural gas in the Netherlands, the gas distribution grid must be capable of withstanding the influence of hydrogen. To investigate the effects of hydrogen on the integrity of the gas distribution system, an assessment of the most important properties was performed in this pilot project.

The gas grid was extended with a test section and a reference section to determine the effects of hydrogen enriched natural gas compared to the non-enriched natural gas. The test and reference sections both consisted of short lengths of different materials including joints. The reference section was exposed to natural gas only, whereas the test section was exposed to hydrogen enriched natural gas. The applied pipeline materials and joints are typical for the Dutch gas distribution grid. After four years of exposure the different materials and joints were tested to determine whether the quality of the pipes and joints were comparable.
Apart from a visual inspection of the pipes and joints, mechanical and chemical research was performed to determine whether any degradation due to hydrogen enriched natural gas exposure occurred.

The results of the most important tests are summarized in table 3.

Test	Unplasticized PVC	Impact-resistant PVC	HDPE
Heating curve, indicating physical ageing and extrusion temperature, by differential scanning calorimetry, based on ISO 18373-1	No effect	No effect	No effect
Tensile-impact energy, indicating resistance to impact loadings, by tensile tests, based on ISO 8256	No effect	No effect	n/a
Tensile strength and max. strain, indicating resistance to general loadings, by determination of ring stiffness, based on ISO 9969	No effect	No effect	No effect
Material composition, indicating material stability, by fourier transform infrared spectrometry	No effect	No effect	No effect
Hydrogen permeation constant by permeation test [$ml \cdot mm \cdot m^{-2} \cdot bara^{-1} \cdot day^{-1}$]	71	82	87

Table 3: Test Results of Pipeline Materials (Mains)

Table 3 indicates that the most important properties of the examined pipeline materials originated from the reference and test section show no effects after four years of exposure to hydrogen enriched natural gas. One of the concerns when distributing hydrogen is the possible high amount of hydrogen permeating through the pipeline wall. Therefore some permeation tests were performed. The overall permeation is low, not expected to lead to any (safety) problems. Eye catching is that the permeation of a hydrogen / natural gas mixture has a lower permeation constant than hydrogen only. Visual inspection did not identify hydrogen related defects on the pipeline material also.

Additional to the pipeline material itself, attention was paid to joints and other accessories like rubber hoses, service governors and gas meters. For joints, the quality of exposed and non-exposed joints was assessed by taking samples from the reference and the test sections. The hoses, service governors and gas meters were assessed in a different way because these accessories were not installed in the reference section. In case of service governors the initial and final quality were measured and compared. The exposed gas meters and rubber hoses were compared to new non-exposed gas meters.

Table 4 summarizes the results of the most important tests on accessories.

Test	POM fitting	Rubber sealing of sleeve coupler	Tombac coupler / copper pipe	Rubber gas hose for the gas hob	Service governor	Gas meter
Tensile strength by tensile tests, based on - ISO 10838-3:2000 - ISO 9969 - EN 1254:1998 - Gastec QA 34:1996	No effect	No effect	No effect	No effect	n/a	n/a
Hydrogen permeation constant by permeation test [$ml \cdot mm \cdot m^{-2} \cdot bara^{-1} \cdot day^{-1}$]	n/a	n/a	n/a	In progress	n/a	n/a
Verify operational performance / closing pressure, indicating the stiffness of the diaphragm, based on certification requirement Gastec QA 11:1996	n/a	n/a	n/a	n/a	No effect	n/a
Visual inspection indicating cracks	No effect	No effect	No effect	No effect	No effect	No effect

Table 4: Test Results of Pipeline Fittings and other Accessories

The joints exposed the hydrogen enriched natural gas did not show any degradation as well as the service governors and gas meters. Visual inspection did not identify hydrogen related defects or pollution. Therefore the conclusion can be drawn that, for the test period of four years, the integrity of the grid including pipelines and accessories was not compromised by using hydrogen enriched natural gas.

Cooking Appliances and Boilers

The gas quality affects the gas appliances of the end users. However, analysis shows that the downstream gas quality will not be adversely affected since the Wobbe index of Groningen natural gas (G25) mixed with 20% hydrogen will not be outside the statutory requirements of low calorific gas (L-gas), see figure 6. These low calorific gas specifications are the design parameters for Dutch cooking appliances and boilers.

