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The role of underground gas storage facilities in the development of a hydrogen market in Germany

Development potential and regulatory framework

1 SUMMARY

Germany has a well-developed storage infrastructure that could also play an important role in the development of a hydrogen market in Germany going forward. The possibilities it offers in terms of long-term energy storage should also be utilised in view of the macroeconomic benefits they provide. In addition to this, the existing gas storage infrastructure in North Rhine-Westphalia, central Germany and Lower Saxony, for example, is located in close proximity to expected centres of consumption or could be made available across Germany because it is linked to the existing grid infrastructure. This makes the efficient development of a hydrogen infrastructure possible along the entire value chain.

At the present moment, gas storage facilities are primarily used on a seasonal basis. As a hydrogen market emerges, this being driven primarily by demand, one of the key features of the usage profile of hydrogen storage facilities will be higher storage and withdrawal rates. In this way, industry's steady demand for hydrogen can be met while also allowing the fluctuating volume of green hydrogen produced using renewable energy sources to be evened out.

Gas storage caverns are a more efficient option than storage in porous storage facilities due to the potentially higher injection and withdrawal rates they offer. In addition, the former is extremely well suited for hydrogen storage because of the geological conditions available in the caverns. Gas storage caverns can be converted fully to hydrogen, while much more research is needed to determine the extent to which hydrogen can be stored or blended at porous storage facilities.

At approximately 262 TWh, Germany has the largest domestic natural gas storage capacity on a volume basis in Europe, with about two thirds of the storage infrastructure consisting of gas storage caverns and just under one third of porous storage facilities. Gas storage caverns are primarily located in north-western and central Germany, whereas porous storage facilities are chiefly situated in the south of the country.

Due to hydrogen's lower energy density and different compression characteristics, an 80% reduction in energy storage capacity can be assumed for hydrogen compared to natural gas. In other words, the amount of hydrogen that can be stored has only 20% of the energy content of natural gas.

Based on simulations carried out as part of development projects, a storage capacity equal to roughly 10% of annual hydrogen demand would be needed according to current assumptions (by comparison, around 30% of natural gas by volume is stored in Germany). At a hydrogen demand of approx. 100 TWh in 2030 in the base case scenario under consideration, an annual hydrogen storage of 10 TWh would be required based on the simulations and goals set forth in the national hydrogen strategy. To achieve this capacity, about 50 TWh, or 30% of all natural gas storage caverns, would need to be converted to hydrogen by 2030.

In view of significantly higher demand for hydrogen that is projected by 2050, demand for storage could be almost completely met in the low case scenario under consideration if all current gas storage caverns were converted to hydrogen. In the base and high case scenarios, all gas storage caverns would also have to be converted to hydrogen and/or the added demand that would be needed could be covered through technical measures such as reflushing or conversion. Expansion of hydrogen storage capacity by 14 TWh would only be needed in the high case scenario.

Experience from initial pilot projects shows that the conversion costs for storage of all hydrogen in existing underground storage facilities make up at least 30% of the new investment costs for a gas storage cavern. Extrapolated to include all existing gas storage caverns in Germany, this would require an investment of at least €30 billion from now until 2050 in order to convert the facilities for hydrogen storage.

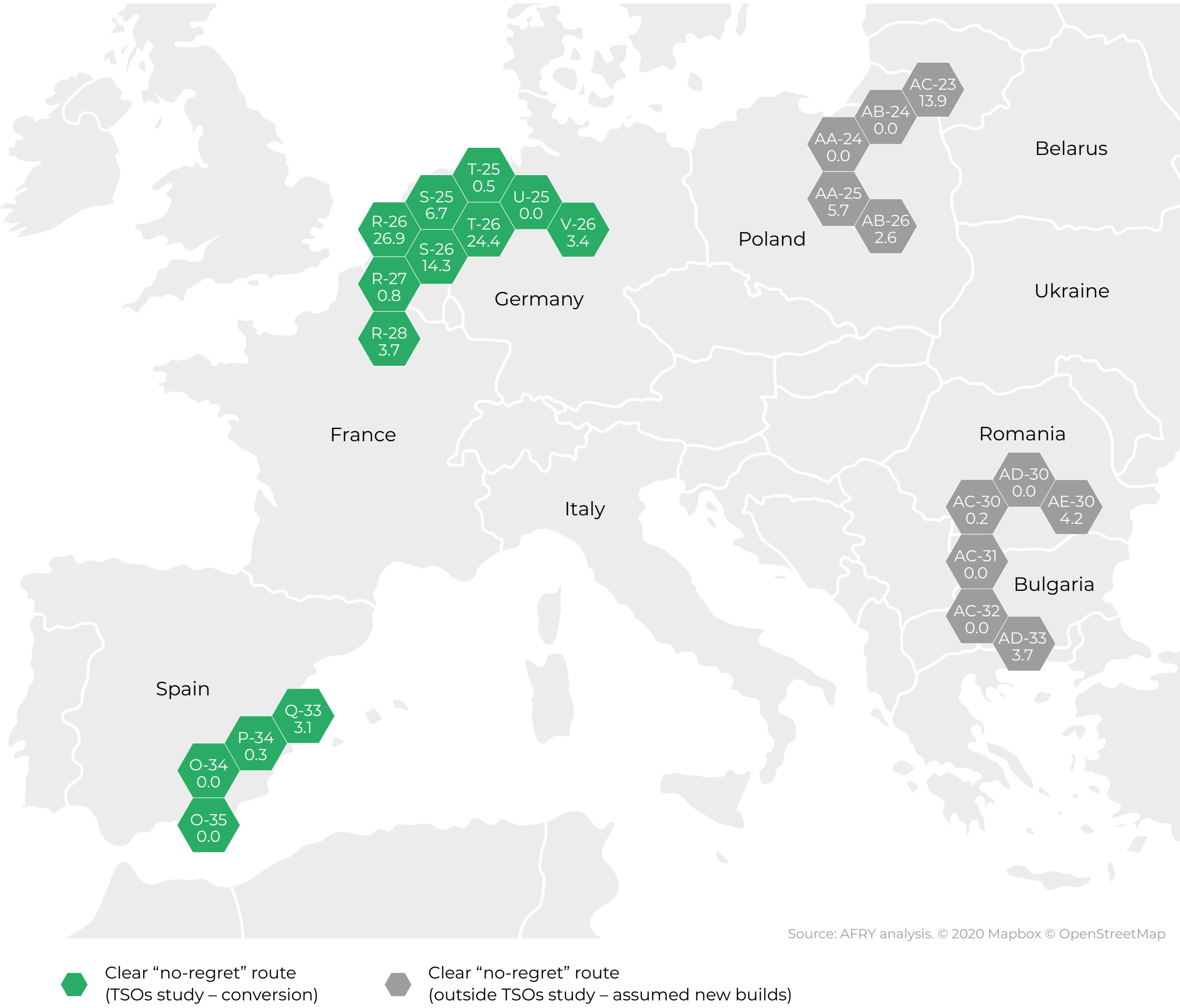
Changes to the legal and regulatory framework must be explored in order to allow hydrogen storage to contribute to a stable, demand-driven and efficient hydrogen economy.

