HyDelta 2

WP7 – Conversion of natural gas distribution networks to hydrogen

D7.2 – Model conversion plan

Status: FINAL

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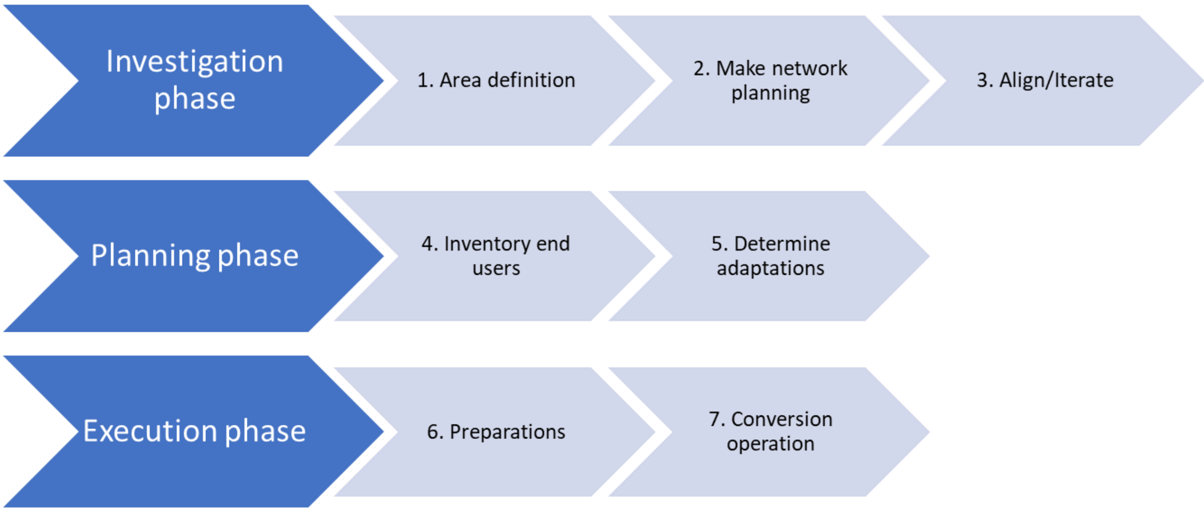
Executive summary

In work package 7 of HyDelta 2 "Conversion of natural gas distribution networks to hydrogen", a model conversion plan has been developed for the large-scale conversion of existing gas distribution networks to almost pure hydrogen. This model conversion plan is based on experiences and insights gained in hydrogen projects and conversion studies in the Netherlands and abroad. In order to understand in more detail what a conversion plan entails, two case studies have been developed for this project. The generic conversion plan offers regional network operators a basis for a specific conversion plan. Because each region and the gas distribution network located therein is unique, the generic conversion plan will have to be adapted to the specific characteristics of the gas distribution network.

Structure of the conversion plan

The model conversion plan contains a description of more than 50 activities to be carried out, divided into 3 phases and a total of 7 steps:



Alternatives are possible for some activities. The choice between alternatives depends, among other things, on the availability of devices/components and availability of suitably qualified personnel, or on the preference of the grid operator. Sometimes there are alternatives that require further research.

Time planning

Part of the conversion plan is a time schedule. Assumptions and preconditions apply to the time planning, such as the number of personnel to be deployed or the maximum duration of the gas interruption during the conversion. The lead time of the various steps and phases depends on the size of the distribution network and the number and types of end users. The lead time of steps and phases can be influenced by changes in assumptions and preconditions. During the execution phase of the conversion plan, the time schedule may have to be adjusted on the basis of the information obtained in the planning phase.

Tasks and responsibilities

A large number of parties will be involved in the implementation of the conversion plan: municipality(ies), distribution system operator, operators of the natural gas and hydrogen transport network, hydrogen suppliers, installers and end users. The model conversion plan indicates for each activity how the tasks and responsibilities can be divided. Because the conversion is a complex and time-consuming process, good coordination is essential. The municipality is the appropriate party to coordinate the conversion of the distribution network to hydrogen, because municipalities are designated to decide on and implement the energy transition at a local level. It has the necessary powers to do so, can make a broad assessment of interests and is supervised by a democratically elected council. The execution of work can be outsourced by the parties involved to contractors and consultants.

The parties involved will have to inform each other and good coordination is necessary for certain activities. The municipality is responsible for communication with the end users and will draw up a communication plan for this. Multiple communication forms and channels can be used. In addition, the municipality can set up an information point where end users can go with their questions during the entire conversion process.

Conclusions
This research has yielded the following insights:

- Coordination, responsibilities and communication:
  - A large number of parties are involved in the implementation of the conversion plan. It is essential to make good agreements about the responsibilities of the tasks to be executed.
  - Because the conversion is a complex and time-consuming process, good coordination is essential. The municipality is the appropriate party to coordinate and communicate about the conversion of the distribution network to hydrogen.
  - Parties involved will have to inform each other optimally and good coordination is required for certain activities.
  - Support by the end-user is an essential precondition. This concerns the public acceptance that the energy supply with natural gas can no longer continue to exist, that hydrogen is a good replacement for natural gas, i.e. safe, affordable (compared to alternatives such as all-electric) and security of supply is guaranteed.
  - The municipality is responsible for communication with the end users and will have to draw up a communication plan for this.
- Duration of the conversion plan:
  - The conversion of a part of the gas distribution grid (from planning phase to execution phase) can take several years. In the two cases studied, this varies from about 3 years (3,700 connections) to more than 6 years (30,000 connections).
  - If a different choice is made for replacing natural gas, such as for a heat network (construction of a new network) or for all-electric (grid reinforcement), a plan will also have to be drawn up and implemented. The activities are partly comparable to those of the conversion plan to hydrogen and will also entail a considerable lead time. However, no comparison has been made in this study.
  - The duration of the conversion plan is determined by the size of the distribution network (i.e. the number of connections) and the required number of qualified personnel or by new Hydrogen Distribution Station(s) (HDS) to be realised and expansion/upgrading of the distribution network, including the lead time of permit granting. The latter requires a joint planning by the national and regional gas network operator.
  - The execution phase (preparatory work and conversion operation) takes up more than 70-80% of the total time.
  - The duration of the conversion operation, during which the gas supply to end users is interrupted, can be limited by carrying out as much work as possible during the preparatory work (such as replacing the existing central heating boiler with an H_2-ready boiler). Even if this saves little time in total, this shift does provide more flexibility in the implementation.

  - The physical conversion (last step of the conversion plan) can be shortened considerably if a dual-fuel boiler and dual-fuel gas meter can be used and flushing the gas pipes with nitrogen can be omitted. This makes the conversion process less complex, shortens the total lead time of the conversion plan and can lead to cost savings.
  - Most technically trained personnel are required for inspection of the installations at the end users (planning phase) and replacing the gas installations (execution phase). By deploying more personnel, the lead time can be reduced.
- Dividing the distribution network into sections:
  - For the conversion, the gas distribution network will be divided into sections. The number and size of these sections depends on two preconditions: the duration of the gas interruption and the number of installers to be deployed to convert the gas equipment at the end users.
  - If dual-fuel devices/components can be used (such as gas meter, central heating boiler), the sections can be larger or no sectioning is required at all.
  - The order in which the sections are converted from natural gas to hydrogen depends on the position of the hydrogen and natural gas feed-in points in the grid. It may be necessary to use a temporary feed-in point (for example a tube trailer with hydrogen or natural gas or via an additional pipeline to be installed).
- Security of supply:
  - Because existing gas infrastructure is used and adjacent areas have to be supplied with natural gas in addition to the area being supplied with hydrogen, it is often impossible to maintain the security of supply of the hydrogen distribution network at the same level as in the situation when natural gas was still being distributed. The risk of an interruption of the hydrogen supply to end users will then have to be dealt with in a different way.
- Alternatives:
  - Replacing the central heating boiler with an H_2-ready boiler or with a dual-fuel boiler (if available) during the preparatory work: A dual-fuel boiler saves time during the conversion operation. The lead time for the preparatory work remains the same as for replacement by an H_2-ready boiler.
  - Whether or not to flush the distribution pipe, connection pipe and/or indoor pipe with nitrogen: If flushing with nitrogen can be skipped, this simplifies the work during the conversion operation.
  - Whether or not to use gas stoppers at every customer: These are now being used for new connections, but they are not present for existing connections.
  - Temporary gas supply from the existing gas network or with tube trailers: During the conversion, end users who have not yet been supplied with hydrogen will still have to be supplied with natural gas. This is possible if the distribution network that is being converted still has a city gate station that is connected to an RTL on natural gas or is connected to a gas distribution network that remains on natural gas. Alternatively, a tube trailer can be used for the temporary supply of natural gas or hydrogen.

Recommendations
This research leads to the following recommendations:

- Lessons learned from current pilots: Various pilot projects will be carried out in the coming years. The experiences and insights gained (also with regard to coordination, responsibilities and communication) can form an important input for the further development of the model conversion plan.

