# Experience with the Injection of Hydrogen into a Naturally Grown Natural Gas Distribution Grid

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## Introduction

Power-to-Gas is an elaborate and much discussed concept supporting the energy transition process. Superfluous electrical energy from fluctuating renewable sources is transformed into Wind Gas and fed into the natural gas grid. The grid provides a high potential for storing, transporting and using this part of renewable energy otherwise not usable.

Yet, further developments are still needed to actually implement this concept in practise. A number of projects especially within the DVGW Innovation campaign are currently underway to investigate different approaches, electrolyser types, injection methods, and the behaviour of components along the whole natural gas transportation and distribution network, the functionality of gas appliances and the impact on natural gas storage [1], [2], [3], [4], [5], While there are still some restrictions for specified applications and natural gas storages, engineers are generally optimistic about future prospects, and new projects are being started to solve the remaining issues. A first cautious field test with 16 houses equipped with lab-tested appliances has been carried out by KIWA [6].

## Goal and approach of the project

The goal of the project is to demonstrate the feasibility of injecting up to 10 vol.% of hydrogen into an existing gas distribution grid and offer extensive research support. First lab tests, which are still ongoing, seem to indicate that domestic and light commercial appliances as well as components in distribution grids will not show any serious problems. The project seeks to investigate today's gas appliances under real live conditions, i.e. across the whole range of operating modes, weather conditions, installation conditions and adjustments made as well as varying gas qualities. Also, the design and operation of an injection unit for injection rates of up to 10 vol.% will require some practical questions including communication with the grid operator and the public, technical guidelines, measurement and billing, etc. to be resolved. With distribution and end use appliances being the main focus, this project will not investigate production aspects. The solutions developed may be a blueprint for future projects and will provide guidance for the implementation of Power-to-Gas in practise.

This project is being executed by E.ON Technologies in collaboration with E.ON Hanse and Schleswig Holstein Netz AG supported by the Engler-Bunte-Institute (EBI) in field investigation of the installed appliances. The activities are part of a project within the DVGW Gas Innovation Campaign which includes additional tests carried out at the laboratories of the EBI (Karlsruhe) and Gas- und Wärme-Institut (Essen).

Preparations for the project included the following steps:

- Identification of the requirements on the distribution grid and selection
- Elaboration of a measuring and billing concept and approval by the calibration authority
- Design of the injection unit based on these requirements and on the measuring data of the gas consumption
- Buildup of the injection unit in line with the technical guidelines and approval by authorized experts of the TÜV
- Inquiry and measurements of all installed gas appliances as well as the grid components
- Communication with the local authorities and grid clients
- The execution phase consists of several steps with hydrogen injection rates of 2 vol.%, 4 vol.%, 6 vol.%, 8 vol.% and 9.9 vol.%, which are being accompanied by measurements on the appliances installed. The appliances examined are divided into groups of similar types, e.g. condensing boilers, wall-mounted conventional boilers, cookers, etc. so that one representative appliance of each group can be investigated for each injection rate. The gas quality recorded during these tests will also be taken into account.

**Description of the selected distribution grid**

In 2010, Schleswig Holstein Netz AG (SHNG) took over operation of the natural gas and electricity grids in Schleswig-Holstein and in the north of Lower Saxony from E.ON Hanse. The local municipal utilities in the area are partners of SHNG. With their support and input from E.ON Hanse the desired parameters of the test region were carefully examined and, based on the detailed knowledge of the SHNG partners, the region of Klanxbüll/Neukirchen in the very north of Germany just east of the island of Sylt was selected. The characteristics of the distribution grid are listed in **Table 1**. Gas supply to the grid is via a single injection point at the pressure regulating station near Klanxbüll. Having a hydrogen injection unit at this site would ensure that the whole downstream distribution grid sees the same gas quality. There is no filling station for natural gas vehicles connected to this grid, and there are no plans to build one in the next few years.

With only about 170 gas customers, the effort and costs involved in testing the appliances are limited. At the same time, given that the buildings are of very different ages, the tests can provide a representative picture for a range of different appliances. As the gas distribution grid is relatively new, there are mostly modern gas appliances and a high percentage of condensing boilers. Gas consumption in the area is only about 170 $m^3$/h (NTP) or 1200 $m^3$/day (NTP), so that the quantity of hydrogen injected is limited too.The gas pressure regulating station is situated outside of the village Klanxbüll. It is connected to the high-pressure East–West pipeline which in turn is ties into the DEUDAN transmission pipeline of Gasunie Deutschland. The direction of flow in this pipeline changes from time to time, so that local grids connected to the pipeline receive either Danish or mixed natural gas of northern Germany. The gas qualities are known for the interconnection point.

