Interconnecting H2 Infrastructure Summary Report (D6.4)

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1 From idea to realization

The development of the onshore hydrogen network in the Netherlands is currently underway. While some sections have been completed and others are under construction, significant progress is still anticipated. Additionally, there is potential for developing an offshore hydrogen network. This report (D 6.4) by Gasunie outlines the status of these plans, from conception to realization.

Gasunie initiated plans around 2016 to repurpose existing natural gas pipelines for hydrogen transport, leading to the HyWay 27 project. This project has evolved to its current state, with ongoing construction and future plans to develop a similar offshore network.

The report comprises five chapters. The first chapter introduces the HyWay 27 concept. Subsequent chapters detail the current status, including completed and upcoming construction. To facilitate knowledge sharing, we present a best practice example from the Northern Netherlands, in the heart of our hydrogen valley.

The report concludes with some appendices containing critical information on safety, risks, and specifications (quality and temperature). These standards, while not set by Gasunie, are crucial for producers, off takers, and the operation of our hydrogen network.

2 The Idea

Gasunie started around 2016 with the first plans to re-use some of the existing natural gas pipelines for the transport of hydrogen. This plan resulted in the HyWay 27 project. The HyWay 27 project explored whether, and if so under which conditions, parts of the existing Dutch natural gas network can be repurposed for the transmission of hydrogen.

The study answered 3 main questions:

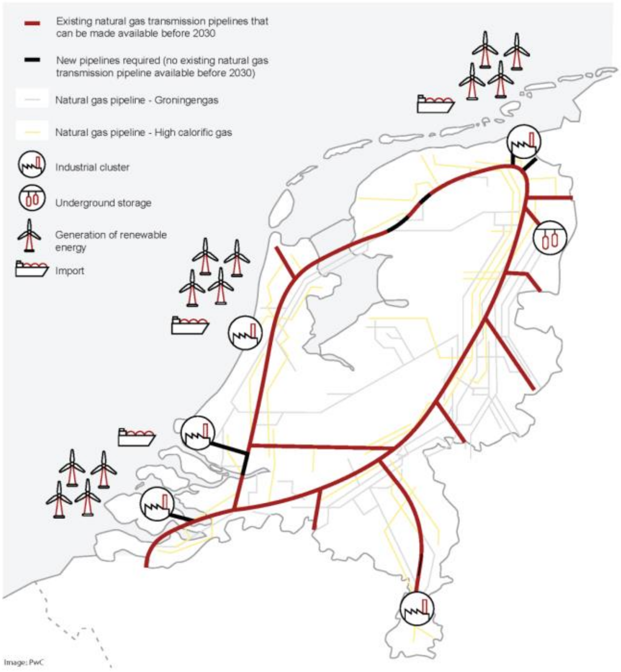
1. **Do we need a transmission network for hydrogen, and if so, when?**
   - In a climate-neutral economy, a pipeline-based hydrogen transport network is needed to efficiently connect consumers to suppliers of zero-carbon hydrogen and hydrogen storage facilities.
   - To achieve the ambitions for 2030, in the coming years transmission capacity aimed at facilitating the first large hydrogen projects will be needed. Transmission demand will also arise as a result of the need for storage.

2. **Can the existing natural gas network be used for hydrogen transmission, and if so, would that be desirable?**
   - The existing natural gas network can be used to accommodate the interregional transmission flows that are expected in the long term: key pipelines can be freed up entirely and repurposed for hydrogen transmission.
   - Reusing existing natural gas grids is more cost-effective than laying new pipelines for hydrogen transmission. A transmission network connecting all industrial clusters to producers and storage locations requires an investment of around €1.5 billion.

3. **What government intervention will be required to create a transmission network for hydrogen?**
   - The refurbishment of transmission networks requires a government intervention because investments involve a high risk of slow capital recovery due to slow uptake while also being strongly linked to the development of the hydrogen supply chain as a whole.
   - Our advice is to decide in principle to use part of the existing natural gas networks for the transmission of hydrogen. To achieve the 2030 ambitions, it is necessary to initiate decision-making now

HyWay 27: Realisation of a national hydrogen network

The Ministry of Economic Affairs and Climate Policy, together with Gasunie and TenneT carried out the HyWay 27 study. The study concluded that the current natural gas transmission network provides a cost-efficient basis for safe hydrogen transmission. The national hydrogen infrastructure, including connections to storage facilities, is needed to realise the Netherlands' hydrogen ambitions by 2030. This report makes the following recommendations.



1. Take a decision in principle
Zero-carbon hydrogen requires new transmission supply chains, both in 2030 and in the intervening years as well. In order to achieve this in good time, a decision in principle must be taken in the short term to repurpose a part of the existing natural gas transmission networks for the transmission of hydrogen. Existing pipelines will be ready sooner for the transmission of hydrogen and repurposing them is cheaper than building new pipelines.

2. Draw up a rollout plan
Where will the transmission network be located and what actions have to be taken? Draw up a rollout plan containing the envisioned contours of the transmission network in 2030. Describe the actions that will be needed in the coming years. Striking the right balance is key. On the one hand, the rollout plan must provide potential hydrogen consumers with clarity on when the infrastructure will be available and, on the other hand, a step-by-step rollout must ensure that there is room to adapt to developments as these emerge.

