NATIONALER WASSERSTOFFRAT

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Hydrogen transport

EXECUTIVE SUMMARY

Hydrogen transport plays a central role in the timely development of a market-based hydrogen economy in Germany. Regional transport of hydrogen connects producers and consumers and integrates the German hydrogen market into a European hydrogen grid. Underground hydrogen storage facilities connected to the regional transport network shore up the system as seasonal storage facilities, enabling generation and consumption to be independent of one another in terms of time. There are currently 51 underground natural gas storage facilities in Germany that can store around 230 TWh, or about 30% of Germany's annual natural gas consumption. In addition, there are other suitable geological formations, such as salt caverns, for hydrogen storage at various places around Germany.

Smaller quantities of hydrogen can be transported flexibly for trucking and larger quantities via pipeline or by ship. Within the context of Europe, hydrogen transport via pipelines, even in newly built pipelines, is the most economical option for distances of up to about 10,000 km. In terms of pipeline-based transport, the study on the European Hydrogen Backbone (EHB)[1] has determined specific transport prices of approximately €0.16/kg per 1,000 km transport route with long-distance pipelines that are almost fully utilised. However, utilisation will be lower, especially at the beginning of the hydrogen economy, meaning that the first adopter customers of such a grid will have to shoulder higher transport costs. This can be mitigated by government support for the development of this infrastructure.

The transport prices determined in the EHB study are based on a significant share of retrofitted natural gas pipelines in the planned system. These lines already exist, which means that – once these lines are utilised – system costs can be reduced, implementation can be accelerated, corresponding environmental interventions can be avoided and as a result acceptance in society will increase. In addition to the use of existing plant components, the resulting hydrogen transport system will be supplemented by selected new construction of facilities if natural gas pipelines cannot be converted in a timely manner for reasons of supply security.

Existing natural gas pipelines are suitable for the safe transport of hydrogen and can be converted from natural gas to hydrogen – which has been confirmed by an expert opinion from TÜV Nord. A practical example of this process was demonstrated in the retrofitting of a natural gas pipeline in southwestern Netherlands[2]. In the process, individual components that are not suitable for use in hydrogen grids, such as metering and control systems or compressors, were replaced and the integrity of the line to be retrofitted was inspected. Further technical measures, such as fitting an inner liner, are not necessary when it comes to transport. There are already established solutions available today for the components to be replaced, especially the compressors, and these are being continuously developed.

The hydrogen quality is ensured during transport in converted natural gas pipelines and the specifications of the German Technical and Scientific Association for Gas and Water (DVGW) G 260 (2021)[2] werden eingehalten.

Natural gas distribution grids at the local level are generally suitable for transporting a natural gas-hydrogen mixture or pure hydrogen, as the pipeline materials used in the distribution grid (low-alloy steels, plastics such as PE and PVC) generally have the corresponding material compatibility. Other grid components (such as fittings) must be evaluated according to the rules of technology for the specific application.

In terms of volume, hydrogen has a lower calorific value than natural gas. However, the density of hydrogen is also lower so it is possible to attain higher flow rates in pipelines for long distance transport, so that a natural gas transport pipeline converted to hydrogen can ensure 80–90% of the original energy transport capacity under otherwise identical conditions. Thus, hydrogen pipelines can realise the high energy transport capacity that natural gas transport achieves, with approximately eight to ten times the energy transport capacity of a power line.

In the energy system of the future, biogas/biomethane and synthetic natural gas (SNG) will find their application alongside hydrogen and electricity. There will also be methane grids in future at the transmission and distribution grid level in order to continue to supply consumers who are dependent on the predominantly material use of methane.

Planning of the future hydrogen grid must be efficient and transparent. The process for grid development planning in natural gas provides a good basis and is now being further developed for hydrogen. At the same time, a closer interlinking of infrastructure planning for electricity, gas and hydrogen is necessary in order to implement sector coupling as efficiently as possible. Considerations on the transport of derivatives and on international aspects will be dealt with in a separate statement.

