Enabling the Dutch hydrogen ambitions

To help achieve the targets set out in the Dutch climate agreement, Gasunie has been assigned by the Dutch government to develop a hydrogen network by 2030, connecting large hydrogen production facilities nationwide – including 4 to 8 GW of electrolyser capacity – with industrial clusters, storage facilities and neighbouring countries. This high-capacity hydrogen network has a length of approximately 1,200 km, of which 80% consists of repurposed natural gas pipelines with an average diameter of 36 inches. In the German part of the Gasunie network, the HyPerLink project realises a 660 km hydrogen network using a similar approach. The HyWay27 study has shown that existing pipelines can be repurposed at minimal cost compared to the development of new pipelines.

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In addition to onshore activities, the Dutch government anticipates the importance of offshore electrolysis and hydrogen transport, including interconnections to countries surrounding the North Sea. Gasunie has begun assessing feasible options for an offshore hydrogen network that delivers large quantities of hydrogen ashore, as shown in Figure 1.

Hydrogen transport via reused and new pipelines

Natural gas transmission volumes in the Netherlands will drop to around 40% in 2030 compared to current levels. As a result, and because the Dutch natural gas transmission network is largely made up of multiple parallel pipelines, Gasunie can reorganise existing natural gas transmission flows in a way that frees up transmission pipelines for alternative uses.

Studies have shown that pipelines currently used for natural gas transmission can be reused for hydrogen transmission. This will, however, require a few changes to the existing pipelines and how they are operated and maintained. It is needed to separate them from the natural gas network, clean the pipelines with cleaning pigs, replace the valves, replace or reconfigure metering equipment, and implement new management and maintenance methods. These measures and proper technical design and engineering of pipelines will solve problems in advance, including the prevention of hydrogen emissions.

Large volumes of hydrogen can be efficiently transported over long distances through pipelines. A reused gas pipeline has an average diameter of 36 inches, which offers a capacity of 10 to 15 GW, depending on the pressure level. In many cases, producing and transporting hydrogen close to the source of renewable generation is cheaper than transporting electricity and carrying out electrolysis on-site at the consumer's location. A pipeline-based hydrogen transmission network can boost the development of the hydrogen market due to its high transport capacities and relatively low costs. The more producers and consumers are interconnected by the network, the greater the security of supply and freedom of choice for consumers.

Hydrogen can be transported safely

The design factors of natural gas pipelines used in the Netherlands, which are standard in the industry, are similar to the design factors of

Hydrogen network 2030

Fig. 1. Gasunie is developing an onshore and offshore hydrogen network in the Netherlands and Northern Germany to be ready by 2030.

new hydrogen pipelines. In practice, Gasunie has been successfully operating a 12-km long hydrogen pipeline since 2018. This hydrogen pipeline is the first large-scale retrofit of an existing 16” natural gas pipeline and a 12” new pipeline that runs between the Dow Chemical facility in Terneuzen and the ammonia producer Yara’s facility in Sluiskil.

At this moment, there is hardly any legislation or regulation regarding the transport and distribution of hydrogen. To keep pace with the energy transition, the Dutch government stated that for the time being the existing laws on regulation of natural gas also apply in the context of hydrogen. This means that companies transporting hydrogen by pipeline must fulfil the requirements set in (1) the decree on the external safety of pipelines (Bevb), (2) Dutch pipeline standard series NEN 3650 including approval of an accredited body, and (3) zone plans of municipalities, describing activities performed regionally.

The Bevb focuses on pipelines for the transport of hazardous substances, including hydrogen as a commonly used process gas in the industry. The Ministry of Infrastructure and Water Management has recently decided that the safety calculations of hydrogen pipelines are allowed in the same way as for natural gas pipelines, including use of existing failure frequencies. This applies to the entire future Gasunie hydrogen network, i.e., 4–48” pipes in a pressure range of 40–80 bar. There is one major difference: for hydrogen, an ignition probability of 100% must be used. On behalf of the government, the Human Environment and Transport Inspector (ILT) supervises Gasunie in line with regulations stated in the Bevb.

Before a natural gas transmission pipeline can be used for hydrogen, a declaration of conformity is required as stated in the NEN 3650. Gasunie has made an assessment plan that focuses on the technical part of compiling, assessing and approving pipeline data and properties. Based on this file, the accredited body can assess whether the natural gas transmission pipeline is suitable for hydrogen transport and can give approval. The result of the assessment is recorded in a so-called declaration of conformity of the amendment by an accredited body with specific reference to the applicable operations for pipeline systems according to the NEN 3650 series.

Regarding the physical properties, there are a few differences between hydrogen and natural gas that can have an impact on the safety and integrity of the network. Hydrogen is somewhat lighter and easier to ignite than natural gas. The separation from the natural gas network and replacement of the existing valves are, therefore, the most important measures Gasunie will take, also because of the potential indirect global warming potential of hydrogen.

