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

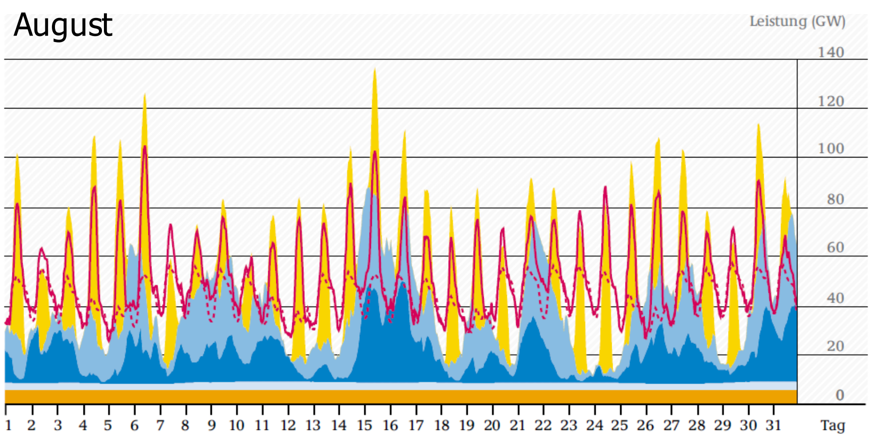
- The German „Energiewende“ implies a strong increase of energy production from renewable sources like wind power, solar power, biomass, solar heat and geothermal energy.

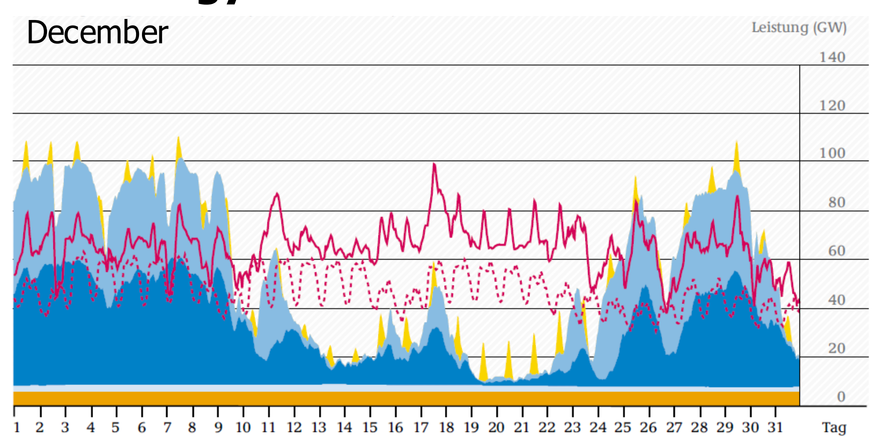
- **Fraction of renewables used for electricity & heat**

Year	Electric power consumption	Heat consumption
2011	20.3 % (123 / 606 TWh)	10 % (143 / 1305 TWh)
2014	27.8 % (160 / 580 TWh)	10 % (131 / 1320 TWh)
2050	130 %	67 %

UBA, 2010

Prognosis of energy production and energy demand for 2050





Introduction

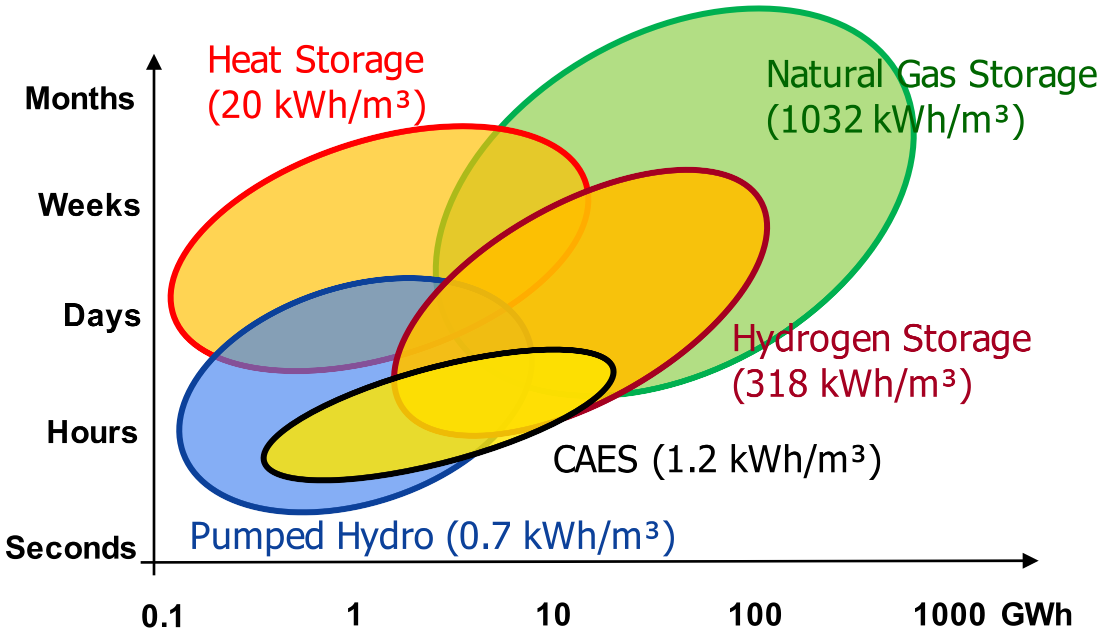
- Large storage capacities are required to compensate short-term, mid-term and seasonal fluctuations in elec. power production
  - **Estimated storage demand: ~ 50 TWh in 2050**
  - **Surplus power ~ 140 TWh**

