Large Scale thermohaline salt cavern- & Small Scale urban home-energy geostorages - a geomechanical view

Frank Wuttke & Henok Hailemariam

Kiel University

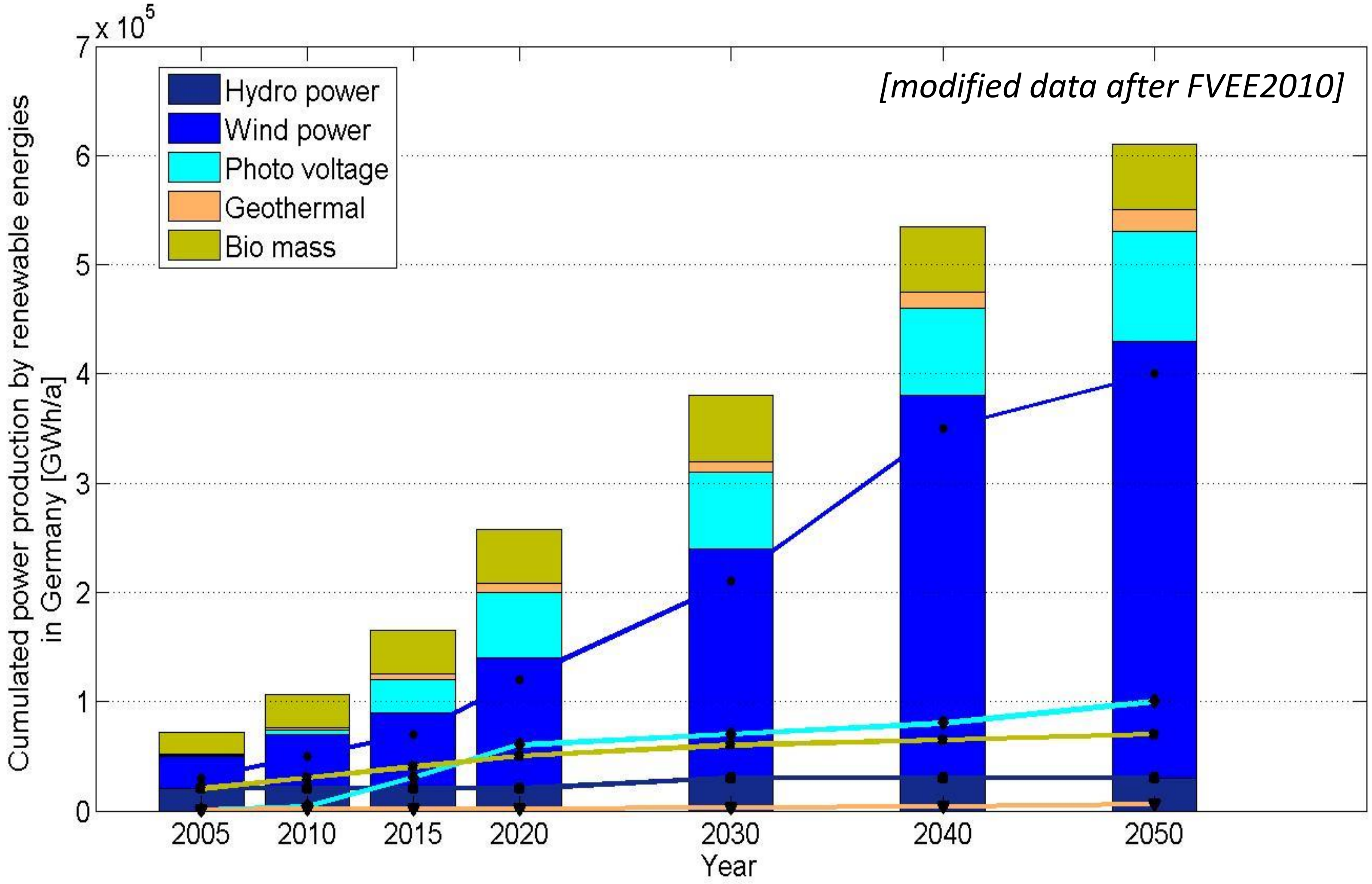
Outline

1) Introduction into Energy Geo-Storage Systems

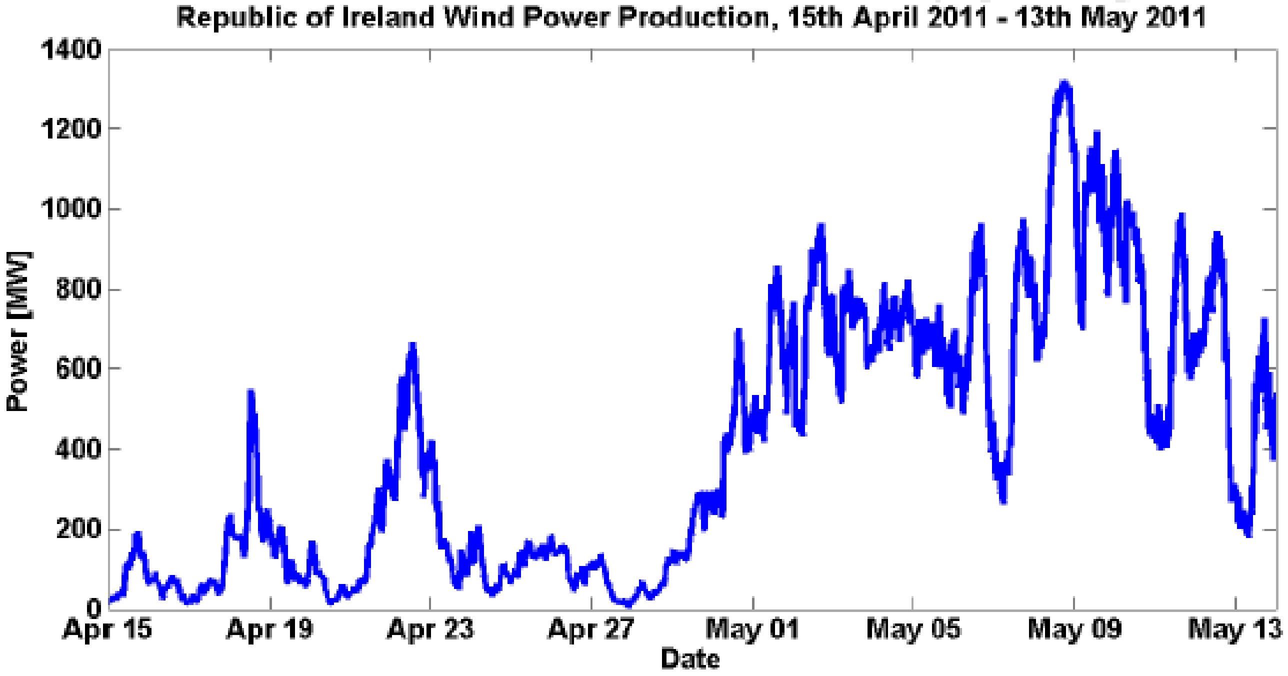
2) Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

3) Urban Energy Geo-Storage (Small Scale Geo-Storage)

Introduction into Energy Geo-Storage Systems

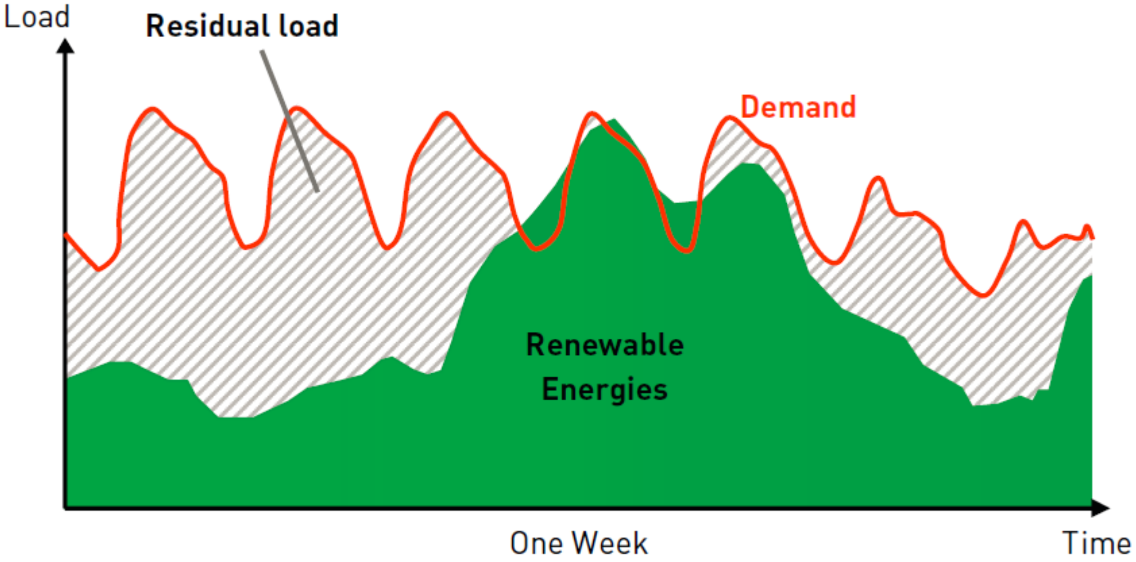


Introduction into Energy Geo-Storage Systems



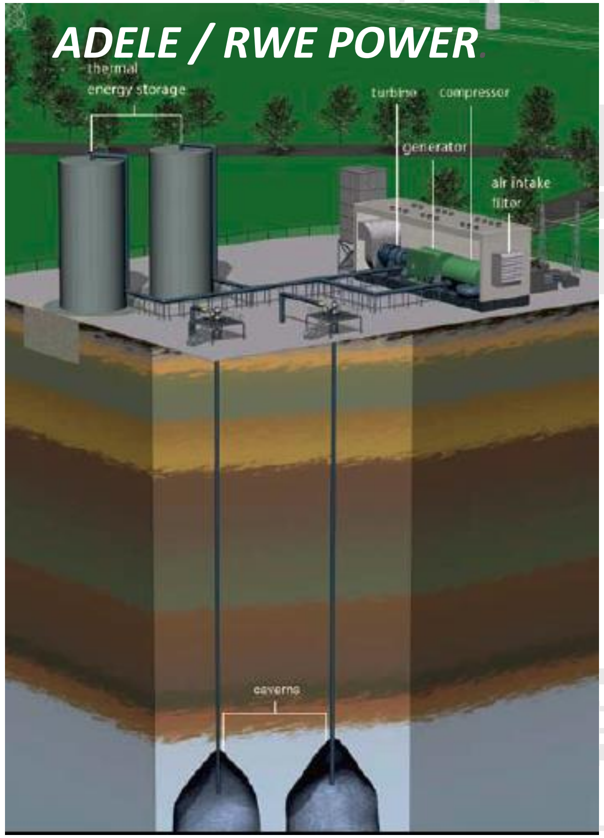
Connolly, D.(2010) Fluctuating Renew. Energy

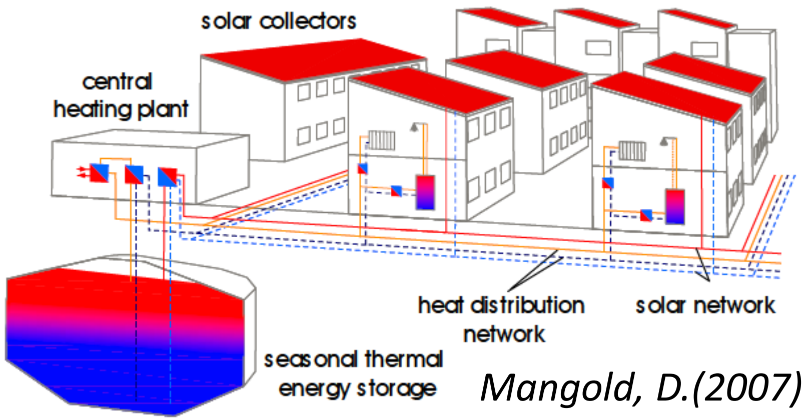
Fossil power plants for demand-supply gaps



