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

ERE 5.6 Process quantification and modelling in subsurface utilisation

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Study Motivation

- High penetration of weather-dependent renewables in the energy system triggers storage demand
- Power to gas in combination with subsurface hydrogen storage is one of the options to balance this fluctuating availability

Hydrogen storage in porous media:

- How large can the storage site be and can we dimension it in the 100% renewable energy system?
- How would the storage site hypothetically be utilized in future energy system?
- How large can induced hydraulic effects be and how to identify and quantify these effects?

Energy system scenarios

Energy balanced load profile with high frequent loading, unloading and shut-in modes:

- Four future energy system scenarios
- Annual required storage demand in TWh scale
- Expected H_2 converting losses are taken into account in load profile
- Volumetric flow rate is derived by H_2 energy density of 2.95 kWh/sm^3 (LHV)

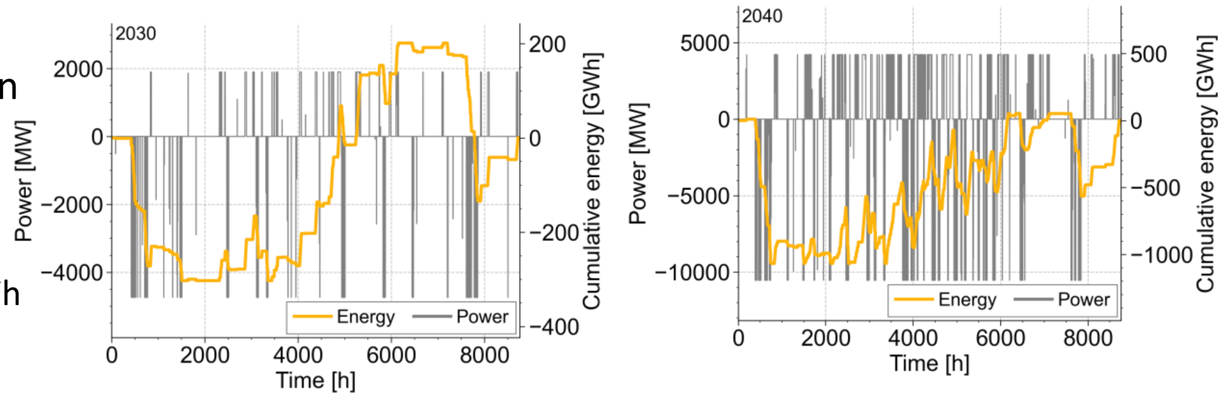
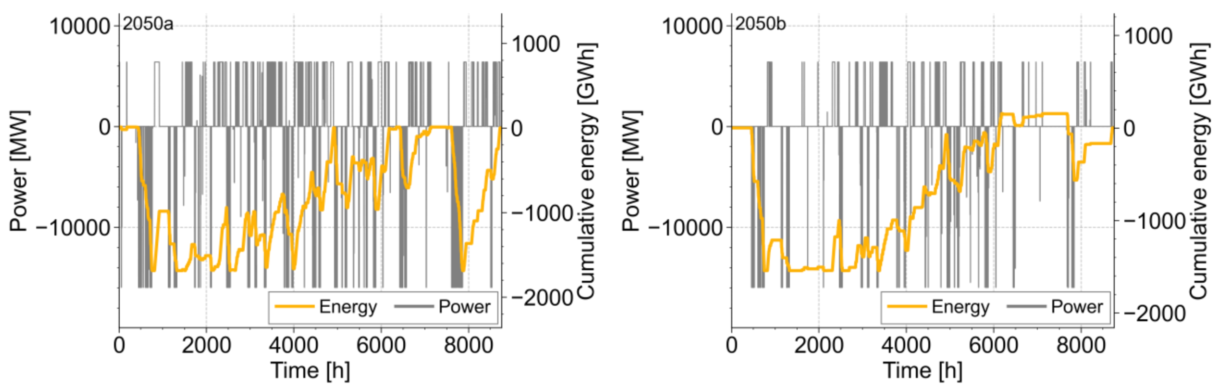


Fig. 1 Load for 4 scenario years with max loading and unloading rates, and cumulative energy (Hilpert et al. 2020), the power in minus sign is storage unloading rate and plus sign is storage loading rate