Fraunhofer IWES

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

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

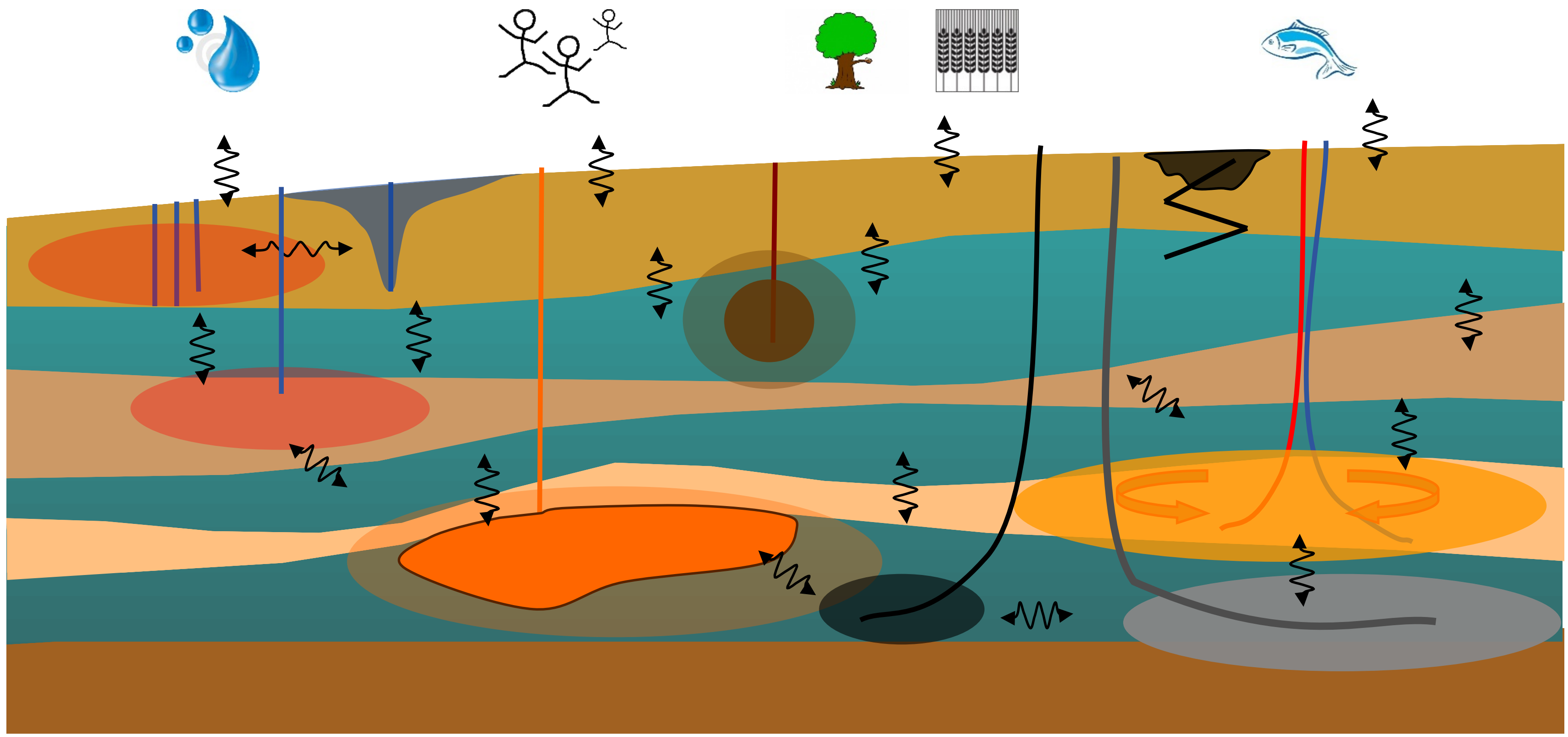
Suitable geological formations
- Caverns in salt deposits
- Porous reservoirs



Use of the geological subsurface

protected entities

ground water | humans | soil / vegetation | fauna



Bauer et al., 2013

type of use

near surface geothermal systems

heat storage

ground water abstraction

natural gas and hydrogen storage

compressed air storage

conventional / unconventional hydrocarbon production

mining

deep geothermal energy

CO_2 or nuclear waste disposal

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

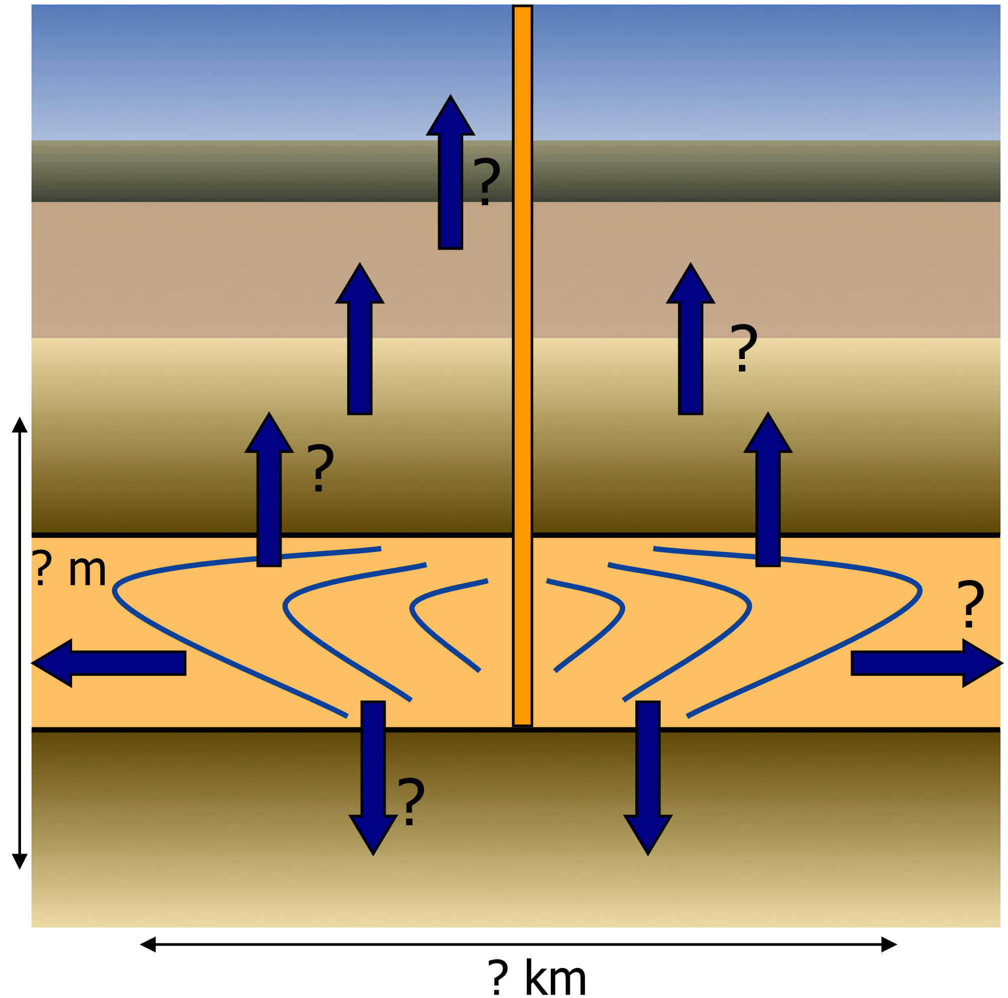
Scenario 1: Porous medium hydrogen storage