While the market-based selling of storage capacity has a proven track record and should also carry on in this form with hydrogen, converting natural gas storage facilities over to hydrogen requires considerable financial support. This will be needed both directly in the form of investment and operating subsidies and indirectly by lifting grid fees and surcharges that could potentially undermine the economic viability of gas storage facilities for storage users. Grid fees and surcharges for the use of hydrogen storage facilities should therefore be fully eliminated. The extent to which the regulatory framework for the negotiated agreement on access to storage, which has now also been set out in the German Energy Industry Act (Energiewirtschaftsgesetz, or EnWG), is viable going forward should be reviewed again in five years to take any pertinent market developments into account. Furthermore, hydrogen storage facilities should be included in the scenario planning for grid development. Approval procedures for construction and operation should be simplified and expedited. Along with this, the regulations regarding vertical unbundling applicable to the hydrogen value chain should also be preserved.

2 TRENDS IN HYDROGEN DEMAND IN CLUSTER REGIONS

Certain regions will be more suitable for the development of a hydrogen infrastructure than others[1]. Achieving climate neutrality by 2045/2050 represents an enormous challenge especially for regions that are home to energy-intensive production with limited potential for electrification, such as the steel or chemical industries. The use of hydrogen is essential to becoming climate-neutral, which is why we expect strong overall growth in demand for hydrogen in Germany. In a recent study by Agora Energiewende, the think tank identified two key regions (clusters) in Germany from which strong demand for hydrogen is likely to come. The largest cluster is North Rhine-Westphalia, which includes the Dutch and Belgian border regions, with an expected demand of 24.4 TWh in 2050.

Figure 1: Development of hydrogen clusters



Hexagons contain the ID and the demand in 2050 in TWh.

[1] Agora Energiewende study: ‘No-regret hydrogen – charting early steps for H_2 infrastructure in Europe’, February 2021

3 ROLE OF THE UNDERGROUND GAS STORAGE ON A HYDROGEN MARKET

At approx. 262 TWh, Germany has the largest natural gas storage capacity on a volume basis in Europe. This is capable of covering about one third of the country's total annual consumption. In the high-consumption months of January and February, three times the volume can be stored compared to lower-consumption months in summer. By comparison, the electricity storage volume in Germany today is around 0.04 TWh.[2] Germany's gas storage infrastructure is comprised of about two thirds gas storage caverns and just under one third porous storage facilities.

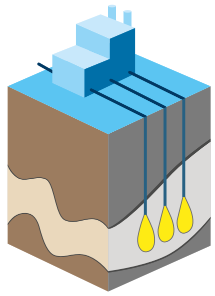
In an emerging market for hydrogen, existing natural gas storage facilities can also play an important role in future. If gas storage facilities are primarily used seasonally today, the hydrogen market that is currently emerging is expected to be largely demand-driven, especially at the beginning. This means that storage and retrieval will be faster and more frequent. On the one hand, expectations are that hydrogen will initially be used primarily for industrial purposes during the market ramp-up phase. To meet this demand, hydrogen must be available in the required quality at all times to enable all industrial users to manufacture their products reliably and without disruption. On the other hand, wind and solar power, and with it the supply of green hydrogen, is weather-dependent. This presents a growing obstacle to uninterrupted water electrolysis the closer the required temporal correlation between the two is. Gas storage facilities are of critical importance here in view of potential volatility in solar and wind power generation. That's because they allow for the short- and long-term storage of surplus energy and are capable of providing the market with the required energy based on demand.

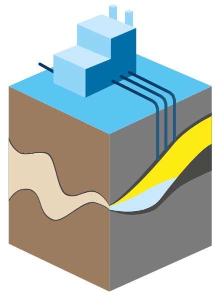
The use of hydrogen storage is also expected to change over time as the market penetration of hydrogen grows. The possible integration of further consumption sectors will also increase the seasonal structuring requirements, which can be met primarily through large-volume underground storage facilities.

Underground gas storage facilities can be divided more or less into two categories: salt cavern storage (man-made cavities in salt deposits) and porous storage (former oil/natural gas fields or aquifers). Porous storage is generally used to cover large-volume seasonal base loads, whereas salt cavern storage is more efficient in terms of their injection and withdrawal rates, making it well suited to cover daytime peak loads in addition to seasonal base loads.

[2] https://www.dwv-info.de/wp-content/uploads/2015/06/DVGW-2955-Brosch%C3%BCre-Wasserstoff-RZ-Screen.pdf

Table 1: Pros and cons of cavern and porous storage of hydrogen





	Cavern storage	**Porous storage**
Characteristics	◆ Cavities in salt domes predominantly in northwest and central Germany ◆ Practical experience with hydrogen caverns already exists	◆ Gas is injected into porous, sponge-like rock, primarily into depleted natural gas or oil fields ◆ A significant amount of R&D into hydrogen storage would be required, as chemical reactions may cause changes in the storage facility
Pros	◆ Cavities can be completely filled with hydrogen (not reactive with salt formation) ◆ Storage and retrieval possible at short notice	◆ Ability to accommodate large volumes of hydrogen to meet seasonal storage requirements ◆ Widely available in southern Germany
Cons	◆ Hydrogen reacts with materials such as steel and cement ◆ Available primarily in regions in northwestern/central Germany	◆ Hydrogen reacts with materials such as steel and cement ◆ Risk of bacterial growth with resulting H_2S production or possible bacterial fouling of the pores

As numerous scientific studies have shown,[3] salt caverns in particular are extremely well suited for hydrogen storage.