3. Determine how the market will be regulated
The further the hydrogen market grows, the more the infrastructure developed will need to be regulated. Who is to be allowed to operate in the market and under what conditions? Only with clarity on how to regulate the hydrogen market can it be decided in the short term who is to be responsible for repurposing the natural gas networks and ultimately for the operation of the newly created hydrogen transmission network.

4. Draw up a plan to kick-start the supply chain
Investing in a hydrogen transmission network is not a sound decision if there is too little supply and demand. That is why government intervention and clarity on financial resources is necessary if we are to develop the supply chain and, this way, achieve the ambitions for 2030. Furthermore, it must be determined how the public money can best be distributed among the different parts of the chain.

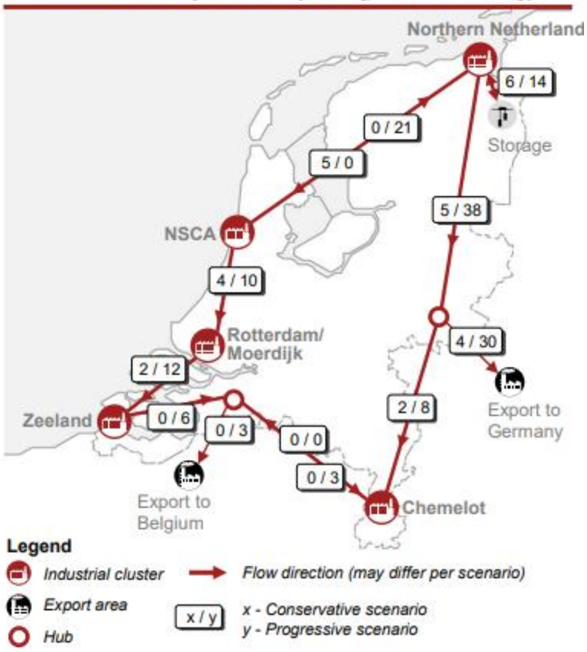
The recommendations in the infographic are a follow-up of the presented conclusions that:

1. A transport system for hydrogen is needed to efficiently connect users and suppliers to each other and to storage in a climate-neutral economy.
2. Transport capacity within and between regions is already needed before 2030.
3. Part of the existing national natural gas network can be made available and technically suitable for interregional transport of hydrogen.
4. It is desirable to reuse the existing natural gas network for this purpose as this is cheaper than building a new infrastructure.

In order to hit the 2030 targets, connections between hydrogen suppliers and hydrogen consumers are needed
To achieve the ambitions for 2030, in the coming years transmission capacity aimed at facilitating the first large hydrogen projects will be needed. Transmission demand will also arise as a result of the need for storage

- The main hydrogen ambitions for 2030 are to have 3-4GW of installed electrolysis capacity and to decarbonise industry by switching to blue hydrogen. transmission capacity is key to realising both these ambitions.
- Initially, transmission capacity will be needed within industrial clusters, i.e. the hydrogen produced will have to be transported to consumers nearby. Most industrial clusters currently lack a fit-for-purpose hydrogen network that can connect potential consumers to suppliers.
- It may also be necessary or beneficial to create transmission capacity between clusters. The expectation is that large-scale green hydrogen production plants will be based along the coast. Potential hydrogen demand from industrial clusters located fu
- rther inland, such as Chemelot, but also potential export destinations such as North Rhine Westphalia in Germany, will depend on a transmission network that transports hydrogen between clusters.

Illustrative analysis of transport flows in 2030 based on the Dutch government's hydrogen ambitions *(Cumulative annual volume in PJ [on an hourly basis]). Source: Strategy&*



The HyWay 27 report can be downloaded[1] for more information on the analyses and above presented conclusions. The report is available in English, German and Dutch.

Research

In recent years, several international studies and trials have been conducted into reusing existing natural gas pipelines[2] to transport hydrogen. One reason for this is that hydrogen molecules are smaller than natural gas molecules. As a result, components like seals and couplings require extra attention. In response to these investigations, many existing natural gas shut-off locations will be removed and replaced. Changes also will be made to other network components, like measurement and control equipment.

[1] https://www.hyway27.nl/en/latest-news/hyway-27-realisation-of-a-national-hydrogen-network
[2] https://www.gasunie.nl/en/expertise/hydrogen/hydrogen-through-gas-pipelines-safe-and-sustainable

3 The realization

The HyWay 27 project marked the initial step towards realization. This chapter outlines subsequent developments in four phases: completed constructions, ongoing projects, future plans, and upcoming initiatives.

3.1 What has been built in the Northern Netherlands

Emmen[3]

In 2022 Gasunie built the hydrogen pipeline in Emmen. A first step in making the industry in this area more sustainable. This 3.6 km long pipeline runs from the GZI Next energy hub in Emmen to Getec Park, where many large industrial companies are located. The construction of the pipeline took place together with the construction of a new natural gas pipeline. This enables companies to switch from natural gas (from the Groningen field) to foreign high calorific natural gas.

In other parts of the Netherlands: Dow to Yara[4]

Gasunie's hydrogen pipeline between Dow and Yara has been brought into operation. This is the first time that an existing main gas transport pipeline has been modified for hydrogen transport. Hydrogen for industrial use will be exchanged via the pipeline, which is no longer being used to transport gas. Underground transport via the gas network ensures that hydrogen will be transported safely and efficiently.
The 12-kilometre-long hydrogen pipeline, which was the subject of agreements signed in March 2018 between Dow, Yara, ICL-IP and Gasunie Waterstof Services, has been brought into use.

