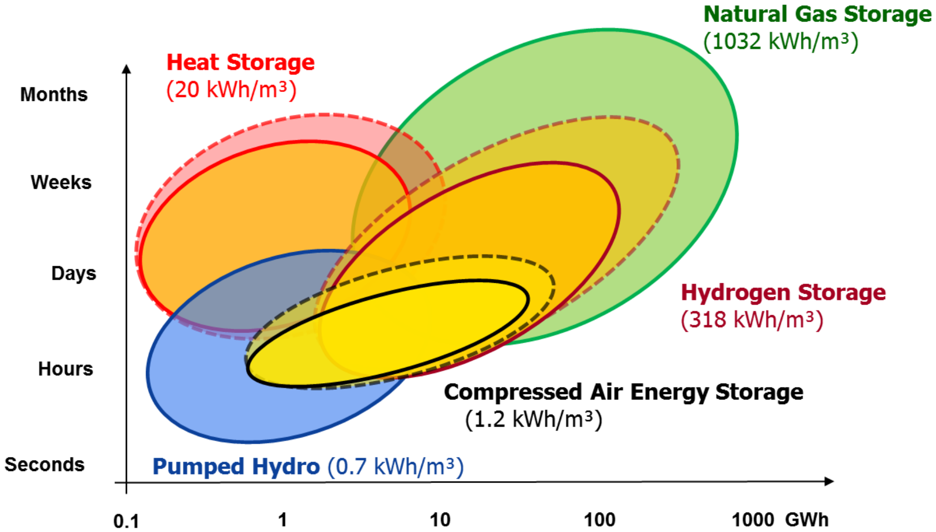
Potentiale und Möglichkeiten der untertägigen Energiespeicherung

Subsurface energy storage – methods and potentials



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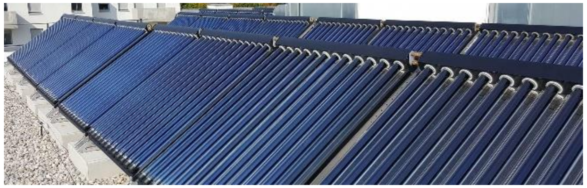
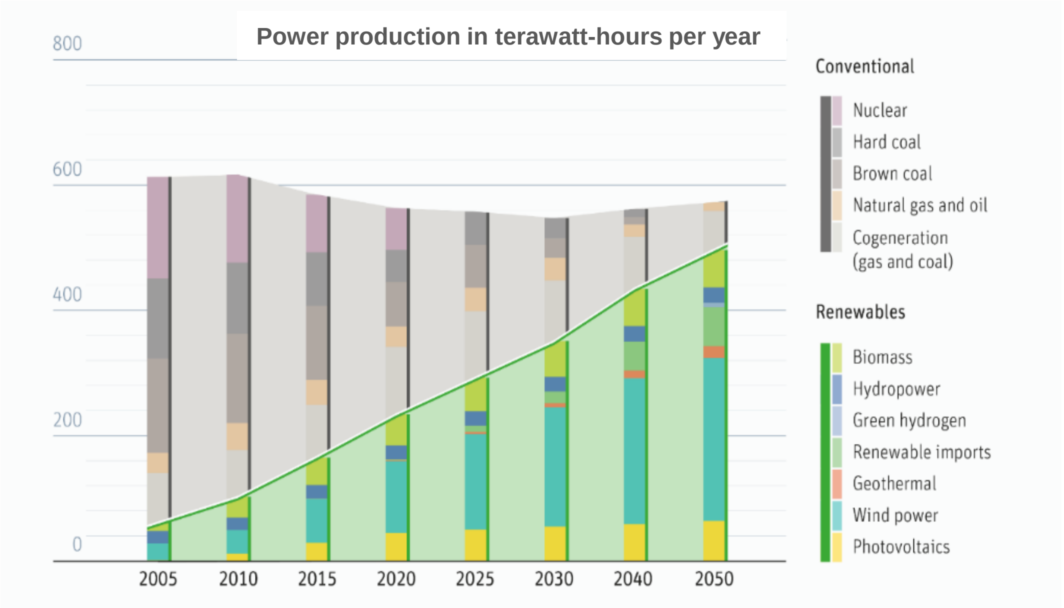
Why we do it

Wind power

Solar power



Solar thermal energy

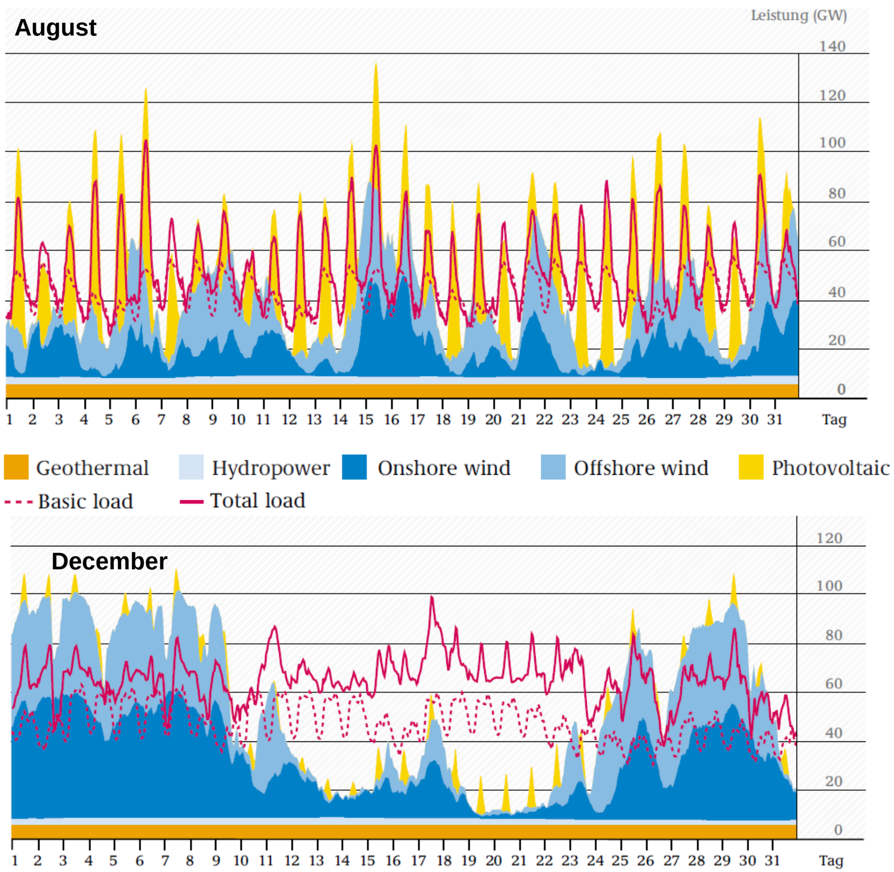


Energytransition.org (2016)

- The „Energiewende" leads to an **increasing use of renewable energy sources** for power generation, mobility, and to cover the heat demand.
- One challenge posed is the **fluctuating production** of renewable power by solar or wind power plants ("Dunkelflaute", "Hellbriese") as well as therequired **integration of additional renewable power sources** as substitutes for fossil fuels.

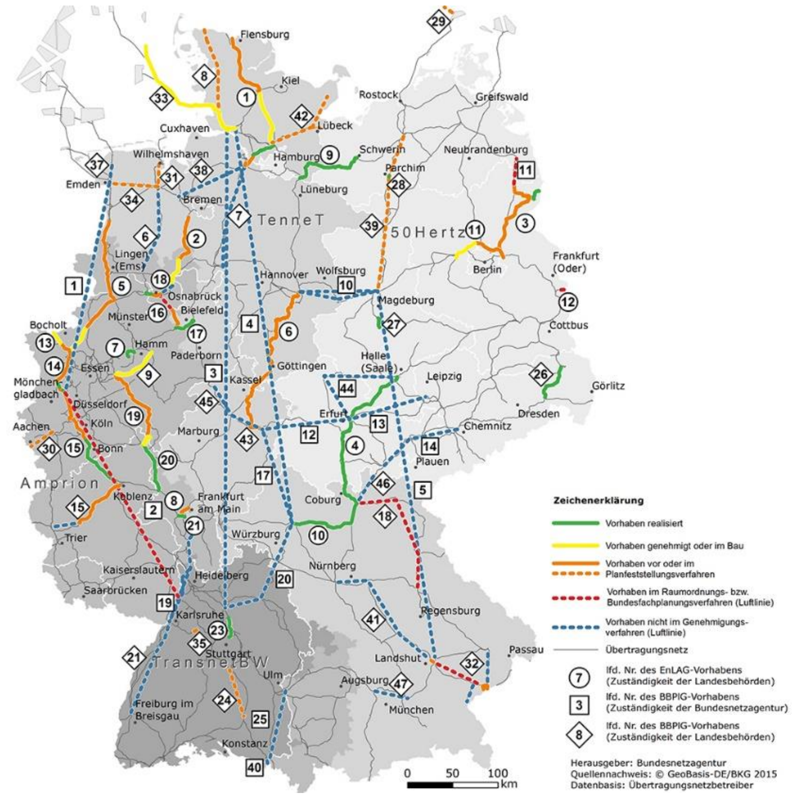
Why we do it

Examples of feed-in from renewable sources in the year 2050



Klaus et al. (2010)