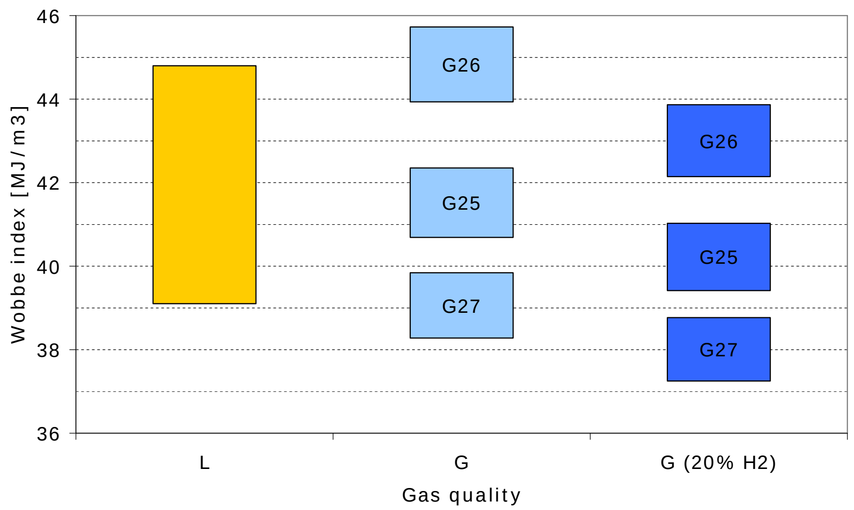


Figure 6: Wobbe Index for Different Gas Qualities and the Influence of adding Hydrogen (G25 is the Reference Gas for Groningen Natural Gas)

The cooking appliances were assessed on their most important safety requirements including CO_2, CO and NO_x emissions, back fire and leakages. The cooking appliances listed in table 5 were included in this pilot project. Table 6 summarizes the tests on cooking appliances.

Specification	Hob 1	Hob 2	Hob 3
Construction	Built-in hob	Stand-alone hob	Hob with electrical oven

Table 5: Installed Cooking Appliances

Test	Hob 1	Hob 2	Hob 3
CO_2, and CO emissions, based on EN 30	Passed	Passed	Passed
Back fire, based on EN 483	Passed	Passed	Passed
Leakage by a pressure decay leak test, based on EN 483	Passed	Passed	Passed

Table 6: Tests on Cooking Appliances

The CO_2 and CO emissions decrease because of the addition of hydrogen to natural gas, see for example the emissions of hob 3 in figure 7. The maximum allowable CO_2 emissions according to EN 30 are 11.5 %. The maximum allowable CO emissions are 1500 and 1000 ppm in case of half gas load respectively full gas load. These figures also show that the gas load decreases due to the addition of hydrogen.

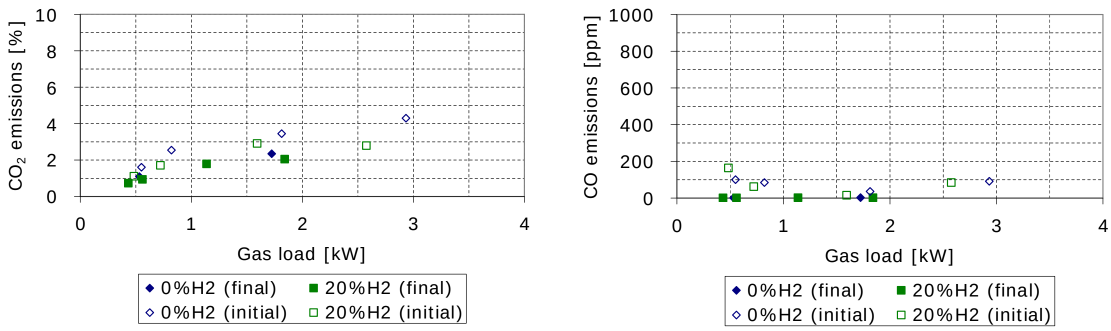


Figure 7: Emissions Hob 3 (Initial and Final Measurements of Different Gas Rings)

The flame speed increases because of the hydrogen enrichment. Therefore the flame burns closer to gas ring, which is presented in figure 8. This implies an increased risk of back fire. However, the cooking appliances fed with hydrogen enriched natural gas easily passed the back fire tests.

0% H_2 *10% H_2* *20% H_2*

Figure 8: Gas Ring fueled by Hydrogen enriched Natural Gas

The cooking appliances passed the leakage test also. Visual inspection including gas ring, injection nipples, igniters, valves, fittings and sealings did not identify hydrogen related defects or pollution.

The boilers presented in table 7 were included in the project.