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

Possible induced effects:
- pressure propagation horizontally (within the geolog. 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

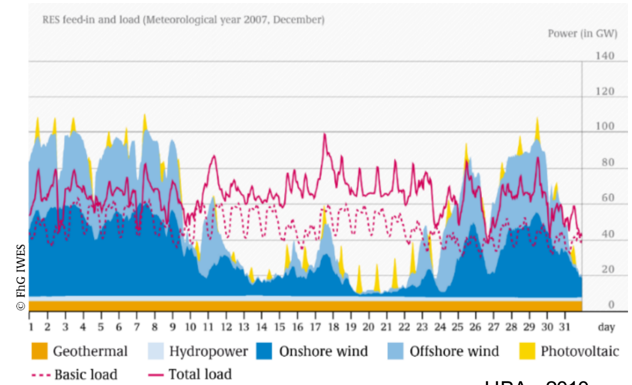


Scenario 1: Porous medium hydrogen storage

Storage demand:

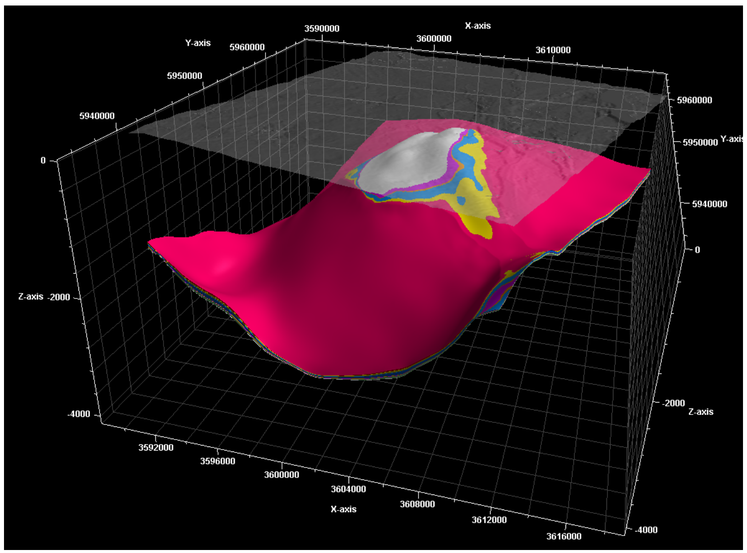
- Electric energy consumption in SH (2011): 42820000 GJ
- Efficiency of re-electrification: 0.6
- Time of no wind/solar power production: 7 days
  - ➢ Required H_2 extraction volume: 129 mio. sm³

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



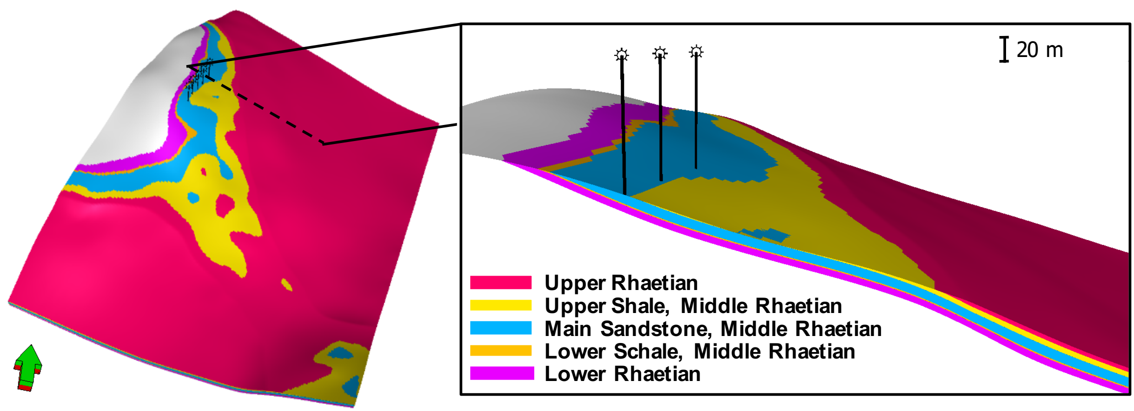
UBA., 2010

Hypothetical storage site:



Data for geological model: Hese et al., 2012

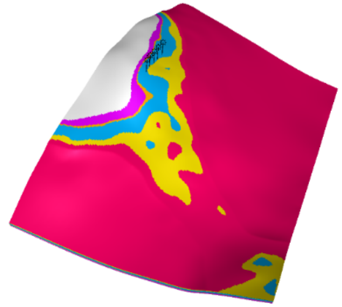
- Faulted anticline in northern Germany
- Sealing formations: Jurassic & Cretaceous deposits
- Storage formation: partially eroded Rhaetian deposits
  - ➢ Depth: 400 – 500 m, Thickness ~13 m at wells
  - ➢ Dimensions: ~ 15 km x 25 km