+ wind power



+ solar power

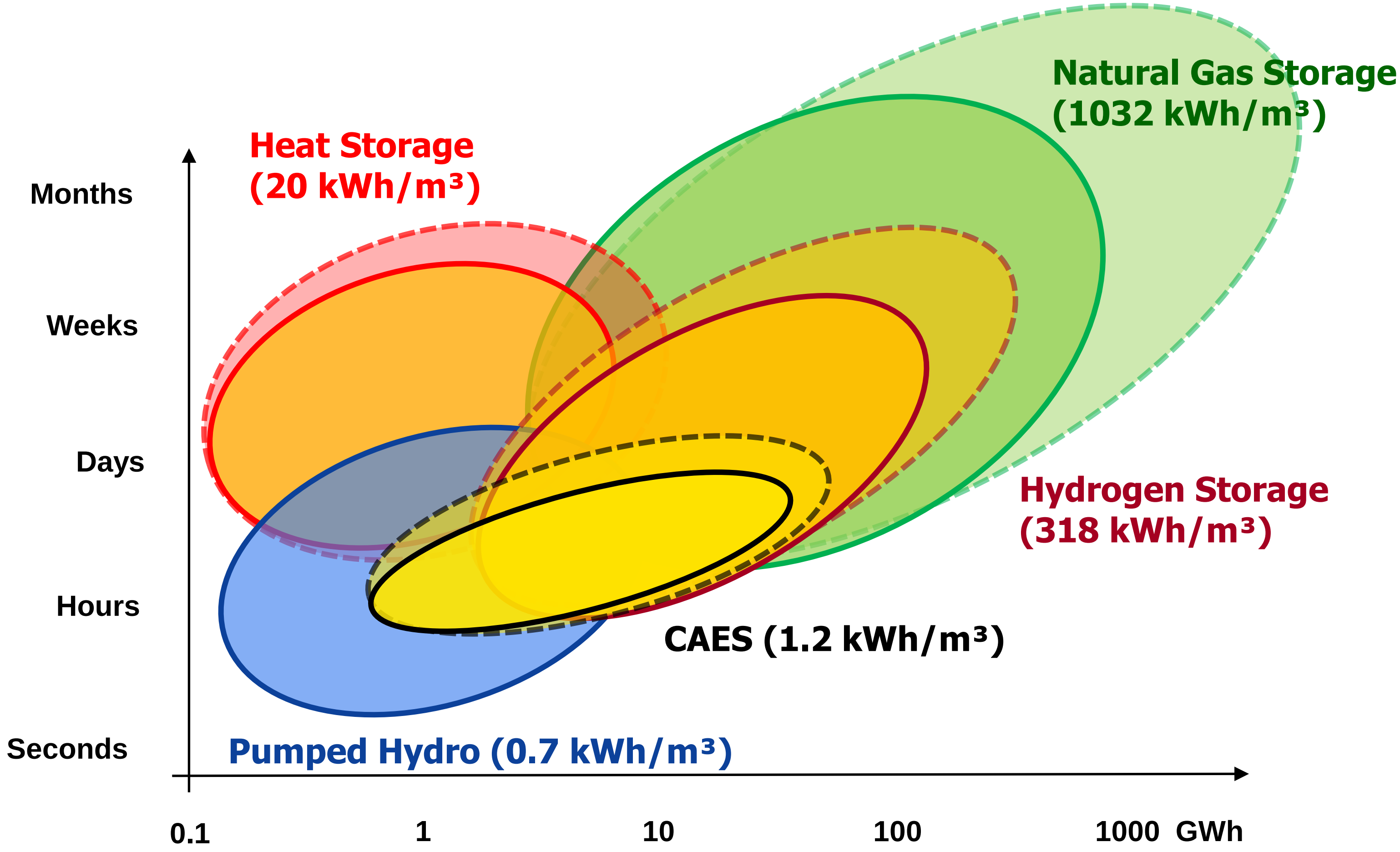
- Therefore, **large storage capacities** (~tens of TWh) for Power2Gas or Power2Fuel / Power2Liquid but also for Power2Heat (Sektorkopplung) are required.

- The **geological subsurface** offers huge potential energy storage capacities as required on the national scale.

Geological storage options

Geological storage options cover a wide range of time scales as well as capacities

Many options exist in Germany, especially the North, so storage sites can be flexibly placed



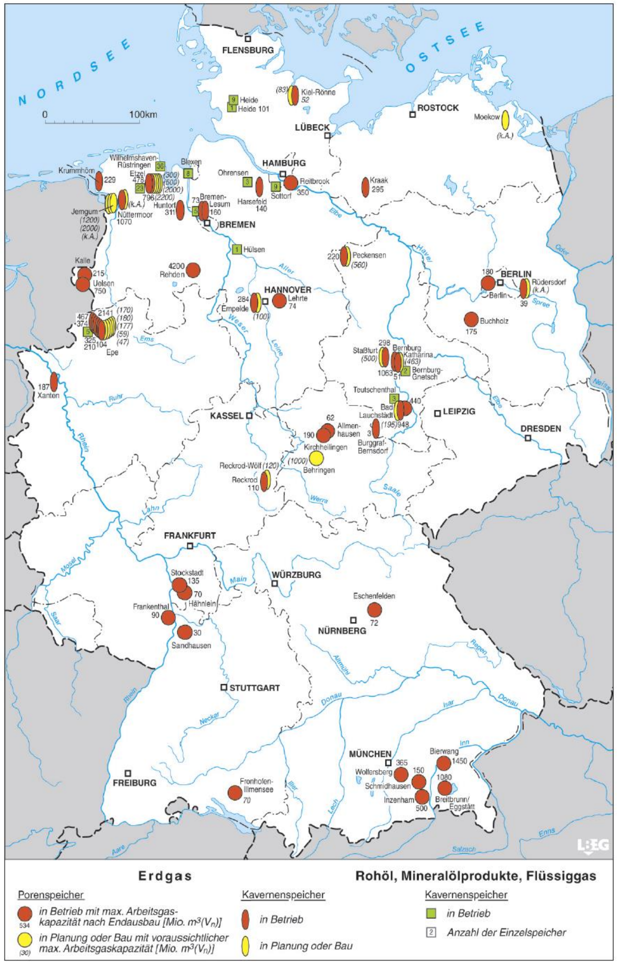
Geological Gas Storage Options

Gas storage for storage of

- hydrogen (~300 kWh/m³)
- synthetic methan (~1000 kWh/m³)
- compressed air (~1 kWh/m³)

From renewable production (wind / solar; Power2Gas)

Gas is the energy storage medium, the subsurface is used as storage container (mass storage)



Porous media storage

- permeable storage formations in suitabel depth with tight cap rock, access by wells
- Very large capacities and rates
- Rates limited by geological setting and formation permeability
- Pressure loss and geochemical reactions possible

Cavern storage

- Salt formations in suitable depth, one well per cavern
- Very large capacities and rates, low pressure losses

Storage potential for both options

For example in Schleswig-Holstein

Porous media storage

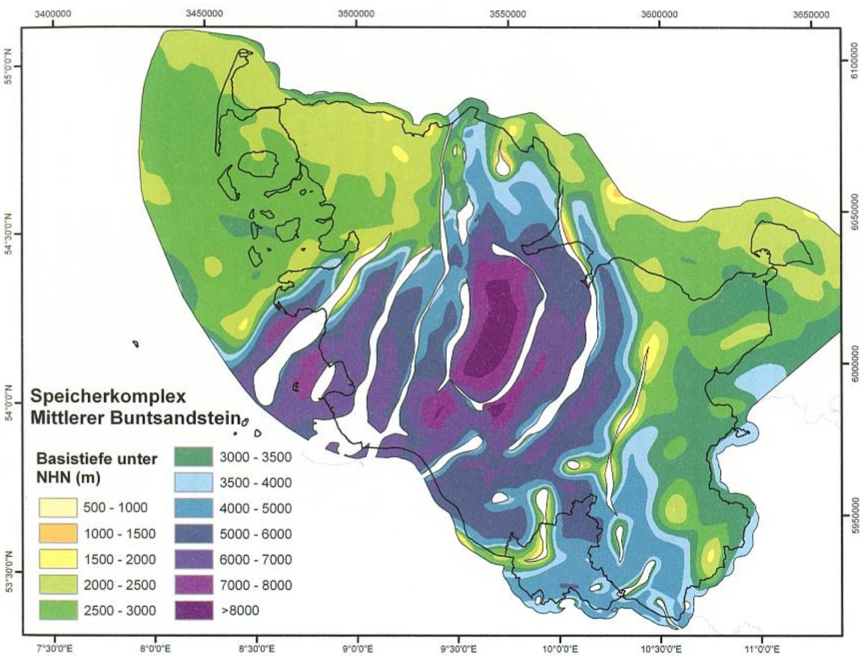


Abb. 5: Verbreitung des Mittleren Buntsandstein und Tiefenlage [Basis] (verändert nach Baldschuhn et al. 2001).