Introduction into Energy Geo-Storage Systems

Energy storage





Mangold, D.(2007) ESTEC

Introduction into Energy Geo-Storage Systems

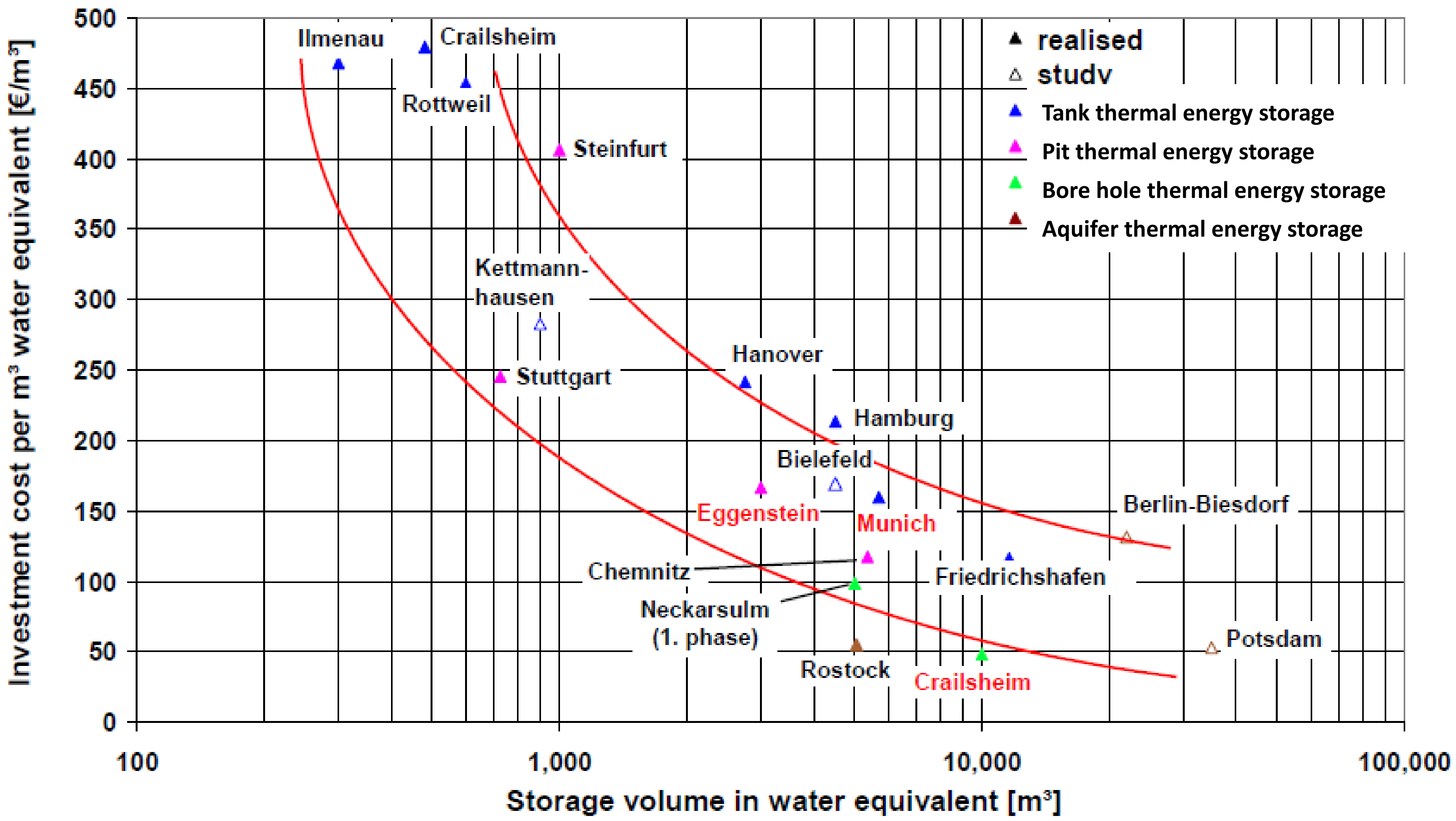
Storage type	Classes	Volumetric Energy density	Storage size
Thermal storage (Sensible energy storage)	Aquifer Storage	30-40 KWh/m³	>100.000 m³
	Thermohaline Storage	60-80 kWh/m³	500.000…10.000.000 m³
	Rock cavern-water storage	60-80 kWh/m³	10.000…100.000m³
	Bore hole heat exchanger	15-30 kWh/m³	10.000…20.000m³ expandable
	Gravel-water thermal storage	30-50 kWh/m³	<10.000 m³
	Soil-water thermal storage	30-60 kWh/m³	<10.000 m³
Phase change Material Energy Storage	Snow-Ice cryogenic storage		<100.000 m³
Mechanical storage	Compressed air storage, adiabatic	2 kWh/m²	300.000 m³
	Pumped hydroelectric storage	1 kWh/m³	12.000.000 m³
Chemical energy storage	Hydrogen storage	410 kWh/m³	70.000…500.000 m³
	Fuel storage / Diesel	9700 kWh/m³	

Large Storage Systems

Urban Storage Systems

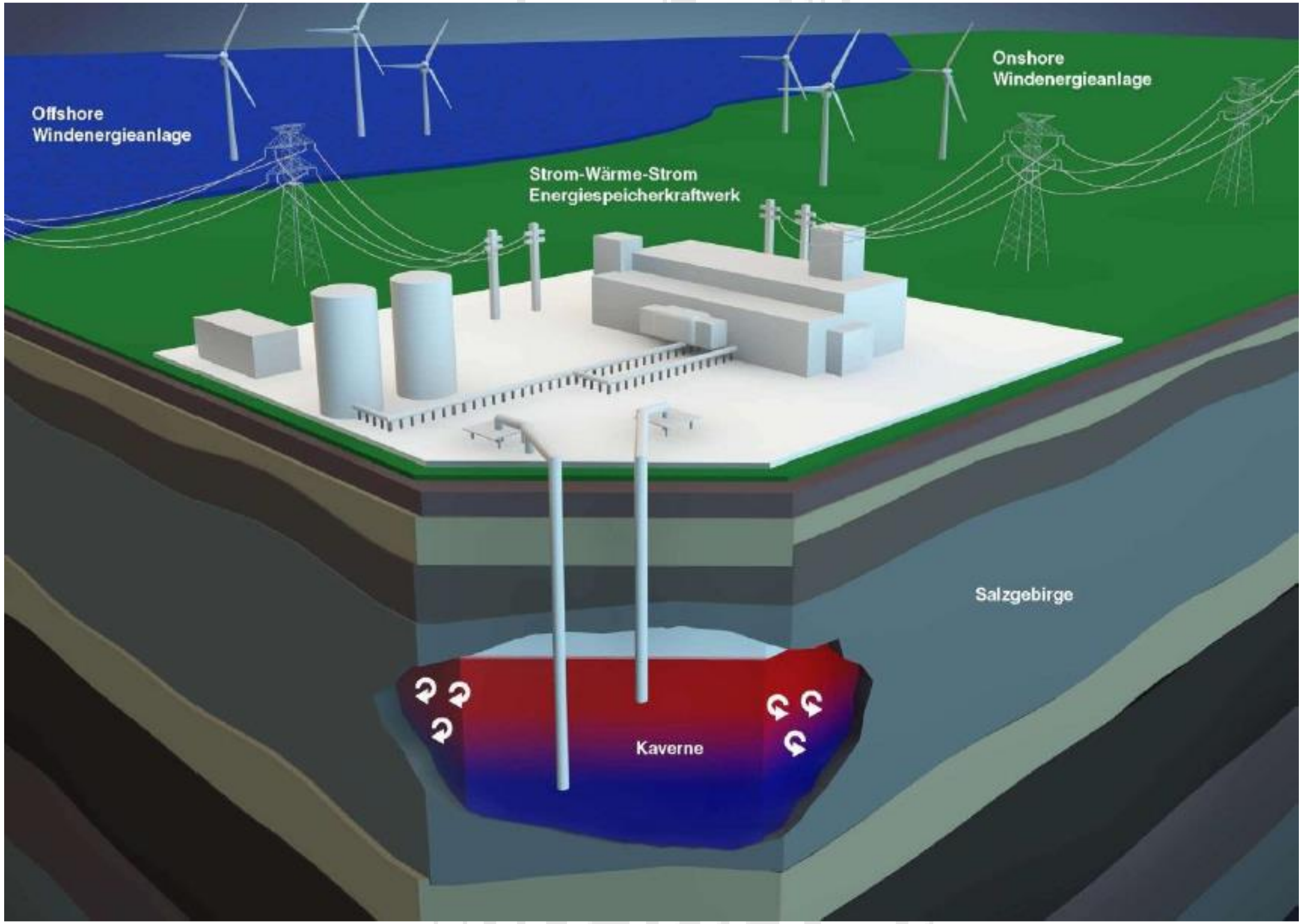
Large Storage

Introduction into Energy Geo-Storage Systems



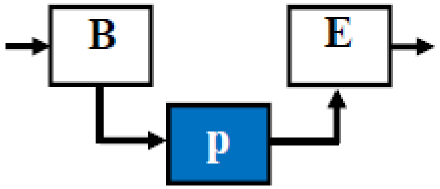
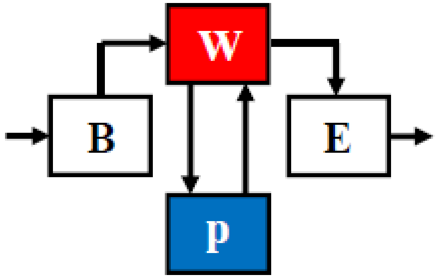
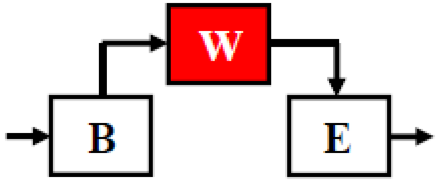
Mangold (2007), SWT Stuttgart

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

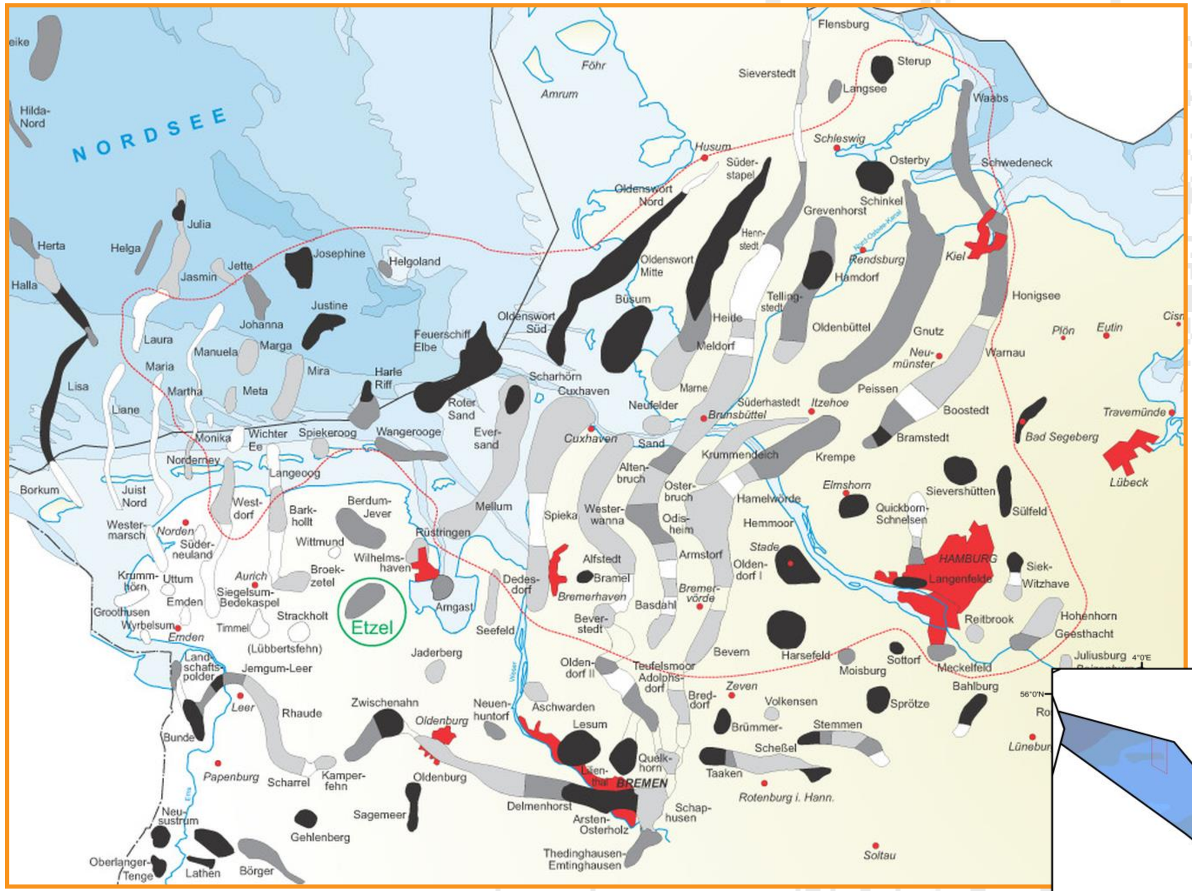


Power – Heat – Power & Power – Heat Technology (Sensible Heat Technology)

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Compressed air storage	Adiabatic compressed air storage	Power – Heat –Power
Existing	Planned	Under Research
 s→p→s	 s→w→p→w→s	 s→w→s
Energy storage - mechanical	Energy storage – mechanical and thermal	Energy storage - thermal
Theor. Efficiency 70%	Theor. Efficiency 100%	Theor. Efficiency 100%
Real Efficiency 50%	Real Efficiency 70%	Real Efficiency – under Research
Realization – site dependent	Realization – site dependent	Realization – site independent

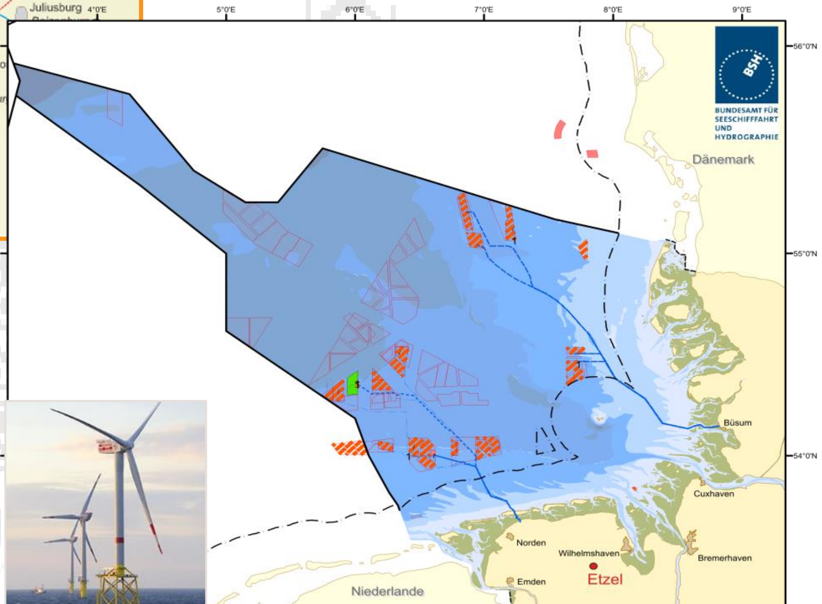
Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)