TRANSPORT OPTIONS FOR HYDROGEN

Various options with different applications are available for transporting hydrogen over long distances. These can be differentiated on the basis of the means of transport used and the medium employed.

Means of transport

Hydrogen can be transported in pipelines or in containers in individual vehicles such as ships, trains or trailers. Road transport will mainly be used for smaller quantities and local distribution due to the low transport volumes that can be achieved. Pipelines play the central role for national and regional transport as well as local distribution in H_2 clusters. Within the context of Europe, pipeline transport is by far the cheapest transport option, but for global imports from countries such as Chile or Australia, transportation by ship is necessary.

Hydrogen can be turned into methane in a process called methanation and transported as green natural gas or SNG via existing LNG infrastructure. Parts of existing or yet to be built LNG terminals are also suitable for the use of pure hydrogen. This suitability applies above all to those parts that are downstream of the regasification process. That is to say, it is mainly those parts that are in contact with hydrogen in a gaseous state that can be considered H_2-ready from a technical standpoint. All other plant components of conventional LNG terminals that come into contact with liquid hydrogen need to have also been designed for this substance, which is very cold. In this respect, the design of existing LNG terminals for the use of hydrogen is technically possible; however, it involves considerable effort and expense – the economic viability of which is unlikely to be given under the current circumstances.

In addition, there is a possibility of importing hydrogen via shipping through the construction of dedicated terminals. In addition to hydrogen, different transport media can be considered. If these derivatives can be used directly, such as in shipping, the energy loss in any conversion back to hydrogen can be removed from the overall calculation and in doing so, also part of the fixed costs priced in Figure 1.

Transport media

Hydrogen can be transferred into different media when transporting it in (larger) transport containers. The simplest option for transport has to be using gaseous hydrogen transported via pipelines. In addition, highly compressed hydrogen is a suitable transport medium. In this method, the medium is filled into individual containers, such as gas cylinders, and transported at pressures exceeding 250 bar (in modern trailers up to 500 bar). This allows several hundred kilograms of hydrogen to be transported. The disadvantage of this medium is its low energy density, despite the high pressure, and the corresponding need for transport actions. For this reason, this option is primarily suitable for smaller volumes with shorter transport routes, such as when supplying filling stations.

Hydrogen can be liquefied to further increase the energy density as an alternative to transporting in a compressed state. However, about 30% of the transported energy must be used for liquefaction and the evaporation – called boil-off – must be taken into account during transport. For larger liquefaction plants, we expect to be able to reduce this to 20% and less.

In addition, it is possible to convert hydrogen into ammonia. Ammonia is already a globally traded commodity with established transport solutions[*]. When evaluating the medium, the losses during conversion to and from ammonia, which are unavoidable, must be taken into account. Ammonia is a hazardous substance for water and health, so appropriate safety precautions must be observed during its transport.

Liquid organic hydrogen carriers (LOHC) have been developed as a transport medium in recent years. These LOHCs absorb hydrogen while releasing heat and release it again when heat is added. The carrier can then be returned to its place of origin without the hydrogen. These necessary conversion losses, as well as the unavoidable empty transport, must be taken into account in the holistic evaluation of the transport solution. In the case of LOHC, the carrier is also classified as hazardous to water and health, which means that corresponding regulations must be taken into account during transport and handling. In addition, hydrogen derived from LOHC must be purified for use in fuel cells.