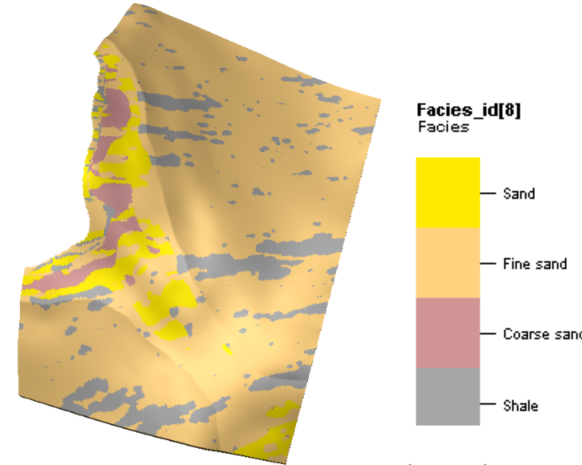


Scenario 1: Porous medium hydrogen storage

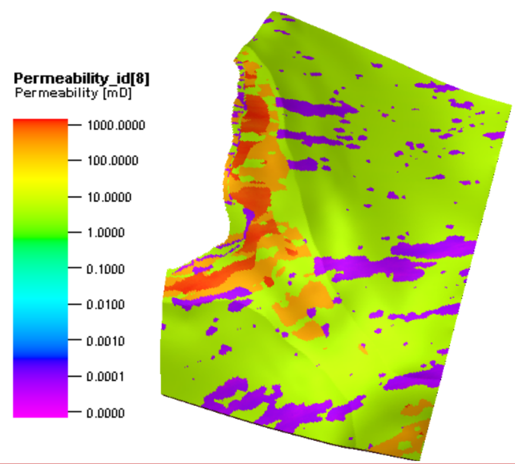
Storage parametrization

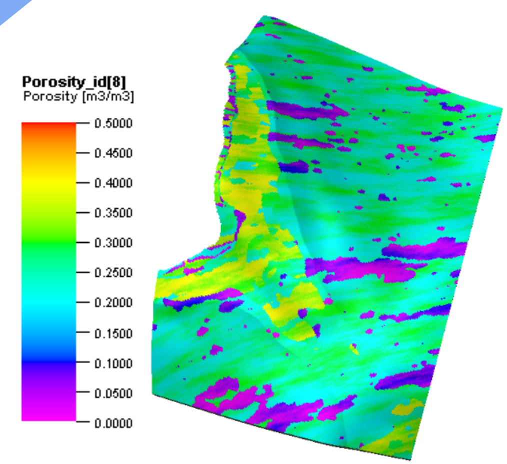
- Only scarce on-site data available
- 15 heterogeneous realizations +1 homogeneous parameter distribution
- 5 wells, Bottom hole pressure limits: +/- 50 % of initial hydrostatic value (30 bar/65 bar)





Component	Permeability [mD] mean	min	max	Porosity (effective) mean	min	max	Srw	k_{rg0}	p_d [bar]
Shale	0.00005	1E-06	0.00001	0.05	0.01	0.1	0.6	0.015	15
Fine Sand	5	0.1	10	0.25	0.2	0.3	0.4	0.3	0.5
Sand	250	10	500	0.35	0.3	0.4	0.4	0.5	0.2
Coarse Sand	1000	500	2500	0.35	0.3	0.4	0.3	0.9	0.1





Storage phases

1. Cushion gas injection: N_2
   - ~ 201 mio. sm³
2. Initial filling with H_2
   - ~ 162.75 mio. sm³
3. Cyclic extraction/injection of H_2
   - 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

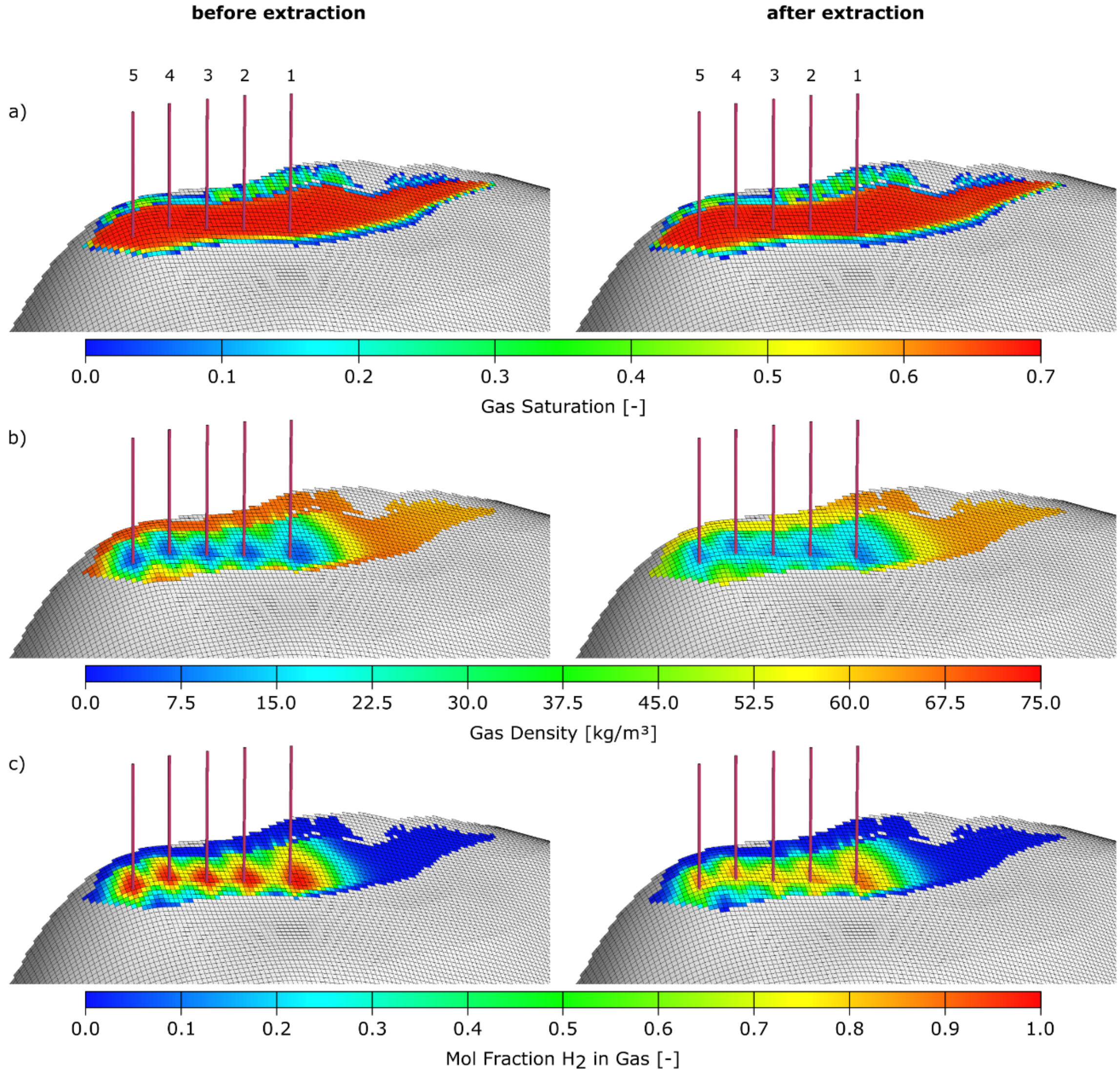
- Gas phase accumulates in the top of the structure (density driven)
- very little visible differences before and after extraction due to compressibilities