Germany, the Netherlands and the UK offer excellent conditions for hydrogen storage in salt caverns of all the geological formations in Europe. The available salt deposits are located in the northern half of Germany and track the demand zone identified by Agora Energiewende in North Rhine-Westphalia along the Dutch border.

[3] HyUnder – a project initiated by FCH JU (Fuel Cell & Hydrogen Joint Undertaking)

One of the largest gas cavern fields in the world is situated in Gronau-Epe in North Rhine-Westphalia, close to the Dutch border. It is used to store natural gas and is linked to the German and Dutch natural gas markets. Other salt caverns that are already being used to store natural gas are located in North Rhine-Westphalia near Xanten and at other sites such as in Lower Saxony near Etzel and in Saxony-Anhalt near Staßfurt. These salt domes with their existing caverns are situated near the major demand centres for hydrogen and offer further potential.

The mandated approval procedures as well as the work required to upgrade the aboveground facilities and the underground caverns must be taken into account for conversion of natural gas storage facilities to hydrogen. The time required for the underground work varies depending on the size of the caverns. An initial hydrogen storage facility with average-sized caverns, such as the one at the Gronau-Epe site, is considered below. In this case, the total conversion time is estimated to be about five years. This includes:

- approx. 2.5 years (rough estimate due to a lack of practical experience in Germany) for the administrative procedure for operational approval (incl. the preparation and submission of expert reports) to be fully completed and for securing civil agreements, in particular easements, road and route crossing agreements and rights to use caverns for hydrogen storage;
- detailed planning and material procurement, which is carried out concurrently;
- approx. one year for upgrades to the aboveground facilities for injection and withdrawal, such as modifications to compressors and facilities for gas drying, cleaning and metering;
- approx. 1.5 years for underground work such as flooding the caverns still filled with residual natural gas, converting the boreholes and initial filling of the caverns with hydrogen.

In cases where an existing natural gas storage facility is not converted for hydrogen storage and a new hydrogen storage facility is instead built with new aboveground facilities utilising caverns that have already been flushed, a similar total construction time of approx. 5.5 years for the storage facility must be assumed. Based on an unchanged approval period estimated at approx. 2.5 years, the time of construction for the new aboveground facilities is projected to be approx. two years longer than for the conversion of a natural gas storage facility. By contrast, the underground work on the caverns that have already been flushed will take roughly one year, which is somewhat shorter because flooding is not needed. If no caverns are available for the construction of a new hydrogen storage facility, the time required for construction of the new storage facility will be at least five years longer, totalling a minimum of ten years.

The numbers presented here show the lead times that have to be taken into account until such time as a hydrogen storage infrastructure is online.

4 ENERGY AND MACROECONOMIC BENEFITS OF UNDERGROUND GAS STORAGE (UGS) IN PROVIDING FLEXIBILITY ON THE HYDROGEN MARKET IN THE PERIOD 2030–2050

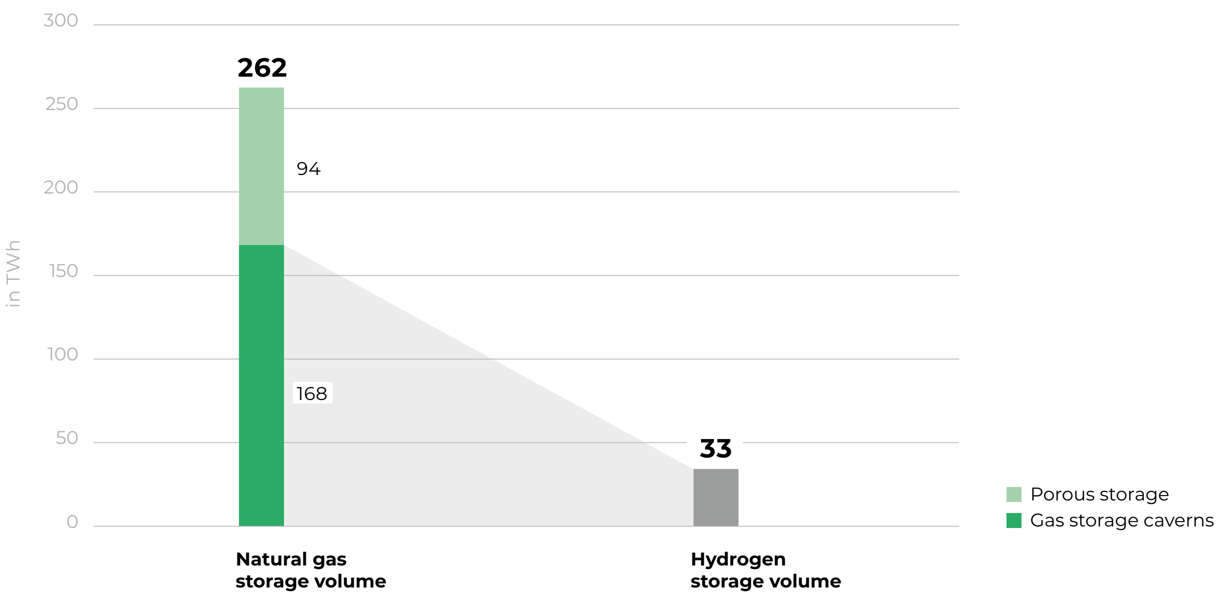
4.1 POTENTIAL OF HYDROGEN STORAGE

It is necessary to take into account that hydrogen has a) a lower volume-based energy density[4] and b) different compression characteristics than natural gas when determining the potential of hydrogen storage. In relation to the amount of energy contained in the working gas volume, an 80% reduction in storage capacity can therefore be assumed for hydrogen compared to natural gas due to these two effects. In other words, the amount of hydrogen that can be stored has only 20% the energy content of natural gas (see Figure 6).

