GT-170272
5 July 2018

Future-proof gas distribution networks

Report Summary

Trust
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Progress

1 Summary

Impact of the energy transition on gas distribution networks

In order to achieve the objectives set forth in the Paris Climate Agreement, the Netherlands aims to reduce its carbon dioxide emissions in urban areas to 0% by 2050. Fossil energy sources will give way to sustainable energy.
This transition will have a far-reaching impact on many, including network operators. With the phasing out of natural gas, an important question emerges as to whether or not there is still a future for the existing gas network. This question is a timely one for regional network operators, as decisions already have to be made regarding long-term maintenance for the gas network.
Studies such as 'Net voor de Toekomst' ('Network for the Future') foresee that the use of sustainable gases such as hydrogen and biomethane will result in expedited availability of a sustainable energy supply. In locations where the gas network is suitable, the option of finding a sustainable gas solution for gas networks is possible, whether temporary or otherwise. The question then is which sustainable gases are to be used and how network operators can prepare for this transition.
That is why Netbeheer Nederland asked Kiwa to investigate what it would take to make the existing gas distribution networks future-proof.

Logic behind removing Groningen gas as the standard for gas quality

These days, less than 1% of the gas added to the natural gas network is sustainable. 'Green gas' of biological origin has virtually the same quality level as conventional (Groningen) natural gas. One valid question is whether the same level of quality for natural gas should be used in the future. A switch to natural gas with a high calorific value, the international standard, is not the ideal solution for urban areas. The climate targets exclude the use of any kind of natural gas in the future. Logically, that means that gas quality in the future will have to conform with that of sustainable gases.
The study 'Network for the Future' is based on two types of sustainable gases.
The first is biomethane, a term that covers a wide range of biologically produced gases. As is the case with natural gas, biomethane is also mainly composed of methane, but combined with a wider variety of different gas components.
The second is hydrogen, which can be produced using sustainable electricity. Hydrogen is currently drawing a great deal of attention as an emission-free energy carrier for mobility, energy storage, industrial use and possibly even for urban areas.
Switching to new quality standards for these sustainable gases will prevent unnecessary costs and loss of efficiency caused by having to process sustainable gases that are compliant with the quality requirements of natural gas.

Utilising over 50 years of experience in natural gas distribution

In close cooperation with regional network management experts, research was conducted into what factors would be involved in switching from natural gas to these sustainable gases. In addition to providing safe, reliable and affordable transport, this would also involve measurements and calculations. The quality of the gas supplied was also included in the study, as well as the impact on the consumer. Currently, no extensive experience has been gathered in the use of hydrogen and biomethane in urban areas. However, there is a great deal of knowledge available from practical tests, laboratory research and technical manuals.
All of this information has been collected for the first time in this report and systematically applied to the Dutch gas distribution network case. The following research questions have been addressed:

- to what extent can the current gas distribution network withstand sustainable gases?
- what modifications are needed to make the existing gas networks suitable?
- what costs are involved for these conversions?

As a guideline, we have attempted to link as much as possible to the materials, standards and methods that now apply to natural gas. These elements have been critically evaluated once again from the perspective of the safe distribution of hydrogen and biomethane.

The results have provided insight into potential risks and control measures. This research forms a solid foundation for a future implementation agenda ensuring that existing gas distribution networks are future-proof.

Existing networks are suitable for the distribution of sustainable gases

The most important conclusion from this research is that, with the application of appropriate measures, the existing gas network can be used to distribute sustainable gases such as (100%) hydrogen and biomethane.
Concerning the distribution of sustainable gases, the gas network of the future can remain largely the same as the current natural gas network.
The most important modifications needed for network operators involves measuring and calculating quantities of supplied energy. An additional measure required is making end user devices suitable for biomethane and 100% hydrogen.

Safe and reliable use of hydrogen and biomethane in urban areas

In order to use these sustainable gases at a level that is at least as safe and reliable as natural gas, an overview of focus areas and potential control measures has been drawn up. The experts consulted expect that these factors will help make safe and reliable distribution possible.
However, a quantitative assessment of the risks and effectiveness of the measures has not yet been conducted.
One minimum precautionary measure required is giving hydrogen and biomethane a recognisable odour, preferably using a sulphur-free odourant.
Another important focus area is the safety measures to be applied for undesirable gas leaks, such as with excavation damage. The safety aspect also deserves special attention regarding the indoor use of hydrogen.