- Acceleration of permit procedures: the lead time of permit procedures can have a major impact on the lead time of the whole conversion plan (e.g. the permit procedure for the HDS). It is recommended to investigate how the lead time of permit procedures can be shortened.
- Remediation: For gas distribution networks that are being converted to hydrogen, it is recommended to replace old pipe sections, including cast iron, in the coming years.
- Suitability of valves: Insufficient research has been carried out into the leak-tightness (both internal and external leakage) of valves running on hydrogen. Further research into this is recommended.
- Inerting indoor pipelines: The extent to which the indoor pipeline should be inertised with nitrogen is still under discussion. It is therefore recommended to conduct additional research into this.
- Filling the gas network with hydrogen: Research must show how a meshed network can be safely filled with hydrogen.
- H_2-ready boiler: The use of an H_2-ready boiler is decisive for the implementation of the conversion. However, a good definition or standardization of an H_2-ready boiler is still lacking. It is recommended to set this up.
- Dual-fuel components: Availability of dual-fuel boiler and gas meters greatly simplifies and accelerates the physical conversion. It is recommended to have a dual-fuel boiler developed or market parties to encouraged to do so. More clarity is also needed about the suitability of gas meters for both natural gas and hydrogen.
- Security of supply: Compared to natural gas distribution, the security of supply of hydrogen distribution cannot always be maintained at the same level due to a smaller number of feed-in points and/or less meshing of the grid. It is recommended that research be carried out into the risk of interruption of the hydrogen supply and how this can be mitigated.
- Increasing conversion efficiency: The costs of the conversion have not been mapped out in this study. A better insight into the conversion costs can be helpful in improving the cost efficiency of the conversion process. In addition, the conversion to hydrogen may be simplified, for example by performing activities more efficiently or limiting the number of actions. Research could be carried out into this.
- Availability of affordable hydrogen: Whether it is attractive for end users to switch to a hydrogen-based gas supply depends on the future availability and affordability of hydrogen. This is an important precondition for converting the gas distribution network. It is recommended that developments with regard to the hydrogen supply be followed closely.

Content

1. Introduction

Government policy is aimed at phasing out the use of natural gas. As part of this policy, municipalities draw up a Transition Vision Heat in which it is determined for various districts how future heat demand will be met. In consultation with the distribution system operator of the gas distribution network, municipalities may decide to supply homes, utility buildings and companies with hydrogen. For this purpose, the existing natural gas distribution network can be converted to almost 100% hydrogen. Gas installations and appliances at end-users should also be made suitable for the application of hydrogen. The local availability of hydrogen will co-determine the decision to convert a gas distribution network to hydrogen. This could be local hydrogen production, the proximity of a hydrogen transmission pipeline combined with nationwide hydrogen suppliers that can guarantee delivery of hydrogen or a combination of both.

Scope of the study

This study developed a generic conversion plan that can be used as a model by grid operators when converting the existing natural gas distribution grid to hydrogen. This assumes that hydrogen is available and that existing assets can be used as much as possible. The conversion plan developed covers the conversion of the gas distribution network from the connection to the hydrogen feed-in in the distribution grid (HDS) to the gas installations at end-users. In time, the conversion plan starts from the decision to distribute hydrogen in a selected area and runs through to the physical conversion of the gas distribution network and connected end-user applications. The conversion plan takes into account that surrounding areas will continue to be supplied with natural gas for some time.

Inventory

This study started with an analysis of some aspects relevant for a conversion plan. The results were published in D7.1 - Inventory of relevant aspects for conversion of gas distribution networks to hydrogen [1]. This included an inventory of Dutch hydrogen projects and conversion studies and some in Germany and the UK.

Case studies

Besides knowledge and insights already gained by grid companies when implementing hydrogen projects and conversion studies, two case studies were also carried out in this research. Deliverable 7.2 in which the case studies are described (appendices to this report) are not publicly available. For these cases, detailed plans were made for the conversion of existing gas distribution networks in Kapelle and in and near Nijmegen. The Kapelle case is characterised by a business park combined with residential areas in a small town. The Nijmegen case involves a combination of urban and rural areas. The conversion plans describe all the activities to be carried out, divided into 3 phases and 7 steps. For some activities, alternatives are possible where the choice depends, among other things, on the availability of devices and components or requires further research. For each conversion plan, a time schedule has been drawn up, taking into account the size of the distribution network and the number and types of end users. The influence that assumptions and preconditions have on the time planning has been made explicit. Implementation of the conversion plan will involve a large number of parties, such as municipality(s), grid operator, natural gas and hydrogen transmission grid operators, hydrogen suppliers, installers and end users. It is indicated per conversion plan how tasks and responsibilities can be divided per activity. As conversion is a complex and time-consuming process, good coordination is essential. Moreover, involved parties will have to be well informed and good coordination will be needed for certain activities. A communication plan will have to be drawn up for this purpose.

Model conversion plan

The developed model conversion plan presented in this report is based on the insights from the hydrogen projects and conversion studies and the two case studies carried out. In doing so, the proposed approach has been made generic so that it can be used as a basis for any gas distribution network. However, any conversion plan will have to be adapted to specific local situations and circumstances. In future, this generic conversion plan will have to be tested against new developments and lessons learned and adjusted if necessary.

Reading guide

This report is structured as follows:

- Chapter 2 provides an overview of the assumptions and preconditions applicable to the model conversion plan. This includes effects and consequences that changes in the assumptions have on the conversion plan.
- Chapter 3 provides an overview of learning points from hydrogen projects and conversion studies conducted by grid operators, as well as a summary of the two case studies conducted as part of this research. The conversion plans for the two case studies themselves are presented in two non-publicly available appendices to this report.
- Chapter 4 discusses the structure of the conversion plan, how tasks and responsibilities can be divided for the various activities, as well as the time schedule and the importance of a good communication plan.
- The model conversion plan consists of 51 activities, divided into 3 phases and 7 steps. Chapter 5 describes these activities for each step.
- Chapter 6 provides an overview of the main insights gained in this project. Recommendations have also been formulated here, including those on research that can help further enhance insights and help improve the model conversion plan presented here.

2. Assumptions

In drawing up the model conversion plan, a number of starting points were used and assumptions made. These are shown and explained in Table 1. Some assumptions can be changed, such as the number of technicians to be deployed. Choices are also possible (options). The effect on the conversion plan of changing the assumptions or making different choices is discussed in Chapter 5.

Based on the current EU proposals, the hydrogen distribution network will be operated by a separate distribution system operator (DSO), separate from the DSO operating the natural gas distribution network. The assets of the existing distribution network that will be used for hydrogen will be transferred to the operator of the hydrogen distribution network. This is in line with the proposed amendment to the European Gas Regulation and the Gas Directive [1]. If a natural gas network is converted in the next 5 years as part of a hydrogen pilot, the ACM's Temporary Framework for Hydrogen Pilots will apply [1]. A pilot must relate to the built environment and have a specific learning objective. Grid operators may carry out the transport and distribution of hydrogen over the grid, but have no role in the production, trade and supply of hydrogen. Hydrogen distribution is subject to specific safety conditions. The Ministry of Economic Affairs has drawn up a temporary policy framework for this. For further explanation of the (future) regulations for hydrogen distribution, see HyDelta report D7.1 - Inventory of relevant aspects for conversion of gas distribution networks to hydrogen [1].

Table 1 - Assumptions

Hydrogen supply and distribution and delivery	• Sufficient hydrogen is available for delivery to end-users. • The hydrogen distribution network will be operated by a separate distribution system operator. The assets of the natural gas distribution network are transferred to the hydrogen distribution network operator. The hydrogen distribution network operator has no role in hydrogen production, trading and supply.
Materials	• The existing grid infrastructure will be used as much as possible. • Necessary materials and equipment are available and do not have exceptional delivery times. This also applies to specialist equipment for the conversion.
Sectioning the distribution network	• Maximum 500 connections per section. This follows from the number of installers to be deployed and the maximum duration of gas interruption during conversion: 50 installers x 2 homes per installer per day x 5 working days per week.

End-user inventory	• Small consumers:
	  ○ 50 surveyors
	  ○ 8 homes per surveyor per day (maximum)
	• Large consumers:
	  ○ 10 surveyors
	  ○ 1 company per surveyor per day

Preparation for conversion of distribution network + gas meter	• 15 technicians per section (own staff grid operator or hired contractors).

Preparing conversion of indoor installation and gas appliances	• Only replacement of central heating boiler in small consumers is included in the conversion plan. The small consumer will have to arrange replacement of other gas appliances, such as cooker, themselves.
	• Availability of an H_2-ready boiler or dual fuel boiler:
	  ○ An H_2-ready boiler can easily be made suitable for hydrogen by replacing control unit/burner during conversion. There are H_2-ready boilers being developed by boiler manufacturers that are suitable for natural gas and can be converted to 100% hydrogen within an hour [1].
	  ○ A dual-fuel boiler can use both natural gas and hydrogen efficiently and safely. It is not yet known whether this type of boiler is under development.
	• The availability of a hydrogen or dual-fuel gas meter; a dual-fuel gas meter can correctly measure the consumption of both natural gas and hydrogen (complies with billing meter requirements).[1]
	• Small consumers:
	  ○ 50 installers
	  ○ 2 installers per home per day
	  ○ Only heating equipment and meters, no cooking appliances.
	• Large consumers/Cluster-6:
	  ○ 50 installers
	  ○ 2 installers per company per day

Distribution network conversion	• 15 mechanics per section (own staff grid operator or hired contractors).