cavern storage

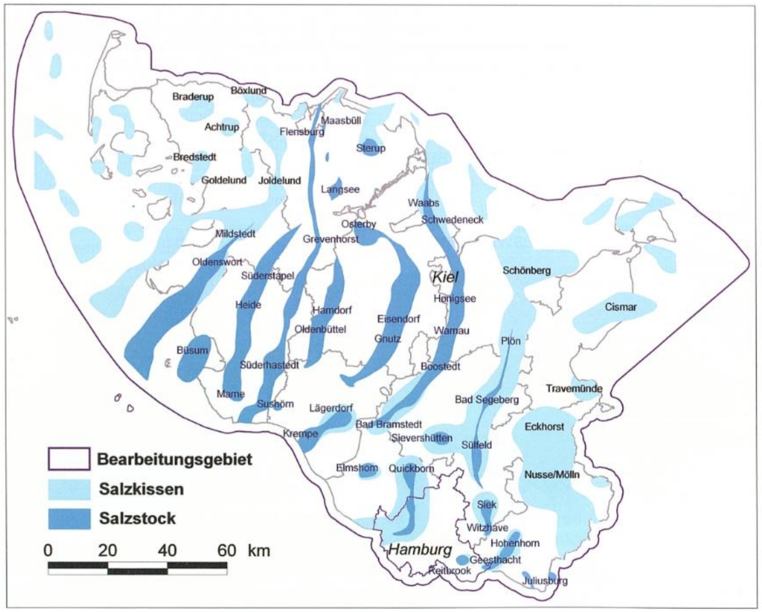
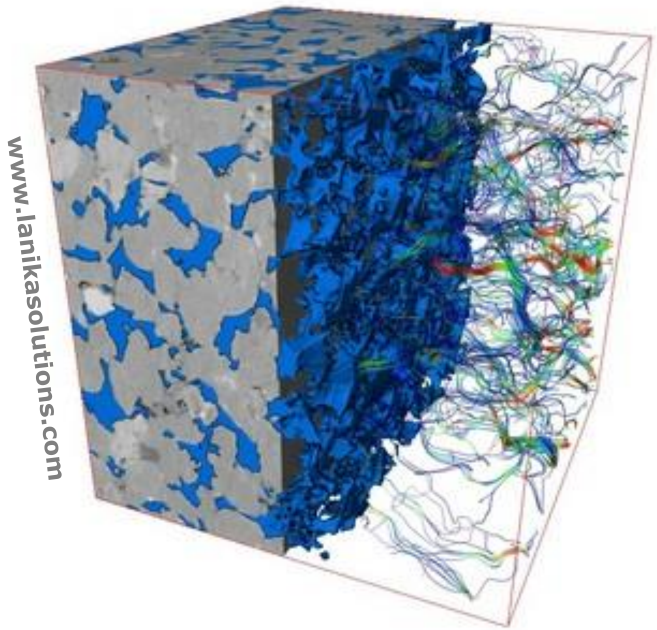
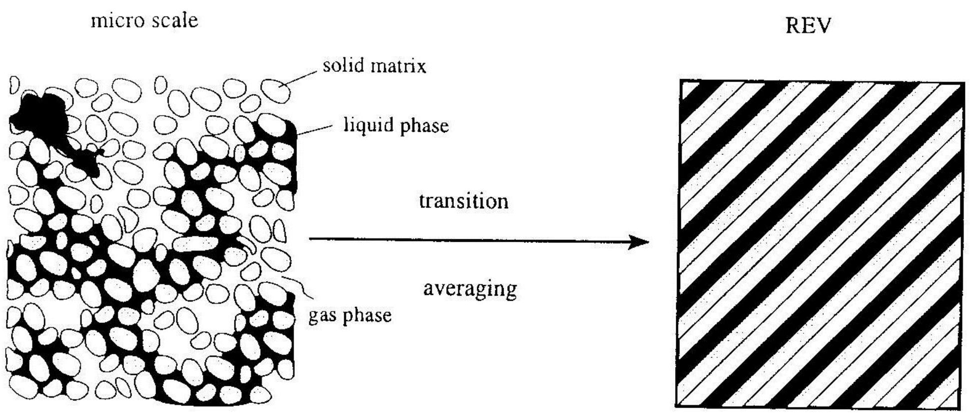


Abb. 2: Verbreitung der Salzstöcke und Salzkissen (Perm-Salinare) in Schleswig-Holstein und Hamburg (verändert nach Baldschuhn et al. 2001).

Hese, 2012

Porous medium approach





Helmig, 1997

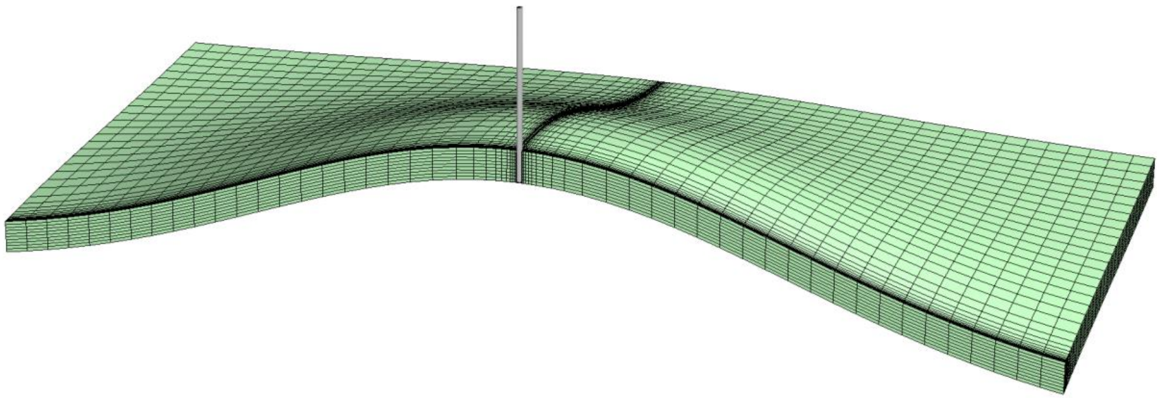
The geological subsurface as a composite, porous medium

water phase, gas phase	->mobile
solid phase	-> solid
V_{gas}, V_{water}, V_{solid}; $\Sigma V_i = 1$	-> volume fractions of subsurface volume
$V_{gas} + V_{water} = n$	-> void space (porosity)
$S_{gas} + S_{water} = 1$	-> mobile fluid phases only in void space

Averaging and homogenization lead to equivalent material and process parameters on the macro-scale.

Modeling of energy storage in the subsurface

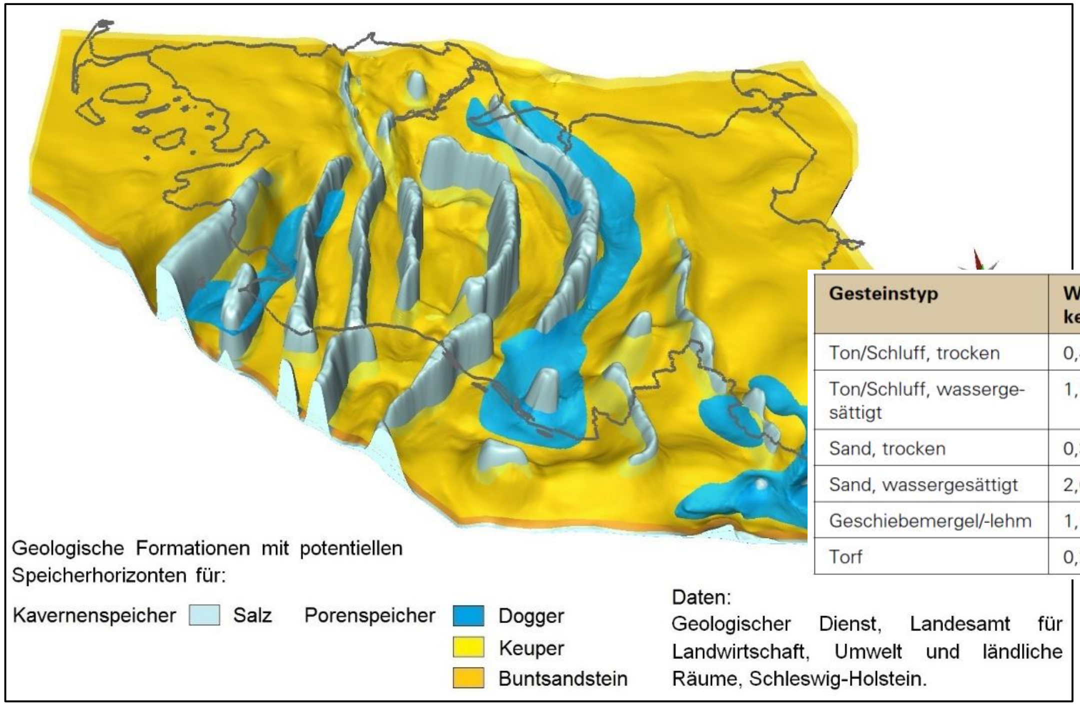
- Fluid flow, heat transport and mass transport are thus described by physical balance equations on the macro-scale.
- The required material parameters for these balance equations need to be determined by (local) measurements. Due to the micro-effects in the composite medium, they are often non-linear and complex
- These balance equations are partial differential equations in 3D space and time and can be solved by analytical and numerical mathematical techniques.
- Due to the heterogeneous distribution of subsurface geological properties, space discretized schemes (FD, FE, FV) are typically applied.



Model Parameter Availability

- Mapping of potential storage formations (Caverns, Porous Media)
- Collection of process and formation parameters

Subsurface Mapping in Schleswig-Holstein



Gesteinstyp	Wärmeleitfähigkeit in W/mK
Ton/Schluff, trocken	0,4 - 1,0
Ton/Schluff, wassergesättigt	1,1 - 3,1
Sand, trocken	0,3 - 0,9
Sand, wassergesättigt	2,0 - 3,0
Geschiebemergel/-lehm	1,1 - 2,9
Torf	0,2 - 0,7

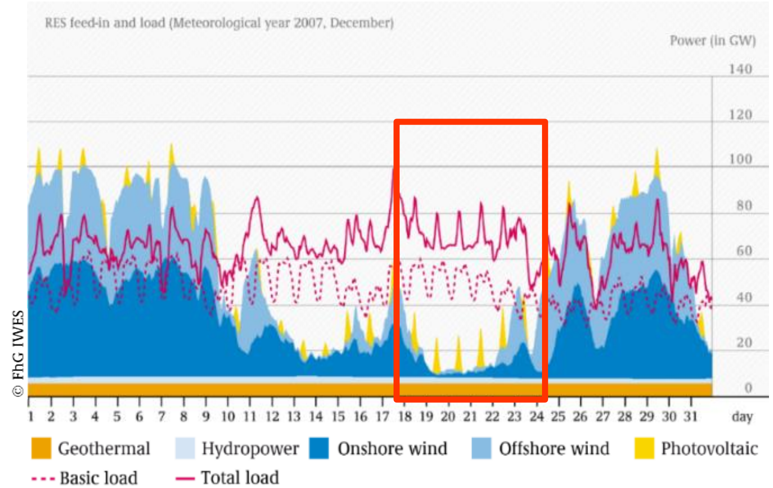
Process-Parameters

Prozess	Phase	Parameter		Verfügbarkeit
Hydraulik (H)	Fluid	Fluiddichte	ρ(p,T,C)	green
		Fluidviskosität	ν(p,T,C)	green
	Gestein-Fluid	hydraulischer Gradient	grad(h)	yellow
		relative Permeabilität	k_r(S)	red
		Kapillardruck	p_c(S,time)	red
		Oberflächenspannungen	σ	yellow
		Benetzungswinkel	α	red
	Gestein	Permeabilität	k_v,k_h(x,y,z)	yellow
		Porosität	n(x,y,z)	yellow
		Gesteinsdichte	ρ(x,y,z)	yellow
…metransport (T)	Fluid	Wärmeleitfähigkeit	λ(p,T,C))	green
		Wärmekapazität	c(p,T,C)	green
		thermische Expansion	$β_T$	green
	Gestein	Wärmeleitfähigkeit	λ(x,y,z)	yellow
		Wärmekapazität	c(x,y,z)	yellow
		Wärmedispersivitäten	$α_{v/h}$(x,y,z)	red
	Gestein	Elastizitätsmodul	E(x,y,z)	yellow
		Possionzahl	v	green
		Matrixkompressibilität	κ	yellow
		Kornkompressibilität	κ	yellow
		Biot's Koeffizient	b	green
		Kohäsion	C	yellow
Komponententransport (C…	Fluid	Diffusionskoeffizient	D_{aq}(T)	green
		Komponentenlöslichkeiten	H(p,T,C)	yellow
		Molgewichte	MW	green
		Reaktionsraten	Kreact(C,T,?)	yellow
		Lösungszusammensetzung	C_i(x,y,z)	yellow
		mikrobiolog. Zusammensetz.	X_i(x,y,z)	red
	Gestein	Tortuosität	τ(x,y,z)	red
		Dispersivität	$α_{v/h}$(x,y,z)	yellow
		Korndurchmesser	d(x,y,z)	yellow
		effektive Porosität	n_e(x,y,z)	yellow
		Mineralzusammensetzung	M_i(x,y,z)	yellow
		C_{org}-Gehalt	C_{org}(x,y,z)	yellow