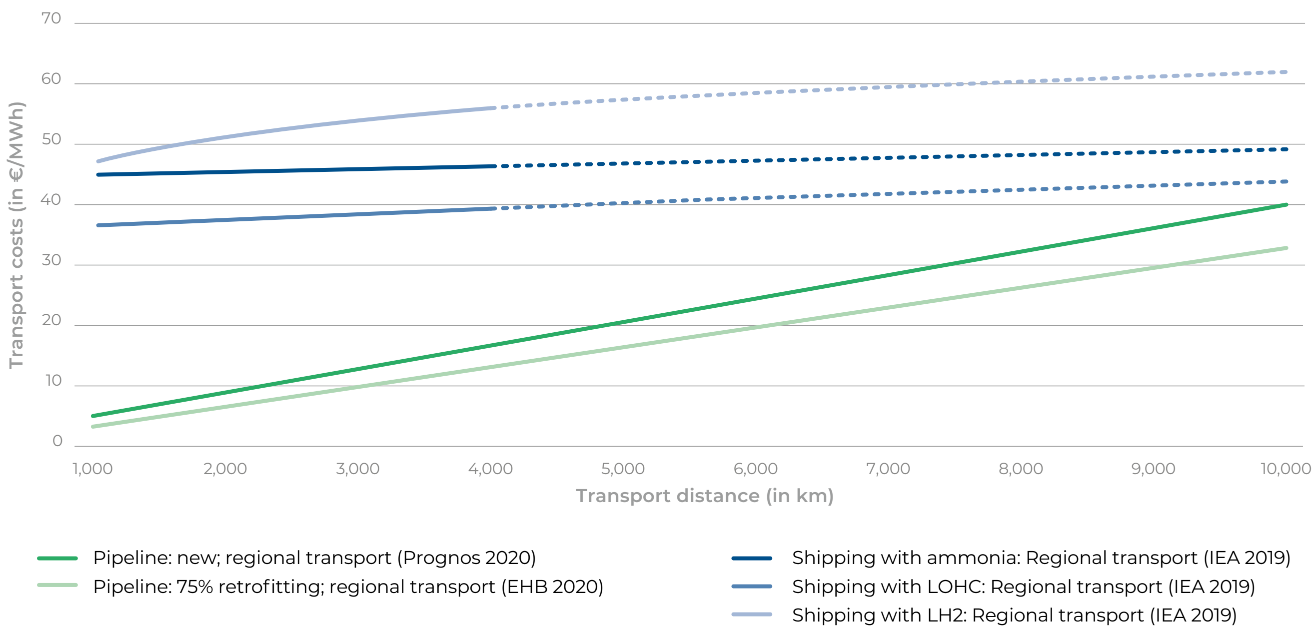
[*] Ammonia is considered in this paper as a transport medium and not as a raw material in industry or as a fuel.

Another medium for transporting hydrogen that holds numerous possible applications is methanol. Methanol has advantages over ammonia. It is a liquid at atmospheric pressure and has a much lower level of toxicity. There are nearly no problems in terms of transport, even via pipelines. The synthesis of methanol is a proven process and can thus be used with green hydrogen and a carbon source for CCU applications.

Comparison of transport options

The comparison of the transport options listed above must take into account not only the investment costs in the required infrastructure, such as long-distance pipelines or ships, but also the investments in the equipment needed to operate the infrastructure, such as liquefaction and evaporation plants or compressor plants, and the associated operating costs.

Figure 1: Comparison of selected hydrogen transport options[1, 3, 4]