Conversion of indoor installation + gas appliances	• Small consumers/large consumers:
	  ○ 50 installers
	  ○ 500 connections per week (1 section)

Conversion	• Maximum duration of gas supply interruption: 5 working days. • 7 months a year (not in period November-March).

[1] While there is currently no complete clarity on the applicability of existing gas meters for hydrogen or availability of hydrogen-ready meters, it is assumed that this clarity will be there by the time conversion will take place.

3. Conversion plans

The model conversion plan is partly based on insights gained from hydrogen projects and conversion studies conducted by grid operators. For this study, an inventory of these hydrogen projects and conversion studies was made (see D7.1 - Inventory of relevant aspects for conversion of gas distribution networks to hydrogen [1]). The inventory includes 11 projects (mostly field tests and pilots) and 8 studies[2]. Of these 19 projects and studies, 14 are from the Netherlands, 3 from Germany and 2 from the UK. In some conversion projects and studies, a step-by-step plan for conversion has been developed. These are projects and studies by Alliander (Lochem, Haarlem, IJmuiden and Drachten) [2, 3], Stedin (Uithoorn, Stad aan 't Haringvliet, Gouda, Noord-Beveland) [4, 5, 6] and H21 (Leeds, UK) [7]. Section 3.1 summarises the key learning points from these projects and studies.

In addition, the model conversion plan is based on two case studies carried out for this study. These are a gas distribution network in and near Nijmegen operated by Liander and a gas distribution network in Kapelle operated by Stedin. The aim of the case studies was to investigate the steps of a conversion plan in more detail. The case studies are described in detail in two non-public annexes to this report: annex A (Nijmegen) and annex B (Kapelle). Section 3.2 summarises the case studies and presents the key insights.

3.1 Hydrogen projects and conversion studies

Although the information provided by different projects and studies on distribution network conversion is very different and difficult to compare, a number of learning points can be drawn from it:

- *Divide into steps*: It makes sense to divide the conversion plan into a number of separate steps for both preparation and implementation of the conversion. Alliander has developed such a step-by-step plan for the conversion of areas with several thousand connections (Haarlem, IJmuiden, Drachten) [2, 3]. In it, 8 steps are distinguished. The first six steps relate to the preparation: (1) define hydrogen area, (2) breakdown into manageable sizes, (3) inventory of the gas network in sub-areas, (4) inventory of customers in sub-areas, (5) technical conversion plan and (6) planning. The last two steps concern the implementation of the conversion plan: (7) convert gas grid and (8) switching.
- *Interruption of gas supply*: For the safe conversion of the gas supply from natural gas to hydrogen, the gas supply must be interrupted. Stedin's assumption in the Stad aan 't Haringvliet conversion plan is that homes will not be without gas for more than one day [5]. Alliander assumes an interruption of one week [3]. The H21 project for Leeds (UK) assumes an interruption during the conversion of 1 to 5 days [6].
- *Switching outside the heating season:* For two reasons, switching with interruption of gas supply during the heating season is less desirable: (1) the impact of the interruption for the customer is the greatest during this period and (2) the gas flow is relatively large, making continuation of the gas supply of the different sections rather critical. For these reasons, switching in the H21 project takes place only outside the heating season (April-September).
- *Dividing the gas distribution network in sections*: The conversion of a gas distribution network with several thousand connections is done in phases. For this purpose, the gas distribution network is divided into sections. The assumption regarding gas interruption affects the size of the sections. In the different conversion studies, the size of the sections varies. Alliander assumes (Haarlem,

[2] Projects are preceded by studies. If there is an intention to actually distribute and supply physical hydrogen, this is called a project. A study refers to an investigation where there is no concrete intention to supply hydrogen to the distribution network.

IJmuiden, Drachten) 3000 connections [3], H21 (Leeds, UK) 2500 connections [6] and Stedin (Stad aan 't Haringvliet) 15-20 connections [5].

- *Order in which sections are switched*: This is determined by where hydrogen is fed into the grid. Sections that have not yet been converted should continue to be supplied with natural gas. The conversion plan should determine the order in which the sections are converted. The H21 conversion plan describes two strategies where the location of the hydrogen feed-in varies. This can influence the duration of the gas interruption.
- *Activities during switching*: Activities during switching involves work on the gas distribution network, such as closing the section of the gas distribution network (closing network isolation valves and gas valve end users), depressurising the pipeline, flushing the gas pipeline and pressurising with hydrogen. In addition, work takes place from and after the meter, such as replacing gas meter, replacing gas appliances (central heating boiler), checking indoor installation for tightness and flushing connecting pipe and indoor pipes. When appliances are already replaced earlier (e.g. natural gas central heating boiler by H_2-ready boiler), this limits the work to be carried out during the conversion [1]. In the Uithoorn conversion project, Stedin flushed the gas distribution pipe with nitrogen before letting hydrogen into the gas grid [4].
- *Responsibility and coordination*: In many of the hydrogen projects, the grid operator is assumed to be responsible for planning and implementation. In pilots aimed at gaining experience, this need not be a problem. However, when implementing conversion plans, the grid operator (i.e. DSO of the hydrogen gas distribution network) is subject to regulatory frameworks that the DSO must stay within. Both the separation of roles and required coordination between the various responsibilities deserve attention. The various step-by-step plans provide only limited insight into who is responsible for carrying out the various steps and activities, such as identifying technical adaptation among end-users.

3.2 Case studies conducted

Nijmegen

For the Nijmegen case, it is assumed that an existing regional transmission pipeline (RTL) will be converted to hydrogen by transmission system operator (TSO) Gasunie to supply hydrogen to two brickworks. The RTL will be connected to the national hydrogen transmission pipeline. Also connected to the RTL are three city gas stations (GOSs) that supply gas to the eastern part of the city of Nijmegen and the area south of the Waal and Rhine rivers and east of Nijmegen. This area includes the towns of Ooij and Millingen a/d Rijn. In total, there are about 30,000 gas connections in this area in both urban and rural areas. It is assumed that the municipalities of Nijmegen and Berg en Dal and the distribution system operator Liander will jointly choose to supply this area with hydrogen and convert the gas distribution network to hydrogen for this purpose.

As a starting point, the physical conversion will only take place in the period April to October, i.e. outside the heating season. For the conversion, the distribution network will be divided into sections of 500 connections each. The conversion of each section will be carried out in one working week. The conversion operation of 60 sections will require a total of 27 months. As a result, the existing distribution network will be simultaneously supplied with hydrogen during the conversion, including during the winter periods, while a part of the end users will still be supplied with natural gas.

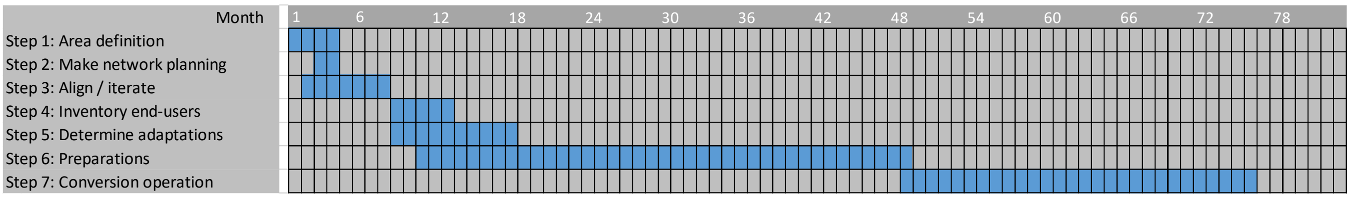
The moment the RTL is supplied by hydrogen, the supply of natural gas to the three GOSs in the area will cease. The towns of Ooij and Millingen a/d Rijn will then no longer receive a supply of natural gas. Although the distribution network in Nijmegen is still connected to other GOSs that remain connected to a natural gas-fed RTL, the capacity of the distribution network is likely to be insufficient to fully absorb the outage of the GOS in eastern Nijmegen. To supply the area with both natural gas and hydrogen during conversion, there are several options: temporary gas supply based on tubetrailers, additional connections to RTL with natural gas and reinforcement of the 3-bar distribution grid with connection to 8-bar distribution grid. The latter two variants require the construction of additional pipelines. To make a choice, network calculations will have to be made, costs will have to be determined and practical and safety aspects will also have to be considered. For the elaboration of the Nijmegen study case, we assumed a temporary gas supply based on tubetrailers for the rural area and connection to an 8-bar distribution network with reinforcement of the 3-bar network for the urban area.