At the pressure regulating station the gas flow is measured and the pressure is reduced to 500 mbar. The existing gas meters have have only been used for operational purposes and are not officially approved by the calibration authority.

| | |
|---|---|
| **Gas Supply Klanxbüll/Neukirchen** | |
| Gas quantity sold | max. 170 Nm³/h |
| Calorific value | 10.8 – 12.3 MJ/m³ * |
| Wobbe number | 14.1 – 15.3 MJ/m³ * |
| Injection of $H_2$ planned | 2%, 4%, 6%, 8 %, < 10% |
| **Grid Characteristics** | |
| Year of construction | 1997 |
| Upstream pressure | 40-60 bar |
| Distribution pressure | 500 mbar |
| Length of the grid | ca. 18 km |
| Odorization | S-Free |
| Piping | PE-pipelines |
| Number of gas entry points | 1 |
| Sector of calorific value for billing | new set up of cv sector for the project for Klanxbüll/Neukirchen |
| **Clients and Buildings** | |
| Number of residents Klanxbüll/Neukirchen | approx. 2000 |
| Number of grid clients | approx. 170 |
| Year of construction of buildings | approx. 1951 bis 1985 |
| Type of buildings | predominant single family houses, holiday houses |
| Commercial clients | some (restaurant) |
| Filling station | Nein |
| **Appliance Technology** | |
| domestic appliances | Condensing boiler, standard boiler, cooking appliances, 1 cogeneration unit |
| commercial appliances | commercial cooking appliances |

Table 1: Characteristic data of the distribution grid, *(0°C/25°C, 1013.25 mbar)

**Billing concept and obligations of the calibration authority**

The measuring and billing concept for the gas customers in the project region was developed in close cooperation with the calibration authority. The grid supplied with a natural gas/hydrogen mixture had to be designated a new zone with a different calorific value for billing. The volumetric gas flow and the relevant calorific value are determined at one-minute intervals. From these data a weighted monthly calorific value is calculated for gas billing. The calibration authority gave the permission to calculate the calorific value of the gas mixture using the volumetric flow rate and the calorific value recorded for the two components, natural gas and hydrogen. This way the expenditure for the installation of an additional PGC, which would have had to be suitable for hydrogen, could be avoided.
Requirements imposed by the calibration authority included:

- Installation of two new gas meters that can be calibrated in the natural gas chain
- Installation of a gas meter for hydrogen that can be calibrated
- Confirmation of the natural gas quality measured with a PGC in the grid
- Certificate confirming hydrogen quality
- First examples of customer billing

**Injection unit design and installation**

Hydrogen supply

As explained above, the goal of the project is to test increasing injection rates of hydrogen for different gas appliances, operating modes, installation conditions, levels of consumption and natural gas qualities. To be independent of any restrictions on hydrogen production, hydrogen is provided in cylinder bundles. Given the calculated average natural gas consumption of about 1,200 m³/day (NTP), 12 cylinder bundles of hydrogen at 200 bar containing some 1,300 m³ (NTP) were delivered to site (**Figure 1**). The bundles have to be replaced every 3 weeks on average and every 4 days on the coldest winter days when injection rates reach maximum.

Fig. 1: Cylinder bundles installed at the pressure regulating station in Klanxbüll/Neukirchen for hydrogen injection into the distribution grid.

Hydrogen measurement

The gas flow rates currently recorded at the injection point for Klanxbüll/Neukirchen show a strong variation between 140 m³/h (NTP) to 160 m³/h (NTP) on the coldest winter days and 15 m³/h (NTP) to 5 m³/h (NTP) in mid-summer. Hydrogen injection rates of 2 vol.% to nearly 10 vol. % for both periods would require a volumetric flow range of 0.1 m³/h (NTP) to 16 m³/h (NTP) to be measured, which is obviously not possible for a single gas meter. The best gas meter available on the market with an adequate measuring range designed for pressures of up to 1 bar is a rotary flow meter from ITRON, which was selected for the project:

Rotary flow meter
DN 40
Qmax = 25 m3/h (37.5 m³/h(NTP))
Qmin = 0.25 m3/h (0.375 m3/h (NTP)
Type: ITRON Delta Compact Aluminium
Class of accuracy 1
Typical error margin Qmin to 0.1xQmax: ≤ ± 1%
0.1xQmax to Qmax: ≤ ± 0.5%

This gas meter can cope with the maximum hydrogen flow rate but not with the minimum flow rate because a hydrogen flow signal that can be calibrated has to be guaranteed at all times. For cost reasons a second parallel hydrogen meter run had been ruled out, so some restrictions to the measuring programme had to be accepted.