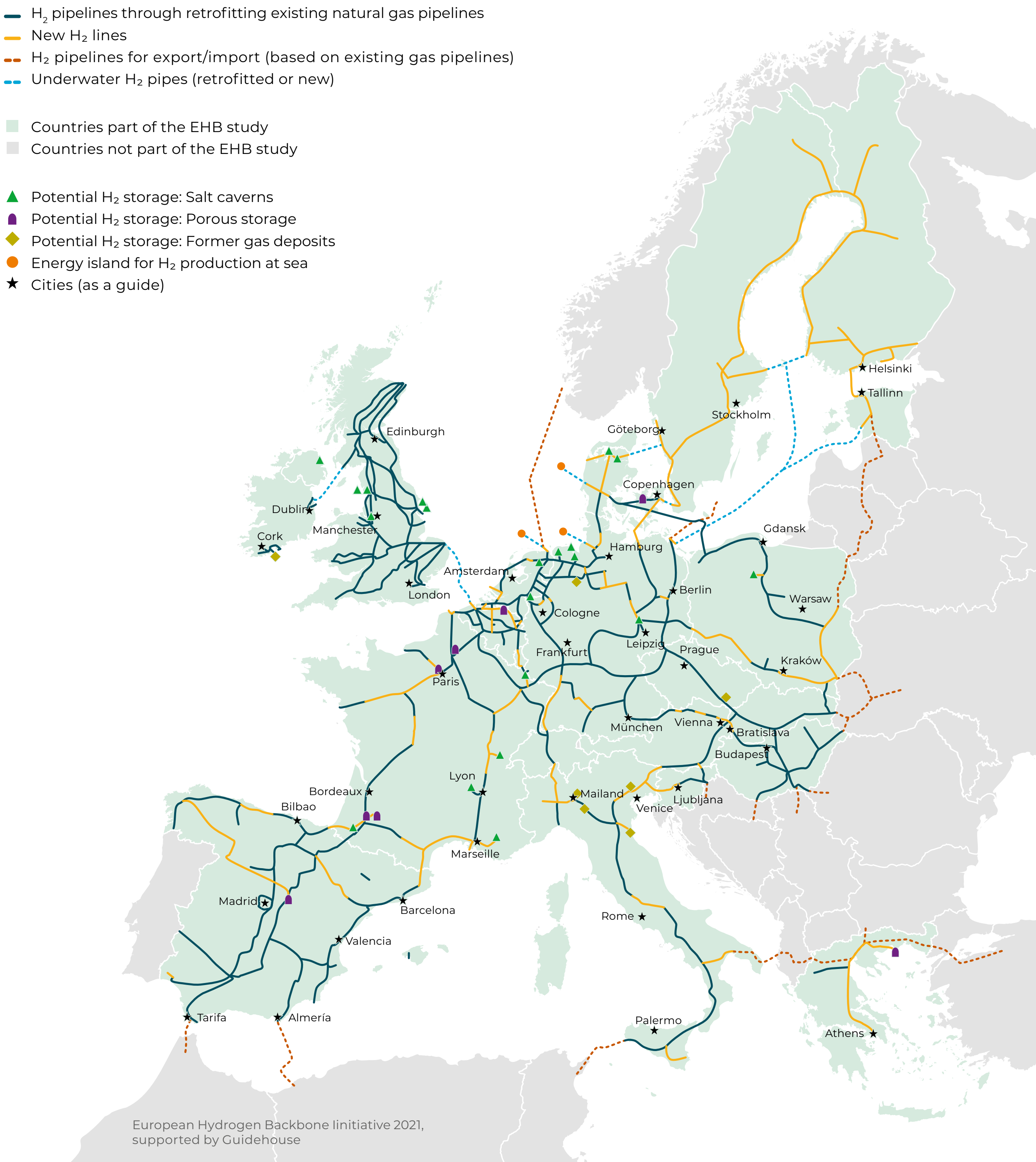
The transport costs for different hydrogen transport options shown in Figure 1 clearly show that transport via appropriately dimensioned long-distance pipelines ('Pipeline: new') is cheaper than shipping for distances of up to 10,000 km. Taking into account existing natural gas pipelines and their retrofitting for hydrogen transport ('Pipeline: 75% retrofitting'), the specific transport costs are further reduced.

Figure 1 also clearly shows that shipping has cost components for the conversion and reconversion of the transport medium that are independent of distances. The distance-related costs are lower than for long-distance pipelines once this conversion is taken into account. It can be seen that different data, which are not conclusively assessed in this paper, can be found in terms of costs, especially in the case of shipping.

European Hydrogen Backbone

The German hydrogen grid will be closely integrated into the European hydrogen infrastructure. European transmission system operators have identified in the draft of the European Hydrogen Backbone a hydrogen grid of the future taking into account the existing natural gas grid.

Figure 2: European Hydrogen Backbone 2040



As shown in Figure 2, this European hydrogen network will in future enable imports of hydrogen to Germany from the immediate European environment (the Netherlands, U.K., Norway), from southwestern Europe, and (south)eastern Europe, but also from North Africa, Ukraine and Russia, for example. The transport costs associated with import are €0.16/kg per 1,000 km of transport distance[1].

