

Peer-reviewed Conference Contribution

# Underground hydrogen storage in Germany: Geological and infrastructural requirements

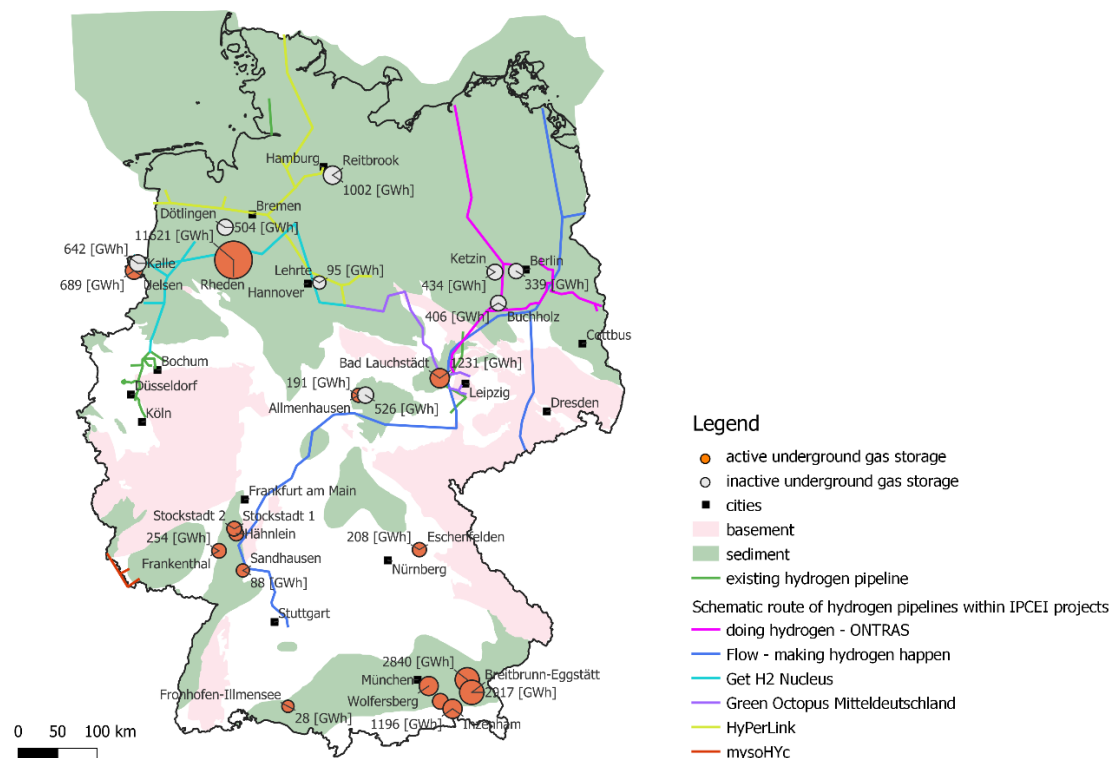
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Hydrogen storage is crucial for the success of the hydrogen economy. In addition to storage tanks and pipes the geological subsurface could also offer cost-effective solutions for storing large quantities of hydrogen in salt caverns, aquifers, and depleted hydrocarbon fields. However, experience with underground hydrogen storage is limited to salt caverns, which have size and space limitations. In this contribution we therefore define positive indicators for pore storage systems and estimate storage capacities based on national CO<sub>2</sub> and natural gas storage assessments in Germany.



**Figure 1:** Simplified map of current hydrogen pipelines and future development plans (IPCEI projects) with potential underground hydrogen storage locations in Germany (green shaded areas). Red shaded areas represent basement rocks, where no pore storage facilities are possible. Green areas indicate the spread of saline aquifers, in which a total of 3.2 to 27.3 PWh of hydrogen energy could be stored. Red dots indicate the storage location and storage potential of hydrogen (TWh) in UGS systems that could be converted to UHS facilities in the future. Grey shaded dots represent decommissioned UGS systems and their corresponding storage capacity in terms of hydrogen energy equivalent (TWh). This Figure has been submitted to *Frontiers in Energy Research*.

With a focus on the geological assessment of potential storage horizons, we first define positive and cautionary indicators for safe storage operations on the basis of a thorough literature review, including theoretical and experimental studies. For example, we find that optimal storage conditions in terms of energy content and hydrogen quality are found in sandstone reservoirs in the absence of carbonate and iron-bearing accessory minerals at a depth of approximately 1100 m and a temperature of at least 40 °C. Porosity and permeability of the reservoir formation should be at least 20 % and  $5 \times 10^{-13} \text{ m}^2$  (~500 mD), respectively. The pH of the brine should moreover fall below 6 and the salinity should exceed 100 mg/L in order to limit microbial activities and hydrogen solubility in brine water.

Second, we estimate hydrogen storage capacities based on published natural gas and CO<sub>2</sub> storage volumes [1,2] and their respective physical properties. These estimates provide an upper bound that is independent of the positive and cautionary indicators defined in here. Nevertheless, we show that up to 8 billion cubic metres, or 29 TWh energy equivalent of hydrogen could be stored in underground gas storage facilities if all natural gas were to be replaced by hydrogen (Figure 1). In addition, saline aquifers could offer storage capacities of 81.6 to 691.8 Mt of hydrogen, based on CO<sub>2</sub> storage assessments [2]. This corresponds to 3.2 to 27.3 PWh of hydrogen energy equivalent. The majority of which (~95 %) is located in the North German Basin. Fig. 3 shows the distribution of all pore storages (active and inactive; red and grey dots) and saline aquifers (green shaded areas) comparing it to the planned grid expansion initiative IPCEI (important projects of common European interests) [3]. These capacities would meet predicted storage requirements in Germany considering industrial, transport, and heating demands of 34 to 667 TWh (final hydrogen demand in 2050) many times over [4].

We conclude that pore storage systems could play a crucial role in the future German hydrogen infrastructure, especially in regions with large industrial hydrogen demand and likely hydrogen imports via pipelines and ships. We therefore recommend that future research focus on assessing the technical storage potential of these sites and their compatibility with planned hydrogen infrastructures and industrial demand.

#### **Data Availability Statement**

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

#### **Contributor statement**

KA conceptualized the study. KA and BA organized the database. BA performed the thermophysical analysis. KA wrote the first draft of the manuscript. KA, BA, MG, and MN wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted.

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