Gas density

- Variable due to compressibilities
- Distribution indicates component distribution

Gas component dristribution

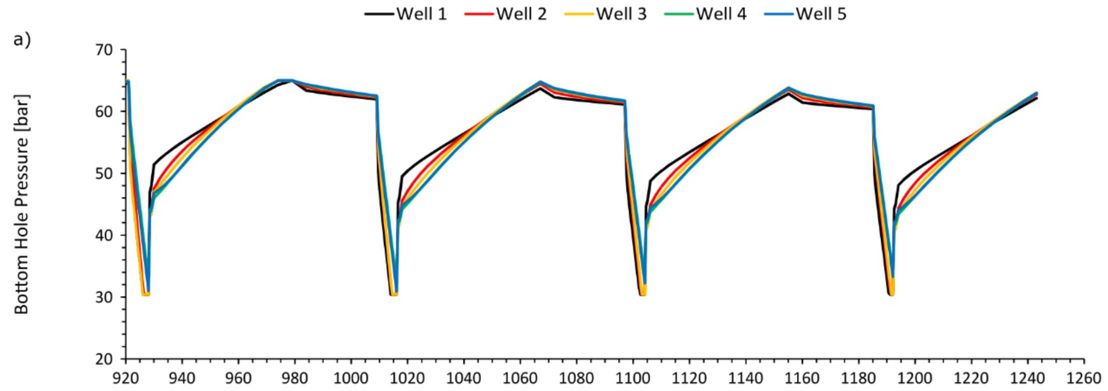
- roughly concentric spreading of H_2 around the wells
- Distribution clearly reflects the state of the storage op.



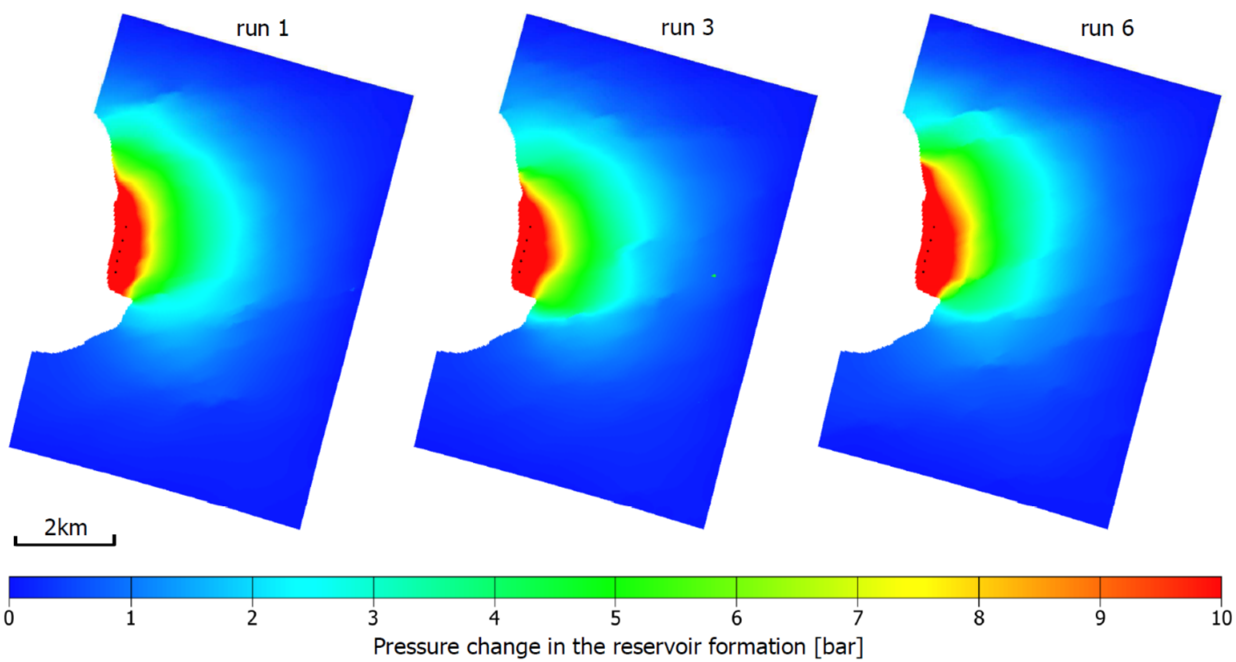
Scenario 1: Porous medium hydrogen storage

Spatial extent of induced effects: Pressure

- Large pressure changes at the wells
  - ~ +/- 20 bar



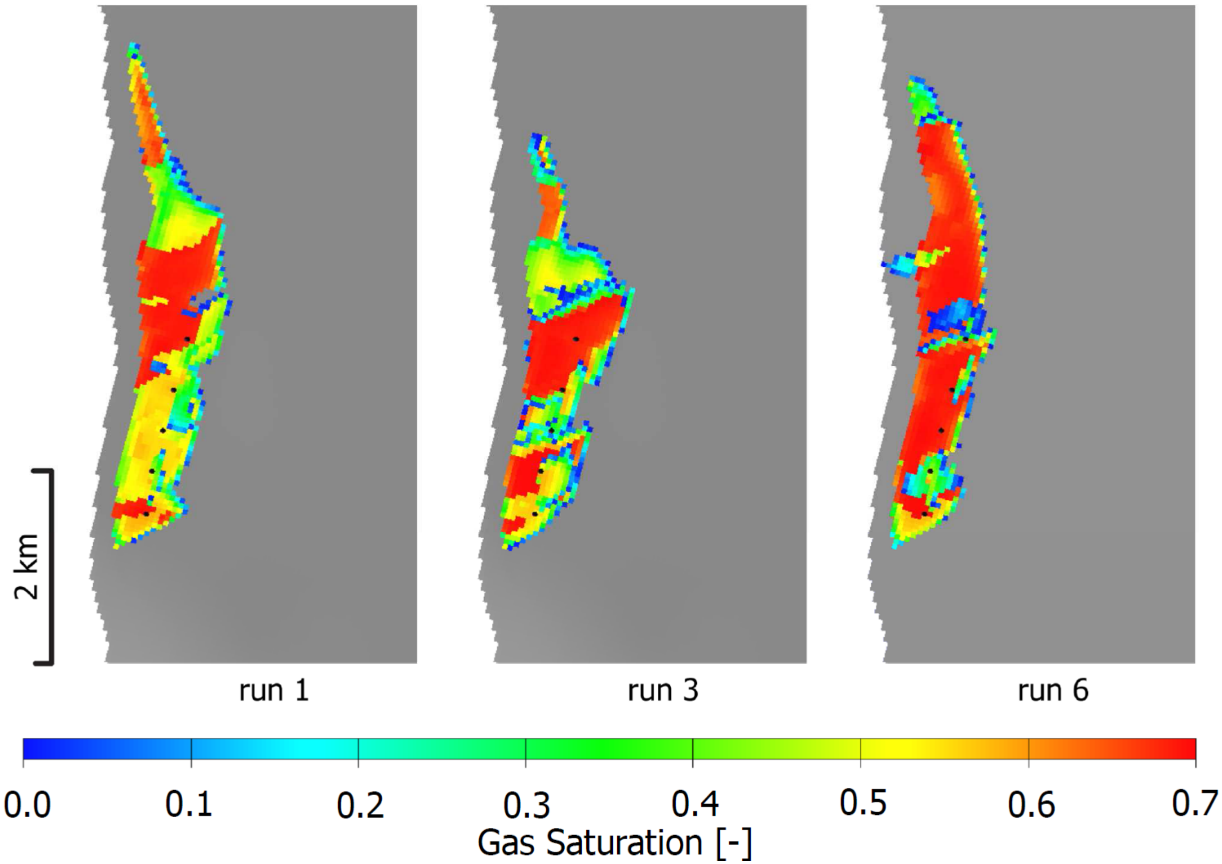
- Δp >10 bar limited to multi phase flow region
- Δp >1 bar can be observed up to 7.5 km from the wells
- total affected area: ~ 88 km²
- Formation heterogeneity has only little effects on overpressure signal