The total conversion for the Nijmegen case is estimated at 79 months. This is divided into a research phase (8 months), a planning phase (10 months) and an execution phase (66 months) – the planning and execution phases have an overlap. This planning is shown in table 2. Based on these estimates, it appears that the lead time in the execution phase is determined by the preparatory work at the small consumers. This assumes that the boiler is replaced by a H_2-ready boiler. This step is estimated to have a lead time of 30 months. During the preparatory works, the Hydrogen Delivery Stations (HDSs) can also be realised (design, permit, realisation – estimated lead time 24 months) and grid reinforcement of the 3-bar grid with connection to the 8-bar grid can be carried out.

For the execution phase, some variants have been worked out:

- The existing boiler will not be replaced during the preparatory works, but during the conversion operation. However, the time gain in the preparatory works is limited because during this period the HDSs have to be realised and the grid reinforcement has to be carried out. This will lengthen the conversion operation, extending the total duration of the conversion plan by 10 months to over 7 years.
- The existing central heating boiler will be replaced by a dual-fuel boiler during the preparatory works of the execution phase. The lead time of the preparatory works remains unchanged. However, the conversion operation can be drastically shortened from 28 months to 1 month. This will reduce the total lead time of the conversion plan to just over 4 years.

Table 2 - Indicative time schedule Nijmegen case (reference)



Kapelle

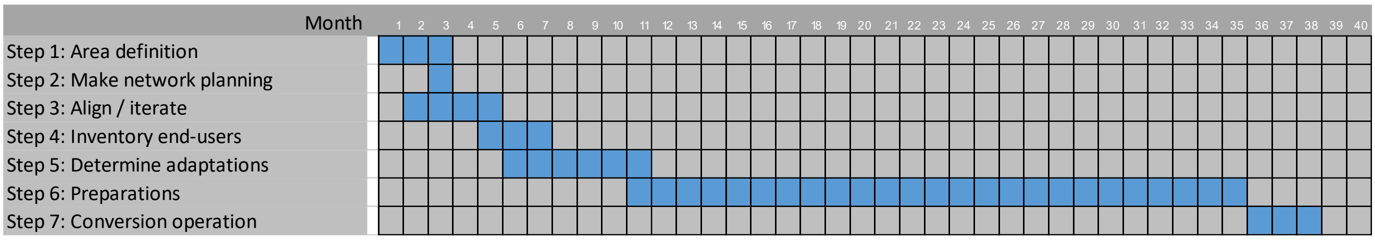
It is assumed that transmission system operator (TSO) Gasunie will construct a new hydrogen transmission pipeline linking the Vlissingen-Oost industrial area (Sloehaven) to the national hydrogen infrastructure (hydrogen production, transport and storage). This new transmission pipeline will be located near Kapelle near the two existing natural gas transmission pipelines. Besides hydrogen being used by industrial customers at the Sloehaven industrial estate, hydrogen produced with electrolysers from (offshore) wind energy can also be fed into the transmission pipeline. It is assumed that the municipality of Kapelle together with distribution system operator Stedin will choose to supply hydrogen to the Smokkelhoek business park (figure 1) and the residential area of Kapelle. To this end, a new hydrogen station (Hydrogen Delivery Station; HDS) will be built. Over 300 companies are located on the business park and there are 171 gas connections (of which 41 with a gas meter larger than G6). In the residential area, there are over 3,500 gas connections.

Figure 1 Business park Smokkelhoek, Kapelle

Hydrogen will be supplied from the hydrogen transmission pipeline, via a newly built Hydrogen Distribution Station (HDS), to the 4-bar distribution network. This pipeline and the five large consumers connected to it will be the first converted to hydrogen. This also applies to the horticulturists, one of which is connected to Gasunie's high-calorific gas network. The existing GOS will continue to supply the 100 mbar natural gas grid. Next, the 100 mbar network will be converted to hydrogen, section by section, starting at the Smokkelhoek business park, which is on the opposite side of the 100 mbar distribution network from the GOS. For this purpose, the 100 mbar grid is divided into 8 sections of about 500 connections each; only the number of connections at the business park is well below this.

The lead time of the investigation phase of the Kapelle case is 5 months. The planning phase takes 7 months and the execution phase 28 months. The conversion plan has a total lead time of 38 months, see table 3. In order to keep the lead time and interruption of gas supply for end-users as short as possible, adjustments are made as much as possible during the preparatory work (such as replacement of central heating boiler by H_2-ready boiler and replacement of gas meters that are also suitable for hydrogen). The conversion operation itself will be carried out in 3 months in the period April-October, i.e. outside the heating season. The lead time of the execution phase is determined by the realisation of the HDS (design, permit, realisation; lead time of 24 months in total). Acceleration of preparatory works and conversion operation at distribution network and end-users will not result in shortening the lead time of the conversion plan.

Table 3 - Indicative time schedule Kapelle case



4. Responsibilities and time planning

4.1 Tasks and responsibilities

Division into phases and steps

The conversion plan can be divided into 3 phases and 7 steps (see Figure 2). Each of the steps can then be divided into a number of individual activities. The number of activities per step can range from 4 to 15; a total of 51 activities is distinguished, see Table 4.

- In the *investigation phase* the area that will be converted to hydrogen is defined and a screening of the end users is carried out (number, type, etc.). In this phase it is also determined how the distribution grid will be supplied with hydrogen (via local hydrogen production, a hydrogen transmission pipeline or both) and, based on information about the distribution grid, it is determined how the grid can be divided into sections and in what order the conversion to hydrogen can take place. Based on the grid topology, variants can possibly be distinguished assuming that gas users outside the preferred hydrogen area will continue to be supplied with natural gas for the time being. In case there are variants, a choice will have to be made from these and it will be definitively determined which part of the gas distribution network and which customers will be converted to hydrogen.
- In the *planning phase,* an inventory of end-users is made, during which an inspection of gas equipment and indoor installation is carried out. The necessary adjustments to the gas distribution network and at the end-users are determined. End-users receive information from installers about the modifications/replacement of gas installations, their costs and a hydrogen supply offer from hydrogen suppliers. End users are also informed about possible alternatives, such as an all-electric solution. On this basis, end-users can make a choice to be connected to hydrogen or not.
- The *execution phase* starts with the planning of preparatory activities and the implementation of the conversion operation. The preparatory activities cover hydrogen supply, distribution network and end-users. A conversion of an existing GOS to a Hydrogen Delivery Station (HDS)[3] or a newly built HDS will require design, permit application and the HDS to be constructed. In the case of a new HDS, the connection to the transmission pipeline will also require a permit and will have to be realised. Although the starting point is to use the existing grid infrastructure as much as possible, adjustments will be needed to it and pipe sections and components may have to be replaced (because they are not suitable for hydrogen distribution or for continuation of gas supply by the distribution grid). Gas meters will be replaced by gas meters suitable for hydrogen. At end-users, gas appliances will be replaced by appliances that are or can easily be made suitable for hydrogen, or by electrical appliances. Adaptations to the indoor installation may also be necessary. After completion of the preparatory work, the conversion operation will begin. This will involve replacing natural gas with hydrogen section by section. The order in which the sections are switched from natural gas to hydrogen is determined in the investigation phase. During the conversion operation, at the end user's premises, the indoor installation will be flushed with nitrogen (optional) and tested, and gas equipment will be converted to hydrogen or equipment replacement will take place.

[3] The Hydrogen Delivery Station (HDS) is the transfer point for hydrogen from Gasunie (transmission system operator) to the regional grid operator.