Net cost adjustments estimated at a maximum of 700 million euros

The future use of new gases in urban areas still brings with it a number of uncertainties. The costs for network conversions depend on which parts of the current gas network will still need to be retained.
Using the four scenarios in the study "Network for the Future", a cost indication for what would be involved in converting the gas distribution network was provided, excluding end user modifications.
The total costs for switching and modifying the networks could add up to 700 million euros. The expected increase in annual network costs for gas distribution is 5 to 50% per home.
The largest expense in the transition to hydrogen involves replacing the gas meters and revising the calculation procedure for gas costs due to differences in gas composition. For biomethane, there are also additional costs for handling different calorific values. One significant periodic expense comes in conjunction with increased supervision of excavation work.
These additional network costs are limited in comparison to the conversion costs expected for end user devices.

Action perspective for network operators

In order to provide a safe and reliable supply of sustainable gas in urban areas, it is necessary to take prudent steps to build upon our experience. Given the momentum of the energy transition, it is important to maintain a calculated balance between the pace of learning and an acceptable level of risk during this learning process.
Responsibility lies with several parties during this gas transition. That means that joining forces in this experience is crucial. This goes beyond gas network operators, as it also affects owners of underground infrastructures, suppliers of end-user equipment, safety authorities, municipalities, etc.
Assuming that the future distribution of sustainable gases will be considered a public duty for network operators, as is currently the case with natural gas, the next steps are recommended to be:

- validating and elaborating on findings from this report in practice as well as developing best practices;
- examining the implications of measurements and calculations of sustainable gases;

- organising and establishing appropriate (international) norms and standards along the entire chain, from production to end user;
- setting up courses and campaigns aimed at increasing public awareness.

Final remarks

This inductive study provides as complete and objective an answer as possible to the question of how gas networks can be used for the future-proof distribution of sustainable gases. Perhaps the most important factor in definitively answering this question lies in human behaviour. Decades of experience with natural gas distribution have shown that issues such as the perception of safety, corporate culture and leadership are essential in delivering a safe and reliable energy supply. This also applies to sustainable gases.
The regional network managers will determine whether and how the gas network will be used for transporting sustainable gases. The answer to the question posed in the research is not presented as a given fact, but as a choice. To this end, this report (with annexes) contains all of the information available for assessing the possibilities and limitations of hydrogen and biomethane in urban areas. The remaining section of this summary contains the most important insights pertaining to each type of gas.

1.1 Distribution of hydrogen

Difference between hydrogen and natural gas distribution

Hydrogen is the smallest molecule in existence and can be created in a sustainable manner by converting water into hydrogen and oxygen using wind or solar-powered electricity. Hydrogen can be used as an emission-free energy carrier and storage medium. No CO_2 is released during the conversion of hydrogen into electricity or heat. The report 'Contouren voor een routekaart waterstof' ('Outline for a hydrogen roadmap') contains recent insights into the use of hydrogen for the energy supply in the Netherlands. Hydrogen can be transported via the existing gas network. However, hydrogen is a different gas to the more familiar natural gas. In comparison to natural gas, hydrogen has a lower ignition temperature, broader explosion limits, is lighter and dissipates more easily. When hydrogen is burned, the flame has low to zero visibility and the burn rate is higher than with natural gas. In addition, hydrogen, like natural gas itself, does not have a natural odour. In order to ensure safe distribution, network operators will have to take these properties into account.