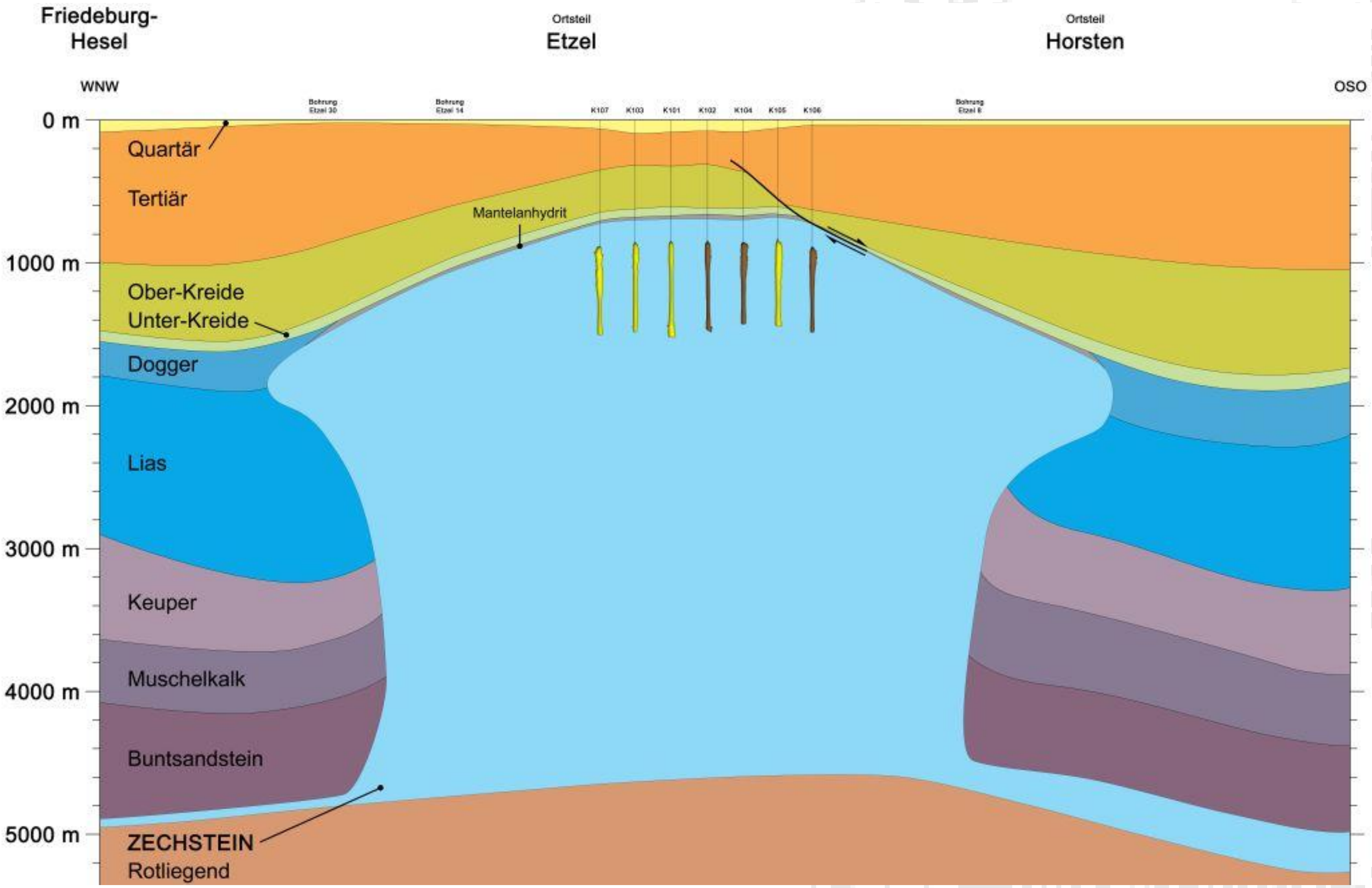
Saltformationen
in Nordwest-Deutschland

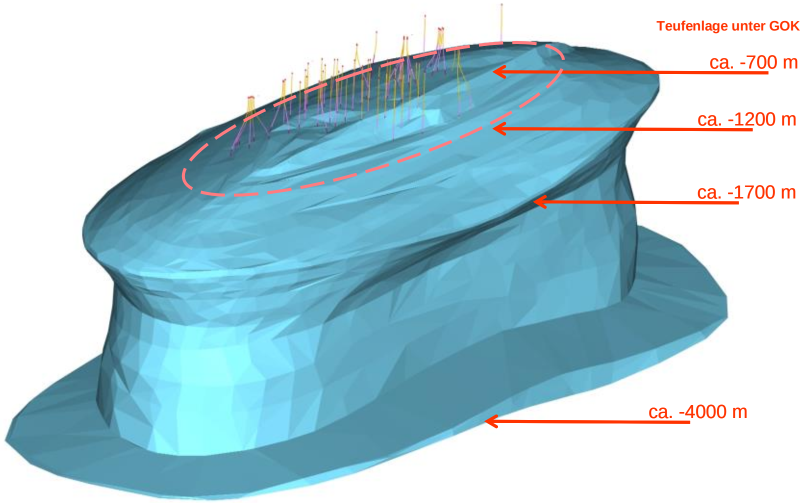
Image source:
Schweinsberg / IVG Caverns (2013)
Workshop -
GeoEngineering Energy Geo-storage

Energie – Lifelining in Nordwest-Deutschland



Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)





Salt dome Etzel

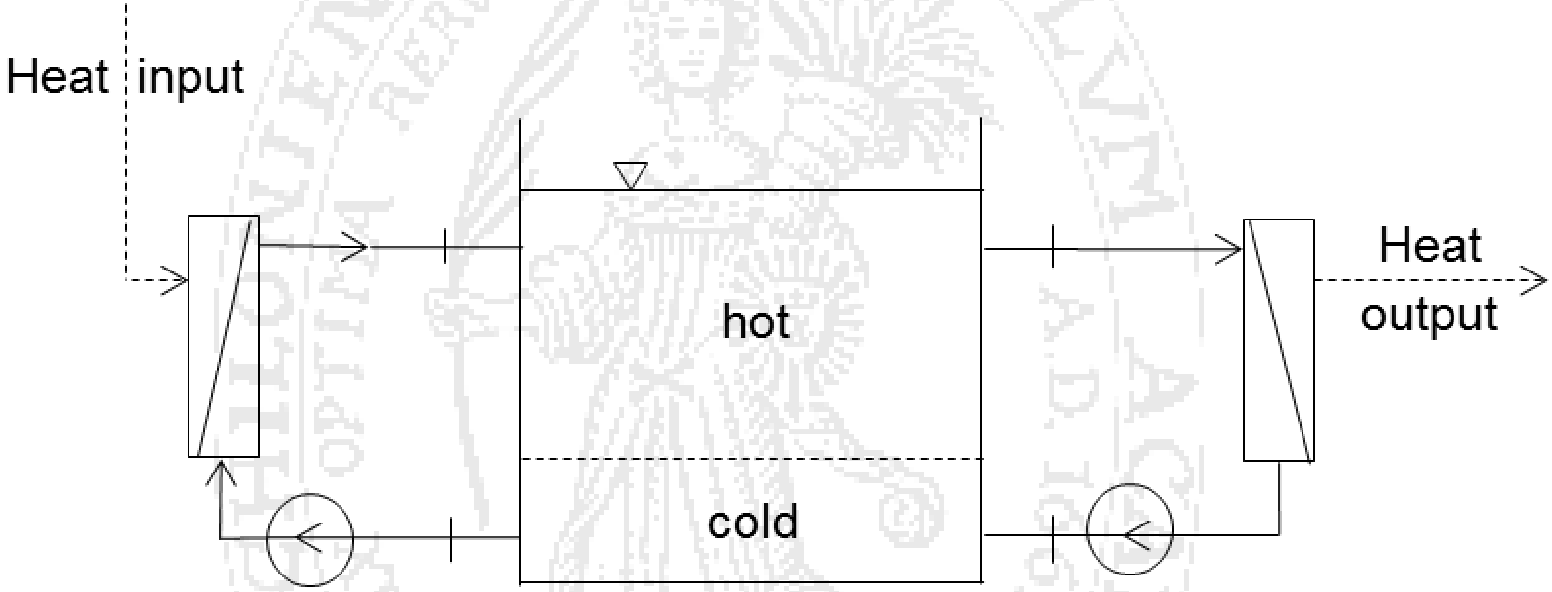
Image source:
Schweinsberg / IVG Caverns (2013)
Workshop -
GeoEngineering Energy Geo-storage

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Proposed Energy Geostorage - Novelty

- Arbitrary size of existing Salt Caverns (>105…108m^3)
- Concentrated brine an approximate 50% higher energy storage
- No need of overburden pressure
- Seasonal Storage in existing Salt Formation distributed in Europe / Worldwide
- Power-Heat-Power & Power-HeatTechnology already existing & strong Reserach
- Natural Heat Buffer
- Natural and cheap storage media (Brine)

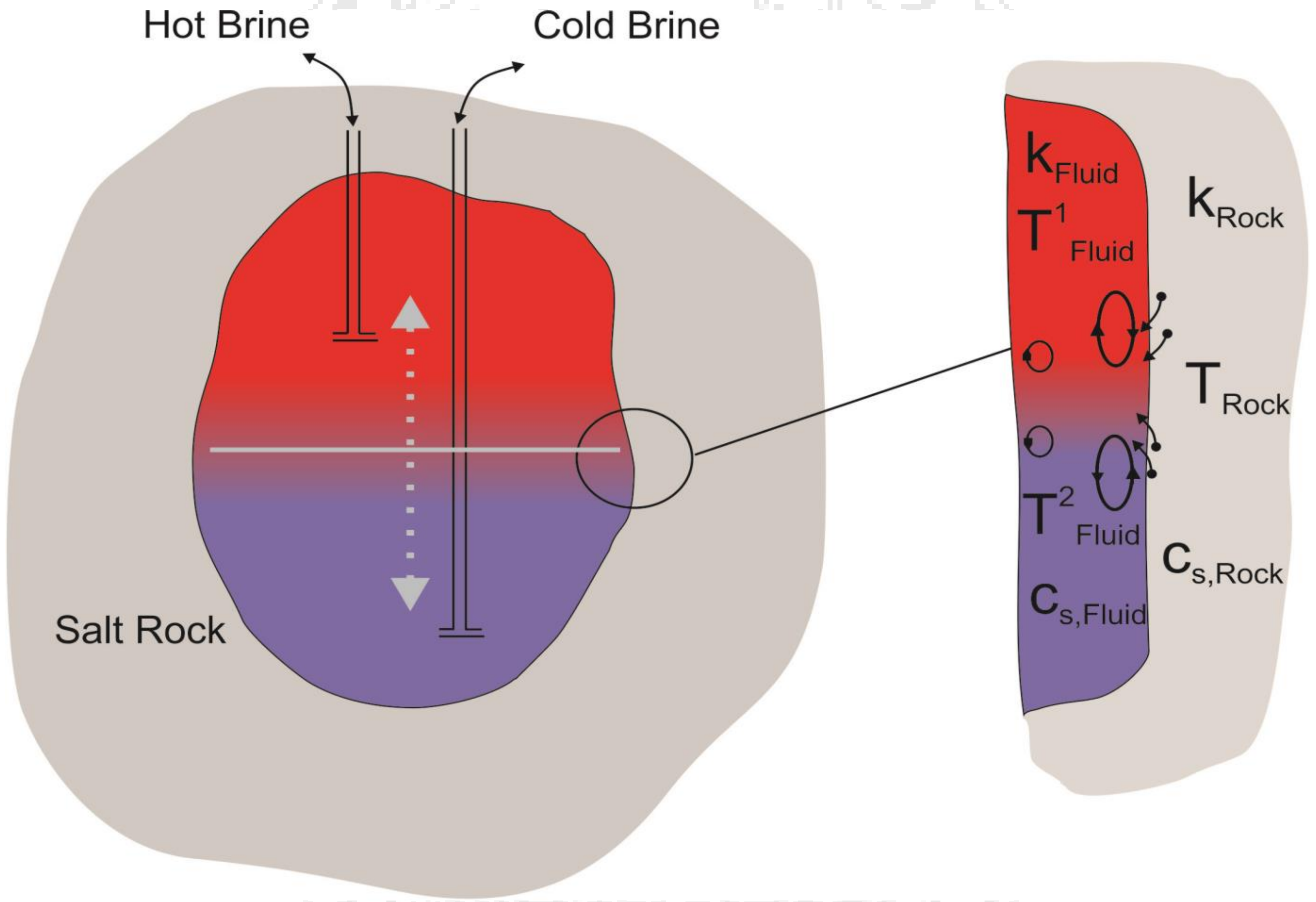
Working Principles



Heat storage in hot and cold salt solution (one tank version)