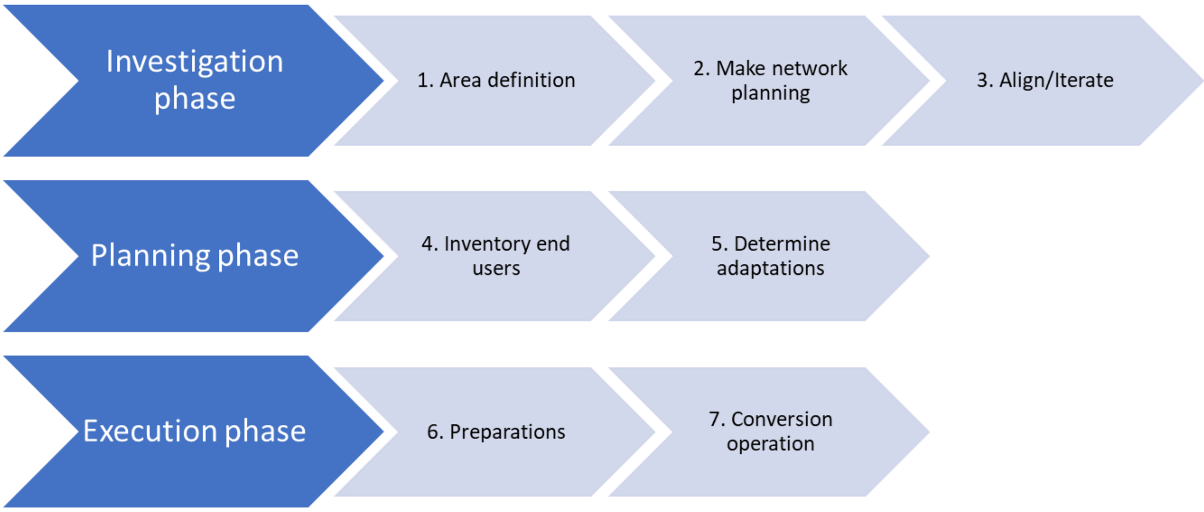


Figure 2 - Phases and steps of the conversion plan

Responsibilities, implementation and coordination

The conversion of a gas distribution network to hydrogen involves several parties. The following parties can be distinguished: municipality(s), distribution system operator (DSO), transmission system operator (TSO) of the national natural gas transmission network and the hydrogen transmission network (Gasunie), hydrogen suppliers, installation companies (directly or via Techniek Nederland) and end users. From central government, municipalities are designated to shape and implement the energy transition at local level (including Regional Energy Strategy, Transition Vision Heat). It is expected that the municipality already has the necessary powers to do so. Moreover, a municipality can make a broad assessment of interests and is controlled by a democratically elected municipal council. Therefore, the municipality is the appropriate party to coordinate the conversion of the distribution network to hydrogen. If several municipalities are involved, they can choose to assign all coordinating tasks to one of the municipalities and/or engage a third party to do so. There is also the possibility of dividing coordination in some tasks, for instance where contacts with end users are concerned. However, the municipalities remain jointly responsible for coordination.

For optimal implementation of the conversion plan, involved parties will have to make clear agreements on their roles: who coordinates, who is responsible for what task, who takes on the implementation, with whom to coordinate and who to inform. Sometimes roles are combined. An example of how agreements on coordination, responsibilities, implementation, coordination and information can be implemented is given in Table 4. The parties listed here may hire other parties (such as contractors) to carry out activities. However, this has been omitted from the table.

Table 4 - Overview of the tasks of the conversion plan and illustrative distribution of roles in implementation.

Legend: Coordinate (C), Responsible (R), Align (A), Execute (U), Inform (I), large consumers (lc)
* If this is not the hydrogen pipeline then involve hydrogen supplier

Task	Municipality	DSO	TSO	Hydrogen supplier(s)	Installers	End-users
Step 1: Area definition						
define transition vision	C/R	A	A	A		
determine hydrogen supply	C	A	R	I*		
screening end-users in preferred area	R/E	A			I	
define preferred areas	A	R/E	A		I	
communication with end-users	R				I	I
Step 2: Make network planning						
distribution network inventory		R/E				
distribution network sectioning		R/E				
determine supply feed-in points H_2 / natural gas		R/E	A			
grid calculations: is grid capacity sufficient H_2 / natural gas?		R/E	A			
Step 3: Align/iterate						
define variants: area + grid planning	A	R/E	A			
calculations/assessment		R/E				
choosing variant	R	A	A	I	I	A (lc)
communication with end-users	R					I
Step 4: Inventory end-users						
which customers are switching, or otherwise disconnected?	R			I	I	E
prepare database with checklist	R/E	A			A	
small consumers survey (<G6)	C	I		I		
[online/existing database] annual consumption, connection capacity	R				E	
inventory: meter cupboard, indoor pipes, gas appliances	R				E	
large consumers survey	C	I		I		R
[online/database] annual consumption, connection capacity	R					E
inventory: meter cupboard, indoor pipes, gas appliances	R					E
interruption / temporary alternative inventory	R					E
Step 5: Determine adaptations						
identify grid adjustments		R/E				
define hydrogen/natural gas supply points	A	A	R/E			
define reinforcement/replacement of pipelines (RTL/distribution)		R/E				
define valves for sectioning		R/E				
grid operator makes choice (and arranges budget)		R/E				
small consumers adjustments						
which gas appliances to replace/indoor piping?	C				E	R
which meters to replace?	C	R				
costs small consumer?	C			A	E	
customer makes choice (whether or not H_2)	C					R

Task	Municipality	DSO	TSO	Hydrogen supplier(s)	Installers	End-users
large consumers adjustments						
which gas applications to replace?	C				E	R
adjust connection capacity?	C	R				
define temporary alternative / interruption	C	A				R
costs large consumers?	C			A	E	
customer makes choice (whether or not H_2)	C					R
Step 6: Preparations						
schedule	C	R/E	I		I	
communication with end-users	C	R				I
realise network adaptations		R				
design & permit for HDS, grid reinforcement and hydrogen supply		A	R			
realising new HDS		A	R			
grid reinforcement		R				
realising hydrogen supply		R				
adjustments small consumers	C					
installing H_2-ready boiler/adapting indoor installation					E	R
gas meter replacement		R				
gas appliances not to be replaced by alternative (cooking/fireplace/...)						R
adjustments large consumers	C					
H_2-ready gas application installation/adjusting indoor installation					E	R
gas meter replacement		R				
gas appliances not to be replaced by alternative					E	R
Step 7: Conversion operation						
communication with end-users	R	A			A	I
network conversion per section		R				
shut off natural gas / flush with N_2 / fill with H_2		R				
small consumer conversion per section						
H_2-ready boiler conversion		C			E	R
gas system testing		C			E	R
large consumer conversion per section						
gas appliance convert from natural gas to H_2		C			E	R
gas system testing		C			E	R

4.2 Time planning

Timetable

From the study cases carried out, it emerges that the lead time in time planning is mainly determined by the time required for design, permit and realisation of the HDS (total of 24 months) and the size of the area to be converted, i.e. the number of sections.

Alternatives

Alternatives can be distinguished at a number of points during conversion:

- Suitability of appliances and components for both natural gas and hydrogen: This applies, for example, to the gas meter and the boiler. If they are suitable for dual-fuel, then replacement can take place during the preparation (step 6) and save time during the conversion operation (step 7) compared to replacement with an H_2-ready boiler.
- Whether or not to flush the distribution pipe, connection pipe and/or indoor pipe with nitrogen: If flushing with nitrogen can be skipped, this simplifies operations during the conversion operation (step 7).
- Whether or not to apply gas stoppers to every customer: They are currently applied to new connections (but not by all DSOs), but not to existing connections. Gas stoppers for existing connections may still be installed in step 6 (preparations).
- Temporary gas supply from existing gas grid or with tube trailers: During conversion, end-users not yet supplied with hydrogen will still need to be supplied with natural gas. This is possible if the distribution network being converted still has a GOS connected to a natural gas RTL or is connected to a gas distribution network that remains on natural. Alternatively, a tube trailer can be used for the temporary supply of natural gas (if the distribution network is supplied with hydrogen) or hydrogen (in anticipation of the final hydrogen supply).

4.3 Communication

As coordinator of the conversion plan, the municipality is responsible for communication with end users. As part of the conversion plan, the municipality will prepare a communication plan. Several communication forms and channels can be used. In addition, the municipality can set up an information point where end users can go with their questions throughout the conversion process. At least on 5 occasions, the end user should be informed:

- At step 1 (area definition), end-users are informed of the intention, as part of natural gas-free heat supply, to supply the area with hydrogen.
- At the end of the investigation phase/step 3, when it is known exactly which connections will be converted to hydrogen, end-users will be informed about the final plan. This will give end-users insight into the planning of the conversion plan, what information they will receive when and what choice will have to be made in the process.
- At the end of step 5 (determine adaptations), end-users will receive an offer for hydrogen supply and will be informed about the costs of adapting the gas installation. In doing so, they are asked to make the choice to switch to hydrogen. If an end user does not make a choice, this end user will not be included in the conversion plan. Should the end user still wish to have a hydrogen connection at a later date, they will be treated as a new customer.
- At step 6 (preparatorions), end users are informed about the planning of the preparatory work.
- At step 7 (conversion operation), end users are informed about the planning of the conversion operation.

Steps 6 and 7 require access to the end-user's installation. In step 6, there is some flexibility in the sequence, but not in Step 7. An end user who is not at home (i.e. there is no access to the premisses), is then skipped and not connected to hydrogen. That connection may take place at a later time, with the consequence that interruption of gas supply may take longer. The end user should be clearly informed about this.

5. Model conversion plan

This chapter explains each step and activity of the model conversion plan.

5.1 Step 1: Area definition

Defining transition vision

Starting point is a municipality's decision, within the framework of the Transition Vision Heat, and in consultation with the regional grid operator, to supply hydrogen to homes, utility buildings and businesses in a certain area. The area can be larger than the territory of one municipality, which means that several municipalities are involved.

The decision will be based on the local availability of hydrogen. This could be the proximity of a hydrogen transport network in combination with hydrogen suppliers that operate nationally and can guarantee a long-term supply of hydrogen or local hydrogen production (e.g. a hydrogen hub) or a combination thereof. Coordination is therefore also needed with hydrogen suppliers and, in case the hydrogen is sourced from a hydrogen transmission pipeline, the hydrogen transmission system operator (Gasunie).