## Injection, control and monitoring of the hydrogen rate

The hydrogen is injected through a 30mm diameter pipe inserted at a right angle into the pipeline on the low-pressure side downstream of the pressure regulating station. The pipe has two rows of 8 holes with a diameter of 4 mm injecting the gas at an angel of 45° against the flow direction of the natural gas (**Figure 2**). This configuration guarantees the best possible mixture of natural gas and hydrogen. In addition there are two downstream pipe bends for additional mixing.
Hydrogen injection is controlled as a function of the signal coming from the natural gas flow meter. The injection rate actually achieved is calculated by combining the results of the hydrogen and the natural gas meters. This signal serves as a feedback signal for injection control.
Both signals are calibrated signals that have a high reliability, so the adjusted flow rate has the same reliability. However, it has been recognised as important to have an independent validation. For this reason the gas flow in the output line is continuously monitored. A pipe joint on the output line has been fitted with a sampling probe (**Figure 2)** to allow a continuous gas sample flow to be piped to a hydrogen sensor installed in the regulator room. After a series of tests at the E.ON Technologies lab [7], the Ansyco sensor (type HN 1700 ATEX) was selected. Its measuring range is 0 to 15 vol.%.
The display allows the desired hydrogen flow rate and two cut-off flow rates to be selected for the calculated and the measured rate, respectively. Hydrogen injection is stopped when the volumetric flow rate drops below the lower limit of calibration, i.e. 0.375 m³/h (NTP).

Fig. 2: Lance for hydrogen injection into the natural gas pipeline and gas sampling device for monitoring the hydrogen content.

## Gas quality - Injection limits

The project group decided to only distribute gases which are compliant with DVGW codes of practice G 260 [8] and G 262 [9]**:** “Investigations showed that hydrogen levels in the single-digit percent range in natural gas are in many cases uncritical if the specifications for combustion (e.g. Wobbe number and relative density) defined in DVGW G 260 are met.” [8, p. 17].
As hydrogen admixture lowers the Wobbe number and the relative density, the following conditions have to be considered:

Hydrogen content < 10 vol.%
Wobbe number > 13.6 kWh/m³ (0°C/25°C, 1013.25 mbar)
Relative density > 0.55

Design and configuration

The modified pressure regulating station consists of four main parts:
(a) Natural gas measurement system incl. pressure reduction to 500 mbar
(b) Hydrogen storage in 12 bundles incl. pressure reduction to 16 bar
(c) Pressure regulator, volume control unit and injection of hydrogen into the natural gas pipe
(d) Piping for test gas flow and hydrogen sensor

The design and configuration of components (a) and (d) are fully compliant with the DVGW guidelines [10], [11]. Although these guidelines do not apply to components used purely for hydrogen, component (b) was designed in accordance with the DVGW requirements following consultation with and approval by TÜV. Component (b) also complies with the Pressure Vessel Directive [12].
The modified pressure regulating station including the hydrogen injection unit was approved by TÜV and handed over to SHNG.

**Technical Guidelines**

During the time of town gas distribution the handling of gas with a high percentage of hydrogen was common and clients were accustomed to use the gas for cooking, heating and warm water production. Nowadays there is a relative high mental reservation on side of gas clients and even technical staffs. Additionally the technical guideline for hydrogen injection sites [13] has still been in discussion. Under this conditions an open and appreciative communication and a careful consideration of the technical guidelines is very important. Where technical guidelines are not yet developed an adaptation of existing guidelines is helpful. Together with SHNG the tasks and responsibilities are clearly agreed.