The European hydrogen backbone could and should be realised faster than planned so far with an appropriate political situation and regulatory framework, especially in view of the ambitious climate protection targets.

RETROFITTING OF NATURAL GAS PIPELINES TO HYDROGEN

If an existing natural gas infrastructure is to be used for the transport of hydrogen in the future, the first step is to have the technical condition of the pipeline determined by an independent expert. For this step, both the plant documentation and current condition inspections are used. Based on this information, the independent expert defines technical and operational measures for further operation. These measures can include replacement of components, reduction in operating pressure or shortened inspection cycles, for example. The basis of the test is that the infrastructure after retrofitting for hydrogen is at least as safe as it was before when operating with natural gas.

The technical procedure for retrofitting existing natural gas pipelines for future use with hydrogen is regulated in DVGW G 409[5].

Safety aspects

Some safety-relevant aspects have to be considered when transporting hydrogen in retrofitted natural gas pipelines due to the different physical properties of hydrogen compared to natural gas.

Flammability and leakage

The different flammability properties of natural gas and hydrogen will be taken into account in the safety assessment of a new pipeline or plant to be constructed or retrofitted. This takes into account that hydrogen is lighter and flammable in a wider mixing ratio than natural gas and behaves differently in the event of possible leaks. In addition, the flammability of hydrogen plumes results in higher overpressures compared to natural gas, which means that the release of hydrogen needs to be handled in a different manner. The necessary technical safety measures are determined in such a way that hydrogen-operated plants and pipelines are just as safe as natural gas-operated plants.

The wall thicknesses of long-distance pipelines are determined such that no leaks can occur. This means that theoretically an ignitable mixture can only be formed in the area of valve stations with aboveground components. Therefore, these stations are structurally secured against unauthorised entry.

Hydrogen embrittlement and pressure load change

The independent expert also assesses possible effects of the transport of hydrogen on the material properties of the pipeline and, if necessary, defines changes to the operational specifications when retrofitting a natural gas pipeline for hydrogen. It is known that under certain conditions hydrogen can lead to embrittlement of the steel materials typically used in gas pipelines. The absorption of atomic hydrogen can increase the possible crack growth rate, especially in the area of already existing material defects, such as recesses or cracks. In order to be able to evaluate the effects of this process, fracture mechanics analyses according to ASME B31.12[6] were carried out and validated by physical checks for the majority of the steel materials used. These analyses have shown that the steels used in natural gas pipelines and plants are suitable for use with hydrogen and that the dimensioning and design of the pipeline for use with hydrogen can be confirmed.

Further investigations and measures, such as a limitation of the permissible number of pressure load cycles, may be required as determined by the independent expert depending on the planned operation of the hydrogen pipeline. This also means that there is no need to introduce gases that decrease embrittlement, which in turn would pose other technical challenges.

Transport capacities and hydrogen quality

Hydrogen and natural gas have different material properties. Due to its low density, hydrogen has a lower calorific value than natural gas – in relation to its volume, by a factor of 3. Which is why the flow velocity must be increased by this factor in order to be able to transport the same amount of energy in a pipeline. This change in velocity is associated with only a slight increase in pressure loss due to the lower density of hydrogen, so that it is possible to achieve nearly the same energy transport capacity at comparable inlet and outlet pressures when a long-distance gas pipeline is retrofitted from natural gas to hydrogen.

Quality

The quality of hydrogen transported in long-distance gas pipelines is to be regulated in DVGW G 260 (2021)[7] ,which is currently being revised. In this regard the group A of the new 5th gas family with a minimum hydrogen content of 98% is of relevance. This quality is sufficient for the majority of hydrogen applications as a reducing agent, such as in steel production, or fuel, such as in the generation of process heat, and takes into account possible hydrocarbons still in retrofitted natural gas pipelines at the beginning. Initial investigations have shown that the hydrogen quality is only slightly affected by these residual materials.