The indirect greenhouse gas effect of hydrogen

As with methane emissions from natural gas transport, Gasunie is fully committed to minimising hydrogen emissions. Why is this important? Concerns have been raised regarding the potential global warming impact caused by hydrogen emissions. Although hydrogen is neither intentionally emitted to the atmosphere nor a direct greenhouse gas, hydrogen emissions will impact the lifetime of other greenhouse gases, namely methane, ozone, and water vapour, indirectly contributing to the increase of the Earth’s temperature. The reaction of H_2 with OH leads to a feedback mechanism where less OH is available to react with methane. Since the reaction with the hydroxyl radical is the primary sink for methane ($CH_4 + OH\ (+O_2) \rightarrow CH_3O_2 + H_2O$), the lifespan of methane in the atmosphere is extended under the assumption that OH concentrations will decline. To minimise the

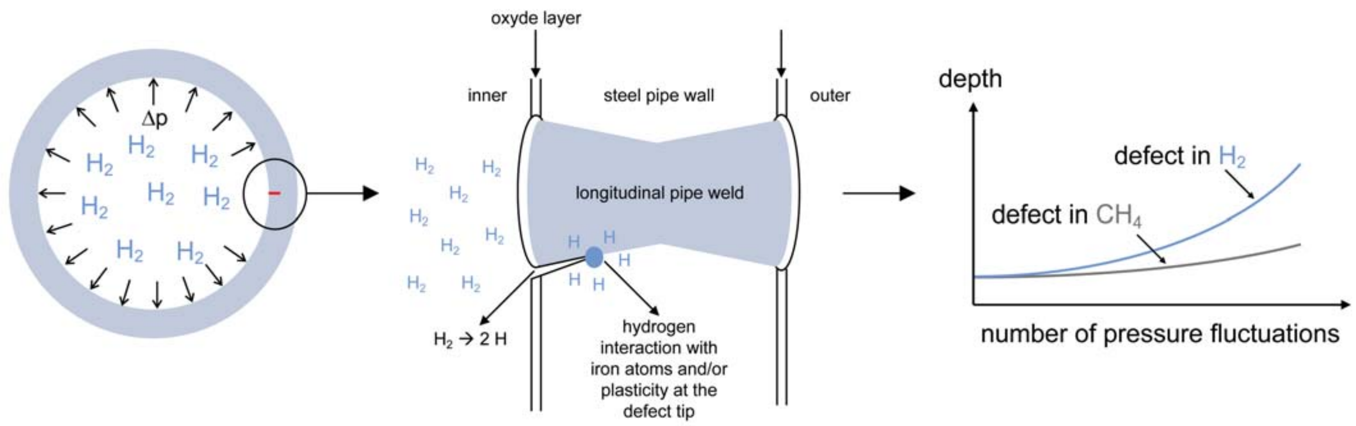

Fig. 2. In steel pipes, the crack growth rate is a factor ten times higher in hydrogen than in natural gas under fatigue loading.

potential climate impact of a hydrogen economy, losses should therefore be minimised, prevented, and monitored. The IPCC has not yet determined a global warming potential (GWP) for hydrogen. However, in a few scientific publications various proposals have been made with GWP values ranging from 4 to 11.

The European Commission proposes regular checks to detect potential emission leaks for all hydrogen network operators. Gasunie will apply its extensive experience with these detection methods to diminish hydrogen emissions from the transport system to a percentage lower than 0.01% of the total volume transported – the current methane emission performance of Gasunie's natural gas network.

Hydrogen-enhanced fatigue

Hydrogen is very often, unjustifiably, associated with the occurrence of embrittlement of pipelines. Embrittlement due to hydrogen will never occur spontaneously under normal pipeline conditions (5–30°C, 8–100 bar) unless hydrogen molecules are split into atoms. Under these normal conditions, a catalyst such as iron is needed for the dissociation of hydrogen molecules. A steel pipe is protected with an oxide layer, which means that a clean iron surface can only be exposed in the event of a rare welding defect on the inside of the pipe and under the influence of pressure fluctuations. This can also happen in natural gas and is not very concerning. The difference is that hydrogen atoms can penetrate into the steel at such a rare defect. In experiments with a piece of steel with an artificial crack, it was found that the crack growth rate is a factor ten times higher than in natural gas under fatigue loading. This means that a welding error exposed to hydrogen can grow slowly (Figure 2).

Fortunately, there are two important control measures to prevent this. First, the high-quality carbon-steel pipelines used for hydrogen transport must be checked for major existing defects and welds validated for quality. These preconditions can be secured with EMAT inline inspection and non-destructive investigation. Second, fatigue loading of the pipelines must be prevented as much as possible by limiting the frequency and amplitude of pressure fluctuations.

