Impacts of the use of the geological underground for thermal, electrical or material geoenergy storage – Prognosis of induced effects by scenario analysis

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Motivation

• The German „Energiewende“ implies a strong increase of energy production from renewable sources like wind power, solar power, biomass, solar heat and geothermal energy.

• Fraction of renewables used for electricity & heat

<table>
<thead>
<tr>
<th>Year</th>
<th>Electric power consumption</th>
<th>Heat consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>20.3 % (123 / 606 TWh)</td>
<td>10 % (143 / 1305 TWh)</td>
</tr>
<tr>
<td>2014</td>
<td>27.8 % (160 / 580 TWh)</td>
<td>10 % (131 / 1320 TWh)</td>
</tr>
<tr>
<td>2050</td>
<td>130 %</td>
<td>67 %</td>
</tr>
</tbody>
</table>

UBA, 2010

Prognosis of energy production and energy demand for 2050

August

December
Introduction

- Large storage capacities are required to compensate short-term, mid-term and seasonal fluctuations in electric power production
  - **Estimated storage demand:** ~ 50 TWh in 2050
  - **Surplus power**
    - ~ 140 TWh

- The geologic subsurface offers large potential storage capacities for long-term storage, e.g. natural gas storage

Storage options
- Natural gas storage
- Hydrogen gas storage
- Compressed air energy storage (CAES)
- Heat storage

Suitable geological formations
- Caverns in salt deposits
- Porous reservoirs

- Fraunhofer IWES
Use of the geological subsurface

Protected entities:
- ground water
- humans
- soil / vegetation
- fauna

Type of use:
- near surface geothermal systems
- ground water abstraction
- natural gas and hydrogen storage
- heat storage
- compressed air storage
- conventional / unconventional hydrocarbon production
- mining
- deep geothermal energy
- CO₂ or nuclear waste disposal

Bauer et al., 2013
Planning of the geological subsurface

Conflicts of use in the subsurface can be due to:
- multiple uses of one storage formation/site or
- induced effects of other types of use already present or intended in future
- monitoring requirements of other types of use.

Therefore, planning and weighting of the individual types of use for possible storage locations is required, i.e. a subsurface use planning, as e.g. definition of regions reserved for a specific storage option. This planning has to include the surface infrastructure and conditions.

For this, not only the storage locations but also the effects of an individual storage/usage operation have to be considered, as well as monitoring requirements.

Conflicts of use occur both in the deep (mass energy storage) as well as the shallow subsurface (i.e. heat storage – drinking water supply).
### ANGUS+ project objectives and methods

#### Development of concepts for planning the use of the subsurface

Analysis and dimensioning of storage capacities for mass and heat storage, considering the mutual effects of the individual storage options, the effects on protected resources (e.g. drinking water) as well as the surface conditions.

#### Scenario analysis

Realistic numerical scenario analysis of impacts and of monitoring for storage of mass and heat storage in porous formations and caverns.

### Parameterization

- Development of type scenarios
- Parameterization of the deep and shallow subsurface
- Experimental determination of
  - geomechanical parameters
  - geochemical effects induced
  - microbial populations

### Model development

- Development and implementation of numerical process models for the simulation of coupled thermal, hydraulic, geomechanical and geochemical (THMC) processes
  - quantification of effects
  - development and verification of monitoring methods
Scenario 1: Porous medium hydrogen storage

Type of usage:
- storage of hydrogen, (similar for methane or compressed air)

Possible induced effects:
- pressure propagation horizontally (within the geologic formation)
- pressure propagation vertically (across cap rock)
- brine displacement horizontally and vertically
- brine intrusion into shallow drinking water aquifers
- superposition with effects of other types of use

Monitoring requirements
Scenario 1: Porous medium hydrogen storage

Storage demand:
- Electric energy consumption in SH (2011): 42820000 GJ
- Efficiency of re-electrification: 0.6
- Time of no wind/solar power production: 7 days

- Required H₂ extraction volume: 129 mio. sm³

Data: MELUR (2013), Klaus et al. (2010), Cardon & Paterson (1979)