Specification	Boiler 1	Boiler 2	Boiler 3	Boiler 4
Power (80/60°C)	5.5 – 24.0 kW	5.6 – 22.5 kW	4.8 – 22.9 kW	8.7 – 24.0 kW
Burner Principle	Cylindrical burner surface of thin steel	Cylindrical burner surface of thin steel	Perforated plane ceramic burner surface	Cylindrical burner surface of thin steel
Heat Exchanger	Stainless steel cylindrical exchanger	Aluminium casted block with fins	Aluminium casted pipe with fins	Stainless steel cylindrical exchanger
Ignition	Spark ignition	Spark ignition	Glow plug	Spark ignition
Flame supervision	Flame ionization detector	Flame ionization detector	Flame ionization detector	Flame ionization detector

Table 7: Installed Gas Condensing Boilers

The boilers were assessed on CO_2, CO and NO_x emissions, ignition, back fire, leakages, flame stability and flame supervision which are the most important safety requirements. The test results are presented in table 8.

Test	Boiler 1	Boiler 2	Boiler 3	Boiler 4
CO_2, CO and NO_x emissions, based on EN 483	Passed	Passed	Passed	Passed
Ignition, based on EN 483	Passed	Passed	Passed	Passed
Back fire, based on EN 483	Passed	Passed	Passed	Passed
Leakage (pressure decay leak test) based on EN 483	Passed	Passed	Passed	Remark*
Flame stability, based on EN 483	Passed	Passed	Passed	Passed
Flame supervision according to manufacturer specification	Remark**	Passed	Passed	Passed

* incidental small leakage detected
** not in accordance with manufacturer specification but breakdown has not taken place

Table 8: Tests on Gas Boilers

In the initial as well as the final tests the most important safety requirements for boilers were passed. Figure 9 shows that the CO_2, CO and NO_x emissions decrease as well as the gas load because of the addition of hydrogen to natural gas.

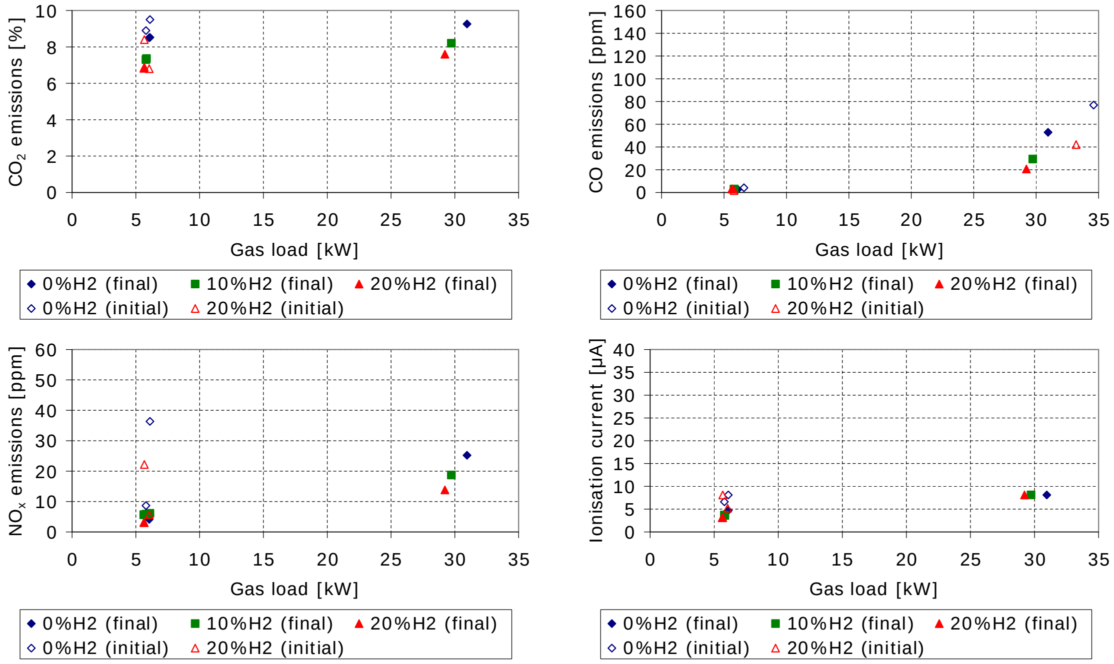
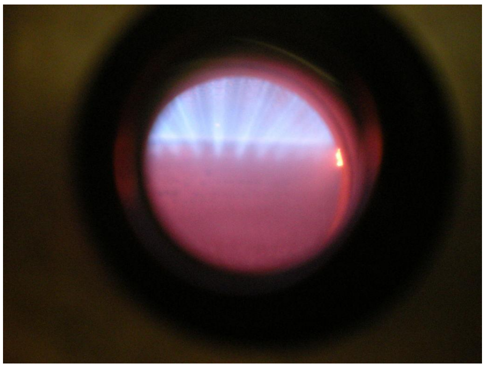
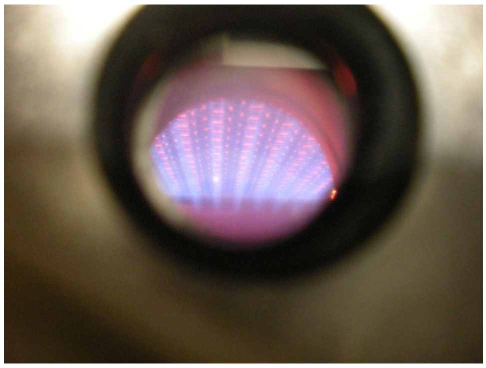