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

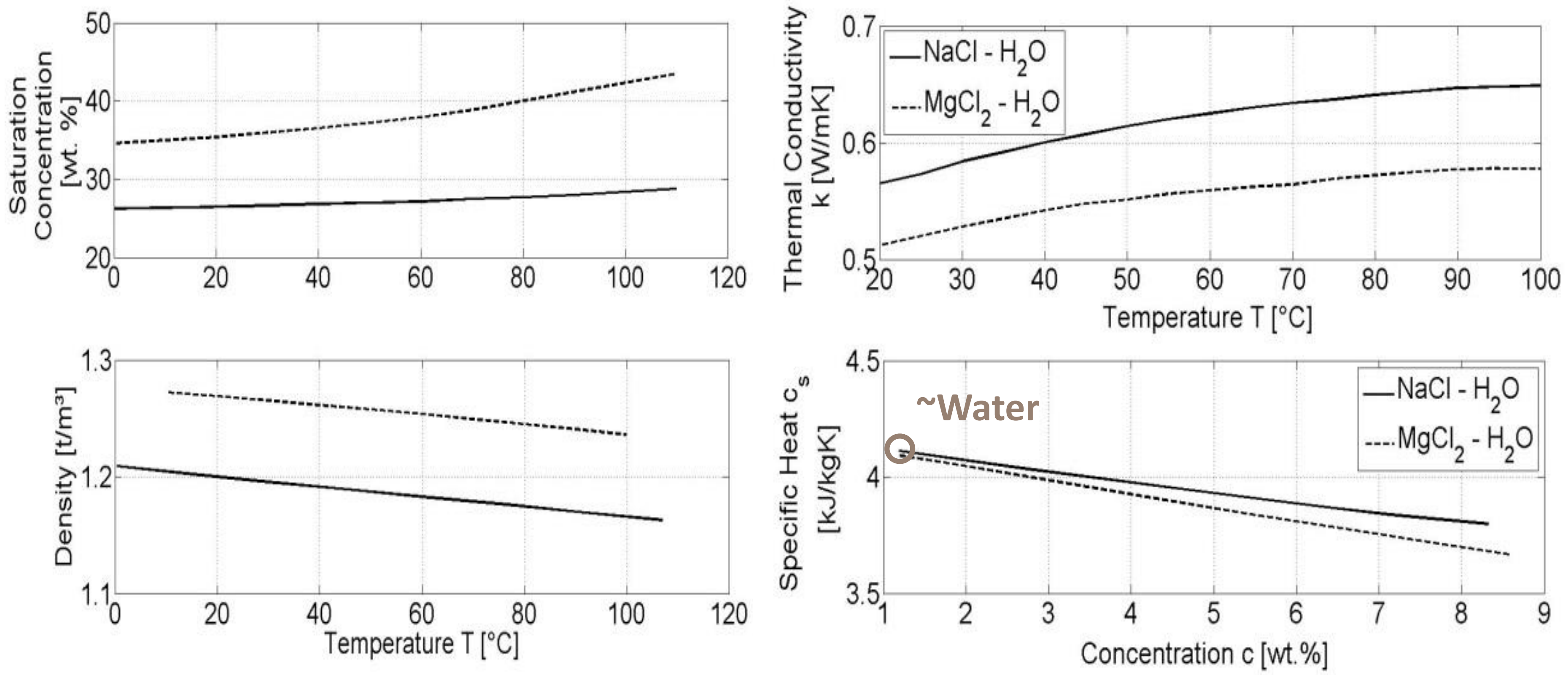
Working Principles



Heat storage application in former salt caverns

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Fluid Parameters

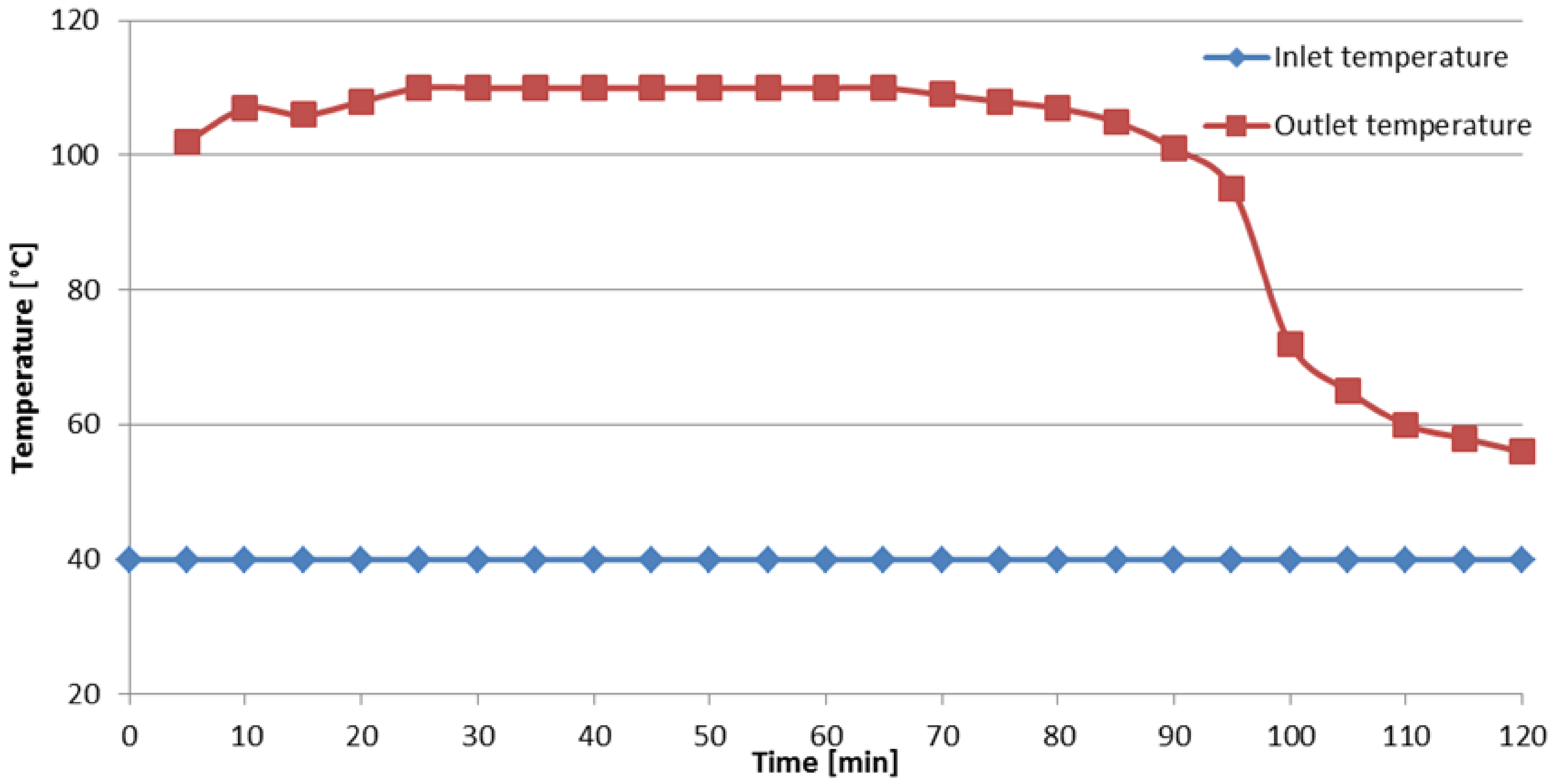


NaCl-H2O / MgCl2-H2O - Fluid mixtures: 10 / 15 / 20 / 25 and 30 [wt.%]

Rock salt blocks (NaCl): density 2.1-2.4 g/cm³, cs= 850 J/kgK, k=0.6 W/mK

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

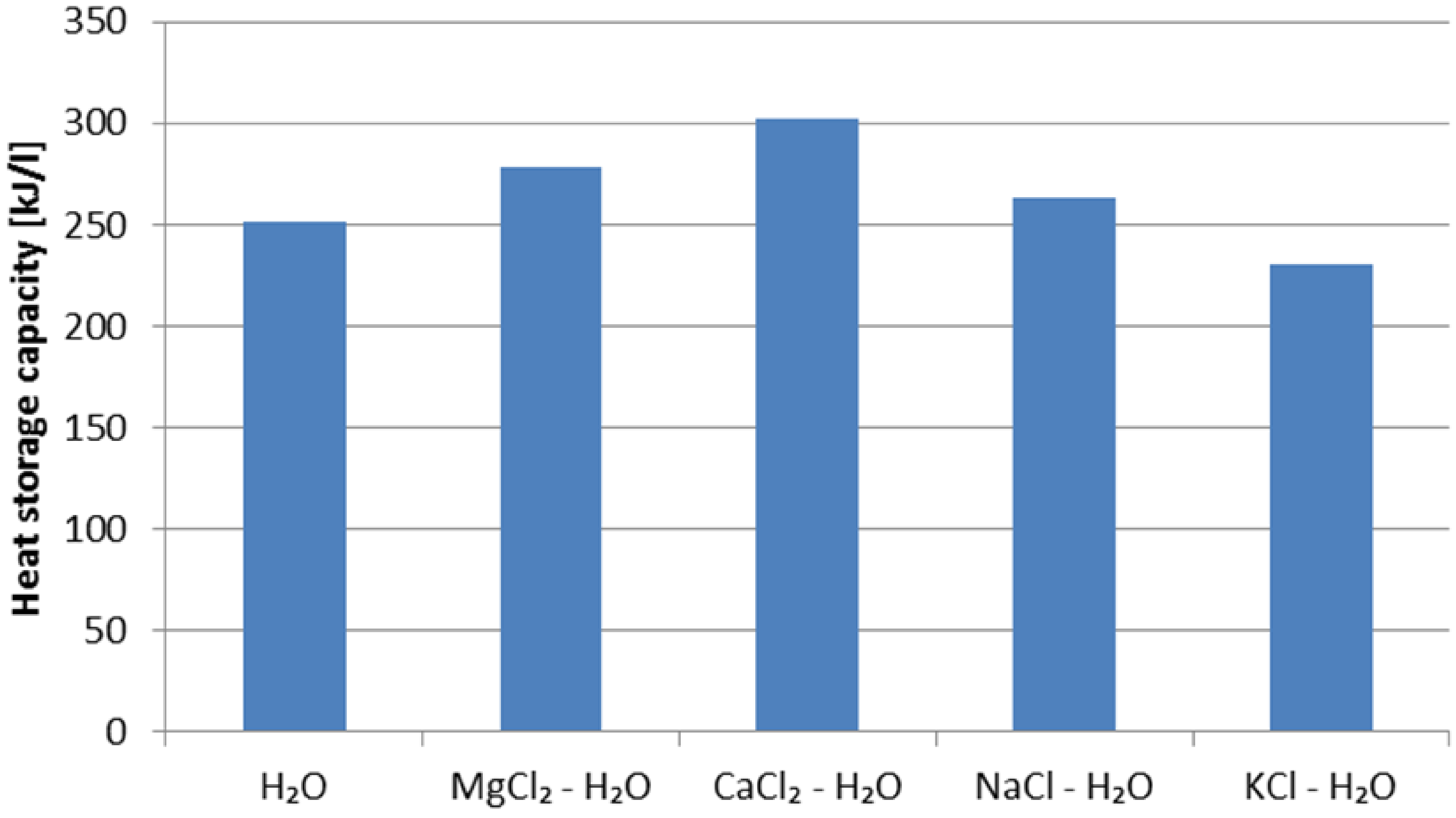
Fluid Parameters



Typical temperature of heat output (large scale test)

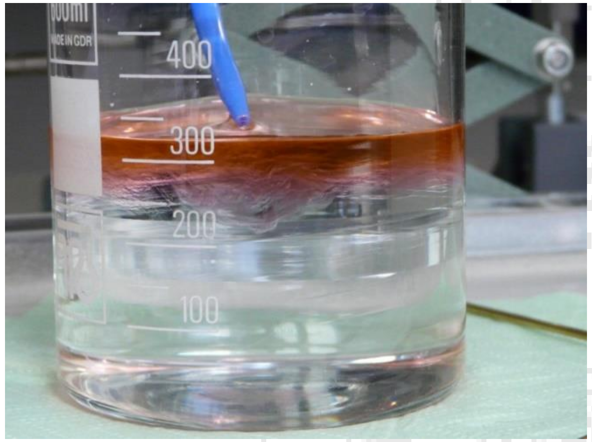
Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

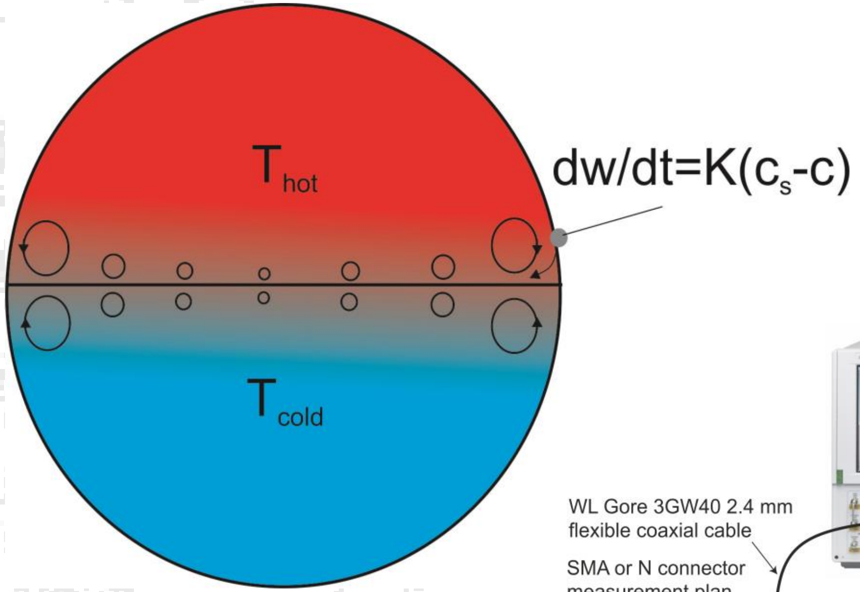
Fluid Parameters

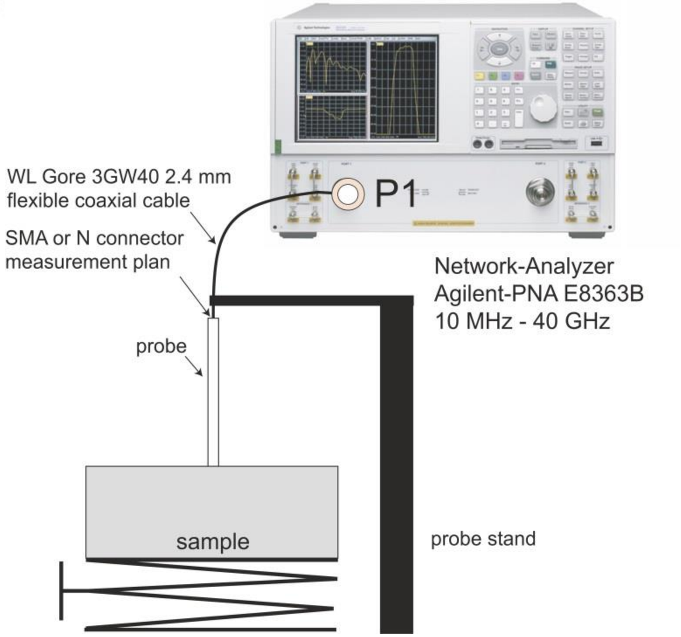


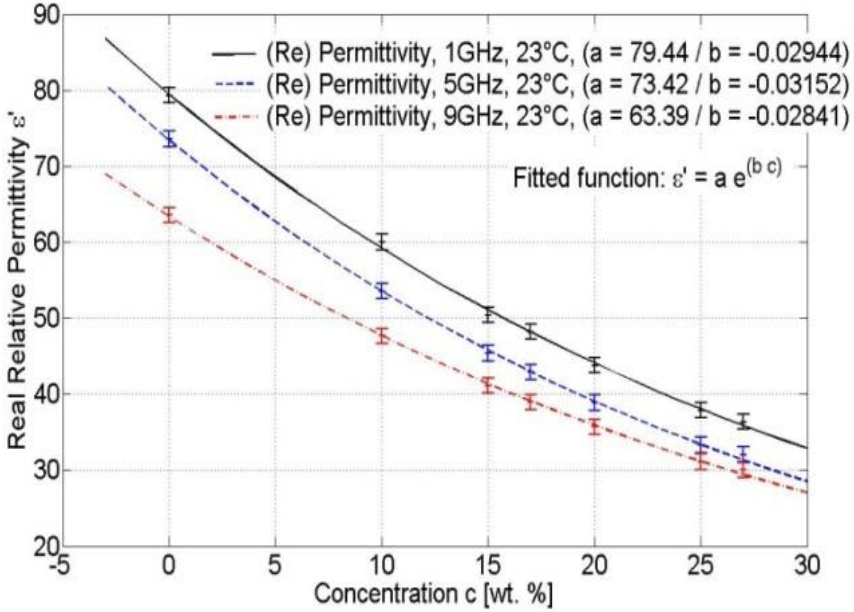
Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Convection / Fluid-Fluid-Interface Stability