Experience gained from the petrochemical industry, scientific research and practical tests

Hydrogen is being transported and used on a large scale in the petrochemical industry. There is also extensive scientific literature available on the effects of hydrogen on materials. A comprehensive overview of the knowledge and experience currently available has been compiled for the regional gas networks, partially based on various practical tests. Much of the basic knowledge gathered on the material resistance of plastics, metals and rubber materials is available in standard works and manuals used in the industry.
The most important scientifically based studies on the effects of transporting and distributing hydrogen via the existing gas network were carried out during the European NaturalHy project. This was followed by the multi-year Dutch EDGaR study. In addition to extensive literature reviews, any remaining lack of knowledge has been supplemented with experiments on gas distribution materials. Due to the fact that a sufficient level of information on the effects of 100% hydrogen was already available during this literature review, no additional tests using 100% hydrogen were performed during EDGaR (though syngas containing up to 62% hydrogen was tested). In these studies, researchers conducted laboratory tests on the resistance of metals, plastics and rubber materials. These involved effects on quality and residual lifetime, such as embrittlement, tensile strength, hardness and toughness of pipe materials and seals.
The most relevant practical experience in the field of hydrogen distribution in gas networks was gained in a practical test in Ameland. Here, up to 20% hydrogen was added to the natural gas in a specially

designed test network and supplied to a variety of domestic gas installations. The test network consisted of conventional constructions using old and new materials and connections.
A second practical test was carried out in Denmark where the transport of 100% hydrogen through new and used PE and steel pipes was tested over a period of 10 years.
In addition, numerous sub-studies have been conducted internationally, the results of which correspond with the results from the above studies.
This research has provided in-depth insight into material effects. These effects have then been examined together with known failure mechanisms to draw conclusions concerning the suitability of gas distribution networks.

The gas distribution network is resistant to hydrogen

The overall findings from this research conclude that the current gas distribution network will not be significantly affected by hydrogen. For all known materials, the most important of which being steel, PE and PVC, no noticeable degradation was observed or can be expected based on the literature consulted, laboratory tests and practical tests.
Utilising the current gas network involves one important focus area. The reason is the lower energy density of hydrogen. Given a consistent demand for energy, the volume of gas requiring transport would be three times the current amount. The means that the vast majority of gas meters, which are based on volume measurement, would likely have too low a capacity during peak periods. In order to measure the same (maximum) energy flow, a volume three times larger would be required. The extent to which this would make the current gas meters unsuitable in practice has not yet been investigated.
Lower energy density also results in a higher flow rate.
In addition, the transport capacity of the pipes remains the same as that of natural gas.
Any other effects are unknown or negligible.

Existing equipment is not suitable for 100% hydrogen

There are virtually no existing end user devices that are suitable for use with 100% hydrogen. Hydrogen combustion in existing boilers may result in flame damage and damage to the burner. Also, the safety principle (ionisation current) used for existing devices is not applicable to 100% hydrogen. This also applies to most gas cookers. One increased safety risk concerning cooking appliances is that the combustion of hydrogen does not produce a visible flame.
The availability of hydrogen makes the use of fuel cells possible. Fuel cells are highly efficient in converting hydrogen and oxygen into electricity and water. Pure hydrogen is important for the lifespan of fuel cells. The quality of hydrogen that could be supplied via the gas network and to what extent this would pose any limitations for the use of fuel cells is not yet known. Experience with natural gas and green gas shows that some contamination is inevitable due to moisture ingress, permeation of oxygen and nitrogen, and the presence of dirt in the pipes. Also, the fragrance compound currently used for natural gas and green gas, the sulphur-containing THT, is not recommended for use in combination with fuel cells.

Transitioning to hydrogen requires a review of standards and working methods

In order to the manage the risks involved with natural gas and green gas, a number of standards, work instructions and training courses for technicians and other experts have been developed over the years. This has made the natural gas network in the Netherlands one of the safest and most reliable in the world.
Other properties of hydrogen require a critical assessment and review in order to maintain the current level at a minimum. The amount of practical experience gathered is still not sufficient enough to quantify the risks of 100% hydrogen distribution. That is why a qualitative approach was chosen based on the bow-tie method and expert interviews. This has helped provide insight into the potential risks and necessary focus areas pertaining to work activities, leaks and emergency situations. Related control measures have been specified. These must be validated and optimised in practice.
Based on research conducted by experts, it is not possible to determine whether distribution and use of hydrogen in urban areas is inherently safer or more dangerous than natural gas. An important advantage of hydrogen is that it does not involve the risk of carbon monoxide poisoning. In addition,

the volatility level of hydrogen reduces the risk of fire or explosions. On the other hand, there is increased risk due to the broader range of explosion limits, the lower combustion temperature and the lower ignition energy. In a practice study in the United Kingdom on hydrogen leaks in a test farm, it was not possible to create an explosive mixture under normal circumstances. In short, there are arguments that lead to an increased risk and others that indicate a lower risk as compared to natural gas. The question of which measures are necessary to adequately manage the risk of fire or explosions in the event of hydrogen leaks cannot yet be definitively addressed.
Finally, there are two other phenomena that are often related to hydrogen. These include the permeation of hydrogen through plastic pipes, and the hydrogen embrittlement of steel. Both effects are negligible under the the most common conditions in distribution networks and do not cause significant degradation or an increase in the safety risk.