Figure 9: Emissions and Ionisation Current of Boiler 2 (Initial and Final Measurements)

Ignition, back fire and leakage test were passed. Notice that a small internal leakage in one gas valve was detected. It has been assumed that this leakage is incidental, since other gas valves of the same type were leak proof and because of the limited amount of boilers in the project do not allow for statically significant conclusions. The flames burn closer to the burner surface; hence the influence of hydrogen is visible in figure 10. Similar effects are visible in case of switching from high gas load to low gas load. In that case the lower gas flow rate makes the flame burn closer to the burner surface. Although the visible influence of hydrogen addition, the boilers passed the flame stability test.



Groningen Natural Gas



Hydrogen Enriched Groningen Natural Gas makes the Burner Surface glowing

Figure 10: Burner Surface of Boiler 3

All boilers included in this project have a flame ionisation detector for flame supervision. Most boilers operate in accordance with manufacturer specification, including boiler 3 for which the ionisation current is presented in figure 9. The ionisation current changes in particular in case

of low gas load. One boiler's flame supervision did not comply with manufacturer specification but breakdown has not taken place.
The boiler control unit's memory was read out. No hydrogen related failures were registered. Visual inspection including burner, ignition, flame ionisation detector, heat exchanger, gas valve, condensate drainage, fittings and sealings did not identify hydrogen related defects or pollution.

Opinion of the End-users
The residents of apartment complex “Noorderlicht” look back upon a positive experience of heating and cooking on hydrogen enriched natural gas. The project was presented on different media. Besides the initiatives of project partners, including the internet website and television programme Green Dream District on National Geographic Channel, the media widely picked up the project and informed society. The press published tens of publications. Local and national television reported on the project, as well as many internet websites. Furthermore many (inter)national visitors came to Ameland and watched with interest the “Sustainable Ameland” project, amongst which interested civilians, representatives of a number of major West European utility companies and representatives from the technical association of the European natural gas industry (Marcogaz).

5. Evaluation and Future Perspectives

The injection of hydrogen up to 20% into the natural gas grid has been demonstrated successfully in the “Sustainable Ameland” project. The addition of hydrogen seems to be an effective means of "greening" natural gas. This project confirms in practice the conclusion of the Naturalhy project that the pipeline system and domestic appliances are not a restricting factor for mixing hydrogen up to 20% with natural gas. In a period of four years, no "show stoppers" have been identified. Practical experience has been gathered with the mixing process, electrolyser, pipelines and end-user domestic appliances. Gas boilers and cooking appliances were never before exposed to a hydrogen-natural gas mixture for such a long period of time in the Netherlands. Furthermore, Dutch society had a positive experience with hydrogen enriched natural gas. All parties involved contributed to the project with dedication and enthusiasm, and were proud to contribute to the energy transition.

Nevertheless, there are still some concerns about industrial end-users that have complex installation that were not part of this project. For instance energy producers applying stationary gas engines and gas turbines as well as industrial consumers applying feedstock processing and industrial combustion. These installations may need readjustment or modification if fueled by hydrogen enriched natural gas. These important issues are recommended for further investigation and application in pilot projects to complete the gaps before large scale introduction hydrogen enriched natural gas.

A next step in hydrogen enriched natural gas applications for domestic purposes might be a larger scale (time and size) pilot project. Application of hydrogen enriched natural gas for a longer time increases the insight in life expectancy of pipeline systems and appliances subjected to hydrogen. Furthermore it is recommended to test critical existing appliances, for instance flueless appliances, instead of new appliances since these are widespread and a concern for safety.

A promising concept is to use the gas grid as a buffer for off-peak wind power. This means that off-peak wind power is used to produce pure hydrogen that is stored and distributed by means of the gas grid. This concept offers a great opportunity for sustainable hydrogen production and is recommended for further investigation and application in pilot projects.

To further accelerate the transition to hydrogen enriched natural gas for domestic application, energy policies should stimulate manufactures to introduce wide-band domestic gas applications, enabling future hydrogen enrichment beyond 20%.

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