An important precondition is support from end-users. This involves acceptance that the energy supply with natural gas can no longer continue, that hydrogen is a good substitute for natural gas, i.e. safe, affordable (compared to alternatives, such as all-electric) and security of supply is guaranteed.

Determining hydrogen supply

The entry point of hydrogen into the distribution network is determined. For feed-in from a hydrogen transmission pipeline or from local hydrogen production, there are the following possibilities:

- Feed-in point at the site of one or more existing GOSs converted to or replaced by HDSs.
- A new feed-in point at a different location in the distribution network with a newly built HDS.
- A combination of an existing GOS to be converted/replaced and a new feed-in point.

The location of the hydrogen feed-in point also involves the conversion approach. During conversion, the distribution network in question will be temporarily supplied with both natural gas and hydrogen, with the hydrogen, section-by-section, displacing the natural gas. For this reason, an analysis of hydrogen distribution in the distribution network will also be made.

Screening end-users in preferred area

To understand the type of end users, a screening of end users connected to the distribution network is carried out. This includes the number of small consumers (such as households), number and types of non-residential buildings and companies. In addition to information that the municipality(s) and regional grid operator have on this (e.g. maximum gas off-take, gas meter size), for companies, data from the Chamber of Commerce can be used. Statistical codes (SBI) can be used to find out the business activities of these end-users. Based on the description of business activities, companies can be identified that presumably use gas for process heat.

Define preferred area

The regional grid operator determines the area that will be supplied with hydrogen based on the grid topology. This involves examining how the gas distribution network that will be converted to hydrogen can be logically separated from other parts of the gas distribution network that will continue to be supplied with natural gas for the time being. The starting point is to use the existing assets as much as possible.

Communication with end users
End users are already aware of intentions for natural gas-free heat supply. In this step, end-users are specifically informed about intentions to distribute hydrogen in the provisionally defined area. End-users will be told what this means for them, what steps will follow and what the overall timetable of these steps is, what choice is expected from them, when this will come up, what information they will receive for making this choice and what help they will receive and from whom. Multiple forms and channels of communication will be used for this purpose. Moreover, an information point will be set up where end users can go with their questions throughout the process.

5.2 Step 2: Make network planning

An inventory is made of the distribution network. The inventory involves the components and materials used. It also includes the absence of components (e.g. gas stoppers). To use the distribution network for hydrogen, a number of preconditions must be met:

- Suitability of materials used
  - Not all materials in the current distribution network are suitable in particular cast-iron pipes. Network operators are currently remediating all grey cast iron (see [1]). Preventive remediation is also being determined for connection pipes.
- Capacity current distribution network
  - The current distribution maintains the same capacity when hydrogen is fed-in. The biggest change occurs if hydrogen supply is located in a different location from natural gas supply. It may be necessary to build new pipelines, reinforce existing pipelines or make new connections in the distribution network to ensure security of supply of hydrogen or natural gas. Construction of a temporary pipeline may be necessary to limit too long an interruption during conversion.
- Capacity gas pressure regulating stations
  - Previous research (see [1]) shows that the capacity of gas pressure regulating stations is sufficient when switching from natural gas to hydrogen on a one-to-one basis.
  - If changes are made to the distribution network, such as reinforcing certain pipe sections, adjustments may also have to be made to the capacity of the controllers at district stations to feed the network appropriately.
  - For other components of gas pressure regulator stations, for instance the ventilation or filtering of gas pressure regulator stations, various studies are currently ongoing. As a result, no statement can be made at this time about other modifications to gas pressure regulator stations.

5.3 Step 3: Align/iterate

Variants
In step 2, different variants could potentially arise, such as:

- Variations regarding the distribution network to be converted to hydrogen. For example, the net topology may not fit well with the area preferred by the municipality.
- Variants regarding where the feed-in of hydrogen into the distribution network will take place.
- The conversion will require the distribution network to be supplied with both natural gas and hydrogen. Depending on the local situation, different variants are possible.

Before variants can be compared and a choice made, they have to be clearly defined.

Assessment and choice
The advantages and disadvantages of the variants are put side by side and assessed with regard to costs, security of supply, safety, practicality, etc. The choice of variants will be made by the municipality(s) in consultation with the DSO and other stakeholders (such as Gasunie).

Communications
With the choice of the preferred variant, the area and connections to be converted to hydrogen will be finalised. End users will be informed accordingly.

5.4 Step 4: Inventory end-users

After the decision has been taken to convert an area to hydrogen (step 3), a survey is carried out for each customer in the area to determine what equipment and infrastructure is present in the premises. We distinguish between small and large consumers in the area. The assumption here is that in the case of small consumers, the adjustments will mainly be made to the heating and cooking appliances and the associated indoor installation. It is assumed that no hydrogen cookers will be used, which means that the current gas cookers will be replaced by electric variants. With large (industrial) end-users, other gas applications may also occur

At the end of the conversion, no natural gas will be available through a distribution network in the area. This means that every natural gas customer will be converted, unless customer chooses another energy carrier, such as electricity, or makes no choice (in which case it is assumed that the end user does not wish to be connected to the hydrogen distribution network).

To carry out the survey efficiently, the information already available for the checklist is collected in advance in a database available for conversion. The network operators know which gas meter is installed. This already gives a first indication of the gas consumption for each connection. Where possible, annual consumption can also be requested from the end user. Finally, the information emerging from the survey will also be stored in this database. The progress of the follow-up steps of the conversion will be recorded per connection in this database.

5.4.1 Small consumers

It is determined for each house which natural gas equipment is used and what the indoor installation looks like.

These include:

- Type of gas meter and location (meter cupboard or elsewhere)
- Length, material, diameter indoor pipe work (where possible; non-assessment because the pipe work is not accessible for visual inspection is also an outcome). A leak test on the indoor pipe work can be carried out during the preparations (step 6).
- Type of natural gas appliances (central heating boiler, boilers, gas cookers, decorative fireplaces, etc.)
    - Capacity, place in the house, age.

Besides the technical survey of the house, this is a contact moment with the residents where specific information is provided. For example, information on alternatives to natural gas: hydrogen boilers, alternative to cooking with natural gas, an initial information on contracts and information on the duration and consequences of the conversion (week without gas; can already be checked whether this is acceptable).

5.4.2 Large consumers

There will also be larger consumers in the area to be converted, such as industry, SMEs or residential complexes. These will be surveyed in the same way as small consumers. Basically, the same information is requested as for small consumers. However, other gas applications may also be present, e.g. gas engines, combined heat and power (CHP) installations or (industrial) gas boilers for process heat. Information on the characteristics of these applications (type, age, etc.) is requested.

Besides the survey, this contact moment is also a time to explore possible alternatives for natural gas consumption after, but also during, the conversion. During conversion, natural gas is temporarily unavailable, which may have economic consequences. Possible solutions for this are being explored.

Because the large consumers are more unique, we assume that a smaller group of installers/technical experts will be able to carry out the survey.

5.5 Step 5: Determine adaptations

5.5.1 Hydrogen supply

Feed-in points will be realised for the supply of hydrogen. If connecting to an RTL that will be converted to hydrogen, this may involve one or more GOSs being replaced by a Hydrogen Distribution Station (HDS) (Gasunie responsibility). An HDS can also be realised at an entirely new location. An HDS for feed-in from a local hydrogen production plant is also likely to be realised at a new location (responsibility of local hydrogen producer).

For temporary gas supply during conversion, tube trailers may need to be deployed (responsibility of regional grid operator). It will be determined whether tube trailers with natural gas or hydrogen will be deployed. The locations will be determined, how long the tube trailers will be needed and the number of tube trailers required.

5.5.2 Distribution network

Step 5 determines which measures from steps 2 and 3 need to be implemented and what this will cost. Broadly speaking, this involves the following points:

- Replace/modify district stations in the hydrogen distribution network but also for any remaining natural gas distribution network.
- Define which pipelines need to be reinforced and/or replaced (transmission and distribution pipelines).
- Possibly defining additional valves for sectioning.

If an area is fed-in from one GOS, and the HDS is planned at approximately the same location, it is expected that the biggest adjustments need to be made to the distribution network. Especially during the period of the conversion from natural gas to hydrogen, where both grids may have limited meshing and/or capacity as a result.

5.5.3 Small consumers

Based on the inventoried information, it will be determined which equipment needs to be replaced. When converting to hydrogen, the gas meter and heating appliance will be replaced. Modifications to the pipework in the homes will be considered on a case-by-case basis.