Serve the market but protect pipeline integrity

An increasing share of green hydrogen means that supply and demand will be more widely spread in terms of distance as well as timing. Transport system operators see a role for themselves in solving this issue of imbalance. Hydrogen pipeline networks can efficiently accommodate temporal imbalances via their linepack. However, volatile production volumes of green hydrogen will result in frequent pressure fluctuations, and consequently higher defect growth rates.

Fatigue loading can be limited by controlling the pressure fluctuations, but this limits the maximum available linepack. To take an objective decision between commercial interests and pipeline integrity, Gasunie performed a quantitative analysis of market-driven pressure fluctuations in hydrogen networks and their effect on defect growth and lifetimes of these hydrogen networks. An integrated model was developed for this purpose, that can calculate dynamic network behaviour and give an indication of the corresponding defect growth risks.

The model consists of three steps (Figure 3). First, a network topology design combined with prospect transport volumes and profiles is entered into dynamic simulation software. Second, the resulting pressure profiles are transformed into a more readable format by using the rainflow-counting algorithm – translating a complex profile of peaks and dips into equivalent pressure fluctuations – and Miner's rule to summarise it into a single amplitude and frequency value. In the third step, an adapted version of the ASME B31.12 fatigue crack growth equation is obtained from the NaturalHy project, which can be used with Miner's rule without compromising on accuracy.

Together with the pipeline characteristics, the expected resulting defect growth can be calculated without using a numerical method.

While many different scenarios can be modelled to answer a multitude of questions, this article highlights three cases that are of key relevance for any hydrogen network operator. It must be noted that these results are valid for high-quality carbon-steel pipelines where the aforementioned preconditions of existing defect size and weld quality are validated.

The following conclusions can be drawn from these cases:

1. In the start-up phase of a hydrogen transport system, when the network load is still low and large-scale storage is not yet available, a pressure range of 20 bar can be used safely to store temporal imbalances. A pressure fluctuation from minimum to maximum, and back, will not occur daily in this phase but will be spread over several days or weeks. Such behaviour does not lead to problematic defect growth.
2. In a more mature transport network that is connected to large-scale storage, a pressure

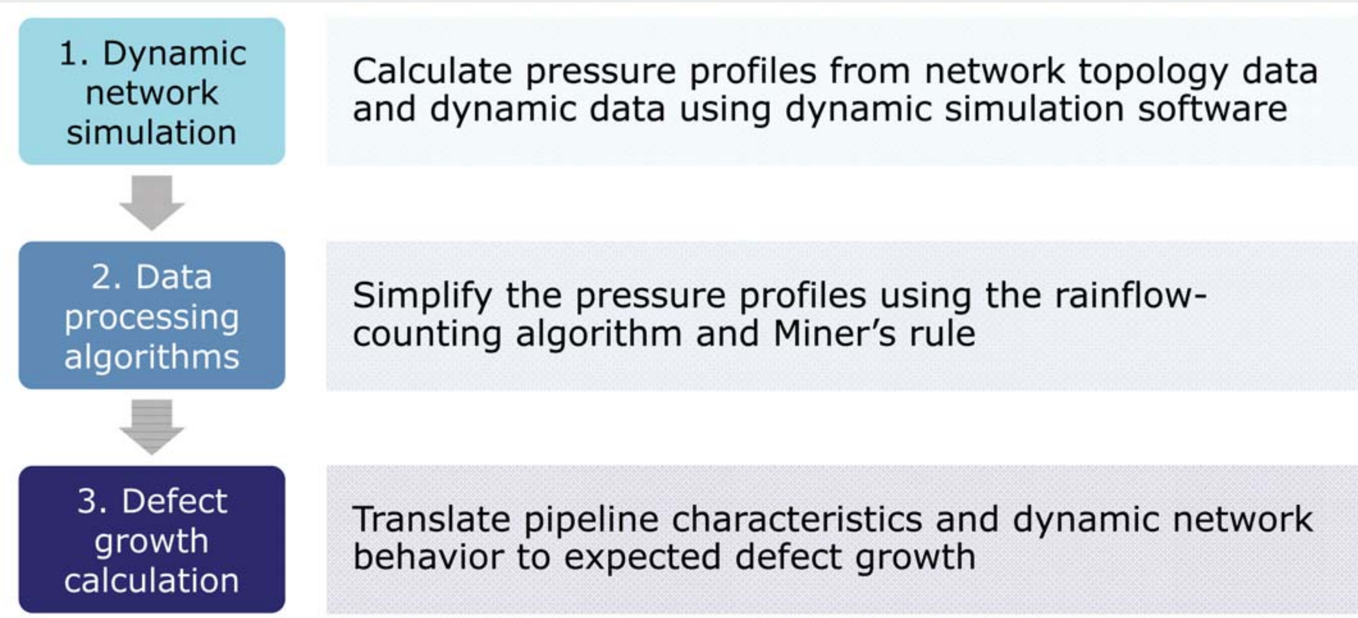

Fig. 3. Integrated model developed to calculate dynamic network behaviour and estimate corresponding defect growth risks