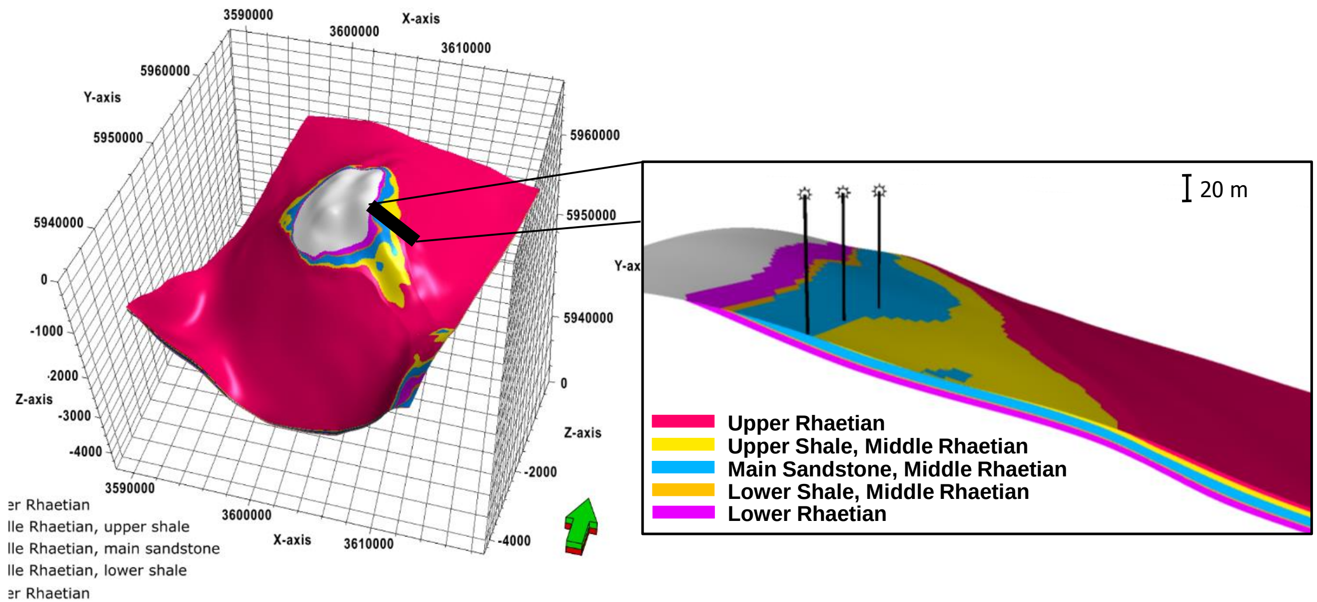
H_2 Storage scenario: Geological setting

Scenario:
Securing electric energy supply during a period of one week with no electricity production from renewable sources in Schleswig-Holstein

- 250 GWh
- Required H_2 volume: 129.12 mio. sm³ at 60% re-electrification efficiency and 0.0106 GJ/m³ energy density



Klaus et al., 2010



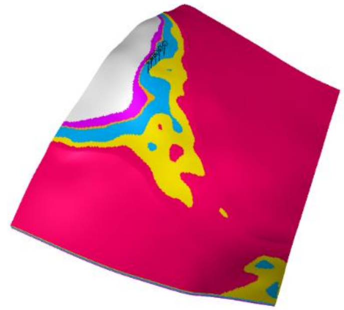
Geological storage site:

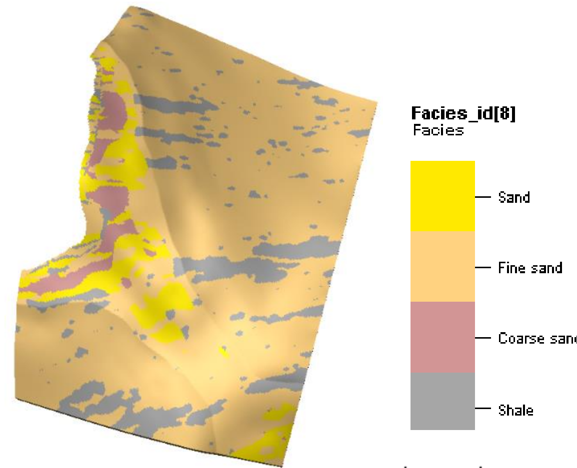
- porous sandstone in anticlinal structure
- 500 m depth
- 5 operation wells
- Pressure ranges from geological setting

Parametrization & simulation setup

Storage parametrization

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

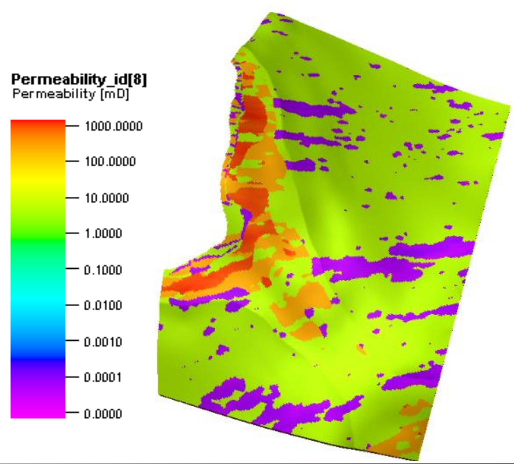


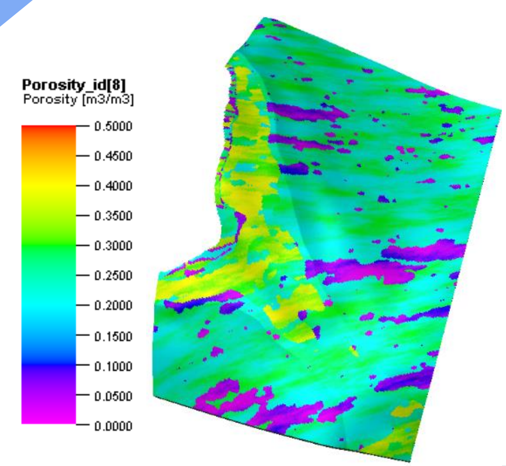


Component	Permeability [mD]			Porosity (effective)			Srw	k_{rg0}	p_d [bar]
	mean	min	max	mean	min	max			
Shale	0.00005	1E-06	0.00001	0.05	0.01	0.1	0.6	0.015	15
Fine Sand	5	0.1	10	0.25	0.2	0.3	0.4	0.3	0.5
Sand	250	10	500	0.35	0.3	0.4	0.4	0.5	0.2
Coarse Sand	1000	500	2500	0.35	0.3	0.4	0.3	0.9	0.1

