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Hydraulic effects of porous media hydrogen storage for different future energy supply systems

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Many countries worldwide have committed to mitigating global climate change by switching to renewable energy generation, leading to continuously increasing shares of renewable energy sources in the energy system. However, one major drawback is the strongly fluctuating nature of those energy sources. Power to gas technology to generate hydrogen and subsurface hydrogen storage is one of the options to balance this fluctuating availability. Depending on the specific development of the energy system, different scales of storage are needed with different scales of impacts on the subsurface that may arise. This study, therefore, quantifies the induced hydraulic effects of hydrogen storage in porous formations, accounting for four possible future energy system scenarios and based on an existing geological storage structure. The aim is to identify and quantify the large-scale and long-term hydraulic effects of the storage operations and to estimate the affected subsurface spaces using numerical simulation models.

The storage structure used was identified in a storage potential study and is located in the North German Basin at a depth of about 1000 m and consists of a Rhaetian sandstone formation. Formation permeability and porosity are derived from regional depth correlations, while boundary conditions are applied considering the local geological settings. For the storage operation, energy and mass balanced load profiles are derived from the four considered scenarios, with charging rates during times of surplus power varying from 1.9 GW to 6.4 GW and discharging rates during withdrawal from 4.7 GW to 15.9 GW, depending on the respective energy system scenario.

Simulation results show that up to 21 storage wells and 2.8 billion cubic meters of storage gas in place volume are required to support the required energy output for all scenarios considered. Scenario analysis shows that significant pressure responses at the well bottom hole are thus induced, which are limited to a geomechanically allowable range of 80 bar to 130 bar. Due to the high withdrawal rates required, storage design is mainly influenced by the lower pressure limit. In the far field, pressure responses of more than 3 bars and 5 bars are found within horizontal distances of up to 7.5 km and 5 km, respectively. The vertical pressure impact is much lower at 5 m and 20 m, respectively. This can be recalculated as a total impacted volume by 3 bars and 5 bars from 1.25×10^9 m^3 - 4.63 $\times10^9$ m^3 to 0.57×10^9 m^3 - 1.10×10^9 m^3, depending on the scenario, respectively. This study thus shows that for grid-scale energy storage subsurface space on the order of tens of millions of m^3 for the hydrogen gas phase will be required, while a much larger volume of 4.6×10^9 m^3 will be affected by pressure changes of 3 bar or more. On the other hand, at least from an energetic point of view the storage structure investigated is sufficient to accommodate the national storage demand. The study results and the approach presented can thus contribute during site selection and storage facility planning to characterize subsurface and energy system requirements.