- The injection unit has to be designed and built in accordance with existing rules and regulations and approved by TÜV. It will be operated by the grid operator SHNG.
- The gas quality including hydrogen concentrations have to remain within the limits specified in DVGW G 260 and G 262. DVGW/EBI has issued a document to SHNG confirming that the gas quality complies with DVGW G 260.
- The project team is responsible for and takes care of adjusting hydrogen injection rates as required. This way, distribution and end use are still compliant with the technical framework.
- An additional inspection of the grid and the in-house installations had to be carried out shortly before the start of the project. The distribution grid is relatively new. An earlier inspection carried out in 2013 showed that it is in a good condition. There were no leaks. Odorisation is checked regularly and will be monitored during hydrogen injection.
- End user appliances: As the distributed gas will be compliant with DVGW G 260, there should be no serious problems with end user appliances, especially in terms of safety. All appliances are tested using the test gases specified in to EN 437, [14], which include the test gas G222 with 23 vol.% hydrogen. The lab results suggest that there will be no operation and reliability problems. In addition all appliances will be recorded and checked as part of a survey conducted by DVGW/EBI.

## Results

Gas quality

The Klanxbüll/Neukirchen region receives its natural gas via the DEUDAN pipeline. In this pipeline the direction of flow changes from time to time, so for years the project region has been supplied with natural gas from both Denmark and Germany. The gas quality is determined at the "Handewitt" interconnection with the Reko System of Gasunie as monthly mean values which have been used for billing since November 2009. In addition, Gasunie has provided the project with hourly mean values recorded since March 2011. The data include superior calorific value, density and $CO_2$ content. Moreover, a new PGC in Nordhackstedt installed by SHNG at a distance of 40 km has been supplying the full analysis of the distributed natural gas as hourly values since May 2013. The Wobbe number range for these data is shown in **Figure 3**. The monthly mean value 11/09 – 07/12 varies by +2 vol.% and -4 vol.% related to the nominal value of 15.0 kWh/m³. But hourly values indicate a much higher range

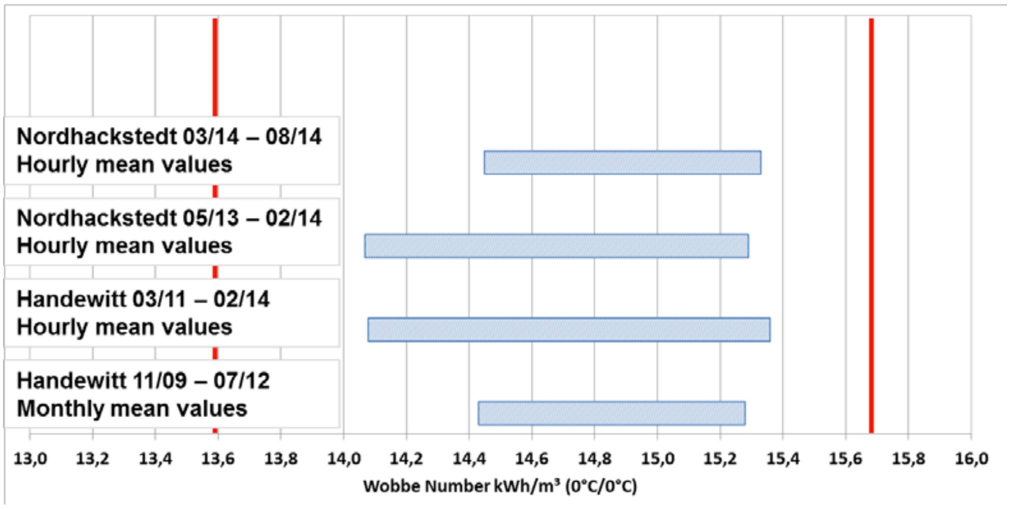


Fig. 3: Range of Wobbe numbers recorded for the natural gas supplied to Klanxbüll/Neukirchen in the past and during the previous project period in comparison to the limits specified DVGW G 260.

of variation by +2 vol.% and -6 vol.%, both for the REKO values of Handewitt as well as for the PGC in Nordhackstedt. So very low wobbe numbers are observed for some hours, but will not be as frequently, as medium values. The observed range is quite large and injection is planned at both ends of the range. Since the start of the project the very low Wobbe numbers have not been observed.

**Table 2** gives the characteristic data of pure hydrogen and some typical and extreme natural gases distributed in Klanxbüll over the last years, as well as the calculated values for a mixture of 90 vol.% natural gas and 10 vol.% hydrogen.