Simulation setup

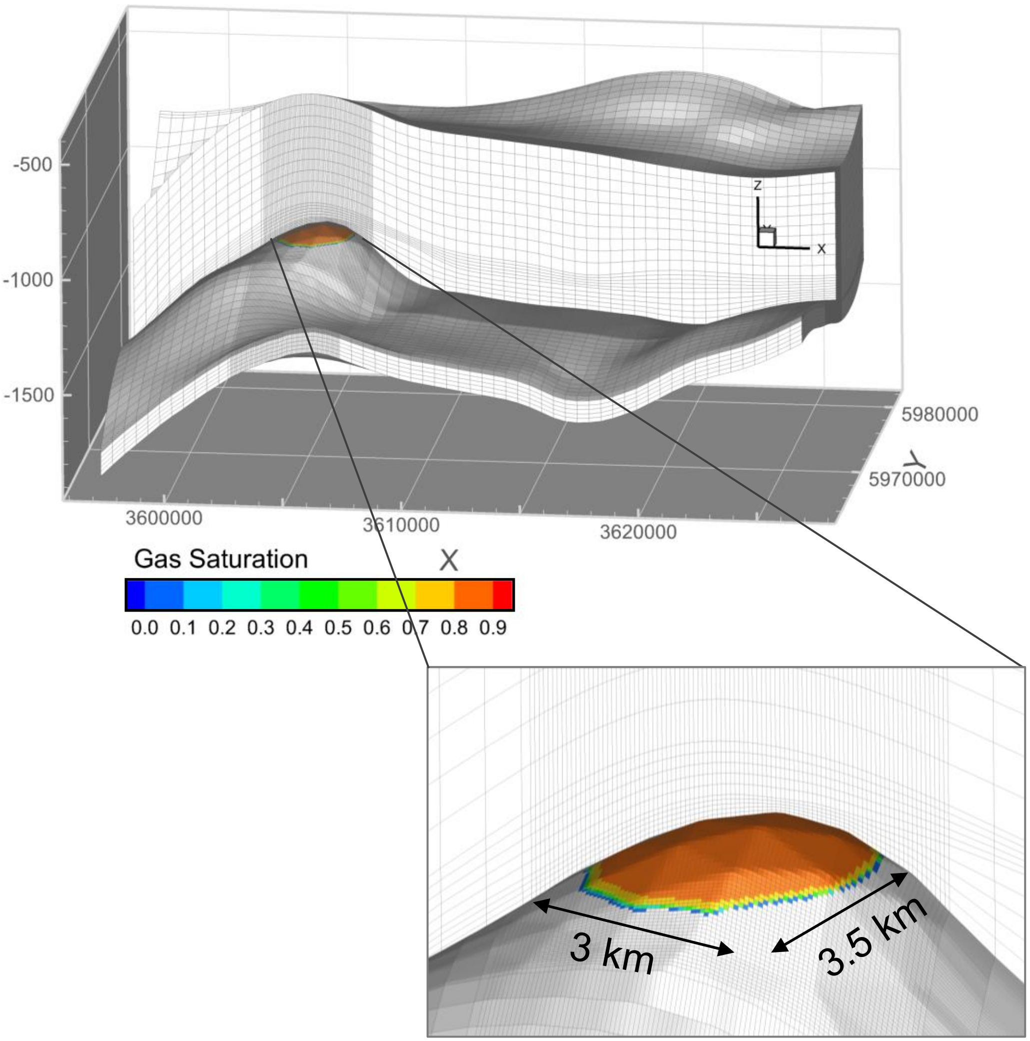


Fig. 2 Numerical model of Eckhorst site with initial H_2 in place volume (explicit initialization)

Eckhorst storage site:

- Potential storage site on existing structure (NGB) with TWh scale storage potential at 1 km depth
- Rhaetian sandstone with 20 m thickness, 700 mD permeability and 28% porosity
- Cap rock formation >50 m thickness and permeability of 0.0001 mD

Numerical model:

- Petrophysical parameters are assumed as homogeneous and isotropic
- Extended boundary condition is represented by large pore volume technique
- Gas water contact (GWC) level is at 1080 m and initial gas in place volume (GIP) is 2.8×10^9 sm^3
- Two-phase flow system with residual water saturation of 15% and 40% (cap rock)
- Capillary entry pressures are 0.1 bar for storage, 60 bar for cap rock
- Numerical simulation with ECLIPSE simulator

Simulation results

Results indicate that potential storage site with **21 vertical storage wells** fully supports target power rates from energy system:

- Storage pressure in the allowable range of 80 bar and 130 bar
- Working gas volume lies between **4-21%** of initial H_2 volume in storage
- Insignificant GWC level changes
- Hydraulic impact on subsurface mainly shows **negative pressure impacts**