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



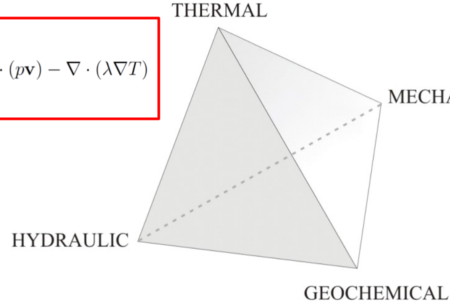
Scientific code development for coupled Thermo-Hydro-Mechanical-Chemical (THMC) systems in the environment

OpenGeoSys - OGS

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

Heat transport

$$\frac{\partial(u\varrho)}{\partial t} + \nabla \cdot (u\varrho\mathbf{v}) + \nabla \cdot (p\mathbf{v}) - \nabla \cdot (\lambda \nabla T)$$



Deformation

$$\nabla\vec{\sigma} - \rho\vec{g} = 0$$

Fluid dynamics

$$\frac{\partial(\rho_\alpha n S_\alpha)}{\partial t} - \nabla \cdot \left(\rho_\alpha \frac{k_{r\alpha} k}{\mu_\alpha}(\nabla p_\alpha - \rho_\alpha g)\right) - q_\alpha \rho_\alpha = 0$$

$$\sum_{\alpha=1}^{\alpha=n_{phase}} S_\alpha = 1$$

$$p_{c\alpha\beta} = p_\alpha - p_\beta = f(S_1, ..., S_{n_{phase}})$$

Transport und Reactions

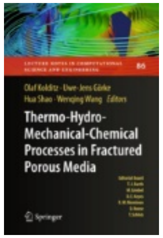
$$\frac{\partial(nS_\alpha\rho_\alpha X_\alpha^\kappa)}{\partial t} + \nabla\left(v_\alpha\rho_\alpha X_\alpha^\kappa - nS_\alpha D_{DD,\,\alpha}^\kappa \nabla(\rho_\alpha X_\alpha^\kappa)\right) - q_\alpha^\kappa = 0$$

$$x_\alpha^\kappa = H_\alpha^\kappa p_g^\kappa$$

$$K_m = \prod_i a_i^{\nu_i} = exp(\frac{-\Delta G_0}{RT})$$

$$r_m = k_{m,T_0}\left(\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right) A_m \left[1 - \frac{Q_m}{K_m}\right]$$

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



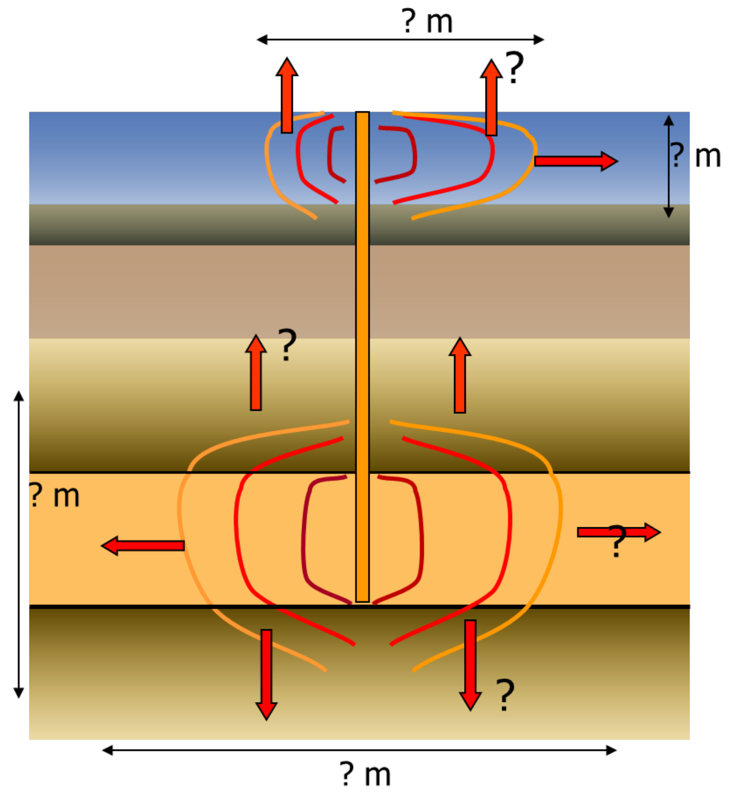
Scenario 2: Heat storage

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)