For injection rates of up to 10 vol.% the Wobbe number never falls below the limit of 13.6 kWh/m³ (see [8], but the relative density for certain gases may drop below 0.55. It may easily be calculated that for relative densities of natural gas higher than 0,603 10 vol.% of hydrogen may be admixed without falling below the density limit The question whether the density alone is the important and deciding parameter for combustion is still unanswered. Up to a final decision for lower densities of natural gas the admixture portion will to be reduced accordant in the project.

| | | Hydrogen | Natural Gas | | |
|---|---|---|---|---|---|
| | | | very low | low | high |
| Ho | kWh/m³ | 3,54 | 10,88 | 11,24 | 12,08 |
| ϱ | kg/m³ | 0,090 | 0,768 | 0,787 | 0,813 |
| d | - | 0,070 | 0,594 | 0,609 | 0,629 |
| Wo | kWh/m³ | 13,43 | 14,12 | 14,41 | 15,23 |
| | | | | | |
| | | | Natural Gas + 10% Hydrogen | | |
| | | | very low | low | high |
| Ho | kWh/m³ | | 10,14 | 10,47 | 11,22 |
| ϱ | kg/m³ | | 0,700 | 0,717 | 0,741 |
| d | - | | 0,541 | 0,555 | 0,573 |
| Wo | kWh/m³ | | 13,78 | 14,06 | 14,83 |

Table 2: Characteristic values of pure hydrogen and some representative natural gase distributed in Klanxbüll/Neukirchen calculated with Gascalc [15]

## Natural gas flow rate and hydrogen injection

The natural gas flow rate differs greatly between winter and summer. **Figure 4** shows the flow rate plotted over the whole year 2011 as a typical example. In winter the flow rate increases to 140 m³/h (NTP), in colder years even to 170 m³/h (NTP). In summer it drops to mean values of 10-20 m³/h (NTP) and can even be zero in midsummer nights. In addition, the flow rate also fluctuates substantially over the course of a day (**see Figure 5)** as an example of the average outside temperatures in spring In the early morning the appliances start to heat up after night set back and a second peak can then be observed in the late afternoon or early evening when people come home.

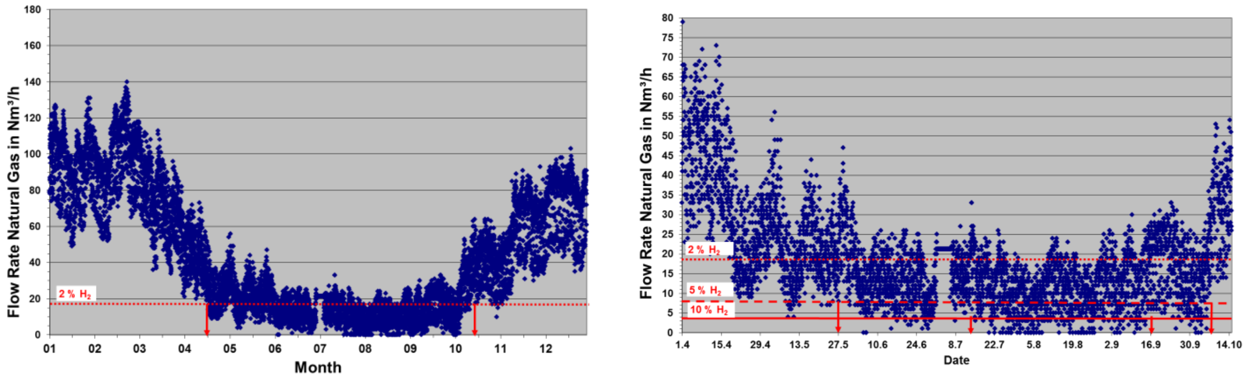


Fig. 4: Natural gas flow rates at Klanxbüll/Neukirchen in 2011. The graphs show the limits for hydrogen injection plotted for the specified hydrogen concentration and minimum hydrogen flow rate of 0.375 m³/h (NTP).

Both effects have to be considered for the design of the injection control system. As explained above, the minimum hydrogen flow rate must be 0.375 m³/h (NTP) because of the calibration range of the gas meter, which means that there are also restrictions for injection rates which are dependent on the natural gas flow rate and the required hydrogen rate. Figure 4 also shows a minimum natural gas flow rate calculated for a