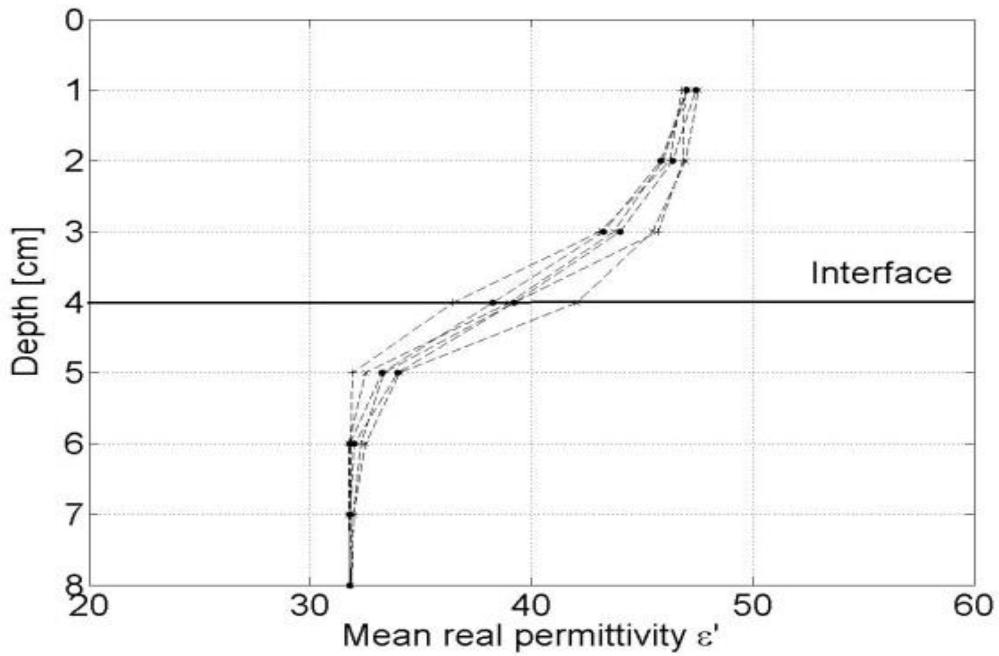


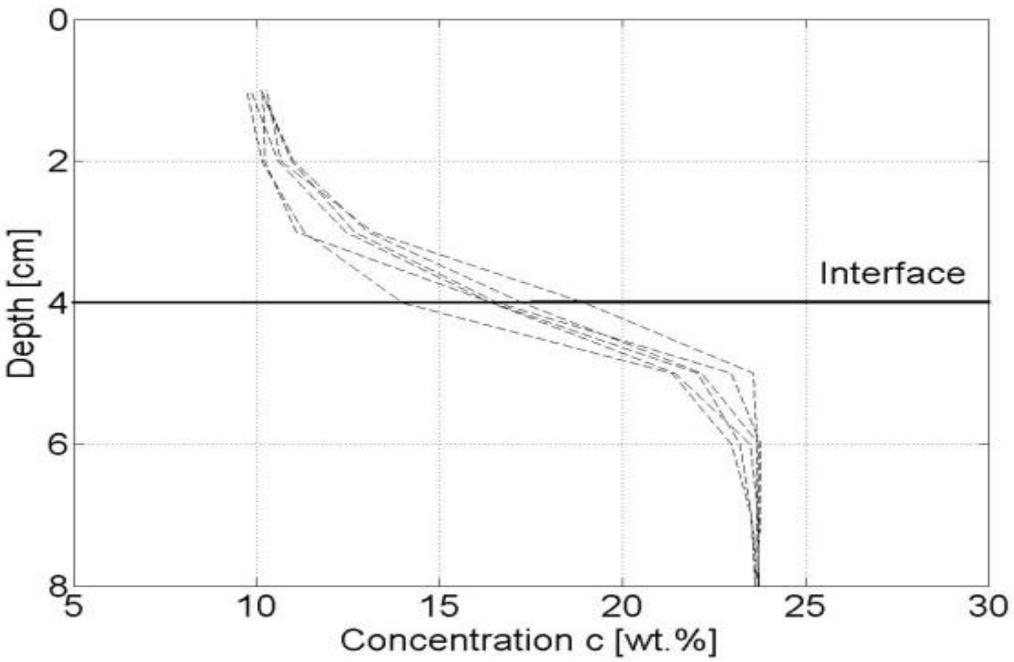
Broadband EM measurements
1MHz – 10GHz range
Open-coaxial Needle sensor
(Agilent Performance Probe)

$$c\left[wt.\%\right] = -\frac{1}{0.0284}\ln\left[\frac{1}{63,39}\left(\varepsilon' + 0.0007\cdot T[°C]^{2.117}\right)\right]$$

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

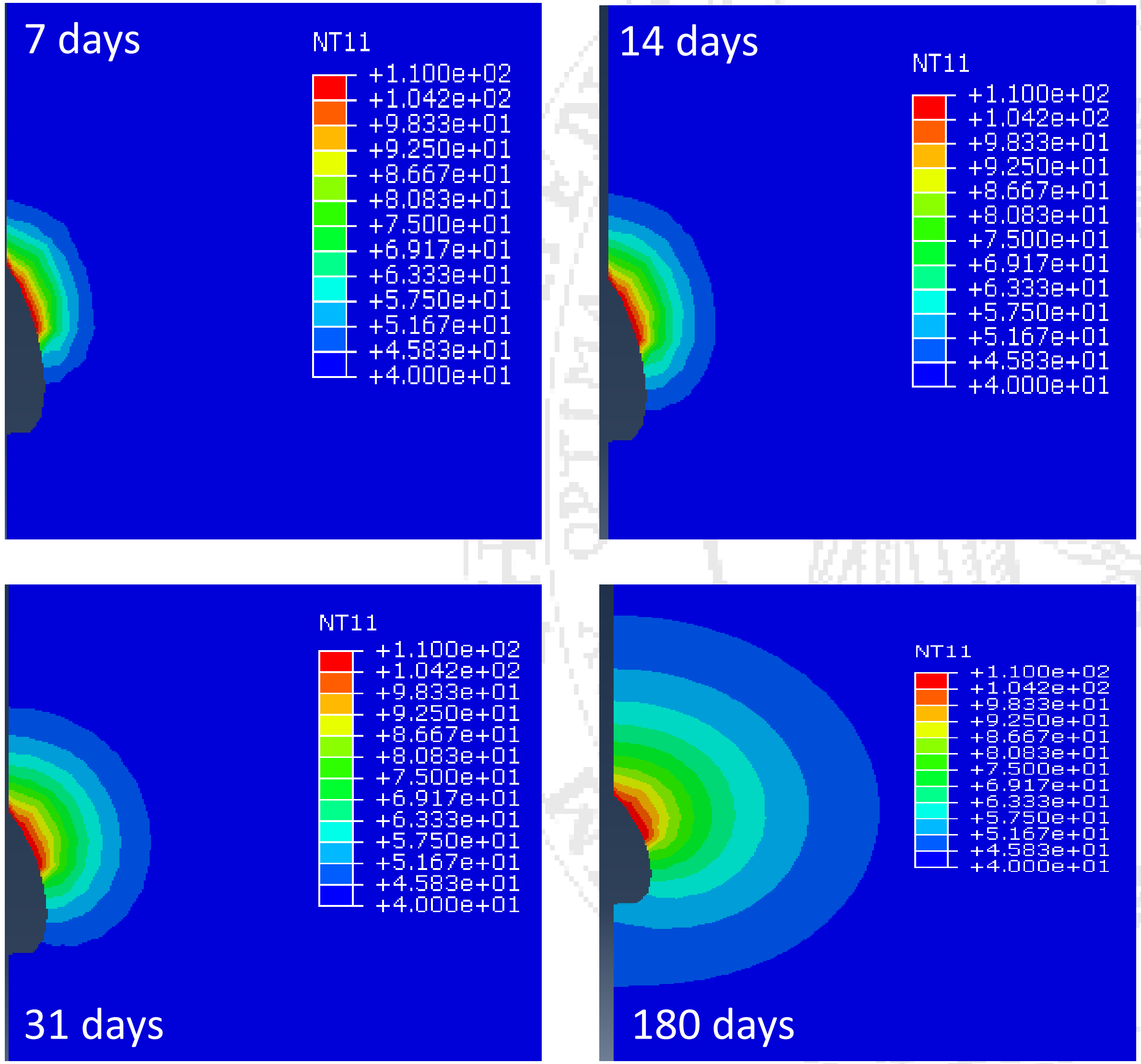
Convection / Fluid-Fluid-Interface Stability

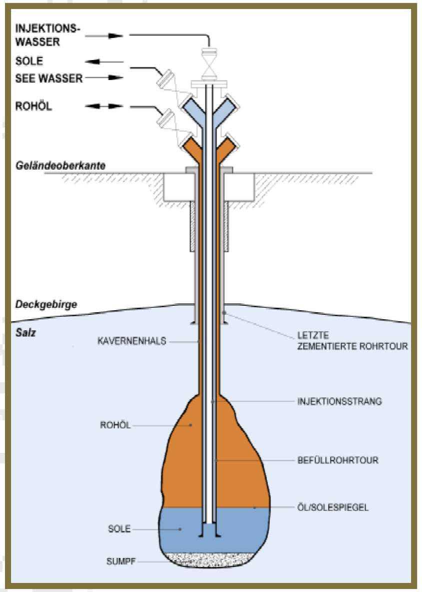




Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Heat transfer





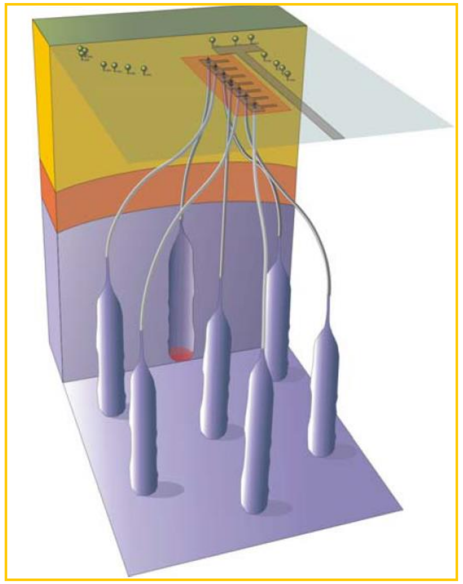


Image sources:
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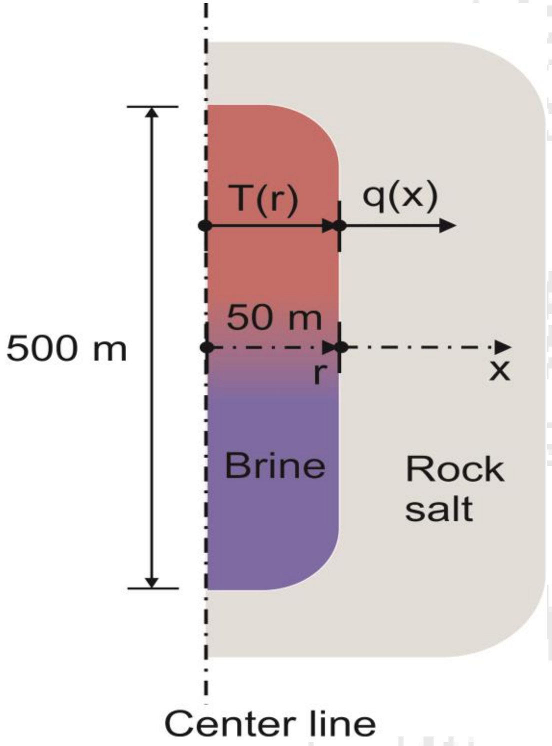
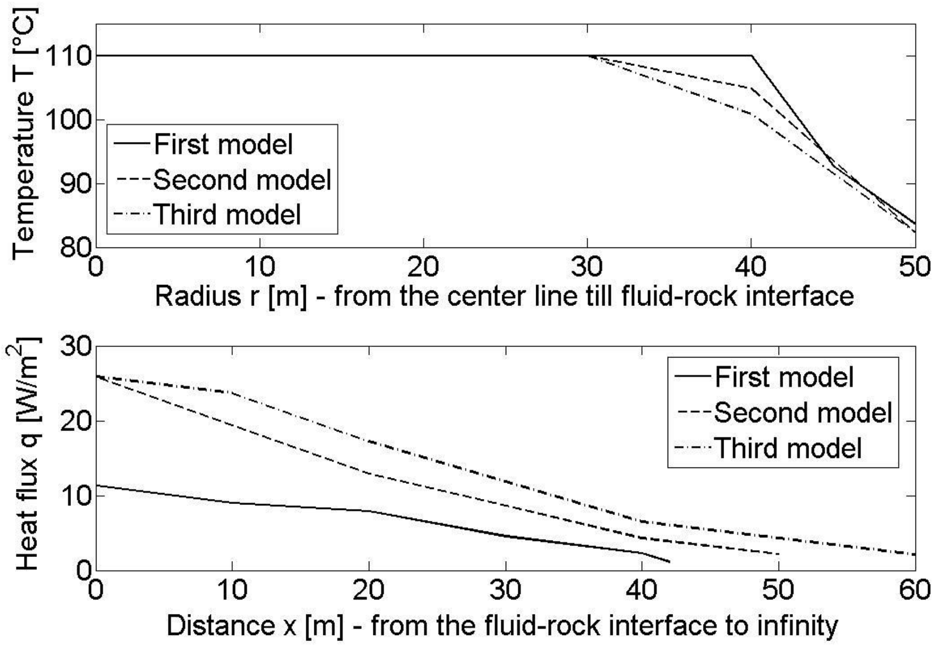
Workshop -
GeoEngineering Energy Geo-storage