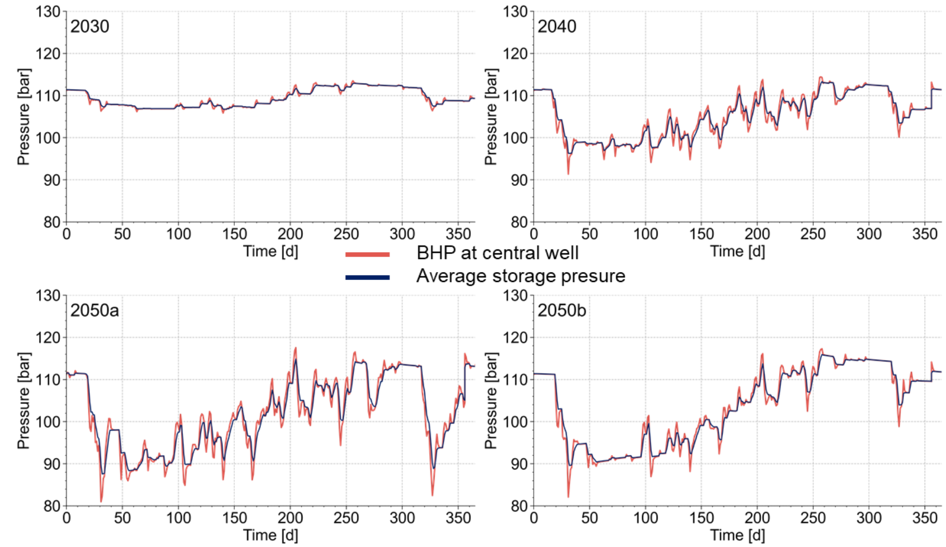


Fig. 3 Pressure signals from storage for all scenarios. Initial pressure for cyclic operation is 112 bar, the start of simulation is January.

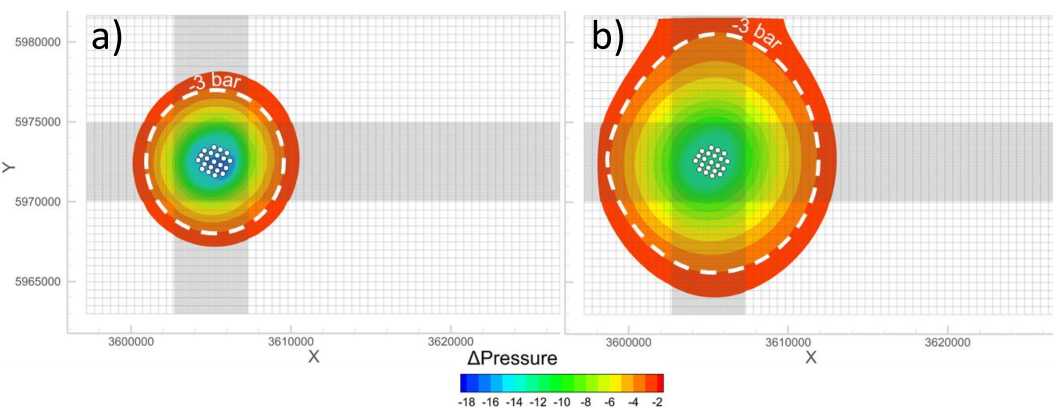


Fig. 4 Pressure response during cyclic operations in the storage for scenario 2040 a) in February, b) in March; the white dots are storage wells

Induced effect:

- For the induced effect analysis daily resampled load is used
- Pressure responses of more than **3 bars** and **5 bars** are found within horizontal distances of up to **7.5 km and 5 km** during cyclic operation, respectively
- The vertical pressure impact 6 bar is much lower at **5 m and 20 m above** the storage crest point

Summary

- For storage demand from 0.3 TWh to 1.68 TWh the required storage volume is 35.3×10^6 m^3 with 2.8×10^9 m^3 GIP volume in storage reservoir
- Frequent storage facility utilization observed in scenario 2050a with high share of renewables (up to 100%)
- Subsurface utilization shows pressure fluctuation of around 18 bar near storage wells and triggers hydraulic impact of 3 bar and 5 bar in the far field

Key findings:

- H_2 storage in porous media meets needs for storage demand in **all 4 future energy systems**
- For grid-scale energy storage the subsurface space on the order **of tens of millions of m^3** for the hydrogen gas phase will be required
- Pressure response of 3 bars can be detected at least **in 5 km from** storage wells taking into account travel time delay for monitoring survey