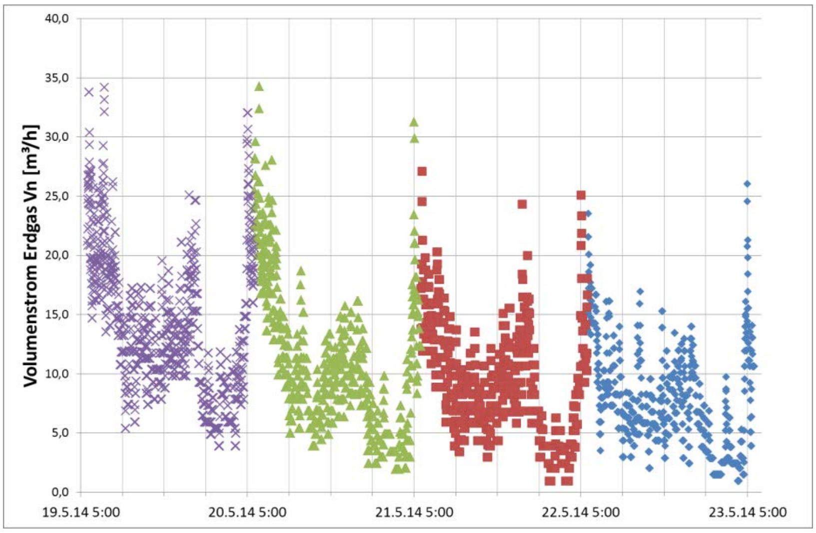


Fig. 5: Natural gas flow rate at Klanxbüll/Neukirchen on three days in April 2014. The flow rate fluctuates significantly during the day and decreases with increasing outside temperature.

given hydrogen concentration as well as the minimum hydrogen flow rate. Obviously a rate of 10 vol.% hydrogen could be injected throughout the year, if midsummer night times were excluded. The time for lower injection rates is limited in a certain range. So the first injection tests with 2 vol.% should preferable be executed during the period from October to April, 5 vol.% experiments should be done between October and May. The control system for hydrogen injection sends a shutdown signal when the natural gas flow rate drops below the minimum flow rate.
Within the project the injection of hydrogen started in April 2014 with hydrogen portions of 2 vol.% and later 4 vol.%.
Hydrogen injection started in April 2014 with injection rates of 2 vol.% and then 4 vol.%. A first analysis focussed on the accuracy of the data for the hydrogen flow rate calculated from the volumetric flow rates recorded by both gas meters and the hydrogen probe in comparison the adjusted target value. **Figure 6** gives an example for the adjusted value of 4 vol.% at natural gas flow rates between 12 and 27 m³/h (NTP). The rolling 15-minute-mean values of the hydrogen rate have been plotted for both the recorded probe signal and the values calculated from the hydrogen and natural gas meter signals.
The $H_2$-probe signal is shifted in time compared to the calculated value for two reasons: first, because the gas sampling point is downstream of the gas meters and, second, because it takes a certain time for the sampled gas to flow back from the sampling point to the hydrogen sensor. With this time shift taken into account in Figure 6 there is quite a good match between both signals. Moreover, the observed hydrogen rate is very close to the adjusted value of 4 vol.%, and it fluctuates by only about ± 0.5 vol.%. Further investigations will have to be carried out on colder days when higher natural gas flow rates are recorded.
Results of the first injection phase from April 2014 to July 2014 are shown in **Figure 7**. The overall injection time per day and the longest injection phase during the same day are plotted. In colder April days a 24 hour injection has been realized for 2 days. With the weather becoming warmer, the injection hours per day are reduced to 15 hours/day, 10hours/day and finally 5/hours/day with very short single

injection phases.

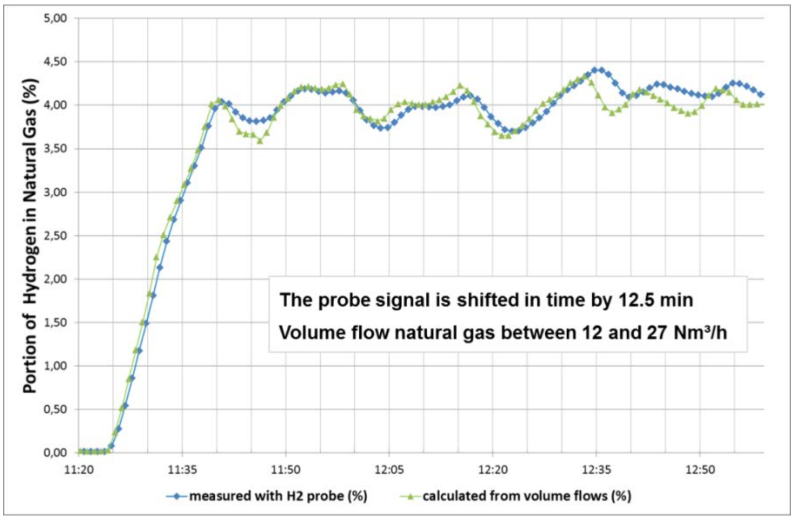


Fig. 6: Hydrogen concentration measured in the distributed gas with the injection rate set at 4 vol.%; comparison of the values calculated from the natural gas and hydrogen flow rates with the measured values. The measured values are shifted in time as they are recorded downstream of the injection point.