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[3] https://www.gasunie.nl/expertise/waterstof/waterstof-en-de-industrie/waterstofleiding-in-emmen-aangelegd
[4] https://www.gasunie.nl/en/news/gasunie-hydrogen-pipeline-from-dow-to-yara-brought-into-operation

to switch from natural gas from the Groningen field to foreign high-calorific natural gas.

3.2 What is under construction - Rotterdam[5]

On Friday 27 October, his Majesty the King of the Netherlands performed the official ceremony to start work on the construction of a national hydrogen network in the Netherlands. The ceremony took place on the building site of Gasunie subsidiary Hynetwork Services in the port of Rotterdam, where the contractor, Visser & Smit Hanab, build the first section of the national network.

The first section of the hydrogen network, a stretch of over 30 kilometres will connect the Tweede Maasvlakte industrial park to Pernis. It is expected to be operational in 2026.

3.3 Plans Hynetwork

In the summer of 2022, the Minister for Climate and Energy published it in a letter to Parliament rollout plan. The purpose of the rollout plan was described as follows in this letter[6]: "[…] the realization of a transport network that runs into the large industrial clusters, connects them with each other and provides access to storage facilities and connects the Netherlands with neighboring countries. "The minister has decided to give Hynetwork the task of developing and managing the national hydrogen transport network according to this rollout plan.
To this end, Hynetwork has been charged with a Service of General Economic Interest (SGEI). Hynetwork proposed and consulted on an adjustment to the rollout plan. This adjustment included joining the Delta Rhine Corridor (DRC) due to its much later date availability of the IJsselmeer route. This meant that the associated west-east route was cancelled in Brabant. In addition, we have informed the market about a delay in the original planning of the national hydrogen network of roughly one to two years. The reasons for this delay were the experiences

[5] https://www.gasunie.nl/en/news/king-willem-alexander-marks-the-start-of-construction-of-gasunies-national-hydrogen-network
[6] https://www.rijksoverheid.nl/documenten/kamerstukken/2022/06/29/ontwikkeling-transportnet-voor-waterstof

gained with the lead times of the first phases of the ongoing project procedures and the not unlimited joint realization capacity from, for example, contractors, engineering firms and relevant government services.

The responses to the consulted proposal showed great commitment to its timely realization
the national hydrogen network and the importance of cooperation and coordination thereof - this importance Hynetwork wholeheartedly endorses it. Due to the delay in the progress of the DRC project and the related government decision-making on the (degree of) integrality the project procedure, it unfortunately turned out not to be feasible to establish an updated rollout plan. After all, hydrogen pipeline in the DRC is a crucial link for industrial clusters in the west, such as Rotterdam, to be connected with the other Dutch industry clusters, with hydrogen storage and with the Ruhr area in Germany.

The government's decision-making on the DRC has recently been completed and clarity has emerged about the modalities in the DRC, the approach and an intended delivery date of the hydrogen pipeline.

Status quo December 2024: In addition, Hynetwork has also updated and clarified the schedules of other routes. Hynetwork currently consults a new proposal to adjust the rollout plan with stakeholders (see next pages for an impression of this proposal). After the consultation period, Hynetwork will incorporate the responses into a final proposal to adjust the rollout plan, which will be submitted to the Minister of Climate and Green Growth for adoption.

3.3.1 The roll-out plan

Hynetwork will realize the hydrogen network in the Netherlands in four phases. The first route that is ready will be in Rotterdam, followed by routes in the other coastal clusters. Then the intermediate connections between the clusters and with Limburg will be realized and ultimately Hynetwork strengthens the whole network. The phases are based on a p90 planning. P90 means that it is estimated that the route in question can be realized within the planning schedule with 90% certainty

Phase 1: Rotterdam (2026)

The first part of the hydrogen network is being built in the Rotterdam port area. Between the Second Maasvlakte and Pernis will be 32 kilometers of hydrogen pipeline. Work started at the end of 2023 and the pipeline will be ready for use in 2026.

Phase 2: Infrastructure in the coastal industry clusters (in or before 2030)

In accordance with the original rollout plan, Hynetwork has started implementation – next to Rotterdam of the infrastructure within the industrial clusters on the coast. This way the network is inside four clusters available before, or in, 2030. This concerns the following clusters:

- Rotterdam;
- Northern Netherlands, including the connection to HyStock (hydrogen storage) and border connections with Germany (Scheemda-Oude Statenzijl and Schoonebeek-Vlieghuis);
- North Sea Canal area;
- Southwest Netherlands, including the first border connection with Belgium: Zelzate.

Phase 3: Connections between the clusters (2031-2033)

In this phase Hynetwork realizes the connections between the clusters and with cluster Limburg. This includes the DRC connection, which connects all clusters with storage and abroad (Belgium and Germany). This specifically concerns the following connections:

- Spaarndam – Mijnsheerenland: the connection between the North Sea Canal area and Rotterdam;
- Mijnsheerenland – Moerdijk: the connection between Rotterdam and Zeeland via the DRC;
- Limburg: the connection from Ravenstein to the Chemelot industrial cluster;
- Rotterdam – Boxtel: the connection between west and east via the DRC;
- Ommen – Ravenstein – Boxtel: the connection between the Northern Netherlands (incl. HyStock) with the DRC;
- Angerlo – Zevenaar: connection with the border crossing to Germany.