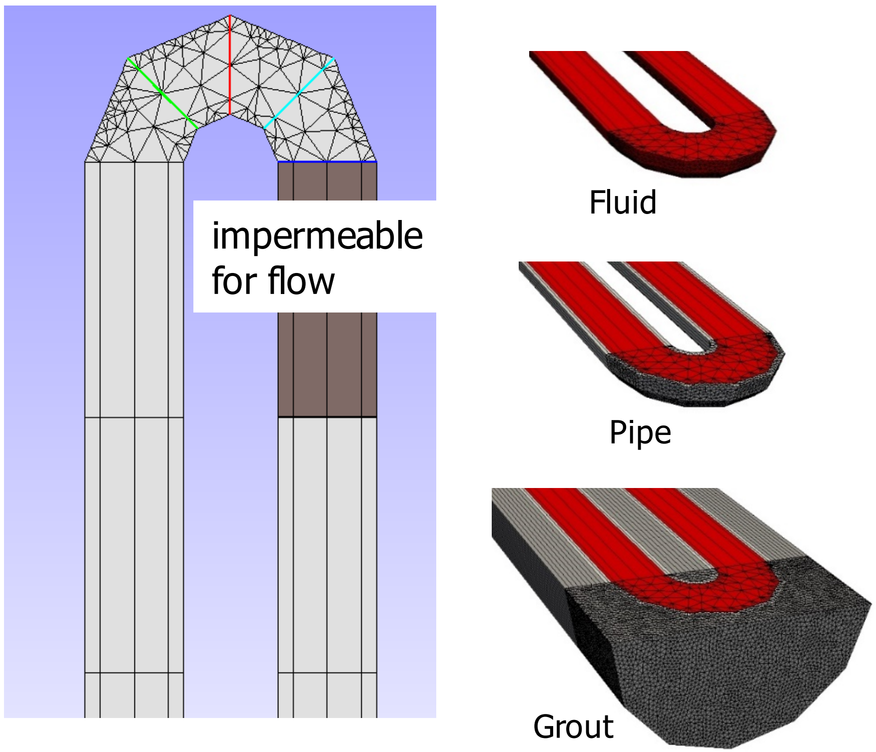
- hazards and conflicts of use
  - interaction with other heat storages
  - interaction with contaminated sites
  - leakage of working fluid