Thermohaline Energy Geo-Storage (Large Scale Geo-Storage)

Heat transfer





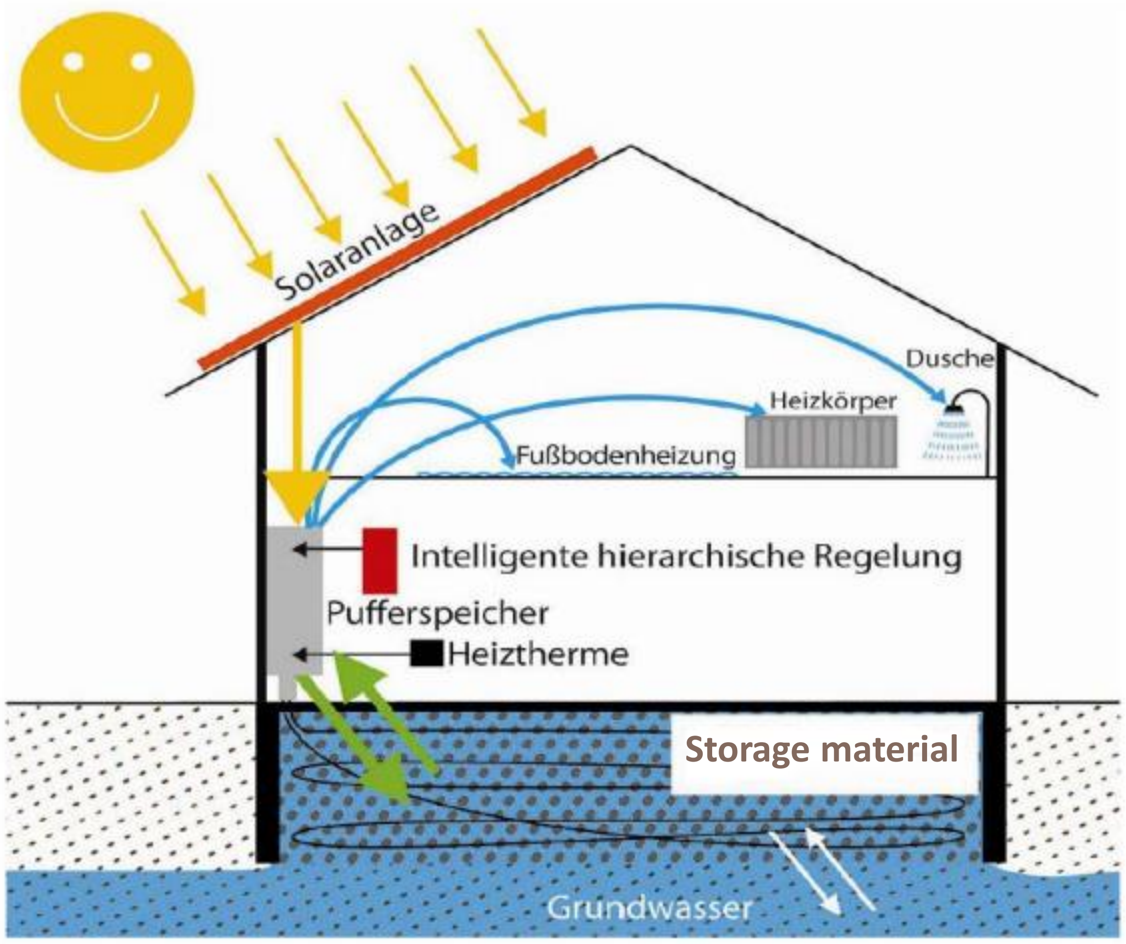
Thermal diffusion time given by the diffusion equation: amount of time needed to decrase the temperature τ inside the cavern and brine in quadratically inreasing with the storage diameter ***r***

$$\tau = r^2/\kappa$$

$\kappa = \lambda/(\rho c_p)$, λ – thermal conductivity, ρ – density and c_p spezific heat capacity.

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Underground thermal energy storage (UTES) – Project IGLU Energy



UTES for single dwellings

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Requirements for a Thermal Energy Storage material

- High specific heat capacity, c.
- Optimum thermal conductivity, λ (higher than 0.3 W/m·K).
- Reasonable initial strength and setting time but ultimate material strength should be moderate to enable future maintenance and/or removal.
- Good workability and self compacting property to enable filling places.
- Operational up to temperature range of 90°C as it is a 'water-based storage'.

Two sets of materials have been developed and studied in detail

- ➢ Thermal buffer material named *''Thermo-Verfüll-Baustoff (TVB)''*
- ➢ Several combinations of *Sand*, *Bentonite, Chalk* and other binders to achieve a sound energy storage material

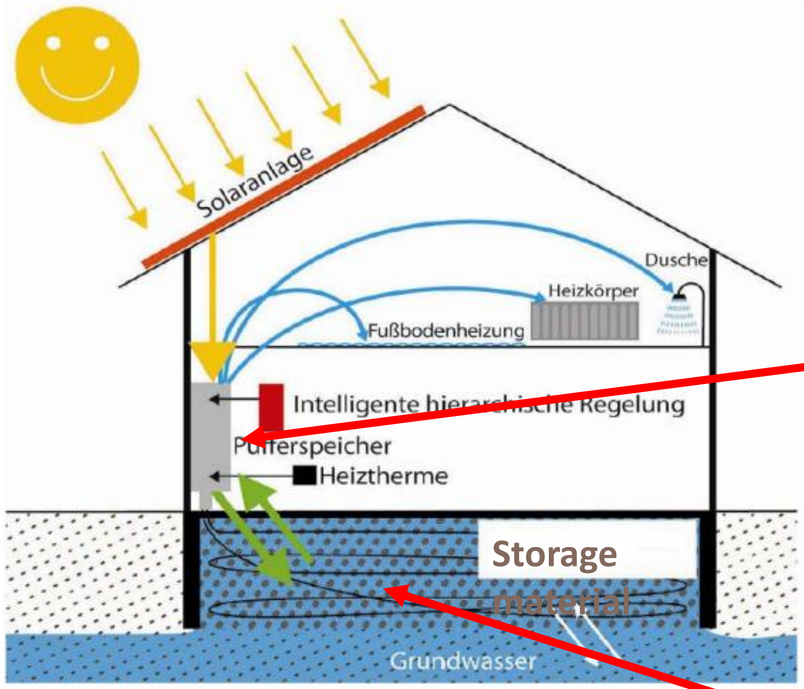
Urban Energy Geo-Storage (Small Scale Geo-Storage)

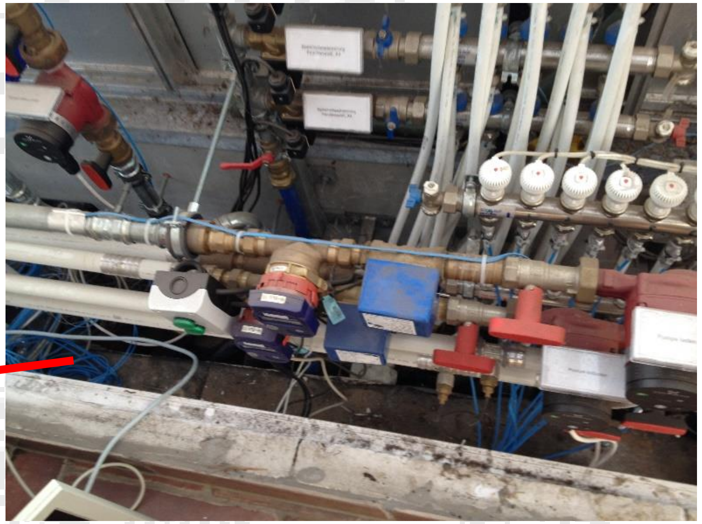
Tested Commercial Materials: Dyckerhoff Dämmer® - cement based material

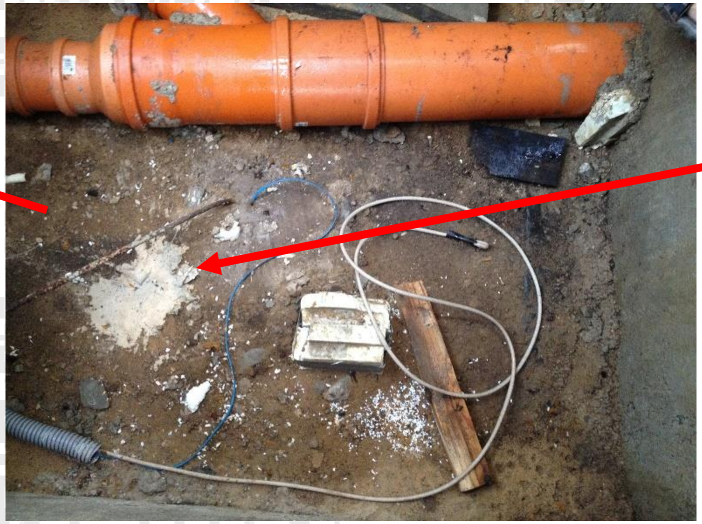
Thermal conductivity – 1,3 W/mK

Hydraulic conductivity – 2x10-9 m/s

Urban Energy Geo-Storage (Small Scale Geo-Storage)







Realized Full Scale test:

Company Scheer & ErgoTop

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Tested Commercial Materials: Dyckerhoff Dämmer® - cement based material

Chemical composition of TVB by X-ray fluorescence (XRF)

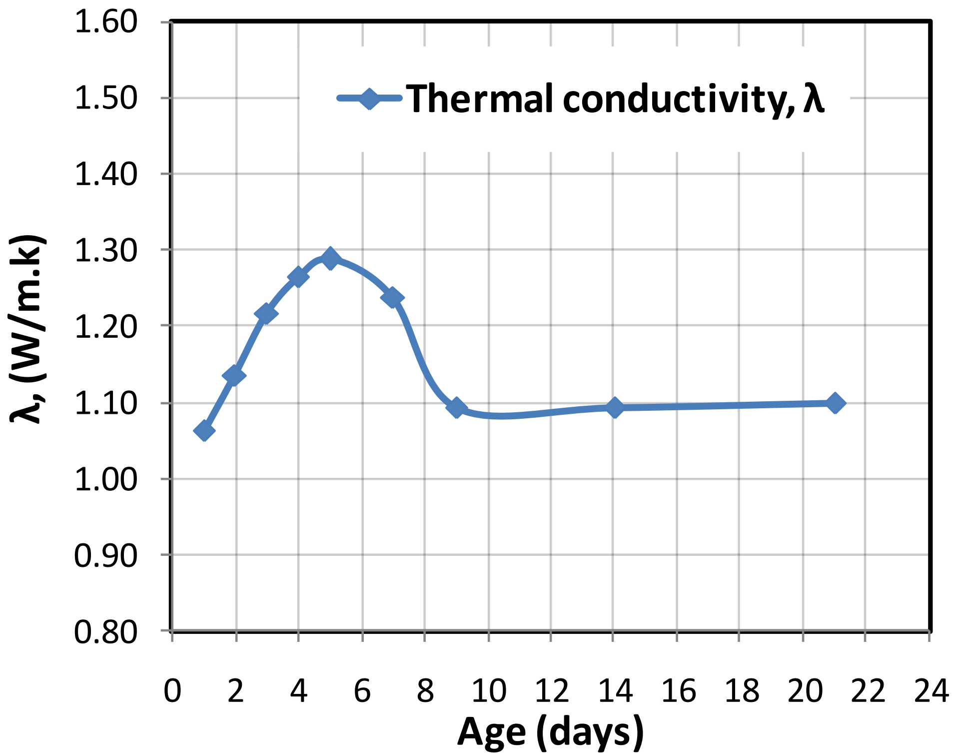
Oxide	% by weight
SiO_2	10.36
Al_2O_3	2.86
Fe_2O_3	1.4
CaO	52.13
MgO	1.11
K_2O	3.77
Na_2O	0.43
TiO_2	0.21
Others	0.272

Quicklime (CaO)

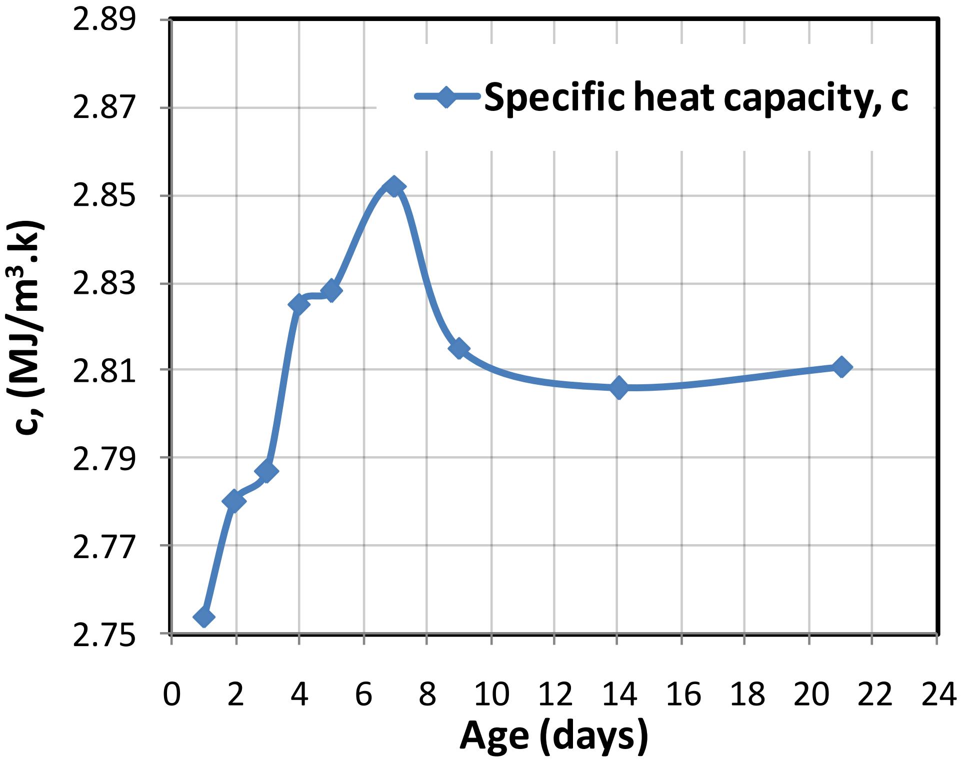
Melting at 1200 °C to homogenize the material mix

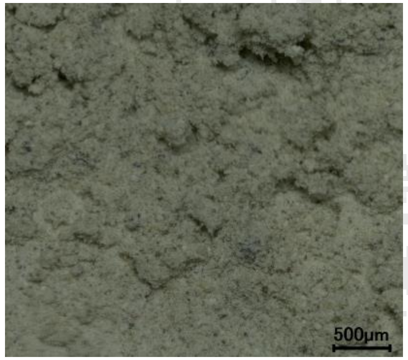
The high heat storage capacity is attributed to the high content of ***CaO***, specific heat capacity of up to 800 J/kg^0K (2.7 MJ/m^3K) @ 293 ^0K.