Porous storage facilities are not included in further discussions on potential in terms of hydrogen storage. Further research is needed on the solubility of hydrogen-gas blends in water and on geochemical interactions with the reservoir rock with regards to porous storage facilities. Unlike gas storage caverns, real-world empirical values are not available at this time. However, initial pilot projects[5] on blending hydrogen in porous storage facilities have already begun.

The potential of hydrogen storage calculated based on existing gas storage caverns is approx. 33 TWh.

Figure 2: Existing underground gas storage facilities[6] and their potential for storing hydrogen in Germany



[4] The calorific value of natural gas is about 11 kWh/Nm3, which is about three times higher than that of hydrogen (3.5 kWh/Nm3). This means that roughly three times the volume of hydrogen is needed at the same pressure to keep the energy content constant.
[5] https://www.underground-sun-storage.at/.
[6] https://www.lbeg.niedersachsen.de/download/162009/Untertage-Gasspeicherung_in_Deutschland_Stand_1.1.2020_.pdf.

4.2 FORECASTED HYDROGEN DEMAND FOR 2030 AND 2050

The German government projects that demand for hydrogen will be approx. 90 to 110 TWh by 2030.[7] To meet part of this demand, electrolysis plants in Germany are to produce up to 14 TWh[8] of green hydrogen by 2030.

Hydrogen production in Germany is currently 57 terawatt hours (TWh) per annum. This is produced almost entirely using fossil fuels. However, recent studies forecast a significantly higher demand for hydrogen. According to estimates published by the Fraunhofer Institutes ISI, ISE and IEG in a metastudy commissioned by the German National Hydrogen Council, initial relevant demand for green hydrogen and derivatives (by volume) will be up to 80 TWh from 2030. Demand is set to increase to 100–300 TWh in 2040. For 2050, demand for hydrogen and hydrogen-based synthesised products ranges from 400 to just under 800 TWh. According to the study, demand for hydrogen and hydrogen-based synthesised products will be highest in the industrial sector. Up to 500 TWh will be required here in 2050. The largest customers are the iron and steel industry as well as the chemical sector. The studies also see strong demand in the transport sector, ranging from 150 to 300 TWh in 2050. At 140 to 200 TWh, international air travel and maritime shipping make up the bulk of demand. In the area of road transport, recent studies see the greatest potential in heavy goods transport. The metastudy sees further consumers in the building sector (up to 200 TWh by 2050) and in the transformation sector for electricity and heat generation (between 50 and 150 TWh by 2050).

Table 2: Potential for hydrogen, synthesised products and biomass in the demand sectors in Germany in the years 2030, 2040 and 2050[9]

	2030	**2040**	**2050**
Hydrogen, synthesised products and biomass	34–232 TWh	119–382 TWh	234–740 TWh
Hydrogen only	0–47 TWh	15 –176 TWh	0–316 TWh
Synthesised products only	0–40 TWh (up to 60 TWh with synthesised products as raw materials)	0–158 TWh (up to 303 TWh with synthesised products as raw materials)	0–653 TWh (of which raw materials up 260 TWh)

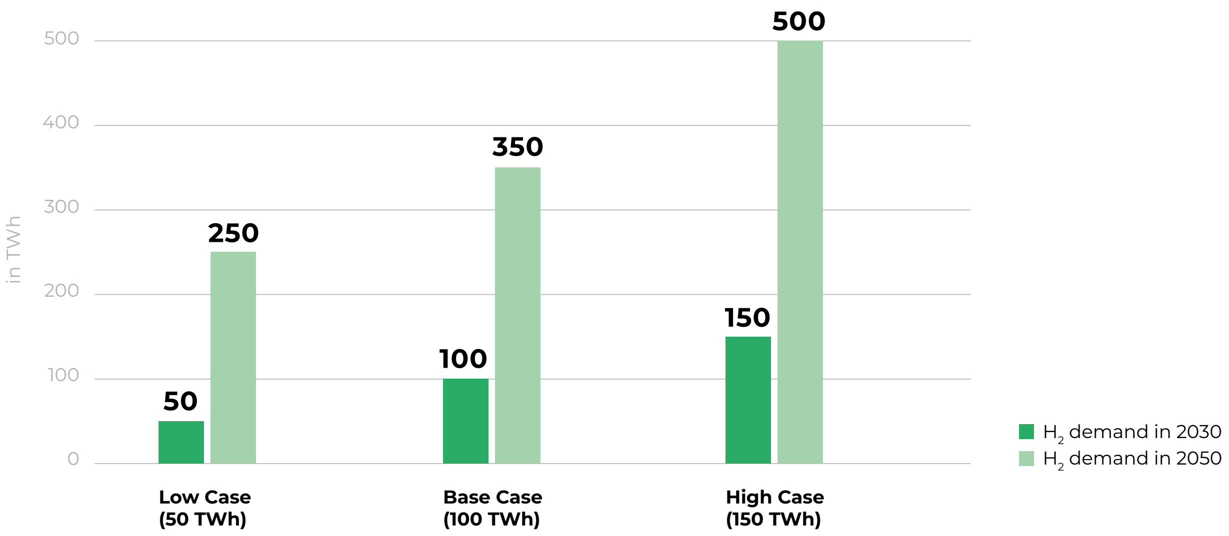
7 The German National Hydrogen Strategy [in German] (bmwi.de), p. 5.
8 The German National Hydrogen Strategy [in German] (bmwi.de), p. 5.
9 Wasserstoff – Auswertung von Energiesystemstudien [Hydrogen – analysis of energy system studies], metastudy commissioned by the Germany National Hydrogen Council, June 2021.

4.3 DEMAND FOR HYDROGEN STORAGE IN THE PERIOD 2030–2050

Estimates for potential hydrogen demand have a significant impact on projections for expected storage demand.

Three prototypical scenarios are presented to provide an estimate of hydrogen storage demand by 2030 and 2050 based on estimates of potential demand from the metastudy as well as the needs assessment of transmission system operators for the scenario framework 2022–2032[10].