Hypothetical storage site:
- Faulted anticline in northern Germany
- Sealing formations: Jurassic & Cretaceous deposits
- Storage formation: partially eroded Rhaetian deposits
- Depth: 400 – 500 m, Thickness ~13 m at wells
- Dimensions: ~ 15 km x 25 km

Data for geological model: Hese et al., 2012
Scenario 1: Porous medium hydrogen storage

Storage parametrization
- Only scarce on-site data available
- 15 heterogeneous realizations + 1 homogeneous parameter distribution
- 5 wells, Bottom hole pressure limits: +/- 50% of initial hydrostatic value (30 bar/65 bar)

Storage phases
1. Cushion gas injection: N₂
   - ~ 201 mio. sm³
2. Initial filling with H₂
   - ~ 162.75 mio. sm³
3. Cyclic extraction/injection of H₂
   - Target extraction rate per well: 1000000 sm³/d → 35 mio. sm³ tot
   - Target injection rate per well: 155000 sm³/d
   - 7 days extraction / 50 days injection
Scenario 1: Porous medium hydrogen storage

Gas phase saturations
- Gas phase accumulates in the top of the structure (density driven)
- Very little visible differences before and after extraction due to compressibilities

Gas density
- Variable due to compressibilities
- Distribution indicates component distribution

Gas component distribution
- Roughly concentric spreading of H₂ around the wells
- Distribution clearly reflects the state of the storage op.
Scenario 1: Porous medium hydrogen storage

Spatial extent of induced effects: Pressure

- Large pressure changes at the wells
  \[ \sim +/\pm 20 \text{ bar} \]

- \[ \Delta p > 10 \text{ bar} \] limited to multi phase flow region

- \[ \Delta p > 1 \text{ bar} \] can be observed up to 7.5 km from the wells

- total affected area: \[ \sim 88 \text{ km}^2 \]

- Formation heterogeneity has only little effects on overpressure signal
Scenario 1: Porous medium hydrogen storage

Spatial extent of induced effects: Chemical effects

- Approximated from gas phase saturation
- Gas phase distribution strongly depends on reservoir heterogeneity
- Footprint of the gas phase approx. 4 km² with lateral extents of over 3 km

![Image showing gas saturation distribution with different run scenarios](image_url)
Model development

Scientific code development for coupled Thermo-Hydro-Mechanical-Chemical (THMC) systems in the environment

OpenGeoSys - OGS

- implementation of governing processes
- process coupling and coupling strategies
- code verification and benchmarking
- Scientific Open Source development

Simulation of coupled processes
- (multiphase) flow
- heat transport
- geomechanical effects and
- geochemical reactions
for use in scenario simulations

-> www.opengeosys.org
Scenario 2: Heat storage

Possibly induced effects of near surface heat storage / use

- during construction
  - e.g. generation of hydraulic shortcuts

- during operation
  - temperature changes
  - changes of the flow field
  - changes of groundwater geochemistry
  - changes of groundwater microbiology
  - impairment of drinking water quality
  - geomechanical effects (uplift, consolidation)

- hazards and conflicts of use
  - interaction with other heat storages
  - interaction with contaminated sites
  - leakage of working fluid
Scenario 2: Heat storage

High resolution numerical model of BHE + geology (glacial till)

High resolution numerical model, due to highly transient temperatures in the borehole heat exchangers (BHE):

- Fluid
- Pipe
- Grout

Model setup of storage site

impermeable for flow

19 BHEs
470,000 nodes
880,000 elements
Scenario 2: Heat storage

Storage setup
- Loading with 90°C inlet temperature for 6 months
- Unloading with 1°C inlet temperature for 6 months

Storage efficiency results
- 1st storage cycle: 2.5 GWh/1.4 GWh
- 4th storage cycle: 2.1 GWh/1.6 GWh
Scenario 2: Heat storage

**Induced effects:**

- maximum temperature in the soil: $\sim 60^\circ C$
- Basically no temperature change beyond 20 m from the wells after 4 cycles

**Temperature Profile: 1 BHE**

- 2. injection
- 2. extraction
- 4. injection
- 4. extraction

**Temperature Distr. 19 BHE**

- delta Temperature $[^\circ C]$
- Temperature Profile: 1 BHE
- Temperature Distribution: 19 BHE
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Thank you very much for your attention!