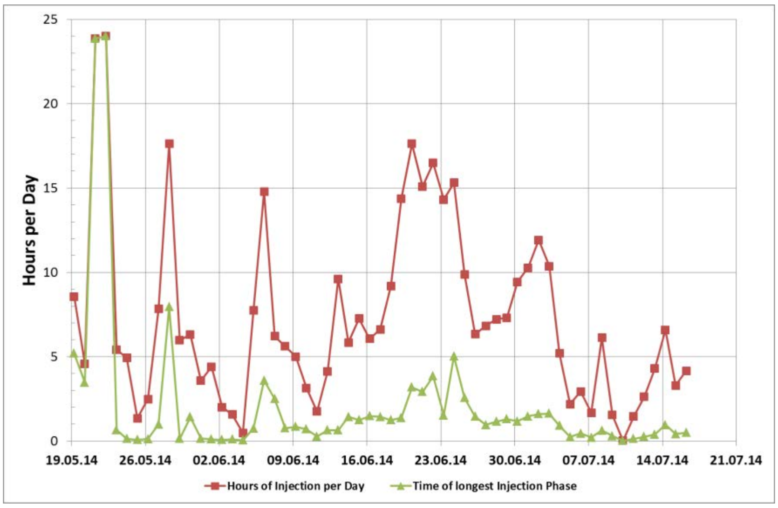


Fig.7: Daily injection times during the first project phase and duration of the longest continuous injection period on a given day.

**Inquiry and analysis of the installed appliances**

Prior to the project start a communication process with the local authorities and the customers has been passed. Information about the context of the project, the goal and the billing during project running time has been given and explained. During an invitation customers could discuss their special questions. Shortly before the planned appliance inquiry a letter with a project flyer and information about the technical visit has been sent to every customer. As gratitude for the inconvenience a gift coupon for maintenance of the appliance has been presented.

Before hydrogen injection the project team working with DVGW/EBI examined all gas appliances installed in the project region. The appliance manufacturer and type were recorded and the $CO_2$ and CO emissions were measured. A total of 27 different manufacturers are represented across the region. Nine of them have at least five appliances installed (**Figure 8**). As expected most of the appliances are condensing boilers, but detailed analyses have shown that quite different technologies are actually in use. The second most widely used appliance is the low temperature boiler (about 20 appliances), but there are also some domestic and commercial cookers as well as one CHP unit. The age distribution is quite even and varies mainly between 3 and 8 years. However for the years after construction there is a peak of 15 and 16 years old appliances.