Figure 3: Hydrogen demand scenarios for the years 2030 and 2050



4.3.1 Hydrogen demand scenarios and storage requirements for the year 2030

As previously outlined, much lower seasonality is expected for storage demand where hydrogen is predominantly used in industry and transport. At the same time, hydrogen production is more volatile over the course of the year, which is why higher injection and withdrawal capacities as well as multiple cycles of injection/withdrawal each year are assumed. Initial investigations into the load profiles of industrial hydrogen consumers at refineries and chemical parks show that there are far fewer structuring requirements than are apparent at this time in the gas market. Based on simulations as part of development projects, it is estimated that storage requirements will amount to roughly 10% of the annual hydrogen demand (by comparison, around 30% of natural gas sales are currently stored in Germany). Once hydrogen is in more widespread use in the building sector and for electricity and heat generation, and it is therefore possible to assume higher seasonal storage demand, it will then be necessary to reassess hydrogen storage demand in the overall energy system.

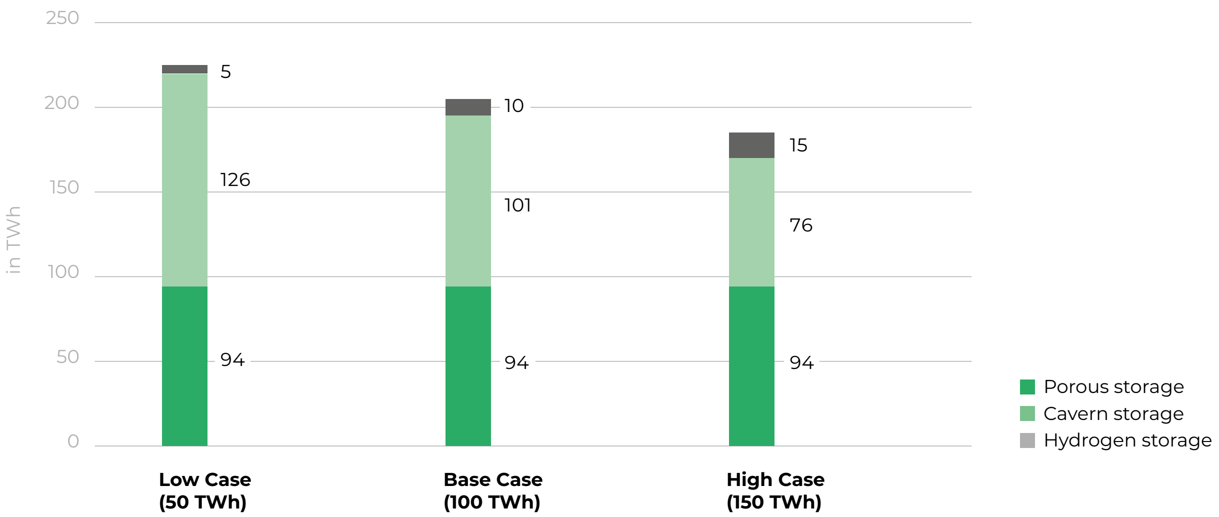
The assessment of potential used in all three scenarios also takes into account the natural reduction in pore volume, or convergence, that occurs in salt caverns. With an estimated average convergence of 1% per annum, just under 10% of the current cavern volume will be lost by 2030.

[10] https://www.fnb-gas.de/netzentwicklungsplan/szenariorahmen/szenariorahmen-2022/.

For 2030, 50 TWh is regarded as the low case scenario, 100 TWh as the base case scenario (corresponds to the estimated demand used in the German government's hydrogen strategy) and 150 TWh as the high case scenario.

Based on the demand scenario, approx. 5–15 TWh of hydrogen storage will be required through the conversion of gas storage caverns. For the natural gas market, a storage volume of approx. 170–220 TWh would therefore still be available in 2030, factoring in convergence.

Figure 4: Storage potential for natural gas and hydrogen under the hydrogen demand scenarios for 2030



4.3.2 Hydrogen demand scenarios and storage requirements for the year 2050

Looking at the different forecasts from the metastudy[11] reveals a wide range in hydrogen demand for the period up to 2050. According to the needs assessment[12] of transmission system operators for the scenario framework, hydrogen demand as reported by market participants will be 476 TWh in 2050. This figure was also used for the high case scenario. For 2050, 250 TWh is regarded as the low case scenario, 350 TWh as the base case scenario (corresponds to the estimated demand used in the German government's hydrogen strategy) and 500 TWh as the high case scenario.

The expected hydrogen storage requirements for 2050 are likewise 10%. That's because even if other sectors such as the building industry as well as electricity and heat generation are included, it can still be assumed that the volumes required will be uniform, though the demand characteristics may well be different. This also takes into account a reduction in volume due to convergence (as described above).

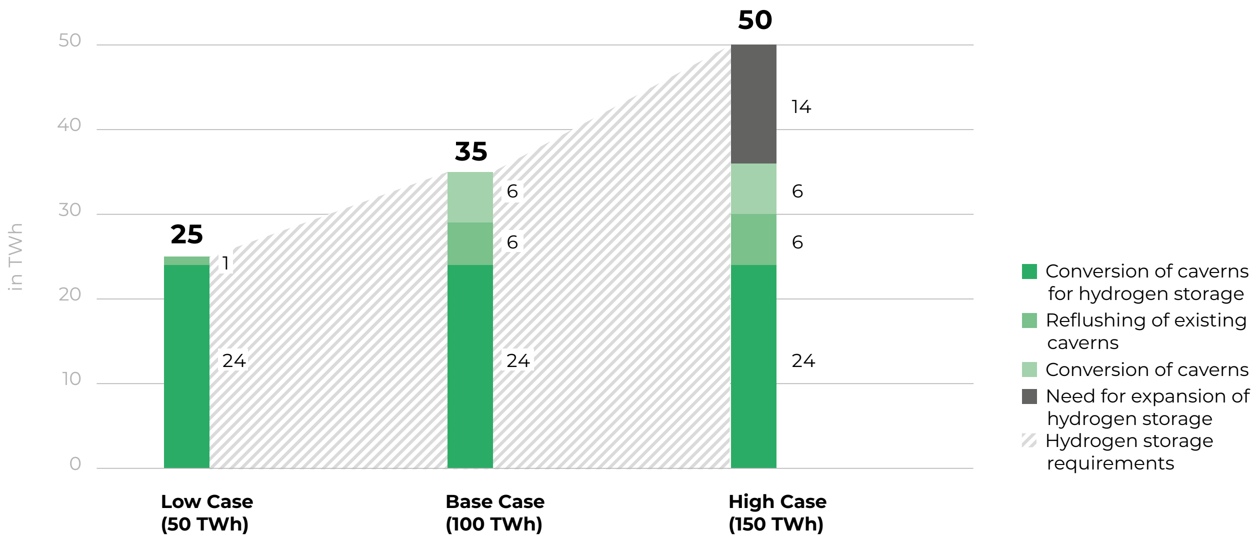
In the low case scenario, demand for hydrogen storage could be met almost entirely by converting all existing gas storage caverns to hydrogen.