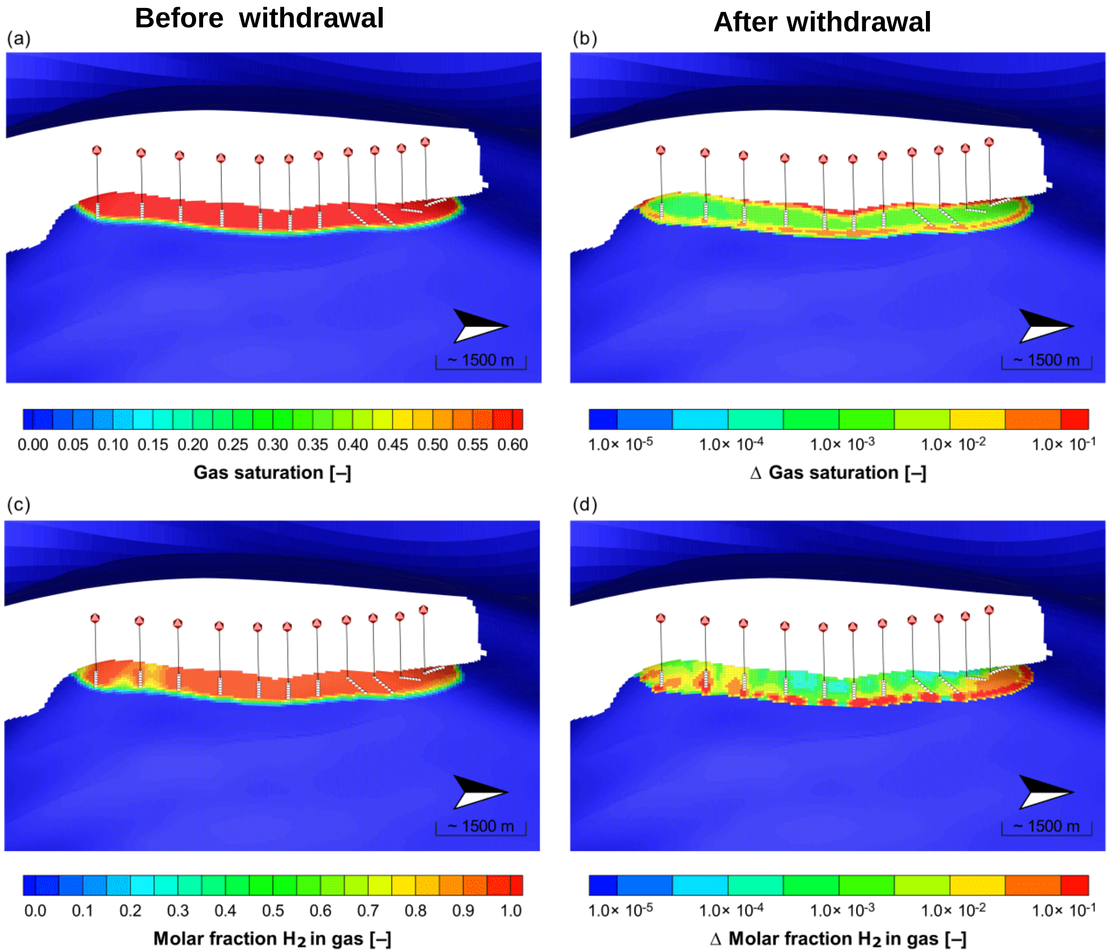
Storage phases

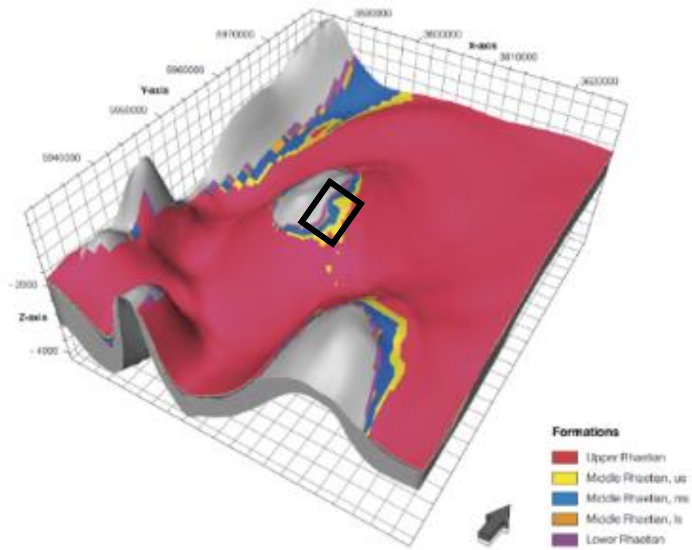
1. Cushion gas injection: N_2
   - ~ 201 mio. sm³
2. Initial filling with H_2
   - ~ 162.75 mio. sm³
3. Cyclic extraction/injection of H_2
   - Target extraction rate per well: 1000000 sm³/d → 35 mio. sm³ tot
   - Target injection rate per well: 155000 sm³/d
   - 7 days extraction / 50 days injection





Model results

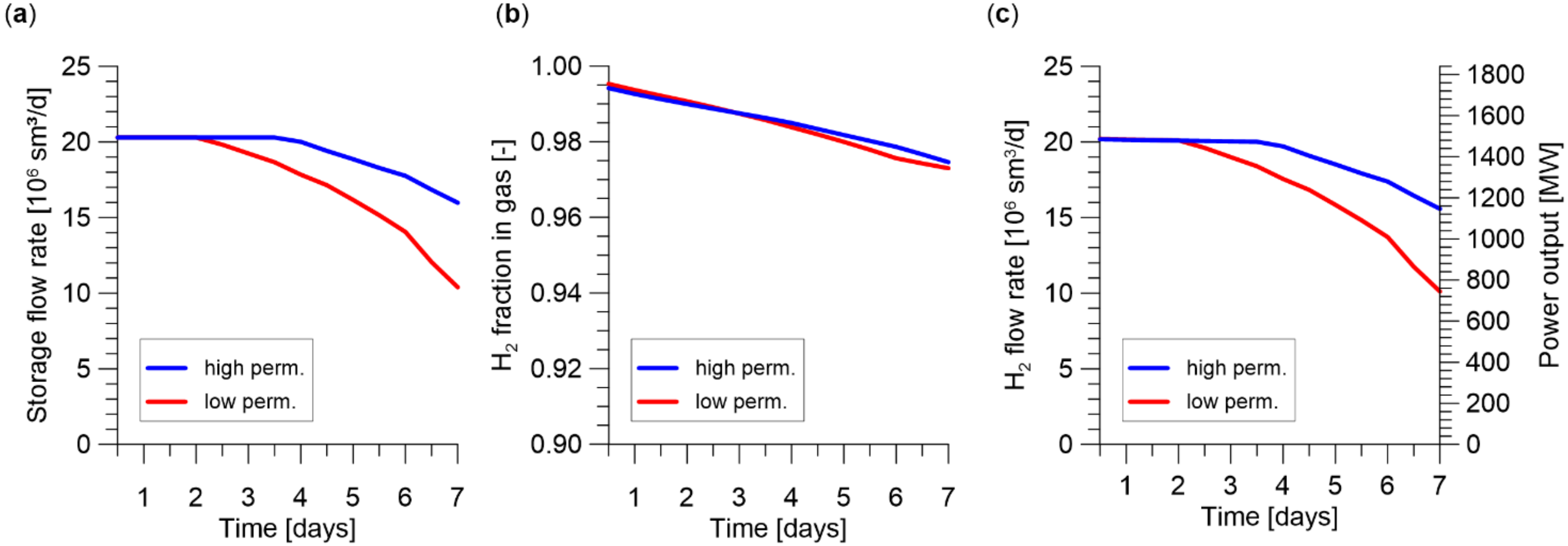




Storage operation

- Gas phase accumulates in the structural top, evenly distributed
- Extent of gas phase: around 7 km x 750 m
- Storage operation mainly through compressibility

Model results



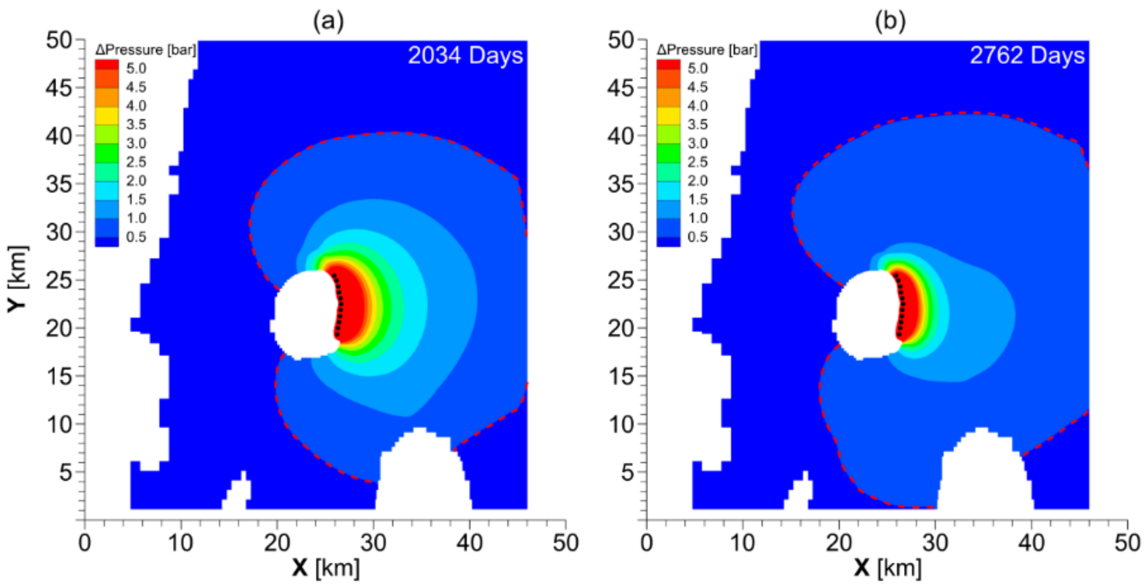
18th storage cycle

Storage performance

- Decrease in flow rates observed during withdrawal
- Sustainable power output: 750-1160 MW
- H_2 provided equivalent to: 205-233 GWh

=> Provides electricity needed in Schleswig-Holstein (2.8 Mio. Inhabitants) for about 1 week.