In addition, Hynetwork wants to investigate the possibility of developing the route Mijnsheerenland – Rhoon – Pernis. This route (approximately 10 – 18 km) makes it possible to reach Rotterdam and directly connect the North Sea Canal area. The realization of this route can be seen as: risk mitigation for unexpected delays in the realization of (the relevant part of) DRC. Depending on the progress of the realization of the DRC and the remaining part of the West Netherlands route, a decision may be made in the future about the permit procedure required for this and about the actual construction of this sub-route.

Phase 4. Strengthen (year not yet known, but after 2033)

Once we have a connected network, we will continue to strengthen it.

This applies for the following routes:

- Den Helder – Beverwijk;
- IJsselmeer route.

And Hynetwork is working on border connections if more border capacity is needed:

- Ommen – Winterswijk (Germany);
- Sanderbout – 's Gravenvelden (Belgium);
- Zandvliet (Belgium).

In addition, in the permit process Hynetwork takes into account the possibility that at some point there is need for a second hydrogen pipeline in the Rotterdam region: Maasvlakte-De Hoek route. This hydrogen pipeline may run from the Second Maasvlakte walk south of the harbor towards the east.

Finally, we expect an offshore hydrogen network to be developed in the future, and that it will be connected to Hynetwork's hydrogen network. Connections to future hydrogen distribution networks may also be on the cards.

3.3.2 Offshore hydrogen network

Gasunie is the intended network operator for the future hydrogen network in the North Sea. This was announced by former Minister for Climate and Energy Policy Rob Jetten in a letter to the Dutch House of Representatives. In his letter on the North Sea Energy Infrastructure Plan 2050, Jetten stresses the importance of designating an intended operator to safeguard public interests. Additionally, the designation reassures the market that infrastructure will be available. In light of the key role that offshore hydrogen production is expected to play in the future growth of offshore wind, Jetten has asked Gasunie to set the wheels in motion towards creating a hydrogen network. This hydrogen network will help achieve the climate goals and energy independence, and improve the Netherlands' competitive position.

Key position for wind power

Like the other countries around the North Sea, the Netherlands has great ambitions when it comes to scaling up and rolling out offshore wind, and it is uniquely positioned to do so. Offshore wind helps to make the energy supply sustainable and affordable and will continue to grow rapidly and robustly. It also makes the Netherlands and Europe less dependent on energy from other countries and improves the Netherlands' competitive position. With the further growth of offshore wind from 2030, onshore as well as offshore hydrogen production becomes essential. From 2030 onwards, it will become increasingly challenging to transmit all the wind power generated offshore to land in the form of electricity.

That is where hydrogen comes in as a great alternative, given the extensive transmission capacity offered by gas pipelines and the fact that hydrogen is relatively easy to store. This is important if we want to have sufficient energy available, also when the wind is not blowing or the sun is not shining. Besides the benefits for the energy system, offshore hydrogen also means that fewer cables and electrolysers will be needed on land. On top of that, hydrogen transmission is very (cost-)efficient, meaning that it will bring down the total energy infrastructure costs. An added benefit is that these pipelines in the North Sea can also be used to import hydrogen from other North Sea countries.

Public interest

The development of an offshore hydrogen network serves a public interest. The minister gave Gasunie the task of safeguarding this public interest in developing the network, classing it as a service of general economic interest. It will see Gasunie team up with pipeline owners to explore the possibilities of reusing pipelines. Gasunie will receive a grant from the Climate Fund for the performance of this task. It will be up to the new government to decide what resources to make available for the construction and operation of the offshore hydrogen network.

3.3.3 European network[7]

The European Hydrogen Backbone (EHB) initiative unites 33 future hydrogen network operators. The mismatch between the supply and demand of hydrogen in Europe led to develop a pan-European infrastructure plan for a dedicated hydrogen transport network.

The EHB initiative aims to accelerate Europe's decarbonisation journey by defining the critical role of hydrogen infrastructure – based on existing and new pipelines – in enabling the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market. We have created a vision on how cross border hydrogen infrastructure develops from 2030 to 2050 and analysed what it takes to build this infrastructure. This vision is already turning into action. The Netherlands has started the creation of its national backbone and the German government has provided support for the German 'Kernnetz' and construction is expected to start soon. In addition, 29 hydrogen transmission projects have been included in the 6th Projects of Common Interest list adopted by the European Commission, and are actively been developed by the EHB partners[8].

[7] https://ehb.eu/
[8] European Hydrogen Observatory. European Commission adopts the 6th list of Projects of Common Interest (November 2023)

4 **Best practice:** Underway with hydrogen pipelines in the north of the Netherlands

The northern industrial areas of Eemshaven and Delfzijl are home to major potential producers and consumers of hydrogen.