- Gas meter:
  - Will be replaced with a hydrogen-ready meter (in case the homes will retain a gas connection) by the grid operator. This can be the current meter where it has been shown to meet specifications or a new hydrogen-ready or dual-fuel meter.
- Heating appliance:
  - Option A: replace with an H_2-ready boiler (whether or not in combination with a hybrid heat pump) that is still used with natural gas at first and later made suitable for hydrogen by replacing control unit/burner.
  - Option B: replace the boiler at the time of conversion.
  - Option C: replace with a dual-fuel boiler (if available) that can be used for both natural gas and hydrogen. During conversion operation (step 7), no modification to the boiler is required.
- Cooker / decorative fireplace, etc.:
  - Not suitable for hydrogen. Will be replaced by electric alternative (e.g. induction cooker). This adaptation in the home is the responsibility of the resident.
- Indoor piping:
  - This will be considered on a situation-by-situation basis. The basic assumption is that existing pipelines will be used for both hydrogen and natural gas. However, checks must be made to ensure that the installation is not leaking. This can be done during the preparations work (step 6). Parts of the indoor installation for equipment that will not be replaced by a hydrogen appliance (cooker, decorative fireplace) will be removed or capped.
- Small consumer offer (costs)
  - Small consumers will have to convert their current natural gas contract to a hydrogen contract with one of the hydrogen suppliers. Several alternatives are possible. It is likely that cost will play the decisive role in the end user's choice to switch to hydrogen, or opt for an alternative (all-electric). One possibility is for the hydrogen suppliers to offer a service contract, including conversion to a leased hydrogen appliance (instead of investing in a boiler, the small consumer chooses a lease contract).

Once the consequences of conversion, both technical and economical, are clear to individual small consumers, they will have to make a choice. This choice and the conclusion of a hydrogen supply contract will be recorded in the database.

5.5.4 Large consumers

For large gas consumers, a similar approach applies as for small consumers. Based on the inventory in step 4, it can be determined which gas applications should be replaced by a hydrogen-capable alternative.

It is likely that some business customers mainly require space heating. In these cases, the approach is similar to the small consumers described in the previous section.

For specific large consumers that currently use natural gas for process heat or as fuel for engines (e.g. horticulturists), a solution will have to be found on a situation-by-situation basis. Industrial burners and engines can be adapted for hydrogen, although implementation depends very much on the installed equipment. In these cases, the capacity of the gas connection will also have to be tested for sufficient capacity after conversion. Special attention is needed for customers who currently use natural gas for both energy and CO_2 such as horticulturists. After a conversion to hydrogen, this CO_2 is no longer available as a residual product from combustion and an alternative will have to be found.

Each customer will make a financial trade-off for its own situation for conversion to hydrogen compared to other (electric) alternatives. Besides the investment in the grid connection and adjustments to the technology, the hydrogen price also plays an important role. It is therefore important for the large consumers to agree on hydrogen supply contracts with hydrogen suppliers.

During the conversion operation, the gas supply will be temporarily shut down, which will also temporarily halt business processes. Arrangements will be made with the operators on how to bridge such a period and what technical options are available for this. For instance, a temporary gas supply could be considered.

Based on the above points, the business customer will make a decision on conversion for his business.

5.6 Step 6: Preparations

5.6.1 Hydrogen supply

Designs are made by the TSO Gasunie (or in case of local feed-in by the local hydrogen producer) of new HDS(s) to be built or existing GOS(s) to be converted to an HDS[4]. Based on these designs (and possibly new pipelines), permit applications are prepared and submitted. Design and permit application have an estimated duration of 12 months.

Subsequently, the realisation of the new HDS(s), conversion of existing GOS(s) and/or construction of new pipelines will take place. For the execution of the work, a lead time of 12 months must also be taken into account.

If tube trailers are needed, the regional grid operator will agree with the supplier of tube trailers on number, duration, delivery quantity, etc. Locations for the tube trailers are coordinated with the municipality(s). This may require a permit.

5.6.2 Distribution network

For the regional grid operator, there are a number of adjustments that need to be made to the grid. The adjustments to the distribution network are carried out. These include the following components:

- Permit applications are prepared and submitted for gas network reinforcement and pipe replacements.
- Reinforcement and adjustment to the distribution network are carried out for the hydrogen and natural gas networks (for both the temporary and final situation).
- Additional section separators may be installed.
- If necessary, replacement of certain pipe sections may also take place (part of regular asset management).

For applying for the necessary permits and carrying out the works, it is estimated that this falls within the timeframe necessary to realise the HDS (see section 5.6.1) and therefore does not fall on the critical path of planning.

5.6.3 Small consumers

At small consumers, the following activities will be carried out during the preparatory work:

- For customers being converted to hydrogen: replacing the existing natural gas boiler with an H_2-ready boiler (option A) or a dual-fuel boiler (option C). In option B, the boiler is replaced

[4] Location may have to be changed.

during the conversion operation and the existing boiler will remain in place during preparatory work.
- For customers that are not converted to hydrogen: replacing the existing boiler with an all-electric alternative (heat pump) and removing the natural gas connecting pipe and indoor installation.
- Replacing the gas meter with one suitable for hydrogen and natural gas.
- Replacing the remaining natural gas appliances, such as cookers and decorative fireplaces, with alternatives. In practice, this means that gas cookers will probably have to be replaced by induction cookers. These have to be fitted into existing kitchens and this has to be arranged by the residents themselves. The internal piping to these natural gas appliances will be removed or capped.

For option A and C: The assumption is that the preparatory work in a house can be carried out within one day by 1 installer. In both cases, the existing central heating boiler is replaced by a new boiler and tested for operation. For larger areas, such as an urban area, the lead time for preparatory work at this stage thus becomes the limiting factor.

For option B: The assumption is that preparatory work at four houses can be carried out in 1 day by 1 installer. Also for larger areas, this phase is greatly shortened and in this situation the realisation of the HDS is likely to become the limiting factor in the lead time.

5.6.4 Large consumers

Replacing natural gas equipment or adapting existing equipment for hydrogen at large consumers will vary from one customer to another. As noted in step 5, for some of the business customers, the adaptations will be similar to those for the retail customers. Given the small number of the large consumers compared to small consumers, it is estimated that the work can be completed in the same period as for small consumers.

For industrial gas customers, an estimate of the work required will be made on a situation-by-situation basis. Replacing and testing an industrial boiler or engine may take several days, but given the limited number of these customers, these activities are not estimated to be on the critical path (<12 months before the realisation of the HDS).

5.7 Step 7: Conversion operation

5.7.1 Hydrogen supply commissioning

The conversion operation starts by decommissioning part of a gas distribution pipeline to which a Hydrogen Distribution Station (HDS) is connected. The HDS is connected to a hydrogen transmission pipeline or a local hydrogen production facility. The HDS is then put into operation (up to a closed valve). After this, the next section of the natural gas distribution network is decommissioned. By opening the separation valve of the HDS, the natural gas in the distribution pipeline is discharged via a flare and replaced by hydrogen. This requires good coordination by the regional grid operator with transmission system operator Gasunie or the local hydrogen supplier.

End users are initially still supplied with natural gas by supplying the gas distribution network with natural gas from one or more GOSs, or linking to surrounding distribution networks that continue to be supplied with natural gas. If this is not possible, customers can be temporarily supplied with natural gas from a tube trailer.

The commissioning of HDS(s) can also take place later. In that case, conversion operation based on tube trailers with hydrogen can be started. After several sections of the low-pressure distribution network have been converted to hydrogen, the HDS will be commissioned. Large consumers, connected the high-pressure distribution network will be converted after the HDS is commissioned.

5.7.2 High pressure distribution network, large consumers

Large consumers, connected via a delivery station to high-pressure distribution network, are each individually converted to hydrogen after the high-pressure distribution network is converted to hydrogen. The procedure may differ for each large consumer and includes equipment replacement and testing. Good coordination (in steps 5 and 6) with the large consumers is essential here.

5.7.3 Low pressure distribution network, small consumers

For the conversion operation at small consumers, the situation where there are H_2-ready boilers present in the homes is assumed, i.e. in step 6 the boilers have been replaced and in the week of conversion only a minor adjustment needs to be made to the H_2-ready boiler.

Assuming a standard week, a section can be depressurised on Monday, then flushed and pressurised with nitrogen, and on Friday the gas network is filled with hydrogen. In the intervening days, the H_2-ready boilers in the houses are adjusted:

- On the first day of the week, the grid operator depressurises the gas grid by placing end caps at the end of the section. This way, a physical separation is made in the grid and there is no chance of mixing natural gas and hydrogen due to, for example, a switching error. The end caps can be placed by setting gas stoppers.
- For each section, it is then determined how to degas. Here, any end point made can be used as a flushing point. There are several options for making the existing meshed gas network natural gas-free:
  - Make a meshed gas network fully star-shaped first by installing gas stoppers and vent points; this way, the gas network can be fully degassed. This does require additional gas stoppers and vent points to be made within the section. Depending on the meshing of the grid, this means that 5 to 15 additional venting points have to be made per section.
  - First flush a large part of the natural gas network with nitrogen through the vent points per section, then the gas network can be kept pressurised with nitrogen. Degassing can then be done per dwelling when modifying the boiler. For this, the indoor pipe needs to be flushed. To what extent the indoor pipe needs to be inertised with nitrogen is still under discussion. Additional (practical) research into this is therefore recommended.
- During the week of the conversion, the customer for each home will be informed when the adaptation of the indoor installation will take place. The starting point is that all homes have already been visited in the preparation step and adapted to the arrival of hydrogen. That is, the boiler has been replaced for an H_2-ready boiler, the pipe to the cooker has been disconnected and the gas meter has been replaced for one that is also suitable for hydrogen. During the week of the conversion, the boiler in the house then still needs to be adapted for hydrogen. This means that in the boiler, the control unit/burner will be replaced and tested for functioning. The connecting pipe will also be flushed until there is no more natural gas in the pipe.
- It is vital that the registration of visited addresses is very accurate. Homes that cannot be visited or adapted during the week of the conversion (or do not have a hydrogen supply contract) should be disconnected from the gas grid. It is preferable to close the connection with the main pipe in the street by placing a plug in the attachment. Small consumers will then

have to make their own arrangements to be connected to the hydrogen distribution network later in time.