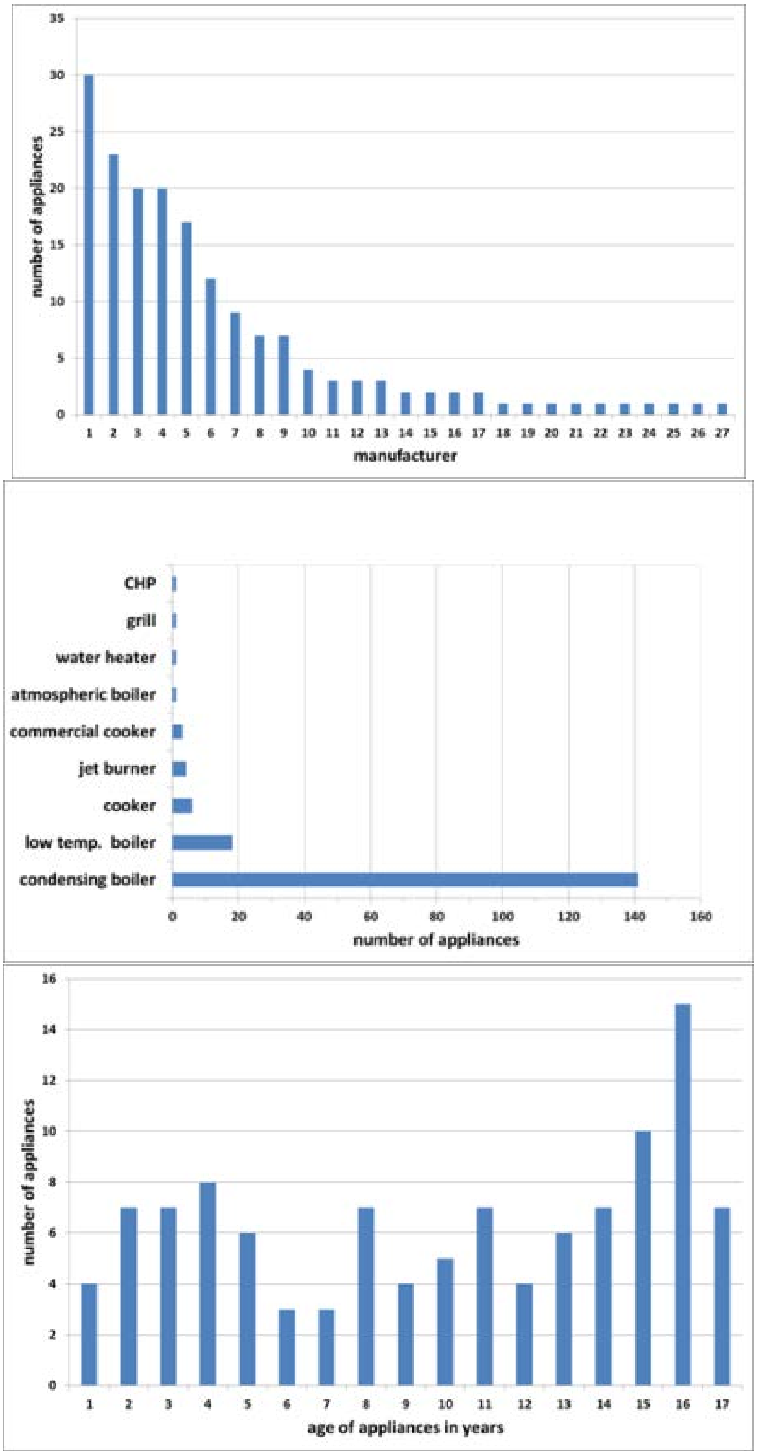


Fig. 8: Data of the appliances installed in the Klanxbüll/Neukirchen service area.

During the gas appliance measurements the gas quality was quite constant with a Wobbe number of 15.2 kWh/m³. The results for most of the appliances were normal and did not exceed CO level of 100 mg/kWh.
Before the start of the project the local installation companies were informed about the project and asked to support the investigations. All of them were given a questionnaire prepared by the project group. In the event of any failure or problems with gas appliances, they are requested to fill out the questionnaire and return it to the project team. During the first injection phases from April to July with hydrogen portions up to 4 vol.% the appliances are supplied during for 433 hours with hydrogen. The single injection phase lasted 2 hours in average, but reached about 15 hours and 24 hours for a hydrogen portion of 2 vol.%. No reports of any malfunctioning or appliance failure in the Klanxbüll/Neukirchen were announced by the customers of Klanxbüll/Neukirchen and the installers. Measurements on representative appliances will be carried out when temperatures fall and the duration of the injection periods begins to increase.

**Summary and outlook**

This project is looking into the feasibility of hydrogen injection into an existing natural gas distribution grid. The project is being executed by E.ON Technologies in collaboration with E.ON Hanse and Schleswig Holstein Netz AG supported by the Engler-Bunte-Institute in field investigations of the installed appliances. The activities are part of a project within the DVGW Gas Innovation Campaign which includes additional tests carried out at the laboratories of the Engler-Bunte-Institute (Karlsruhe) and Gas- und Wärme-Institut (Essen).
Project preparations included selecting an appropriate distribution grid, analysing its grid structure, the gas quality, gas flow rates and appliances used in the service area. Installation of the hydrogen injection unit has been completed and the unit has been approved by TÜV. Hydrogen injection has started and control of the volumetric hydrogen flow rate has been tested and optimised. So far, there have been tests with up to 4 vol.% of hydrogen injected into the natural gas flow. None of the appliances has so far malfunctioned.
The tests will continue in the coming heating season. The hydrogen concentration will be gradually increased to the limits defined in DVGW G 260 and the control system will be closely monitored and adjustments made as necessary. Once injection periods can be extended, there will be a series of measurements of representative appliances.

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