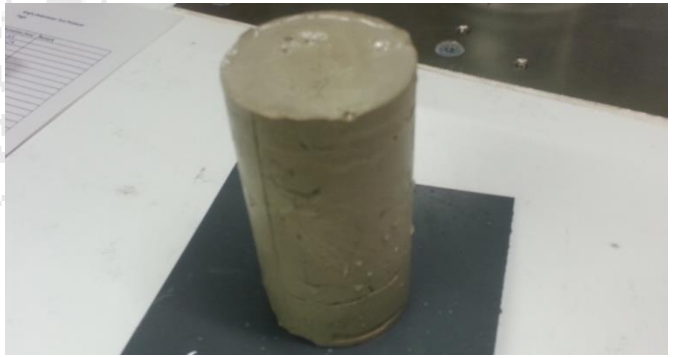
Urban Energy Geo-Storage (Small Scale Geo-Storage)



Thermal properties of TVB







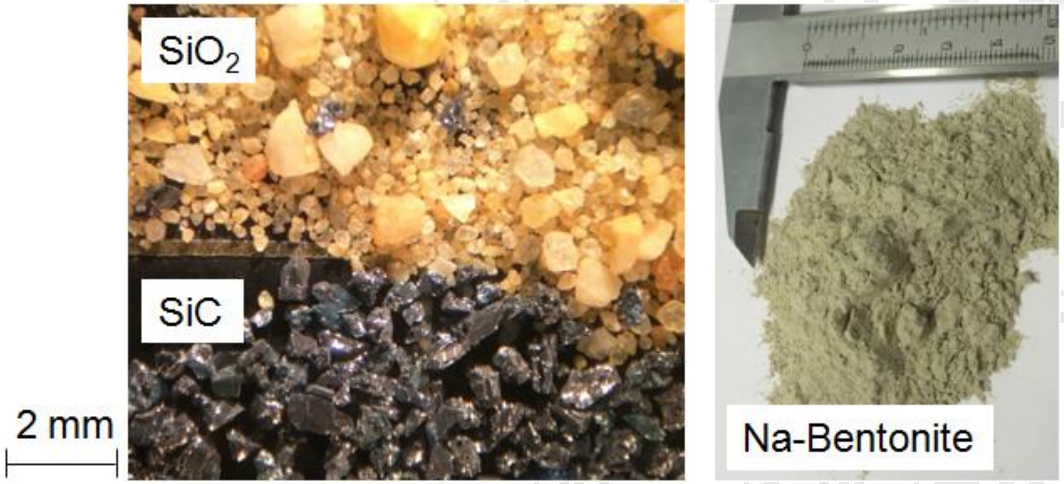
Urban Energy Geo-Storage (Small Scale Geo-Storage)

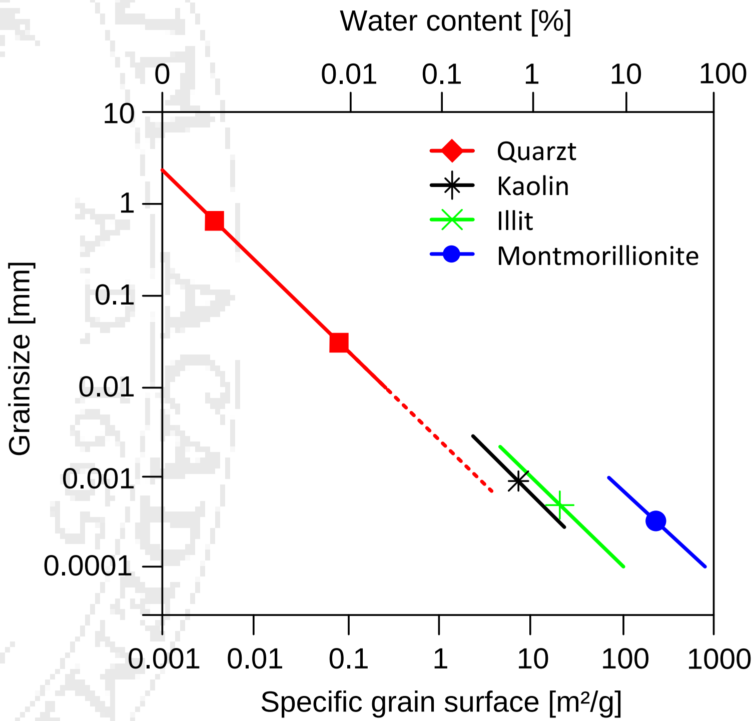
Thermal fill and backfill by ‚liquide soils' (Advantages: sustainability, costs, workability, repair,…)

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Experimental results

Optimization and development with several mix proportion of ***Sand, Bentonite*** and other binders



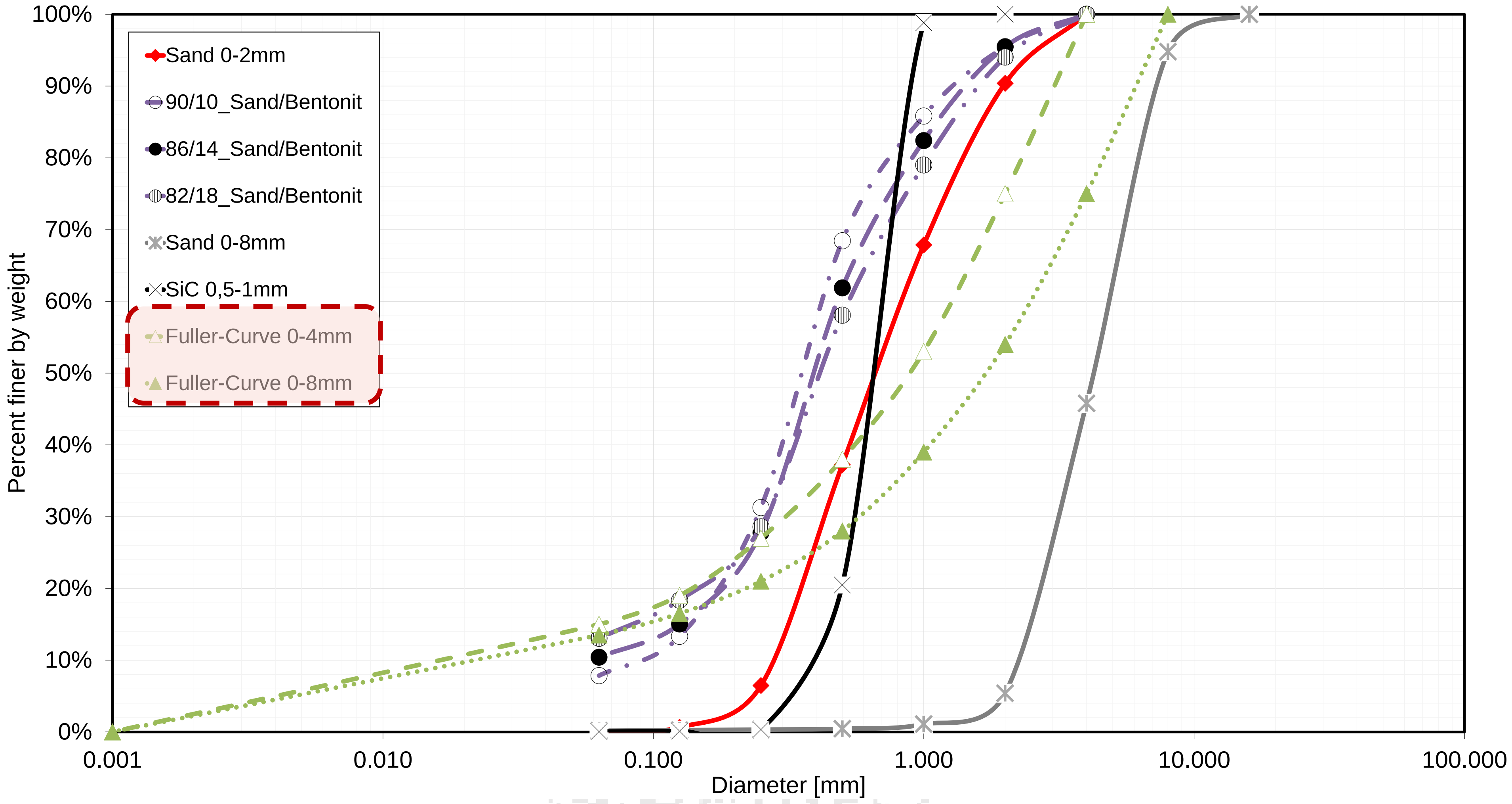


	Pricing	Availability	Thermal Conductivity	Specific gravity
Quartzsand	++	++	1.4 W/mK	2.65 g/cm³
Na-Bentonite	+	++	0.9 W/mK	2.65 g/cm³
Siliciumcarbide	+	++	100 W/mK	3.2 g/cm³

***** Bentonite content of 10 to 20 % of total mass is best mix according to Flow powder test (IAB Weimar)***

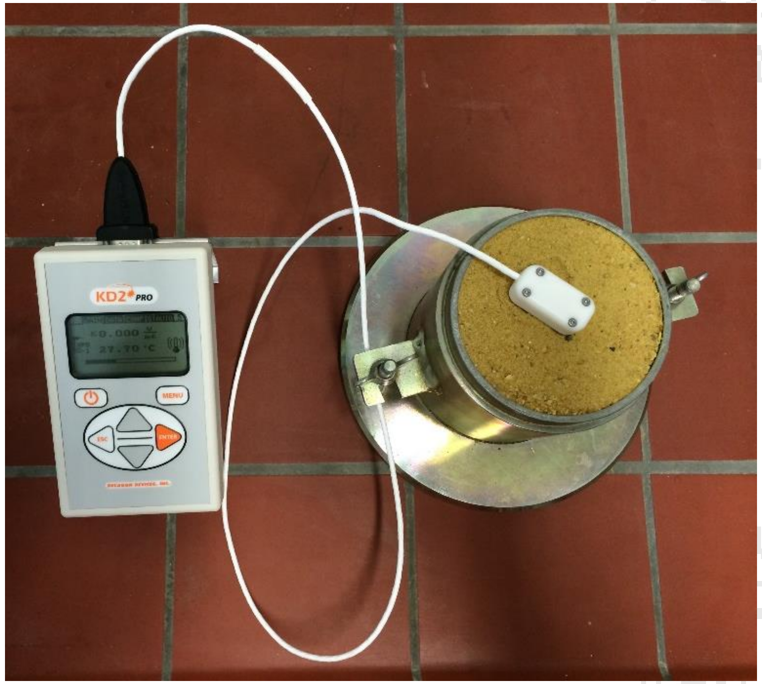
Urban Energy Geo-Storage (Small Scale Geo-Storage)

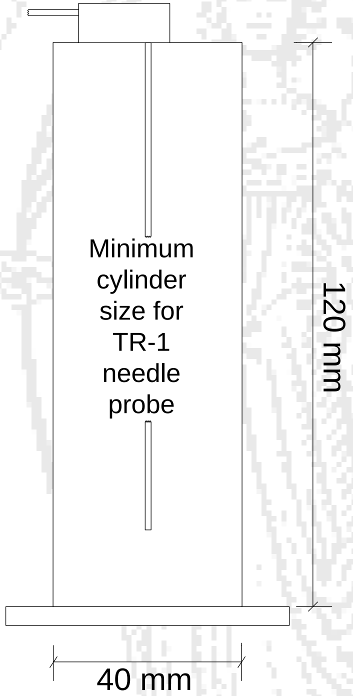
Grain-size distribution



Urban Energy Geo-Storage (Small Scale Geo-Storage)