1.2 Distribution of biomethane

Diversity of gas components in biomethane

Biomethane highly resembles natural gas. The main component is methane, enhanced with various concentrations of other component types. The quality of natural gas and green gas is specified in the Ministerial Regulation (MR) Gas Quality. This allows for limited variation in the concentration of gas components. Biomethane is extracted from a wide variety of organic biomass streams, thus providing a greater range of gas compositions than allowed for in the MR. The most commonly applied production process consists of fermenting biomass such as organic waste and residual waste from the food industry and from manure. In addition, there have been developments in the production of syngas by the gasification of woody biomass and the methanisation of hydrogen. Ultimately, more than 13 different main components in various proportions may occur in biomethane. For this research, biomethane limit values per component have been established based on known production methods.

Research into the broadest possible limit values for biomethane

The current gas must comply with MR Gas Quality. Since 2016, limit values have been included for gas components that may occur in biomethane. Biomethane that meets these quality requirements is called 'green gas' and may be introduced into the existing gas network. These requirements have been established in order to guarantee safety and compatibility with natural gas.
Compatibility will no longer be necessary in the future, meaning that a broader set of limit values for biomethane can be established. In order for these broader limit values to be set, research has been conducted into the influence of gas components on materials and combustion behaviour in end-user equipment.
The most important insights into the gas distribution networks come from EDGaR, where extensive tests have been conducted into material resistance. In addition, experience with transporting cleaned ‘biogas’, which is subject to less stringent quality requirements than green gas, has been gained at various locations in the Netherlands. MR gas quality does not apply to these local applications. Separate safety instructions and work agreements have been established. In general, more knowledge and practical experience is available about the use of biomethane in urban areas than for hydrogen. On the other hand, the published conclusions are less straightforward. While there has been no indication that the use of hydrogen has caused material degradation, there are indications for biomethane that some components can have an impact on the lifetime of the gas distribution network.

Virtually any form of biomethane is permissible for the existing gas distribution network

Biomethane is currently being raised to the same quality level as natural gas. According to the research conducted, this will not necessarily be required in the future, provided that gas measurements and devices have been made suitable for the end users. The network manager can then allow almost any biomethane composition to be used in the existing infrastructure. PE and PVC are particularly resistant to the gas components that can be present in biomethane. Maximum values still apply to some gas components.These maximum values are necessary in order to prevent the degradation of metal parts in the gas network as well as POM material. POM is frequently used in connections, home pressure regulators and gas meters.

The modifications required for end users are not as far-reaching as with hydrogen. Just as with hydrogen, proper measurements and calculations is a focus area. Concerning biomethane, this is due to the larger range of energy content. The volume measurement principle used in the existing gas meters does not take this into account, resulting in less accurate calculations than what is currently required (<0.5%). At this time, there is no measuring principle at comparable costs as what is available for correct individual calculation methods with end users. Apart from designing suitable meters, this can also be solved by allowing limited variation in gas quality (per area) or by introducing gas quality measurement at an area level. What the best option would be from an economical perspective has not yet been studied.

Safe and reliable use of biomethane in urban areas

Biomethane may contain a number of toxic components. Work may not be carried out in an environment where the concentration of these components is above the maximum permissible value. The lowest limit value in which an explosive gas mixture may occur can be used as a maximum value, as work is not permitted in this situation due to the risk of fire and explosion. Experience gathered locally in transporting cleaned 'biogas' shows that following this measure does not result in any additional risk for biomethane as compared to natural gas. The strength of this method depends on proper compliance with the applicable procedures and work instructions, as well as on the supervision provided.