[11] Wasserstoff – Auswertung von Energiesystemstudien [Hydrogen – analysis of energy system studies], metastudy commissioned by the Germany National Hydrogen Council, June 2021.
[12] https://www.fnb-gas.de/netzentwicklungsplan/szenariorahmen/szenariorahmen-2022/.

For the base case and high case scenarios, all existing gas storage caverns would also have to be converted to store hydrogen. To meet the demand for hydrogen storage, these scenarios also take into account that additional capacity can be created by reflushing existing gas caverns or by repurposing (including reflushing) caverns that are currently being used for other purposes. This would necessitate a further expansion of hydrogen storage capacity by 14 TWh via new facilities only in the high case scenario.

There are geological formations in Germany, particularly in the north/northwest of the country, where gas storage caverns could be set up (drilled) after a well is sunk. These feature thick salt domes and allow for the environmentally safe discharge or use of brine. In this way, it would also be possible to accommodate additional demand for hydrogen storage from neighbouring countries.

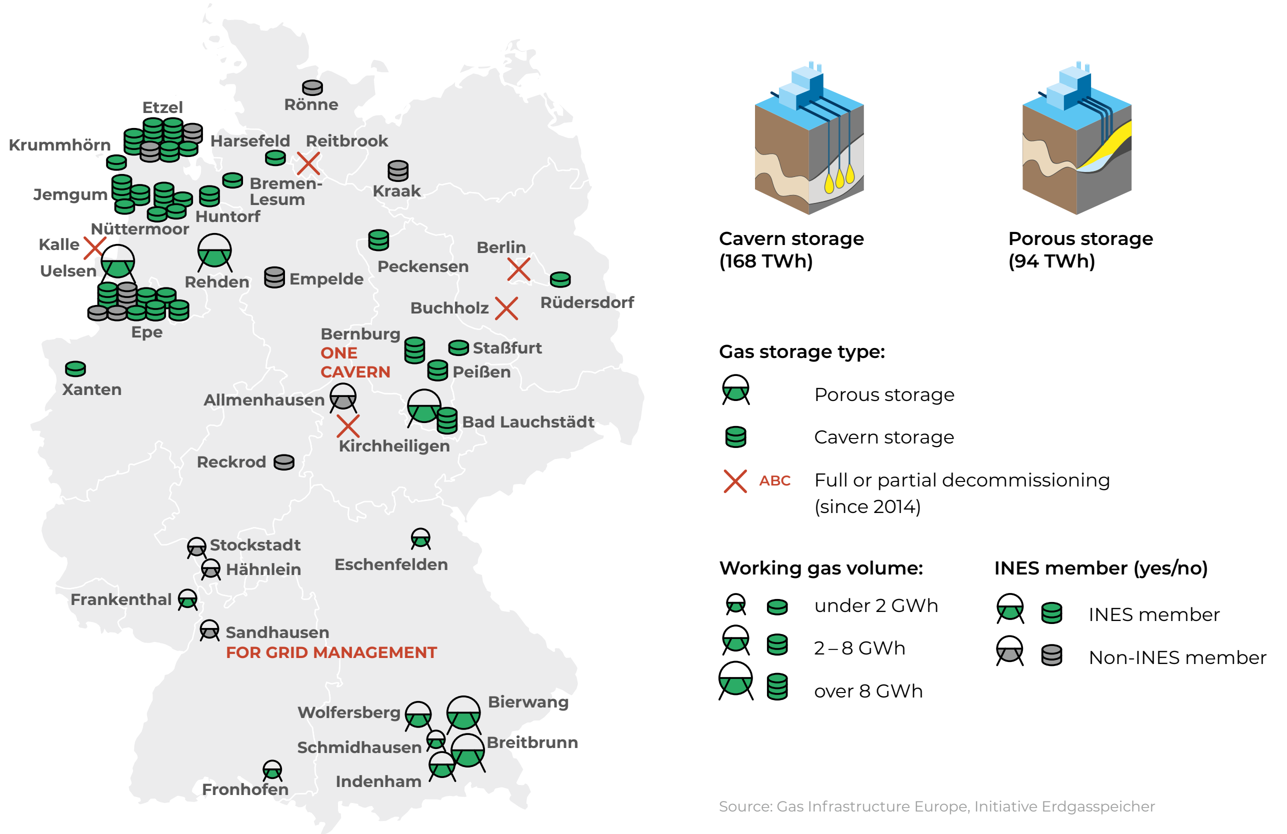
Figure 5: Potential for natural gas and hydrogen storage according to hydrogen demand scenarios for 2050



4.4 INTEGRATION OF HYDROGEN STORAGE FACILITIES INTO THE GRID INFRASTRUCTURE

In terms of the regional distribution of underground storage facilities, gas storage caverns are primarily located in northwestern and central Germany, whereas porous storage facilities are predominantly situated in southern Germany. Since the underground storage facilities are all connected to the German gas transmission system, regional demand for flexibility near the centres of consumption can already be met throughout Germany.