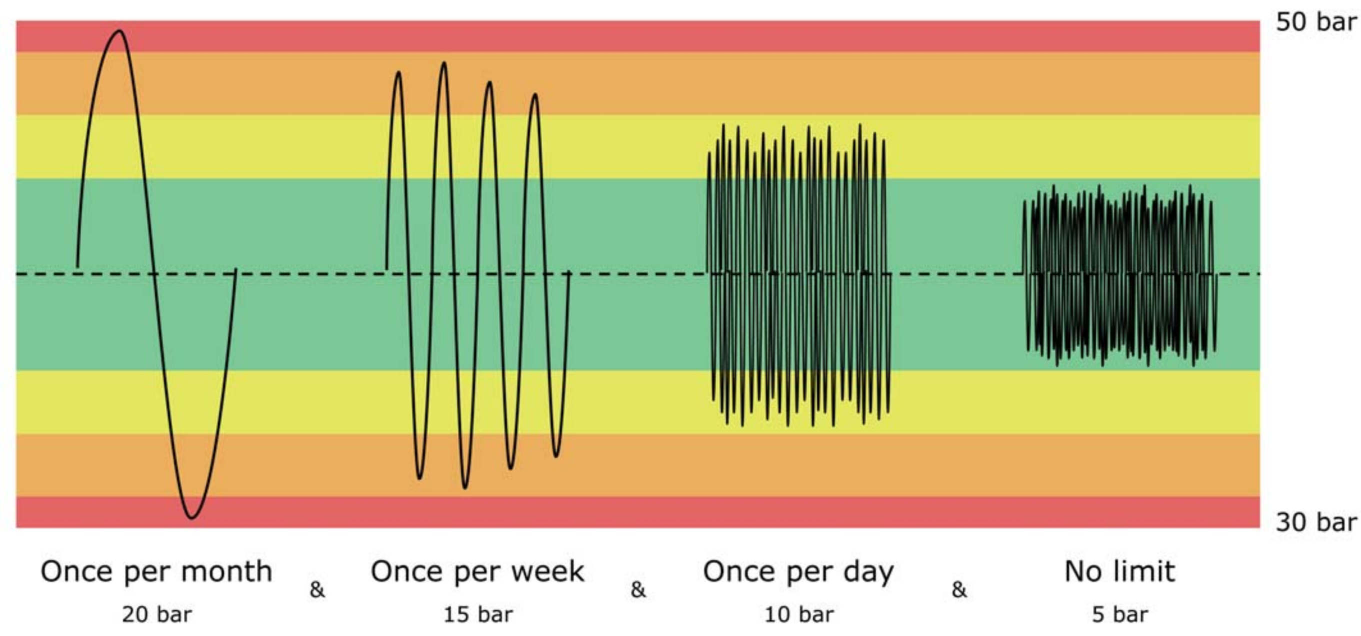

Fig. 4. Safe pressure fluctuations for operating a hydrogen transport network

range of 20 bar can be fully utilised for the pressure drop across the pipes, enabling maximum usage of the capacity given this pressure range. Pressure fluctuations in this scenario will occur more often but remain limited to about half the total pressure range. As a result, pressure fluctuations of up to about 10 bar can be expected on a daily basis, keeping defect growth within safe limits.

3. In the future target hydrogen transport network, a balancing regime is in place that is similar to natural gas balancing regimes. This provides the hydrogen network operator with an additional measure to keep pressure fluctuations to an acceptable level. Setting the buffer zones – the linepack space that the market can use without interventions – in such a way that pressure fluctuations stay below acceptable boundaries preserves the long-term integrity of the transport pipelines.

The overall insights from these cases are summarized in Figure 4 as safe margins for operating a hydrogen transport network, where pipelines have no major existing defects and where the welds have been validated for quality. Gasunie can facilitate the market by making linepack available, while staying within safe limits for network integrity during all phases of development of the hydrogen transport network. The developed model that supports these conclusions can be run during the development phase of a project, but will also prove a valuable tool once the network is in operation. We hope that with this model and the insights on repurposing, emissions and safety considerations, we can also help other network operators to lower the step towards hydrogen transport through existing pipelines.

About Gasunie

Gasunie is a network company for energy that manages and maintains the infrastructure for large-scale transport and storage of gas in the Netherlands and northern Germany. At the moment, this is mainly natural gas, but with the energy transition it will increasingly shift to green gas and hydrogen. Gasunie also participates in the construction and management of networks for heat, LNG facilities and CO_2 grids, ensuring that this part of the energy supply is safe, reliable and as sustainable as possible, so that energy is always available to everyone.