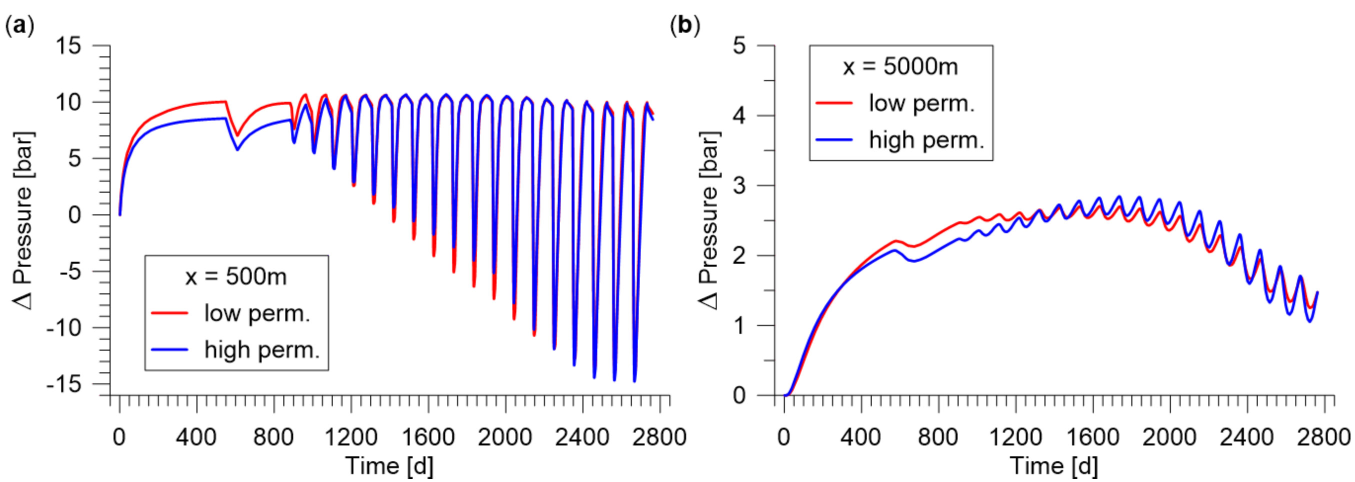
Model results



Hydraulic effects

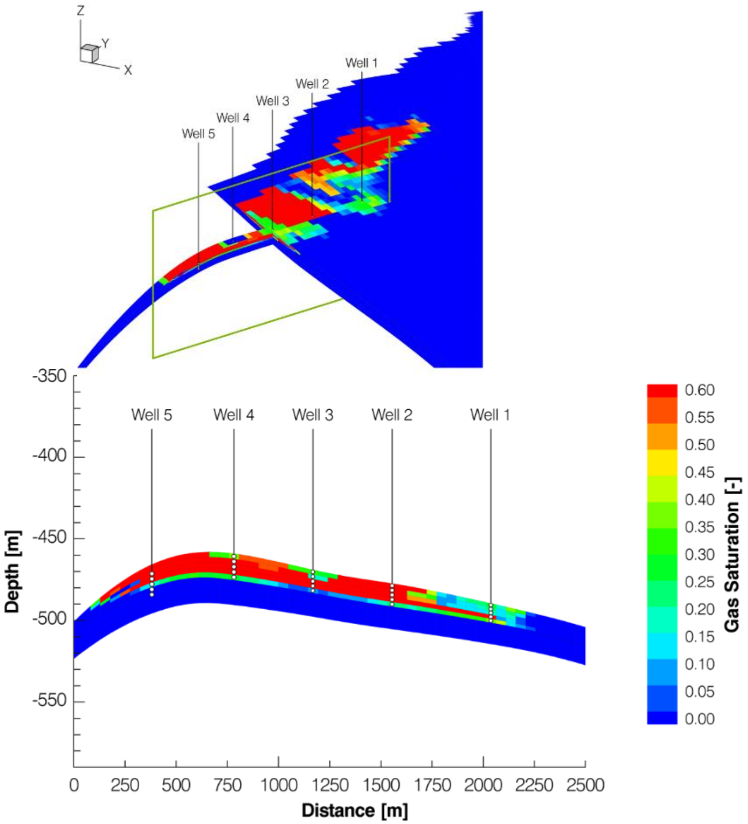
- overpressures due to gas injection:
  - ➢ below 10 bars outside of gas phase
  - ➢ around 20 bars at wells

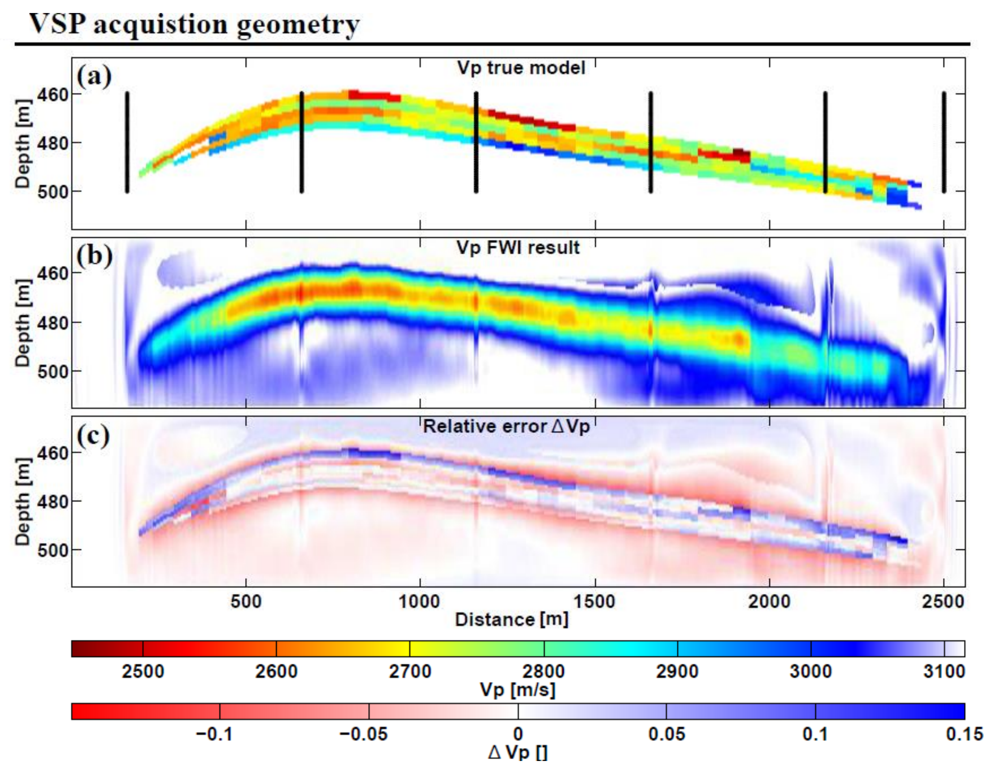
- Long term decline to initial pressure due to BC



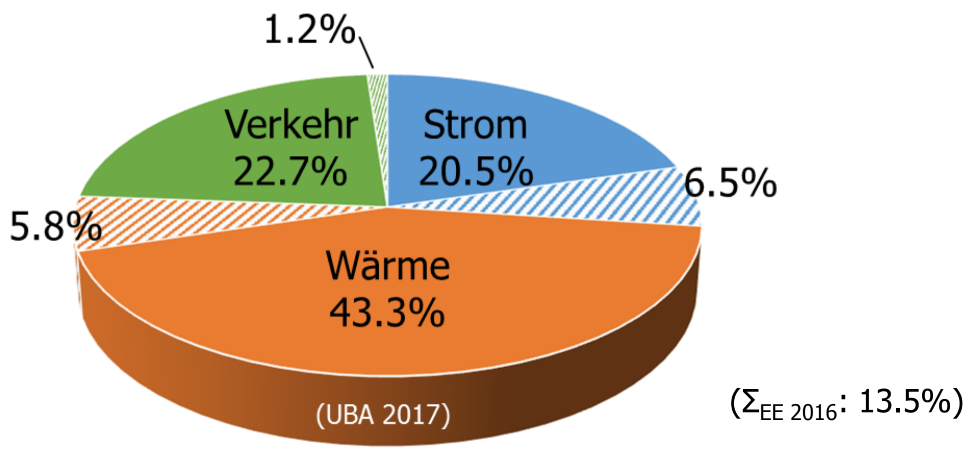
Geophysical monitoring

- Potential Methods: *Seismic*, geoelectric, gravity
- Thin gas phase body makes detection difficult





- Gas phase detection possible with geophysical methods
- High spatial density of measuring points required



Total Energy consumption in Germany 2016: 2895 TWh

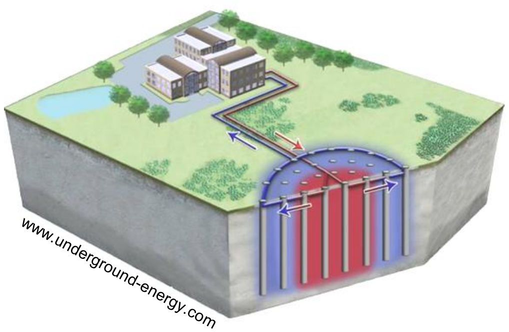
Energy transition until 2050 (BMWi):

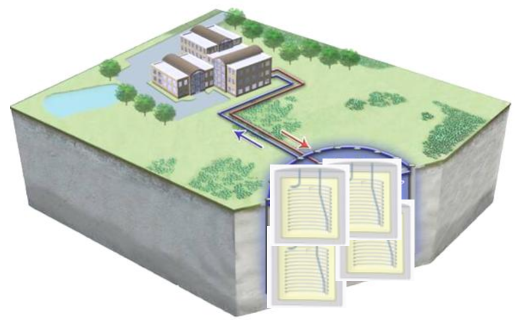
- 80-95% reduction of greenhouse gas emissions
- 60% renewable energy (EE)

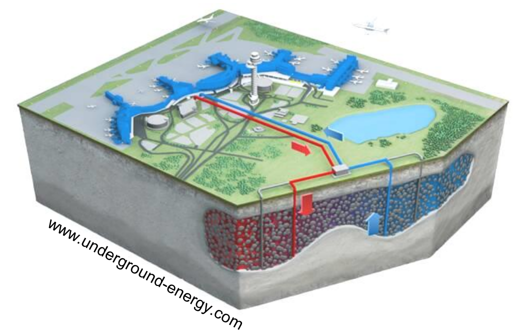
→ Heat market (40-100 Mrd €/a) Has a key role in the energy transition

Tapping of renewable heat sources and daily to seasonal heat storage required

Geotechnical heat storage options







Borehole thermal heat storage (BTES)

- using borehole heat exchangers (BHE) for heat injection / extraction
- work in low permeable geologic settings
- only choice when water cycling is not feasible
- scalable by increasing the number of BHEs

Cement-based thermal heat storage (CBTES)

- using specifically designed cements as heat storage medium with large scale heat exchangers
- Use as part of building construction or basis
- Near surface application
- scalable by increasing the number of individual elements

Aquifer thermal heat storage (ATES)

- using injection and extraction wells for circulating the water
- work in high permeable geologic formations (aquifers)
- high energy rates can be achieved
- scalable by increasing the number of wells

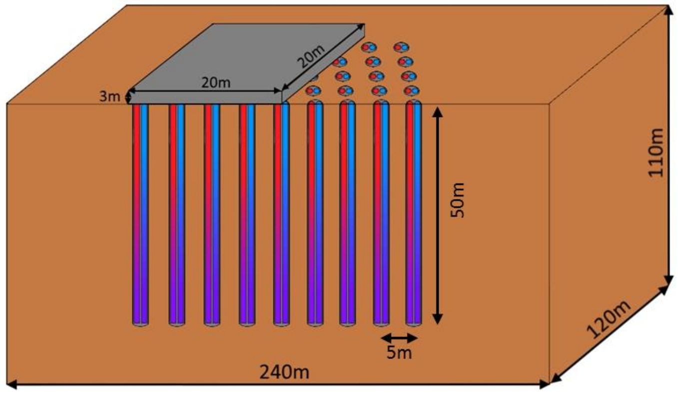
- Geological heat storage scalable up to GWh capacity (20 kWh / m³ @ 35K ΔT)
- Use of higher temperatures (up to 90°C) enhances performance
- Subsurface is storage medium, BHEs are conductive heat exchangers, for ATES the groundwater is used as heat exchanger fluid.