Connection to the national network is therefore important, according to the Ministry of Economic Affairs and Climate (EZK).
This network should serve to further stimulate the supply and demand of hydrogen, Jarno explains[9]: “By connecting to the national hydrogen network we ensure that industry has access to hydrogen as a cleaner form of energy. For example, while the Chemelot Industrial Park in Limburg consumes a lot of energy, hardly any hydrogen is being produced in the area. By linking this site to hydrogen production sites in Groningen, Zeeland and Amsterdam, carbon emissions can be reduced enormously. So, such an expansive network will likely result in an increasing demand for hydrogen.” “HyStock, the Dutch hydrogen storage facility in Zuidwending, will also be connected to the network, and there will be two cross-border connections with Germany as well.” Jarno says, “That’s also important for the importers, and for the hydrogen producers in our cluster, given that they also have consumers in Germany. In short, we are seeing to it that producers and consumers will eventually have 24/7 access to a well-functioning hydrogen network.”

A project to be proud of

‘With this work we are making a concrete contribution to the energy transition. Everyone on my team likes the idea that we are not doing this for ourselves but for future generations. That also really invigorates me, gives me new energy!’

Benefits of preparing now
To build all these connections, in the northern parts of the Netherlands alone Gasunie subsidiary Hynetwork will be converting around 130 kilometres of natural gas pipeline and laying another 80 kilometres of new pipeline. Construction will really pick up steam in 2026 and is expected to continue until the end of 2027.

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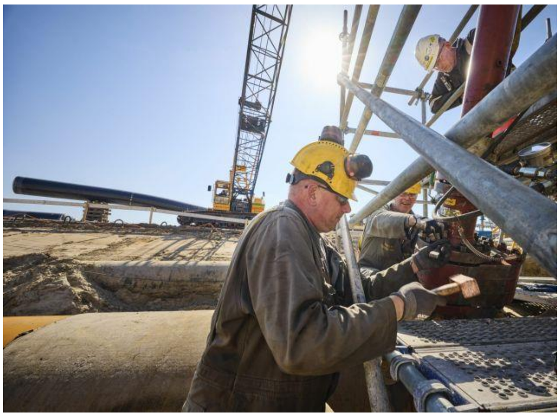
[9] https://www.gasunie.nl/en/news/underway-with-hydrogen-pipelines-in-the-north-of-the-netherlands

‘We are already busy making preparations,’ says Jarno. 'We will be connecting two existing gas pipelines to create one long transmission pipeline, running over 105 kilometres from Tjuchem to the Ommen compressor station. We have moved this part of the work forward because that offers major advantages: this way we only have to inspect one long pipeline instead of two, a move that will save us more than a million euros. And because you have to inspect less this makes it safer too – and so also more environmentally friendly.’

‘There is also a transmission-related technical advantage to connecting the two pipelines at this stage already: this way we can still use the NAM pipeline system. After all, with the closure of the gas fields this will eventually be removed.’

On to the conversion

Once the pipeline between Tjuchem and Ommen has been inspected and released, Jarno’s team can disconnect this section from the natural gas network. ‘And that’s when the major conversion work begins. Because this work will be carried out in an operational natural gas system, we will be regularly performing all kinds of safety calculations and checks. Installing a new hydrogen pipeline is no different to laying a gas pipeline: the pipelines are made of the same material and have the same coating. When carrying out the conversion work we purge the gas from the pipeline using nitrogen; this neutralises the risk of hydrogen coming into contact with oxygen. Then we force out the nitrogen by passing a plug through the pipeline.’

‘Our team works very well together, applying a lot of creativity. For example, we’ve taken sections of pipe already welded together and formed a bend in these, something we had never done before at Gasunie. We also pay a lot of attention to safety, together with the contractors. And we do everything we can to minimise congestion and nuisance in the area. The resources may be scarce, but through creativity and collaboration you can still come up with great solutions.’

5 Appendices

A final decision on the quality specification and temperature will be taken by the Ministry of Climate Policy and Green Growth (KGG).

A1 Quality and temperature

In neighbouring countries, there is increasing support for a minimum purity requirement of 99.5%. The European Commission expects to start a European standardisation process for hydrogen, which is likely to take around 3 years. In the Netherlands, Belgium and Germany, hydrogen flows into the grid are coming on stream earlier. Therefore a number of transport companies in Germany, Belgium and the Netherlands, including Gasunie, have started working on a joint specification based on 99.5% purity.

The Ministry of Economic Affairs and Climate Policy (EZK) will await the outcomes of this joint specification before taking a final decision on the hydrogen specification. The specification could be used in contracts, interconnection-agreements and as input for the European standardization.

Table 1: Indicative quality specification Hydrogen Network Netherlands

Constituents	Unit	Min.	Max.
Hydrogen (H_2)	mol/mol %	99.5	
Total sum of hydrocarbons including CH_4 (C_xH_y)	mol/mol %		0.5
Oxygen (O_2)	µmol/mol (ppm)		10
Total sum of inerts (N_2, He, Ar)	mol/mol %		0.5
Carbon dioxide (CO_2)	µmol/mol (ppm)		20
Carbon monoxide (CO)	µmol/mol (ppm)		20
Total sulphur including H2S (S)	µmol/mol (ppm)		3
Formic acid (CH_3OOH)	µmol/mol (ppm)		10
Formaldehyde (CH_2O)	µmol/mol (ppm)		10
Ammonia (NH_3)	µmol/mol (ppm)		10
Halogenated compounds	µmol/mol (ppm)		0.05
Water dewpoint (H_2O)	ºC @ 70 bara		-8
Hydrocarbon dewpoint	ºC @ 1 - 70 bara		-2
Wobbe index	MJ/m^3 (n)	45.99	48.35
All other impurities	Shall not contain solid, liquid or gaseous material that might interfere with the integrity or operation of pipes or any gas appliance		

Table 2: Temperature

Property	Unit	Min.	Max.
Gas temperature	ºC	5	30

A2 Pressure hydrogen network

Hynetwork sets the pressure regime for Hydrogen Network Netherlands. The operational pressure ranges between 30-50 bar(g). The design pressure of the Hydrogen network Netherlands is 66,2 bar(g). Future developments can cause an increase of the operational pressure to a maximum of 66,2 bar(g) with a matching pressure range. interconnection-agreements and as input for the European standardization.