Figure 6: Gas storage sites in Germany[13]



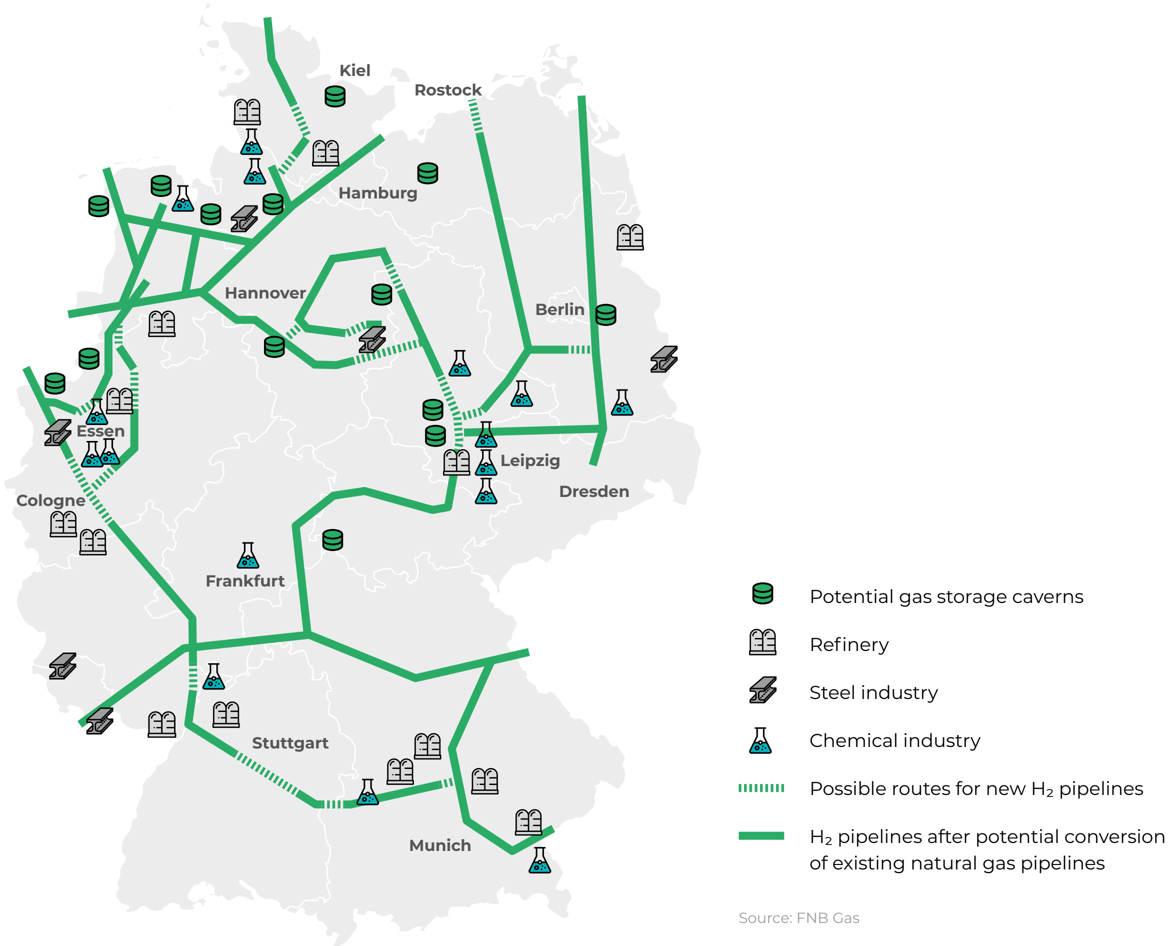
Source: Gas Infrastructure Europe, Initiative Erdgasspeicher

In addition, the gas pipeline system in Germany is designed to transport high volumes of gas from the north to the south and west of the country. The current north–south transmission capacity of the natural gas pipelines at the geographical centre of Germany is 75 GW. By comparison, the north–south transmission capacity in the electric power system is roughly 18 GW.[14]

In addition, the German natural gas grid is closely interlinked with the natural gas networks of neighbouring countries and plays an important role in gas transit. The visionary hydrogen grid initially developed by the transmission system operators in the Gas Grid Development Plan for the years 2020–2030 takes these factors into account. For example, it links the salt cavern storage facilities in Germany to large production and sales regions such as the Benelux countries as well as France. The favourable geological structures in northwestern Germany can be a useful resource for the overall European hydrogen economy and make a significant contribution to ensuring the security of supply. To utilise this resource, the transmission system operators have already identified underground storage facilities as a key cornerstone for a functioning hydrogen grid in the Gas Network Development Plan for the years 2020–2030. This will enable peak loads to be covered in cases where there is a need to withdraw stored hydrogen and help facilitate short-term and long-term structuring.

[13] https://erdgasspeicher.de/.
[14] Frontier Economics: Die Rolle von Wasserstoff im Wärmemarkt [Hydrogen's role in the heating market], brief study for Viessmann Climate Solutions, April 2021.

Figure 7: Integration of underground storage facilities into a cross-regional hydrogen transmission system[15]



Source: FNB Gas

4.5 SECURITY OF SUPPLY IN THE HYDROGEN MARKET

It is clear that hydrogen demand will be largely and increasingly covered by imports in view of the immense potential for hydrogen use in the scenarios explored here. Therefore, to ensure the security of supply and on strategic grounds as well, it will be necessary to set up large-volume storage facilities close to the centres of hydrogen consumption across Germany. There may also be possible to integrate them into a cross-regional grid infrastructure.

Underground storage facilities already provide the necessary conditions outlined above and can therefore play a central role within a hydrogen infrastructure in ensuring the security of supply by means of market-based instruments. Conversely, there are mechanisms in place to ensure the security of supply through state intervention. One such example is strategic petroleum reserves on the oil market. Unlike the oil market, however, there are no storage facility operators who offer their capacities on the gas market. As such, the existence of a strategic reserve does not lead to lower prices for storage capacity offered on the oil market. In addition, the German gas industry has demonstrated over the course of several decades that it is possible to provide a secure supply of natural gas to customers even without a government-established strategic reserve. This can be done if market-based instruments such as long-term options are used whose volume is prescribed by the state and sufficient to cover expected supply bottlenecks. Similar instruments could also be adopted for the hydrogen supply.

[15] https://fnb-gas.de/en/hydrogen-network/

German gas store caverns are of great importance in the European context, since around 80% of existing facilities of this type in Europe are located in Germany. Because of this, Germany could serve as a European hydrogen storage hub.