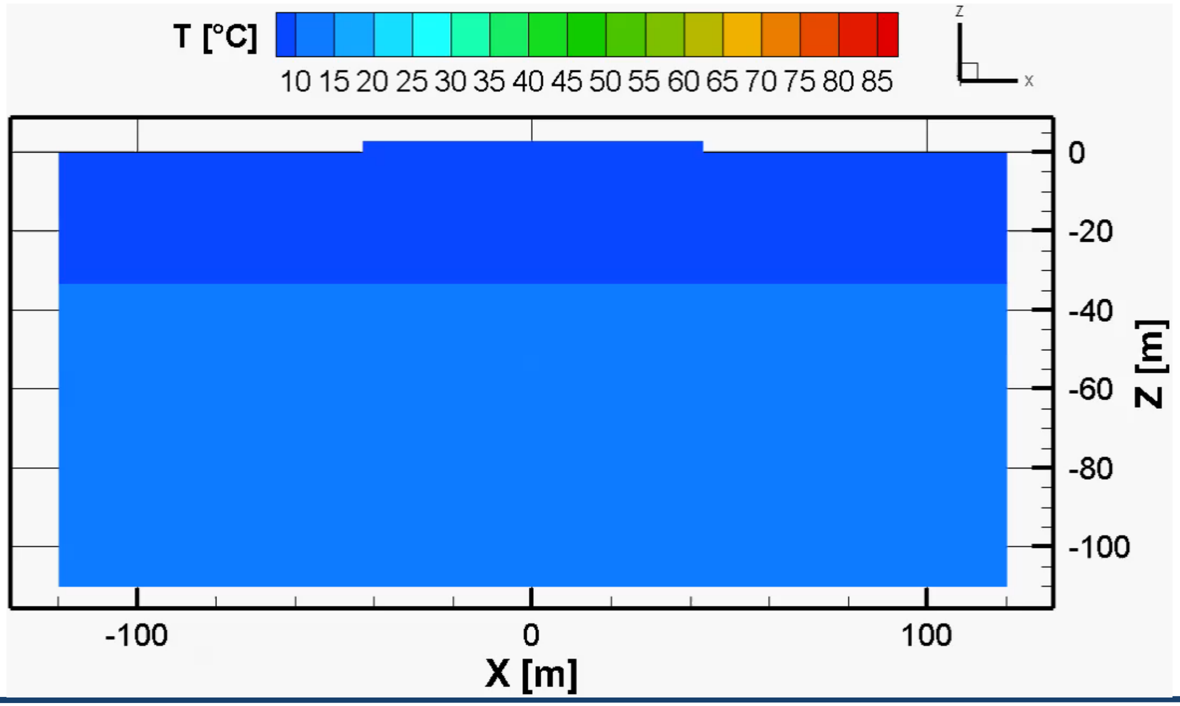
BTES scenario: Set-up

Storage capacity, rates and induced thermal effects of a BTES site

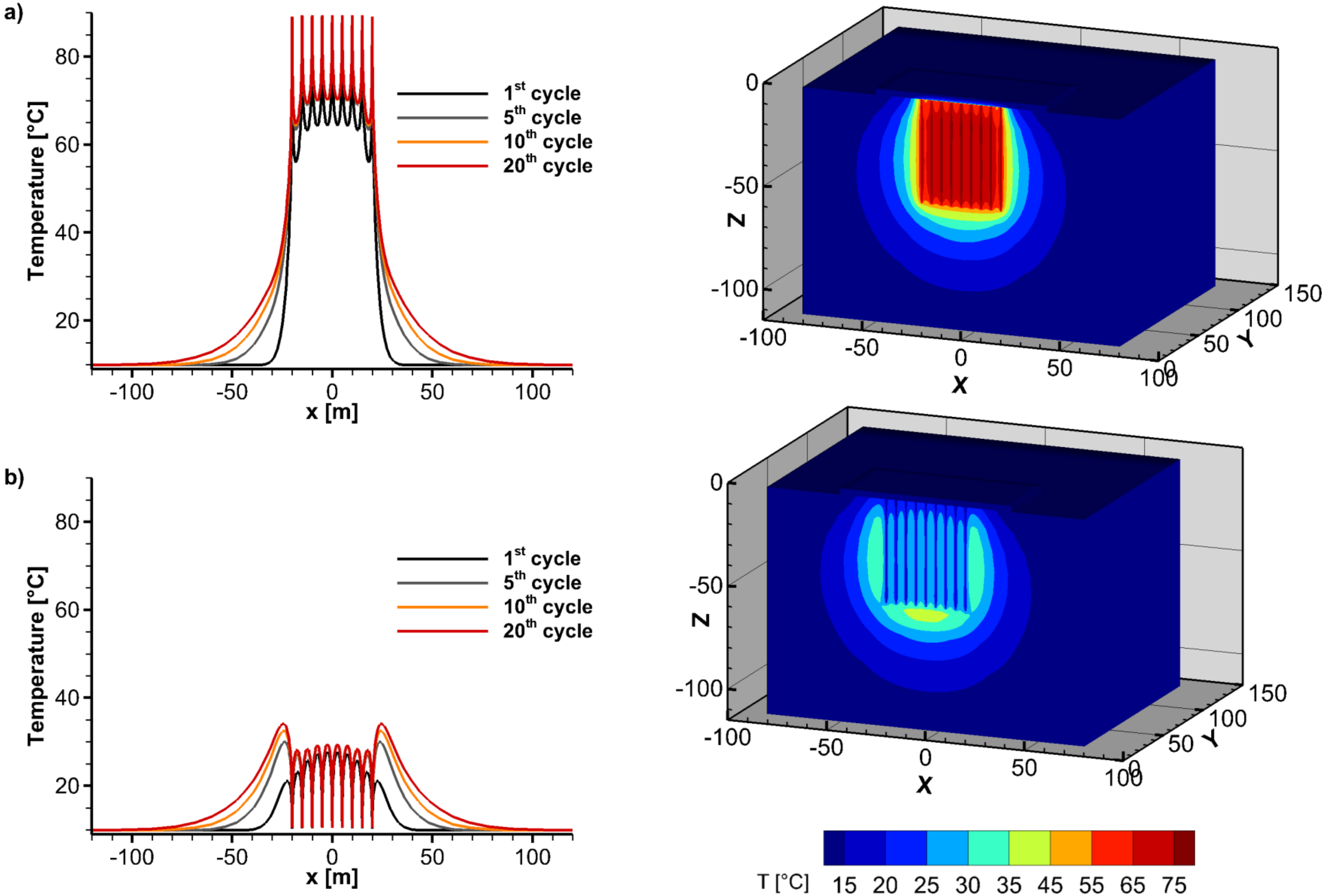
Synthetic scenario of seasonal heat storage (i.e. from solar thermal energy) through a borehole heat exchanger storage site in a typical geological formation:

- 61 Double-U BHEs: 50 m length, 5 m distance
- Simplified cyclic operation for 20 years with
  - heat input in summer at 90°C
  - heat output in winter