Summary table design conditions HNS network:

Design pressure (Pd), the maximum operational pressure:	66.2 bar(g)
Temporary operational pressure regime (*):	30.0 bar(g) – 50.0 bar(g)
Announcement period by HNS to increase operational pressure regime:	40 months
Design temperature (Td), the maximum operational temperature range:	-20.0 °C - +50.0 °C
Temporary operational temperature regime:	+5.0 °C - +30.0 °C

(*) Future developments can cause an increase of the operational pressure to a maximum of 66.2 bar(g) with a corresponding operational pressure regime.

New or reused pipelines for hydrogen transport must comply with the Pd of 66.2 bar(g) so that no restrictions arise in the hydrogen network when the current temporary operational pressure regime of 30-50 bar(g), as determined by HNS, will be increased towards the maximum operational pressure of 66.2 bar(g). If HNS decides to increase the temporary operational pressure, HNS will apply an announcement period of 40 months. The temperature regime of the HNS network is +5.0 °C - +30.0 °C and has temporary been determined by the Dutch government. The temperature range might be changed by the government due to new insights including international alignment, but cannot exceed the design temperature of the HNS network.

A3 Safety and risks

A safe design for the hydrogen network starts with identifying risks, a process known as Hazard Identification (HAZID).
One possible risk could be the interaction of gases with electrical equipment in the network. Once we have a thorough understanding of all potential hazards and risks, the engineers start working on the design. Their aim is to ensure that the system is as safe as possible while making the hazards and risks manageable. For example, they achieve this by selecting certain materials. Naturally, these must be suitable for hydrogen. The engineers also consider the distance to installations or homes. Finally, they consider the safety of the individuals who will be working with the network during future operations. The focus is on providing safe and pleasant working conditions.

Existing pipelines
In building the hydrogen network, we want to use existing pipelines as much as possible. Before we can determine whether they are suitable for the design, we must confirm that they meet the safety and quality requirements for transporting hydrogen. Part of that effort involves inspecting the interior of the pipes to determine if they are still in top condition.

Malfunctions and human errors
Once the design has been put to paper, the next phase begins. In the Hazard Operability (HAZOP) phase, a team of experts investigates the risks associated with using the network. They consider the possible consequences of equipment malfunctions or human errors. Then they develop solutions to prevent malfunctions and minimise risks as much as possible. This phase ensures that the hydrogen network will operate safely and reliably once it is commissioned.

Eliminating risks
Once the final design has been established, we conduct another study to ensure the safety of network construction. The underlying assumption is that the design choices will eliminate these risks as much as possible, but some residual risks will always remain. These might be caused by proximity to other pipelines, high-voltage cables, rail lines or waterways. A team of experts goes through the design step by step and produce a Risk Inventory and Evaluation (RI&E). We then incorporate the RI&E in the plans for Health and Safety (design phase H&S plan). The contractor uses this to carry out the work as safely as possible.

Safety standards for hydrogen infrastructure

The Ministry of Infrastructure and Water Management is responsible for setting safety standards for the hydrogen infrastructure. Research is underway to identify the risks and risk-reducing measures for this infrastructure, as was done for the current natural gas network. The ministry has published three fact sheets (in Dutch) about the safety of hydrogen (and hydrogen carriers). In short, hydrogen will soon not only be a sustainable resource, but also a safe alternative to fossil fuels and feedstocks.

A4 Article: Converting the gas grid to hydrogen, is it really that simple?

Gasunie has plans to gradually convert the natural gas network into a hydrogen network. After all, having a sustainable energy system means that we must move away from natural gas as a fossil fuel. The expectation is that hydrogen will take its place. But is converting the natural gas grid to hydrogen economically and technically feasible? Does it deliver climate benefits? And, first and foremost, is it safe?

Cars, trucks and motorcycles can drive down the motorway. Some vehicles cause the asphalt surface to wear slightly faster than others, but basically everyone can use the motorway regardless of their vehicle. In essence, the same is true of pipelines; in principle, they can be used to transport natural gas, CO_2 or hydrogen, or any other gas. However, just as trucks subject the asphalt to greater loads, the way gases behave in a pipeline depends on their composition, and we need to take that into account.

How safe is it to transport hydrogen by pipeline?

Some critics say that hydrogen can have a disastrous effect on the steel used to make the pipelines. They fear that hydrogen atoms will easily be absorbed by the steel, causing pipelines to become brittle, resulting in cracks and leaks.

‘For me, there’s one simple rule: if it can’t be done safely, we don’t do it’, says Otto Jan Huising, Technical Manager at Gasunie. His job as a materials research engineer is to investigate the feasibility of reusing gas pipelines for hydrogen. ‘To transport hydrogen safely, you have to have a good understanding of the conditions under which that is possible. Because hydrogen’s adverse effect on steel is proven and well documented. The toughness of the steel is reduced, and exposure to hydrogen can cause fatigue cracks to develop faster than when transporting natural gas’, he says.