Thermal properties

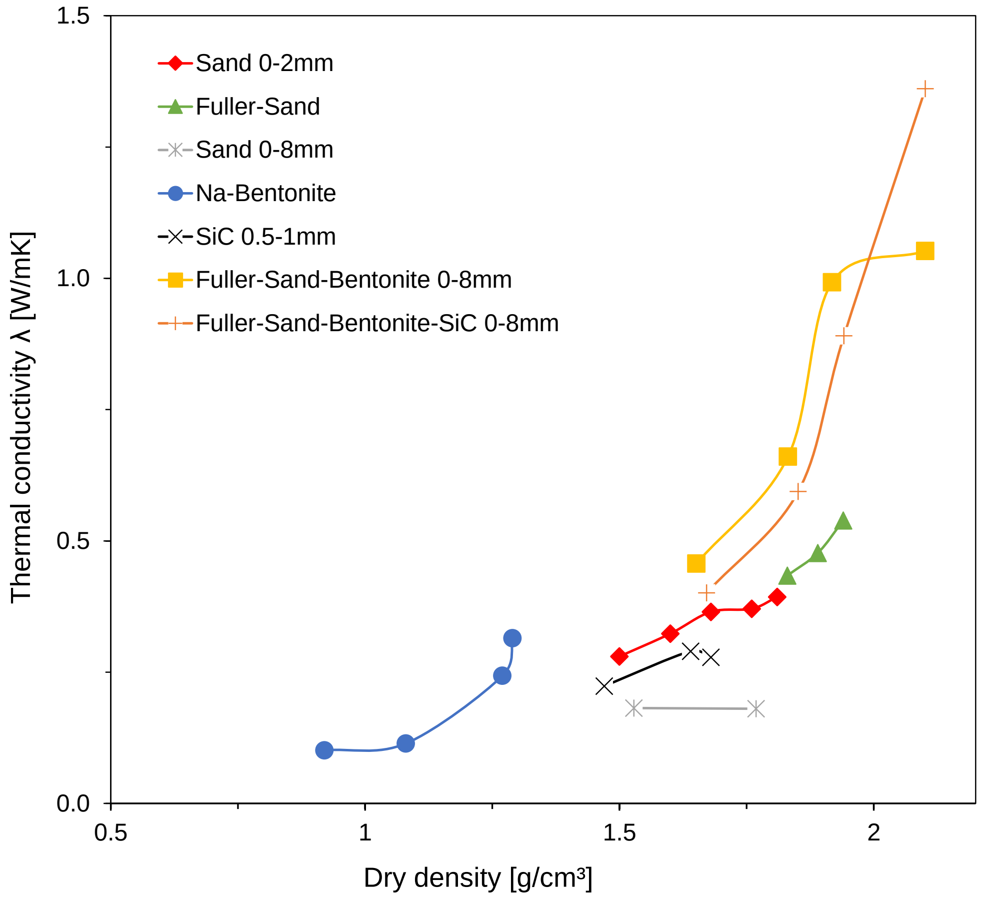


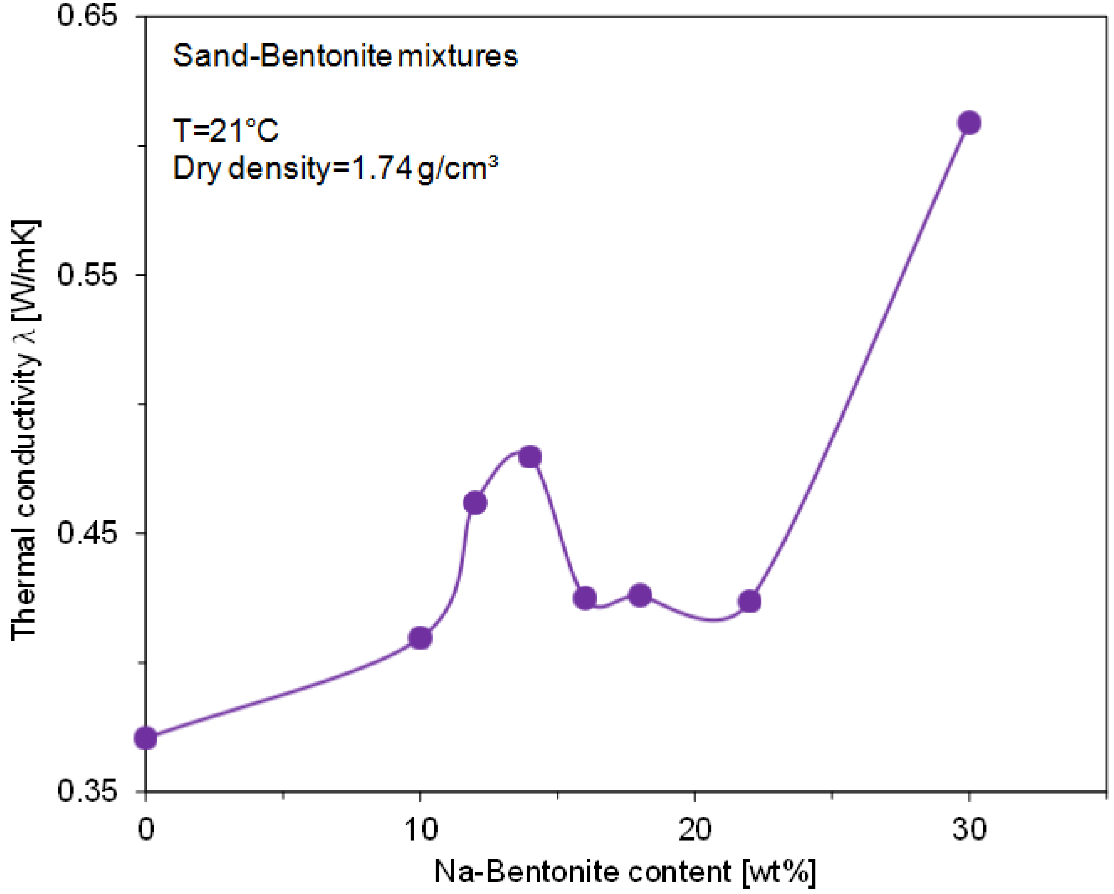


Thermal properties measured with a Decagon KD2 Pro Transient line source

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Thermal conductivity

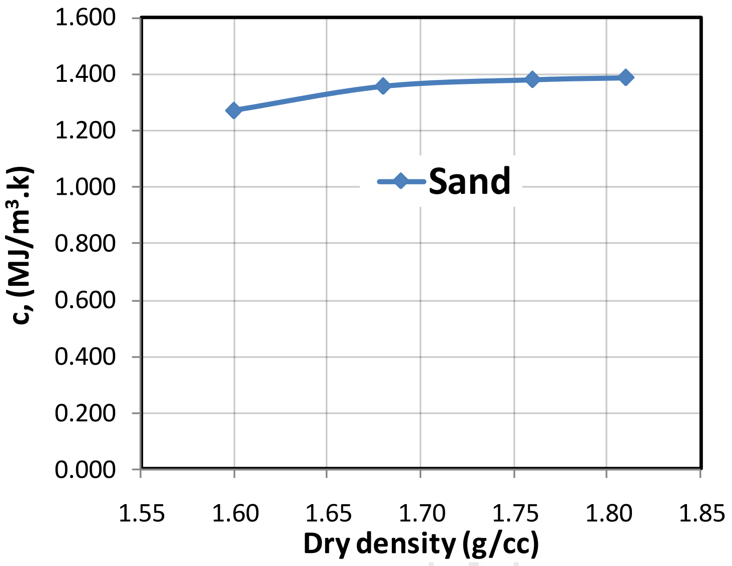


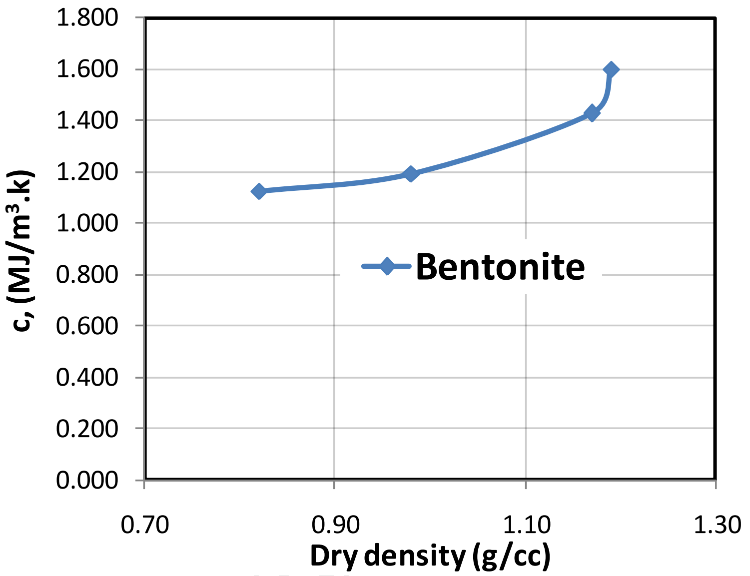


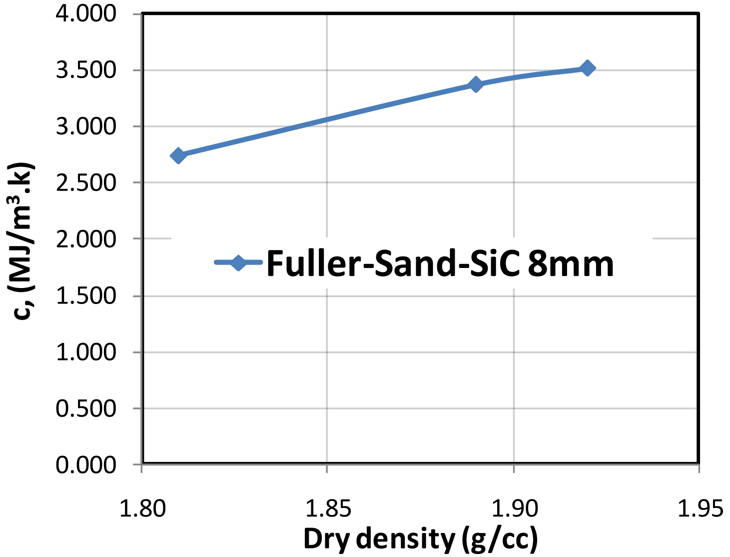
Variation of conductivity with dry density

Variation of conductivity with amount of Bentonite

Specific heat capacity



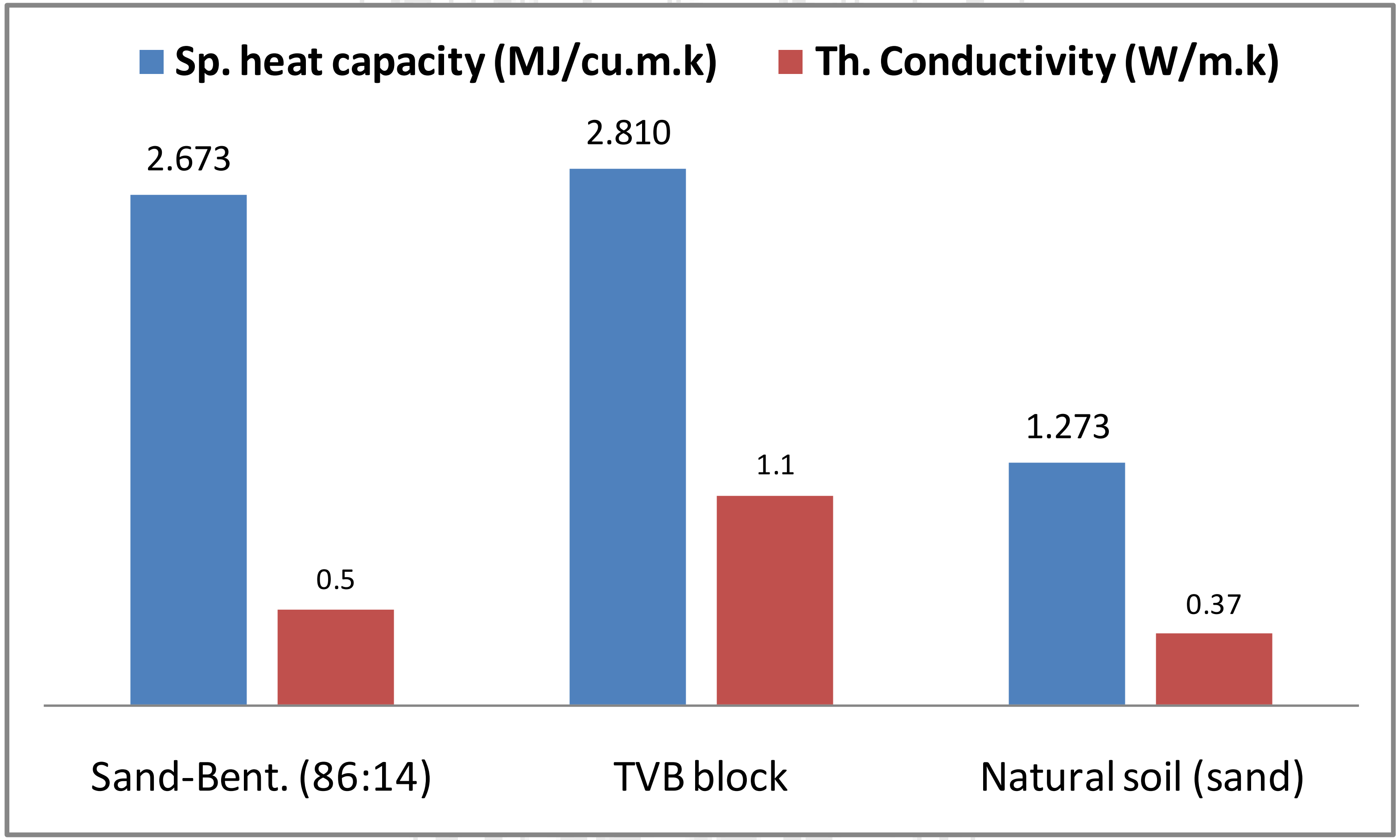




Variation of specific heat capacity with dry density

Urban Energy Geo-Storage (Small Scale Geo-Storage)

Thermal behavior of developed UTES materials



Outcome

- Thermohaline energy geo-storage systems as an easy alternative for existing large scale energy geo-storage systems

- Brine as storage material has excellent conditions (cheap, stable fluid interfaces, less chemo-biologic active)

- By using ordinary geo-materials: sand ($c=1.3$ MJ/m^{3}K) and bentonite ($c=1.1$ MJ/m^{3}K), geo-materials with specific heat capacity of up to 2.7 MJ/m^{3}K and optimum thermal conductivity, 0.5 W/mk, can be achieved → further optimization possible (chalk, fly ash, CaO-materials)

- The analyzed sand-bentonite mixtures have a higher dry densities (Fuller grain size distribution) and water storage system → improvements in specific heat capacity and reasonable thermal conductivity

Photo: Frank Paul