4.6 ALTERNATIVE STORAGE TECHNOLOGIES

A variety of energy storage technologies are already available today. The requirements in terms of storage facilities vary widely based on how they are used and where they are needed. They differ fundamentally in their operating principle and the associated capacity (storage volume) and output (injection/withdrawal rates).

Electrical energy can be stored directly, either at pumped-storage plants, which do not offer volumes similar to underground storage due to a lack of widespread regional availability, or by means of capital-intensive battery storage technologies, which, however, also do not appear at this point to be suitable for large-volume, long-term storage.

In large quantities, electricity can most easily be stored chemically in the form of hydrogen. In addition to the option of storing hydrogen in underground storage facilities, a basic distinction is made between pressurised storage (hydrogen is stored under high pressure in plastic containers or tanks) and liquid storage. In the latter case, hydrogen is liquefied (LH2) and stored under ambient pressure at low temperatures (boiling point: -252.8°C/20.4 K) for hydrogen filling stations, for example.

A comparison of the different technologies for hydrogen storage shows that cavern storage is the best option based on the following aspects[16].

- 'Time dimension' in terms of hourly to seasonal use over several months
- 'Volume and capacity' characteristics in terms of the widespread availability of large storage volumes in short time units
- 'Costs' in terms of the specific storage costs per kg of hydrogen

4.7 ESTIMATED COSTS – CONVERSION OF GAS STORAGE FACILITIES VS. ALTERNATIVE STORAGE TECHNOLOGIES

Experience from initial pilot projects shows that the conversion costs for storage of all hydrogen in existing underground storage facilities make up at least 30% of the new investment costs for a gas storage cavern. Extrapolated to include all existing gas storage caverns in Germany, this would require an investment of at least €6.5 billion from now until 2030 and at least €30 billion from now until 2050 in order to retrofit the facilities for hydrogen storage.

This would be the lower-cost option relative to other storage technologies. For that reason, it would cost 100 times more to store the same amount of energy in a battery than it would in a gas storage cavern.[17]

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16 https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

17 In a typical salt cavern, a pressure of about 200 bar is required to store hydrogen, which equals a storage capacity of about 240 GWh. The total installation costs are roughly €100 million for piping, compressors and gas treatment. By comparison, the investment costs would total €24 billion if this amount of energy would be stored in batteries, with costs of €100/kWh. Storing energy in the form of hydrogen in salt caverns is therefore at least 100 times cheaper than battery storage. https://www.hydrogeneurope.eu/wp-content/uploads/2021/11/2021.11_Hydrogen-as-a-carbon-free-energy-carrier-and-commodity_clean.pdf

5 REVIEW OF LEGAL AND REGULATORY FRAMEWORK FOR UNDERGROUND HYDROGEN STORAGE FACILITIES REQUIRED

The following legal and regulatory framework must be reviewed in order to allow hydrogen storage in underground storage facilities to contribute to a stable, demand-driven and efficient hydrogen economy (see I to IV):

1. **Market-based selling:** Generally speaking, a purely market-based sale of storage capacity has proven successful in the field of natural gas storage in Germany. It is necessary to examine whether this should also be carried over to hydrogen storage, as this form of selling is the best way to achieve a demand-based, cost-efficient provision of flexibility capacity via storage.

2. **Financial support for the conversion of gas storage facilities:** Major investments will initially be needed to convert existing natural gas storage caverns and potentially also to build new plant components for hydrogen storage during the market ramp-up phase for hydrogen. At the same time, it will likely not be possible to fund these investments solely through the sale of storage capacities in light of the still very low market volume for hydrogen. For that reason, it will be necessary in this phase to examine whether a long-term, reliable framework could help prompt the necessary investments:

    a. Based on current expectations, the sale of storage capacity, especially at the beginning, will not be sufficient to fund the investments made (CAPEX) and research required or to facilitate economically viable operation (OPEX). For this reason, financial support along with government subsidies should also be looked into as this relates to the development of hydrogen storage facilities (among other things, to offset the first-mover disadvantage).

    b. In terms of the quantities of hydrogen stored, storage facilities are not a producer or consumer of hydrogen. Instead, they serve to optimise the end-to-end hydrogen value chain. Grid fees and surcharges should therefore not impose further barriers to the sale of hydrogen storage capacity. Along these lines, an exemption from the imposition of entry/exit fees and surcharges on the connected hydrogen grid for the use of hydrogen storage facilities should be explored. This is especially the case where, as has already been demonstrated, the production, transmission, storage and consumption of hydrogen initially take place within clusters.

    c. The cost of electricity to run the compressor units used to store quantities of hydrogen represents a major portion of the operating costs incurred. An exemption from the Renewable Energy Sources Act surcharge and from electricity grid fees for the green power consumed for storage is an effective way to subsidise the economical operation of hydrogen storage facilities.

3. **Review clause for the regulatory framework for hydrogen storage:** The amended Energy Industry Act (Energiewirtschaftsgesetz, or EnWG) contains an appropriate regulatory framework for hydrogen storage with an opt-in option for the negotiated agreement on access to storage for the market ramp-up phase in clusters. Five years after the EnWG enters into force or prior to 2030 at any rate, the market maturity achieved not only for grids but also for hydrogen storage should be examined as part of market tests that are to be carried out. Based on the results of the tests, the depth of regulation should then be adjusted as required.

4. **Integration into the grid development plan:** Hydrogen storage facilities offer tremendous potential in terms of flexibility to ensure stable grid operation, which should be taken into account during scenario planning for the grid development plan.

5. **Expediting the approval procedures:** To speed up the market ramp-up with a view to hydrogen storage facility operation, the question of whether to extend the general operating plans already approved for natural gas storage in abridged, expedited procedures – and not in the form of new procedures – to hydrogen storage should be explored.

6. **Unbundling regulations on storage:** The vertical unbundling between the individual stages of the hydrogen value chain specified in Section 28l of the EnWG is a key cornerstone of the regulatory framework for the hydrogen market. Under vertical unbundling, hydrogen network operators are not permitted, among other things, to own, construct or operate hydrogen storage facilities.

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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