Why is that? The hydrogen molecules (H_2) themselves are not so much the problem. It’s mainly the hydrogen atoms (H) that cause the headaches. Hydrogen molecules are inherently stable; when transported, they only break down into individual atoms in the presence of a catalyst. Iron is one of those catalysts. Steel natural gas pipelines are protected on the inside by a layer of oxide, but if that layer is degraded by welding faults, for example, exposing a clean iron surface, hydrogen molecules can decay into hydrogen atoms at that point, penetrating the steel.

The ’initial defect’, as Huising calls it, then grows as the hydrogen atoms penetrate further into the material. This is called ‘crack initiation’. Hydrogen can cause cracks to grow twenty to fifty times faster than other gases. This happens particularly when there are large pressure changes in the pipeline. In the HyWay 27 report, PwC concluded in 2021 that without additional measures, this embrittlement effect could lead to 'minor leaks' in the longer term (20 to 25 years).

Can leaks be prevented?

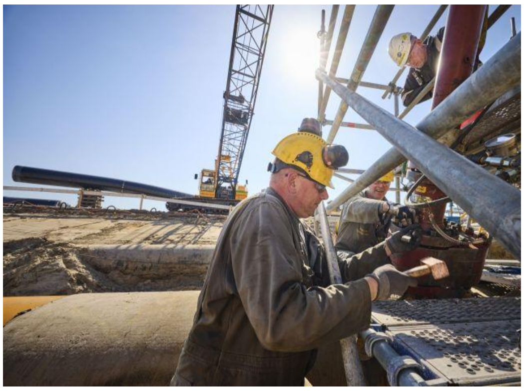
Leaks are obviously undesirable. They can lead to dangerous situations because hydrogen is highly flammable. Leaks are also a form of product loss. Every cubic meter of hydrogen that leaks out can no longer be sold. Furthermore, leaks lead to climate damage because more hydrogen in the atmosphere would slow the breakdown of the greenhouse gas methane.
How safe is it to transport hydrogen by pipeline if leaks can occur? For safety reasons, Gasunie assumes an ignition probability of 100% in the event of a hydrogen leak, though this is not the case in practice: the ignition probability for natural gas is calculated at 40 to 80%, depending on the pipeline diameter and pressure. Martin van Agteren, Asset Manager at Gasunie, tells us about an experiment conducted at the Twente Safety Campus, which involved emptying a section of pipeline filled with hydrogen via a flare vent. 'Even with igniters directly above the flare, we still had trouble getting it to light, and the hydrogen didn't ignite spontaneously either.' This is because although hydrogen is highly flammable, it is also highly volatile, meaning it evaporates very quickly at normal temperatures.

Besides normal combustion, hydrogen can also burn at an accelerated rate, resulting in a rapid build-up of pressure – an explosion. Hydrogen can explode under certain conditions when its concentration in air is at least 10%. However, because hydrogen is so light and volatile, that 10% threshold is not easily reached. 'If a hydrogen pipeline in an open field develops a leak, you won't reach that threshold because of the lightness and volatility of hydrogen', says his colleague Huising. 'In Norway, a firm of consulting engineers, DNV, conducted a test at a hydrogen refuelling station. After creating a leak, they only reached a maximum concentration of 8%, which is not an explosive gas mixture.'

Even though the explosion hazard is limited, Gasunie is still keen to prevent leaks. So once a crack develops, action is needed to slow down the effect of accelerated crack growth. To achieve that, a crack may 'grow by no more than 0.25 mm over an operating period of 100 years' according to Huising. Since pressure changes in the pipeline determine the growth rate of cracks, they should be avoided as much as possible. Based on metal fatigue calculations, Huising can

determine what the maximum pressure changes in the hydrogen network may be and how often they may occur.
'In the case of natural gas, we mainly control pressure based on customer demand. And when the pressure in the pipeline network fluctuates, it doesn't really matter', Huising says. 'In the case of hydrogen, we will also be controlling pressure changes in the network.' To keep the pressure within a limited range, we will use large salt caverns to store hydrogen. These act like an expansion vessel in a domestic central heating system, allowing us to accommodate pressure changes in the system.
Further growth of the hydrogen grid will also help. 'In a nationwide hydrogen network of many hundreds of kilometres, you need a lot of hydrogen to increase pressure by even as little as 0.1 bar', Huising explains. 'The larger the network, the smaller the pressure fluctuations.'

During the first few years of operation of the hydrogen grid, supply and demand will sometimes be insufficiently balanced. The caverns will also not be ready for storage during that period. So pressure changes may well occur. According to Van Agteren, projections show that those fluctuations will be small, both in terms of their intensity and their frequency of occurrence. 'So small, in fact, that we can allow pressure fluctuations up to a safe level if supply and demand are not quite balanced.' This dynamic form of storage is called 'line pack'. Van Agteren says, 'The operating pressure in the pipeline can fluctuate between 30 and 50 bar and will stabilise in practice at around 40 bar. That is lower than the design pressure of 66 bar.'