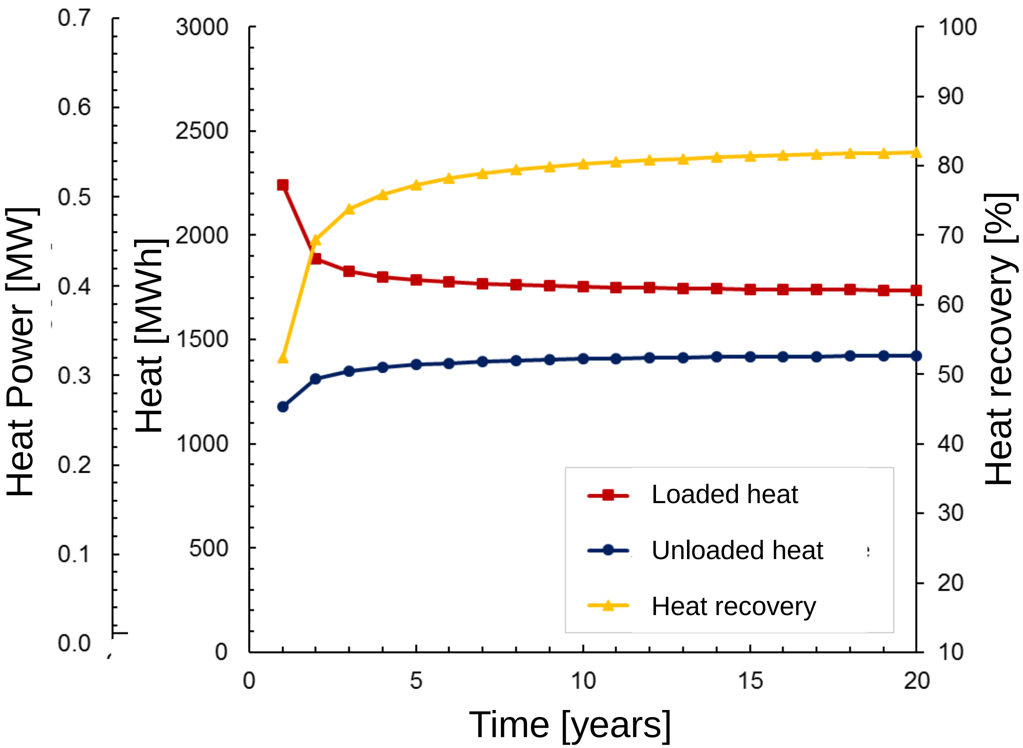


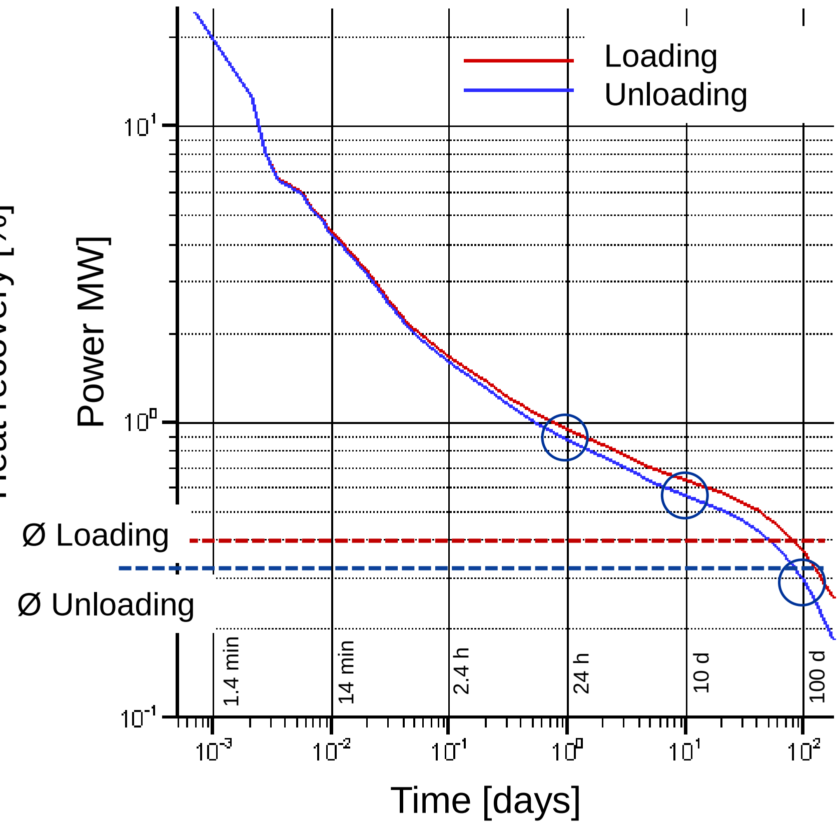


BTES scenario: Storage characteristics



BTES scenario: Storage characteristics





Storage characteristics:

- Storage capacity: 1400 MWh at 0.5a
- Average power: 330 kW
- Heat recovery: approx. 80%

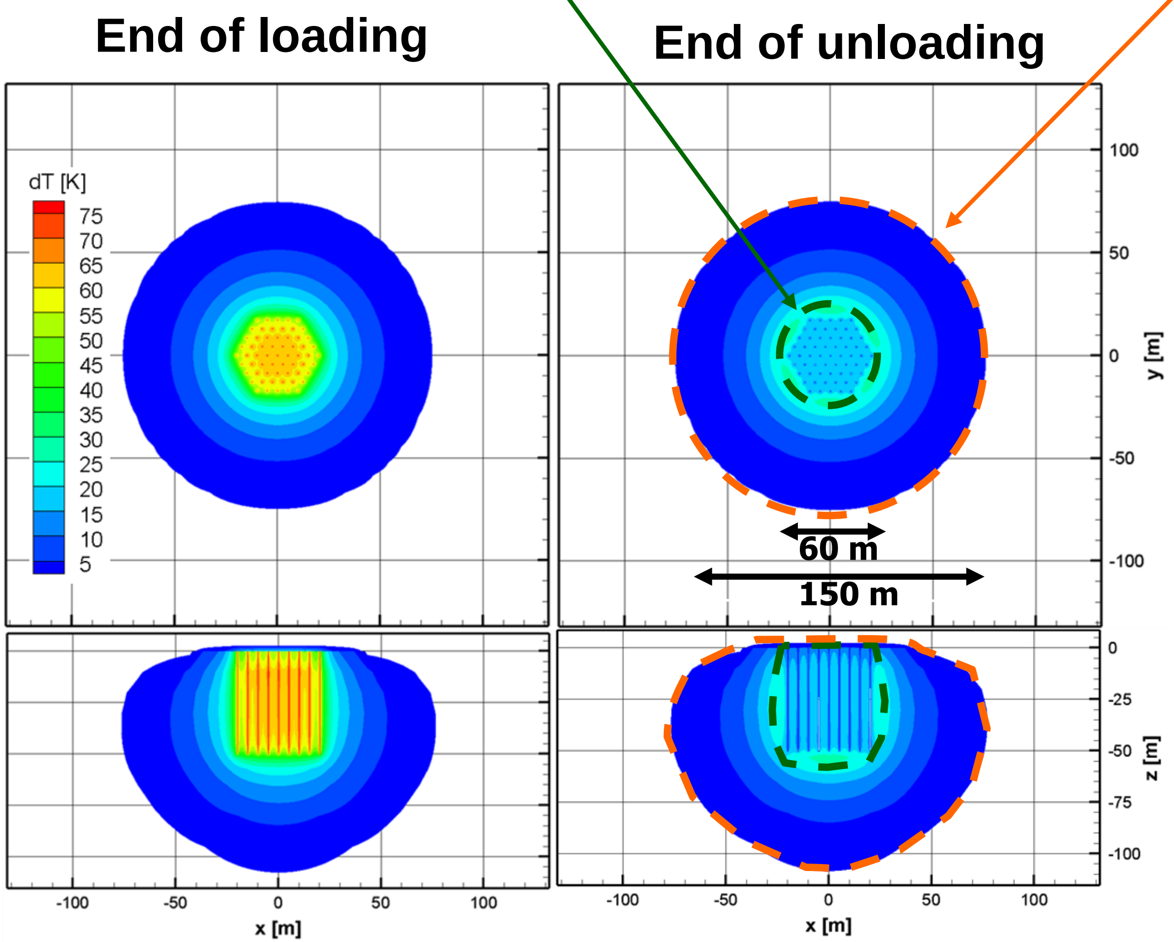
Power output rates:

- 1 day: 0.90 MW
- 10 days: 0.57 MW
- 100 days: 0.29 MW

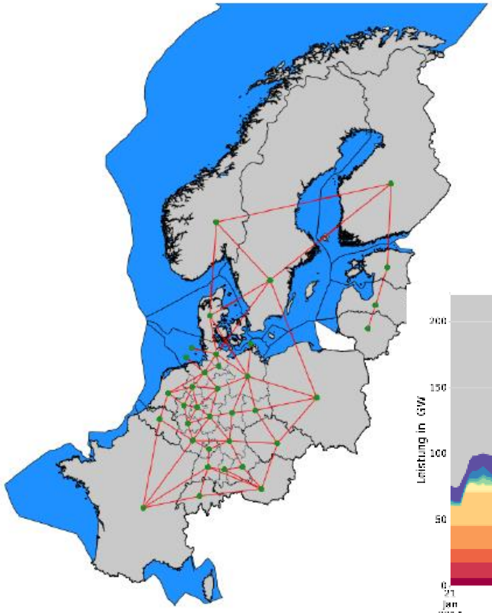
BTES scenario: Use of subsurface space

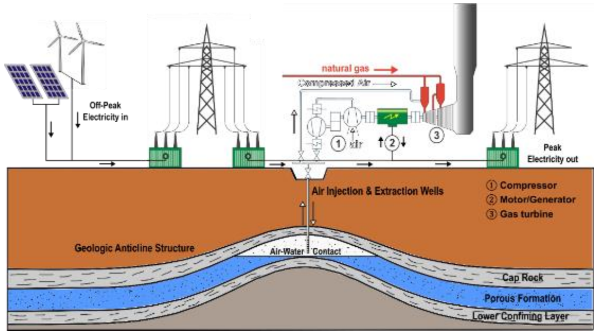
BHE installations
0.003 km² used directly

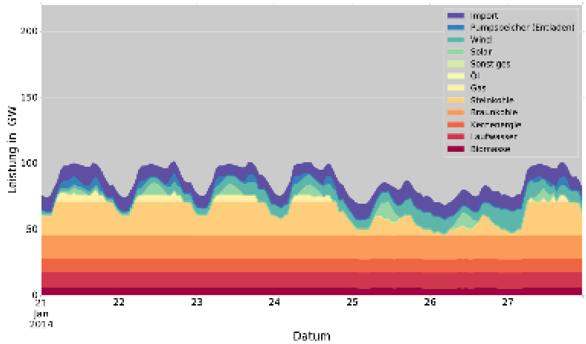
Temperature change Δ1°C
0.018 km² with temperature changes > 1K

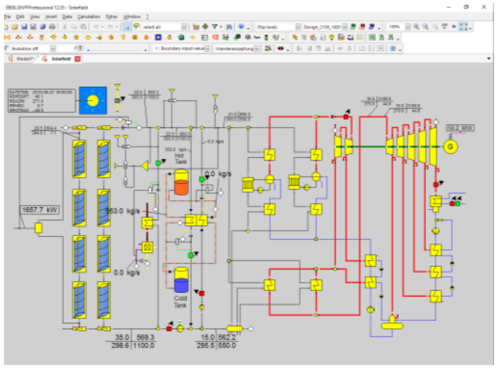


Storage integration into the energy system









Development of simulation tools for power and heat distribution networks and supply and demand units with higher spatial and temporal resolution. This allows the

- Identification of power supply and demand, as well as storage demand and surplus situations
- Identification of optimized operation schedules for power plants as well as sector coupling (e.g. P2H)
- Identification of storage operation schedules and management options in both todays as well as future energy systems

Summary & Conclusions

- For geological energy storage, the geological subsurface is directly used as storage material. Technical installations are only required for injection and extraction of stored energy.
- The basic physical and chemical processes involved in heat and mass storage in the geological subsurface are known.
- Simulation methods are available, but need to be adapted to the specific needs of subsurface geosciences.
- Local measurements of material subsurface properties are required, but expensive and difficult
- Geological storage can provide large capacities (GWh scale) and a wide range of withdrawal rates (60 MW per well hydrogen; 100s kW heat). Storage choice and dimensioning depends not only on geology but also on power / heat grid requirements, power plant configurations, and economics.
- Preliminary estimation of space requirements shows that the subsurface offers much larger storage options than required.
- The determination of the storage demand requires a quantification of the power /heat grid and technical installations. This requires interdisciplinary cooperation of experts from a variety of backgrounds.

Thank you very much for your attention.

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