Figure 3: Hydrogen qualities

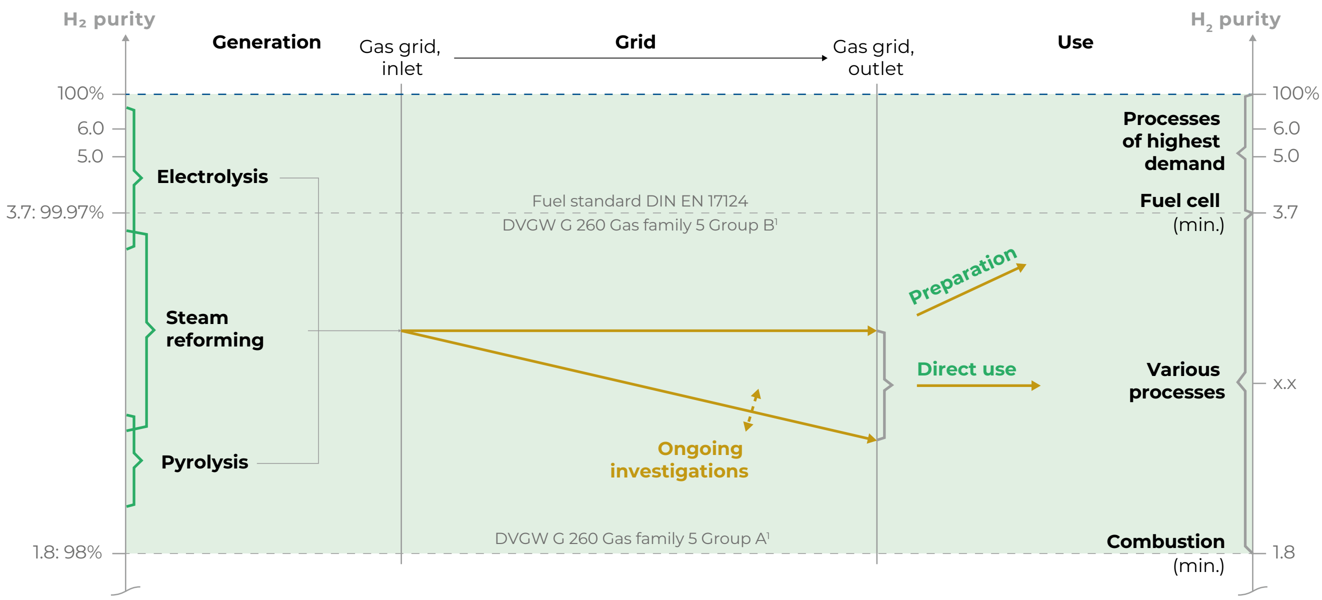


Figure 3 provides an overview of different hydrogen qualities. Typical hydrogen qualities that can be produced by different production methods are shown. This does not take into account out-of-the-ordinary purifications. The highest purity level can be achieved by electrolysis, since in this process only the accompanying gases dissolved in the water can also pass into the hydrogen. Hydrogen produced in pyrolysis or steam reforming can still contain residual natural gases (hydrocarbons).

Purification to the required hydrogen purity may be necessary for use in fuel cells or in certain material applications, such as pharmaceutical production. The hydrogen is already available in the long-distance pipeline with a high degree of purity, which means that this can be done efficiently via membranes or pressure swing adsorption systems, for example.

Technical solutions for components to be replaced

Some technical equipment in the gas transport system has to be replaced to enable the efficient transport of hydrogen due to the different physical properties of hydrogen compared to natural gas.

Compressor units

The compression of hydrogen is more complex than the compression of natural gas due to its higher specific heat capacity. It therefore requires the replacement of the corresponding compressor units for feed-in and transport, or new ones entirely, regardless of the compression principle. Piston compressors are more efficient than rotary compressors. Very similar in concept to those used in natural gas transport, rotary compressors may be used to transport hydrogen in the future. Hydrogen has already been used by industry in large quantities for decades, so that technically mature piston compressors can already compress transport quantities of up to 1,000,000 Nm^3/h per compressor (corresponding to approx. 3.5 GW of transport capacity), for example, from 50 to 100 bar with isothermal efficiencies of over 80%. For this reason, these can also be used in the gas transport system at short notice.