If the requested volumes or capacities increase in the future, 'you simply add a second pipeline instead of using large and expensive compressor stations', Van Agteren explains. 'So the natural gas network will slowly but surely switch over to hydrogen.' Gasunie's network expert does not see a need to build hydrogen network compressor stations before 2035.
Given the limited experience with hydrogen transmission through pipelines, numerous research groups are conducting tests. For example, Huising, with several peers from other gas transmission system operators (TSOs), is actively involved in research projects initiated by the European Pipeline Research Group and the Pipeline Research Council International. 'We are going to run tests with damaged pipes, for example. Suppose an excavator causes a dent, how does the pipe behave in that situation? We have models to explain this for natural gas. And we need a similar tool for hydrogen', he says. Damage to pipes caused by excavation works occurs once every five years on average, according to Van Agteren.

Huising emphasises that the Dutch and European gas network was built in the 1960s and 1970s. The quality of the steel was much higher than that used in the United States, where parts of the main network were built as early as the 1940s. ‘They face much greater challenges in converting the gas grid to hydrogen over there. You can’t simply take the reports that warn about the problems in America and project them onto the transition in Europe and the Netherlands.’

Are the branch lines and valves in the network safe?

When the natural gas network is converted to a hydrogen grid, only the pipelines themselves will be left in place. Everything else will be replaced. This mainly involves the valves. These are the points in the network where, for example, branch lines are installed to connect customers. ‘Many of those valves date back to the 1960s’, Huising says. ‘If you’re going to build a new network, it makes sense to replace them.’

A valve is like a tap in the water supply. In a natural gas pipeline, it is a sort of ball with a hole in it. Turning the ball a quarter turn allows gas to flow through the valve; turning it another quarter turn stops the flow of gas. Gasunie is considering using fewer valves in the hydrogen network, Van Agteren says. The current gas grid has a valve every 15 kilometres. ‘That approach ensures that we can limit nuisance to local communities to no more than one hour, even in the event of a major leak.’

With natural gas, it takes an hour to empty a 15-kilometre length of pipe. ‘Because hydrogen is much more volatile, a pipeline length of 50 or maybe 80 kilometres would empty in an hour. That’s why we would need fewer valves. There are moving parts in valves, which are associated with a greater risk of leakage than the steel pipe.’

What if something does happen?

Before pipelines are put into service, they are inspected internally. There are all kinds of tools for this. For example, there is a tool that can detect cracks and other defects by generating a resonant vibration in the steel.

In emergencies, the valves close. Although 100%‘ pure hydrogen burns with a colourless flame, there are always small amounts of contaminant in the gas, as well as in the air drawn in that is needed for combustion, which make the flame visible. Technicians and inspectors have all kinds of equipment to locate damage and leaks and also to protect themselves, because Gasunie assumes as a matter of course that the hydrogen will burn with an invisible flame. The technicians’ equipment also includes cameras that detect heat radiation, gas detection cabinets and portable ‘gas sniffers’.

Is repurposing a natural gas pipeline for hydrogen economically feasible?

Because existing pipelines have to be made suitable for transporting hydrogen, some fear that the conversion, while technically possible, will be far too expensive. According to Van Agteren, this point has also been given extensive consideration. ‘When developing hydrogen infrastructure in Europe, joint studies have also looked at this aspect. The outcome is that repurposing an existing pipeline costs just 20% of building a new gas pipeline. Hynetwork, a Gasunie subsidiary, which is building the national hydrogen network in the Netherlands, has calculated that the cost of repurposing will be four times lower than new construction.’
In addition to lower costs, Gasunie sees another important advantage. ‘Repurposing has much less impact on the local community than installing a new gas pipeline in the ground. The Netherlands is pretty full, so from that perspective, too, reusing a pipeline that is already there is the preferred option’, Van Agteren points out.

Will it really deliver climate benefits?
In the United States and also European countries with a limited natural gas network, the strategy focuses on blending hydrogen with natural gas. A blend of 80% natural gas and 20% green hydrogen leads to a reduction in carbon emissions of only 7% because of hydrogen’s lower energy density. Why would you invest so much money in the network when the climate benefits are so limited, critics ask.
Although hydrogen blending may be a first phase in many cases, the strategy of Gasunie and other European gas transmission companies is to eventually transport (almost) 100% hydrogen. The reduction in emissions is then correspondingly greater.

Is it possible?
Back to the headline at the top of this article: ‘Converting the gas grid to hydrogen, is it really that simple?’ The answer is: yes, it can be done, but it’s not that simple. As the level of demand for hydrogen from industry, the chemicals sector and transport sector increases, infrastructure will be needed to get it to the customers.
Gas TSOs have been looking into whether and how natural gas pipelines can be used to transport hydrogen for twenty years already. A report on this issue was first published in 2004 under the banner of the European Gas Research Group. Forty European partners investigated how the transition to hydrogen could be facilitated by using existing gas infrastructure to transport a blend of natural gas and hydrogen. The project, known as NaturalHy, received funding from the European Commission.
To this day, researchers in Europe, the USA and elsewhere are investigating hydrogen transmission. This work provides new insights and leads to technological innovations that will increasingly simplify the deployment of hydrogen. Experts such as Martin van Agteren and Otto Jan Huising attend conferences on the subject, conduct field experiments, and share knowledge with researchers and specialists in other countries.

So it's not that simple. However, with the right investments and precautions, transporting hydrogen through natural gas pipelines is safe and economical, and also delivers climate benefits.