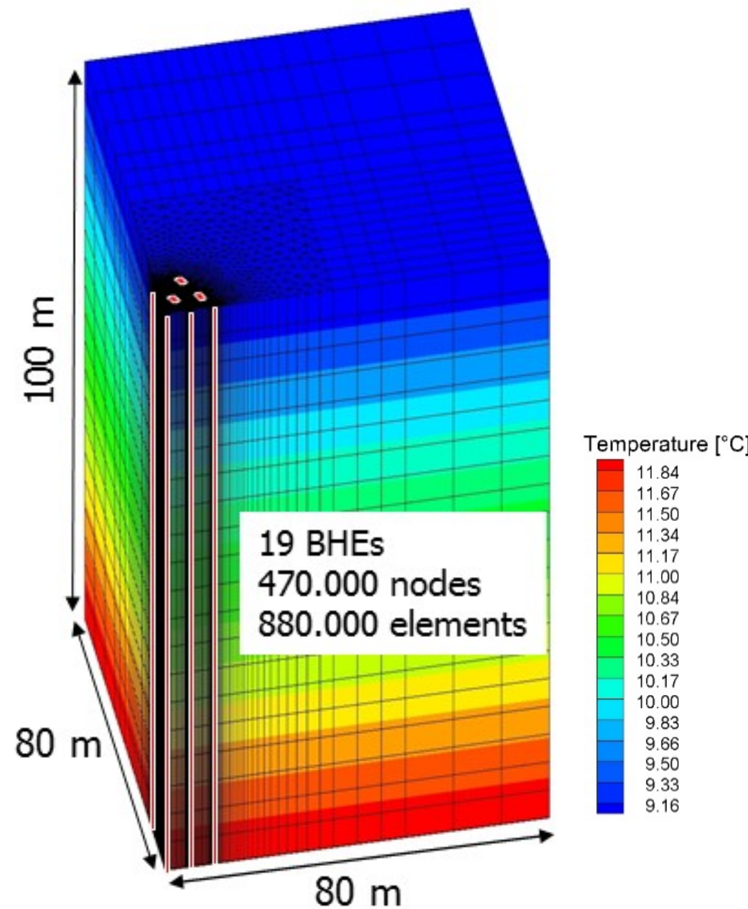
Scenario 2: Heat storage

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

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



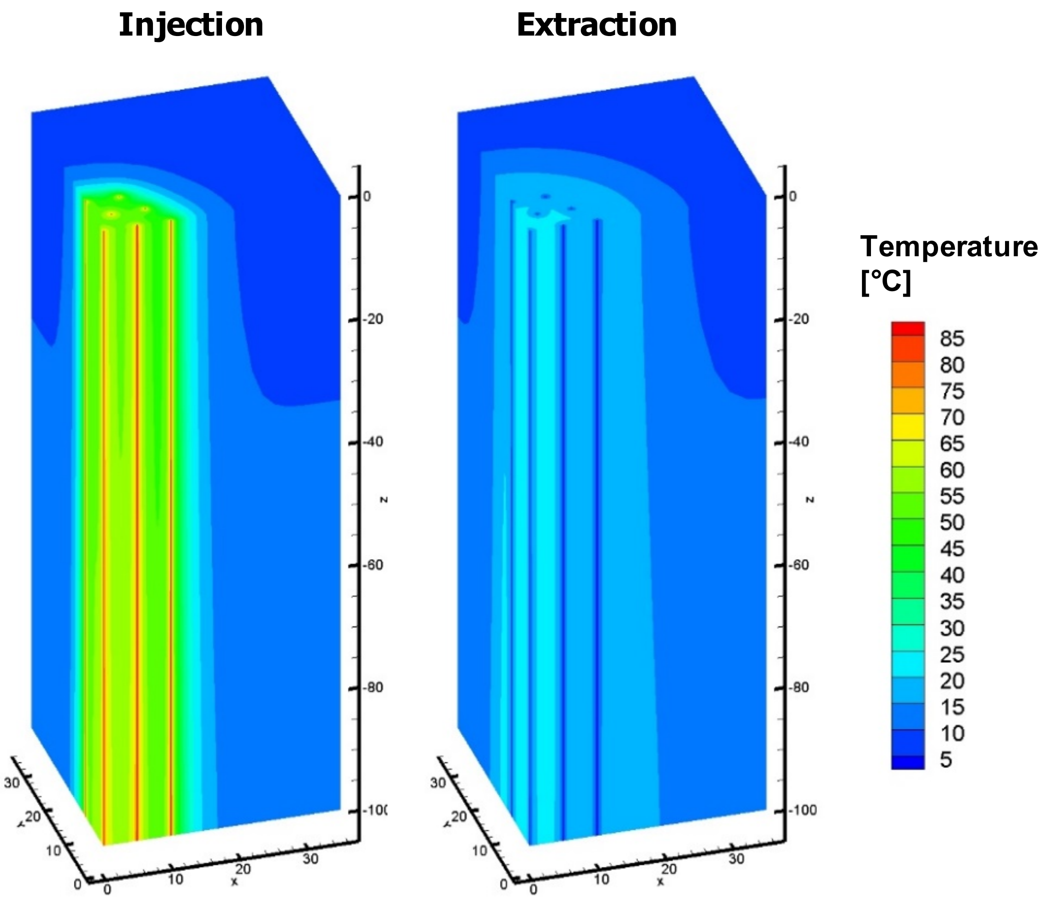
Model setup of storage site



Scenario 2: Heat storage

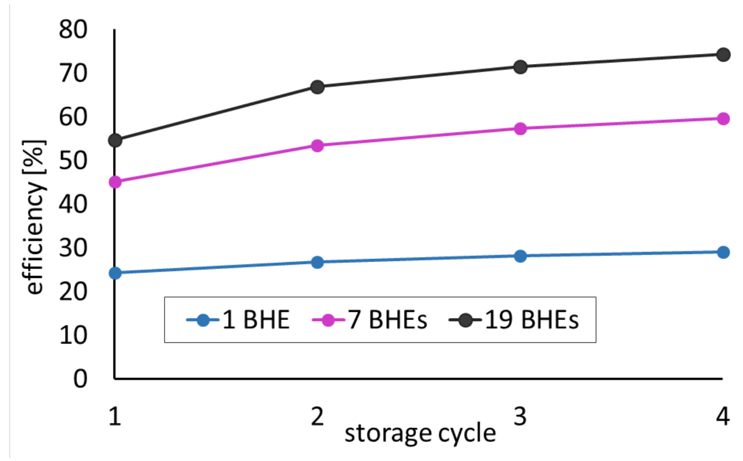
Storage setup

- 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

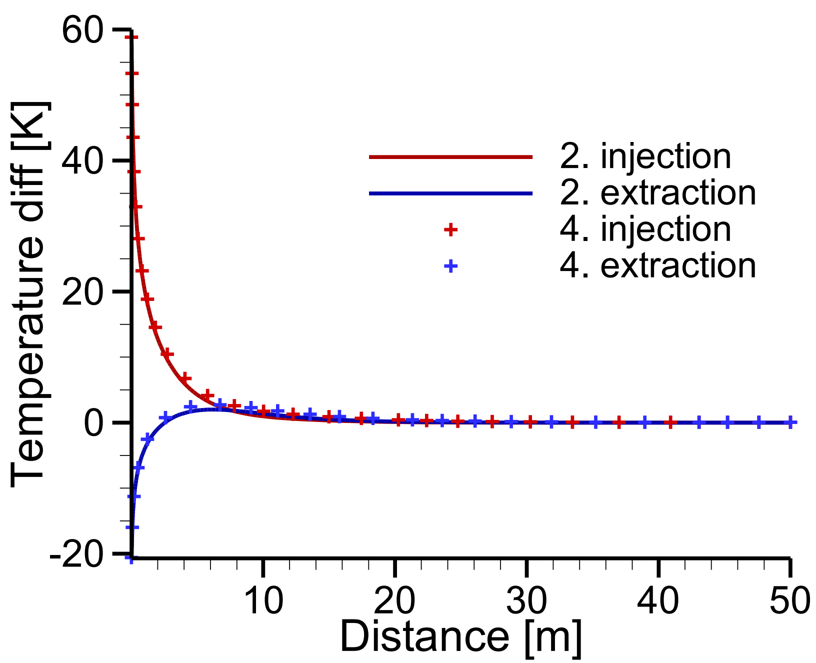


Scenario 2: Heat storage

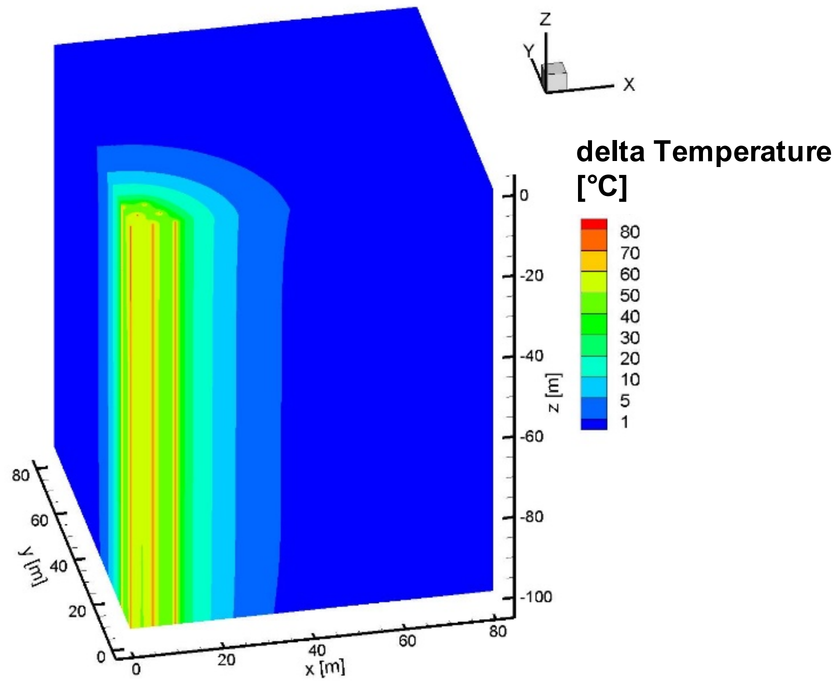
Induced effects:

- maximum temperature in the soil: ~ 60 °C
- Basically no temperature change beyond 20 m from the wells after 4 cycles

Temperature Profile: 1 BHE



Temperature Distr. 19 BHE



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Thank you very much for your attention !

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INTERNATIONAL VIEWPOINT AND NEWS

Impacts of the use of the geological subsurface for energy storage: an investigation concept

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