Metering systems

The metering equipment currently used to measure the volumes of natural gas transported must be replaced in order to be able to measure hydrogen with the same accuracy. Technically mature system concepts that enable rapid retrofitting already exist here, too.

GRID PLANNING PROCESS

In 2019 the transmission system operators cooperating in FNB Gas have forecasted for the first time the hydrogen transport requirements within the framework of a market survey of the future market participants in order to enable the demand-oriented development of a hydrogen network and submitted a corresponding plan for the creation of the hydrogen grid[8]. Further development is currently underway within the framework of the FNB's grid development plan for the years 2022–2032.

At the same time, the interlinking of electricity, heat and gas infrastructures must be promoted in an effort to implement sector coupling. This applies to both national and regional infrastructure planning in order to ensure optimised, sector-integrated infrastructure development. Joint scenarios for the future of electricity, gas and hydrogen provide the basis for systemic optimisation potential, for example, by eliminating bottlenecks in the electricity grid by shifting to the hydrogen grid or identifying suitable locations for electrolysers.

SUMMARY

The energy transition will only succeed if all options for decarbonisation are exhausted. In particular this includes the use of climate-neutral hydrogen in all consumption sectors. The most economical way to transport the required quantities of hydrogen in continental Europe is via gas pipelines. Various transport media come into question for global imports.

The fastest and cheapest way to establish a European hydrogen backbone is to retrofit existing natural gas pipelines, supported by the targeted construction of a few new hydrogen pipelines. The technical prerequisites for these measures are already in place today and will be continuously optimised in the coming years. The primary objective in the construction of a hydrogen network is the safety of the transport system and the security of supply for consumers.

SOURCES USED:

1 Enagás et al. European Hydrogen Backbone. Brussels: Gas for Climate 2021.

2 DOW. Waterstofleiding Gasunie van Dow naar Yara in gebruik genomen. [online] 27 November 2018 [quote from: 26 March 2021]. https://nl.dow.com/nl-nl/news/waterstofleiding-gasunie-van-dow-naar-yara-in-gebruik-genomen.html.

3 IEA. The Future of Hydrogen. s. l.: IEA, 2019.

4 Kreidelmeyer, Sven, et al. Kosten und Transformationspfade für strombasierte Energieträger. s.l. [Costs and transformation trajectories for electricity-based energy carriers]: prognos 2019.

5 DVGW. G 409 Merkblatt 09/2020 Umstellung von Gashochdruckleitungen aus Stahlrohren für einen Auslegungsdruck von mehr als 16 bar für den Transport von Wasserstoff [G 409 Code of practice 09/2020 Retrofitting of high-pressure gas pipelines made of steel pipes for a design pressure of more than 16 bar for the transport of hydrogen]. Bonn: DVGW 2020.

6 ASME. B31.12 – Hydrogen Piping and Pipelines. s.l.: ASME 2020.

7 DVGW. G 260 Draft version of the Arbeitsblatt 09/2020 Gasbeschaffenheit. Bonn: DVGW 2020.

8 FNB Gas. Netzentwicklungsplan Gas 2020–2030 Entwurf. s.l. [FNB's 2020–2030 gas grid development plan]: FNB Gas 2020.

H2 NATIONALER WASSERSTOFFRAT

THE GERMAN NATIONAL HYDROGEN COUNCIL

On 10 June 2020, the German Federal Government adopted the National Hydrogen Strategy and appointed the German National Hydrogen Council. The Council consists of 26 high-ranking experts in the fields of economy, science and civil society. These experts are not part of public administration. The members of the National Hydrogen Council are experts in the fields of production, research and innovation, industrial decarbonisation, transportation and buildings/heating, infrastructure, international partnerships as well as climate and sustainability. The National Hydrogen Council is chaired by former Parliamentary State Secretary Katherina Reiche.

The task of the National Hydrogen Council is to advise and support the State Secretary's Committee for Hydrogen with proposals and recommendations for action in the implementation and further development of Germany's National Hydrogen Strategy.

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