- At the time of preparation and replacement of the boiler and gas meter, a tightness test will also be carried out. This will be carried out from the main valve for the gas meter to the boiler. During the replacement of the burner unit, it is not necessary to retest the indoor installation, as no work is taking place on the pipework at that time.
- The final step is to switch the section to hydrogen. Here the hydrogen is fed from an upstream section or from a tube trailer and, depending on the section, a district station can also be switched to hydrogen from a high-pressure distribution pipe. For filling the entire grid, the similar two options apply as for flushing the gas grid with nitrogen:
  - First make the meshed net star-shaped and fill it completely with hydrogen.
  - Fill a large part of the gas network with hydrogen (because, due to meshed network, 100% flushing is not possible). Because free outflow can no longer take place in a hydrogen network, as is the case with natural gas due to the presence of unsecured appliances, a hydrogen/nitrogen mixture can safely be present in the network. As a result, boilers will need to be reset more frequently at first, but this is something that can be carried out by a resident himself with clear instructions.

Depending on the local situation of the distribution network, one of the two options can be chosen. Here, follow-up research will have to show that this can actually be done safely in practice.

6. Conclusion and recommendations

Conclusions

In this work package, a model conversion plan was drawn up for conversion of existing gas distribution networks and end-user gas installations to nearly 100% hydrogen. This generic conversion plan is based on experiences and insights gained from conversion studies and implemented hydrogen projects and pilots and in the Netherlands and abroad. In addition, two case studies have been elaborated in detail within the framework of this study. These have increased the understanding of what is involved in a conversion plan, which aspects are specific and which are more generic. In addition, the case studies provided the following insights:

- Coordination, responsibilities and communication:
  - A large number of parties are involved in the implementation of the conversion plan. It is essential to make good agreements about the responsibilities of the tasks to be executed.
  - Because the conversion is a complex and time-consuming process, good coordination is essential. The municipality is the appropriate party to coordinate and communicate about the conversion of the distribution network to hydrogen.
  - Parties involved will have to inform each other optimally and good coordination is required for certain activities.
  - Support by the end-user is an essential precondition. This concerns the public acceptance that the energy supply with natural gas can no longer continue to exist, that hydrogen is a good replacement for natural gas, i.e. safe, affordable (compared to alternatives such as all-electric) and security of supply is guaranteed.
  - The municipality is responsible for communication with the end users and will have to draw up a communication plan for this.
- Duration of the conversion plan:
  - The conversion of a part of the gas distribution grid (from planning phase to execution phase) can take several years. In the two cases studied, this varies from about 3 years (3,700 connections) to more than 6 years (30,000 connections).
  - If a different choice is made for replacing natural gas, such as for a heat network (construction of a new network) or for all-electric (grid reinforcement), a plan will also have to be drawn up and implemented. The activities are partly comparable to those of the conversion plan to hydrogen and will also entail a considerable lead time. However, no comparison has been made in this study.
  - The duration of the conversion plan is determined by the size of the distribution network (i.e. the number of connections) and the required number of qualified personnel or by new Hydrogen Distribution Station(s) (HDS) to be realised and expansion/upgrading of the distribution network, including the lead time of permit granting. The latter requires a joint planning by the national and regional gas network operator.
  - The execution phase (preparatory work and conversion operation) takes up more than 70-80% of the total time.
  - The duration of the conversion operation, during which the gas supply to end users is interrupted, can be limited by carrying out as much work as possible during the preparatory work (such as replacing the existing central heating boiler with an H_2-ready boiler). Even if this saves little time in total, this shift does provide more flexibility in the implementation.
  - The physical conversion (last step of the conversion plan) can be shortened considerably if a dual-fuel boiler and dual-fuel gas meter can be used and flushing the gas pipes with nitrogen can be omitted. This makes the conversion process less complex, shortens the total lead time of the conversion plan and can lead to cost savings.

  - Most technically trained personnel are required for inspection of the installations at the end users (planning phase) and replacing the gas installations (execution phase). By deploying more personnel, the lead time can be reduced.
- Dividing the distribution network into sections:
  - For the conversion, the gas distribution network will be divided into sections. The number and size of these sections depends on two preconditions: the duration of the gas interruption and the number of installers to be deployed to convert the gas equipment at the end users.
  - If dual-fuel devices/components can be used (such as gas meter, central heating boiler), the sections can be larger or no sectioning is required at all.
  - The order in which the sections are converted from natural gas to hydrogen depends on the position of the hydrogen and natural gas feed-in points in the grid. It may be necessary to use a temporary feed-in point (for example a tube trailer with hydrogen or natural gas or via an additional pipeline to be installed).
- Security of supply:
  - Because existing gas infrastructure is used and adjacent areas have to be supplied with natural gas in addition to the area being supplied with hydrogen, it is often impossible to maintain the security of supply of the hydrogen distribution network at the same level as in the situation when natural gas was still being distributed. The risk of an interruption of the hydrogen supply to end users will then have to be dealt with in a different way.
- Alternatives:
  - Replacing the central heating boiler with an H_2-ready boiler or with a dual-fuel boiler (if available) during the preparatory work: A dual-fuel boiler saves time during the conversion operation. The lead time for the preparatory work remains the same as for replacement by an H_2-ready boiler.
  - Whether or not to flush the distribution pipe, connection pipe and/or indoor pipe with nitrogen: If flushing with nitrogen can be skipped, this simplifies the work during the conversion operation.
  - Whether or not to use gas stoppers at every customer: These are now being used for new connections, but they are not present for existing connections.
  - Temporary gas supply from the existing gas network or with tube trailers: During the conversion, end users who have not yet been supplied with hydrogen will still have to be supplied with natural gas. This is possible if the distribution network that is being converted still has a city gate station that is connected to an RTL on natural gas or is connected to a gas distribution network that remains on natural gas. Alternatively, a tube trailer can be used for the temporary supply of natural gas or hydrogen.

Recommendations
This research leads to the following recommendations:

- Lessons learned from current pilots: Various pilot projects will be carried out in the coming years. The experiences and insights gained (also with regard to coordination, responsibilities and communication) can form an important input for the further development of the model conversion plan.
- Acceleration of permit procedures: the lead time of permit procedures can have a major impact on the lead time of the whole conversion plan (e.g. the permit procedure for the HDS). It is recommended to investigate how the lead time of permit procedures can be shortened.
- Remediation: For gas distribution networks that are being converted to hydrogen, it is recommended to replace old pipe sections, including cast iron, in the coming years.

- Suitability of valves: Insufficient research has been carried out into the leak-tightness (both internal and external leakage) of valves running on hydrogen. Further research into this is recommended.
- Inerting indoor pipelines: The extent to which the indoor pipeline should be inertised with nitrogen is still under discussion. It is therefore recommended to conduct additional research into this.
- Filling the gas network with hydrogen: Research must show how a meshed network can be safely filled with hydrogen.
- H_2-ready boiler: The use of an H_2-ready boiler is decisive for the implementation of the conversion. However, a good definition or standardization of an H_2-ready boiler is still lacking. It is recommended to set this up.
- Dual-fuel components: Availability of dual-fuel boiler and gas meters greatly simplifies and accelerates the physical conversion. It is recommended to have a dual-fuel boiler developed or market parties to encouraged to do so. More clarity is also needed about the suitability of gas meters for both natural gas and hydrogen.
- Security of supply: Compared to natural gas distribution, the security of supply of hydrogen distribution cannot always be maintained at the same level due to a smaller number of feed-in points and/or less meshing of the grid. It is recommended that research be carried out into the risk of interruption of the hydrogen supply and how this can be mitigated.
- Increasing conversion efficiency: The costs of the conversion have not been mapped out in this study. A better insight into the conversion costs can be helpful in improving the cost efficiency of the conversion process. In addition, the conversion to hydrogen may be simplified, for example by performing activities more efficiently or limiting the number of actions. Research could be carried out into this.
- Availability of affordable hydrogen: Whether it is attractive for end users to switch to a hydrogen-based gas supply depends on the future availability and affordability of hydrogen. This is an important precondition for converting the gas distribution network. It is recommended that developments with regard to the hydrogen supply be followed closely.

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