HEATSTORE

HIGH TEMPERATURE UNDERGROUND THERMAL ENERGY STORAGE

LESSONS LEARNED FROM EXISTING AND PAST UNDERGROUND THERMAL ENERGY STORAGE SYSTEMS

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EUROPEAN WORKSHOP ON UNDERGROUND ENERGY STORAGE, PARIS NOVEMBER 7-8, 2019

HEATSTORE REPORT D1.1

Doc.nr:	HEATSTORE-D1.1
Version:	Final 2019.04.26
Classification:	Public
Page:	1 of 130

HEATSTORE
Underground Thermal Energy Storage (UTES)
– state-of-the-art, example cases and lessons learned

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Please cite this report as: Kallesøe, A.J. & Vangkilde-Pedersen, T. (eds). 2019: Underground Thermal Energy Storage (UTES) – state-of-the-art, example cases and lessons learned. HEATSTORE project report, GEOTHERMICA – ERA NET Cofund Geothermal. 130 pp + appendices.

This report represents HEATSTORE project deliverable number D1.1

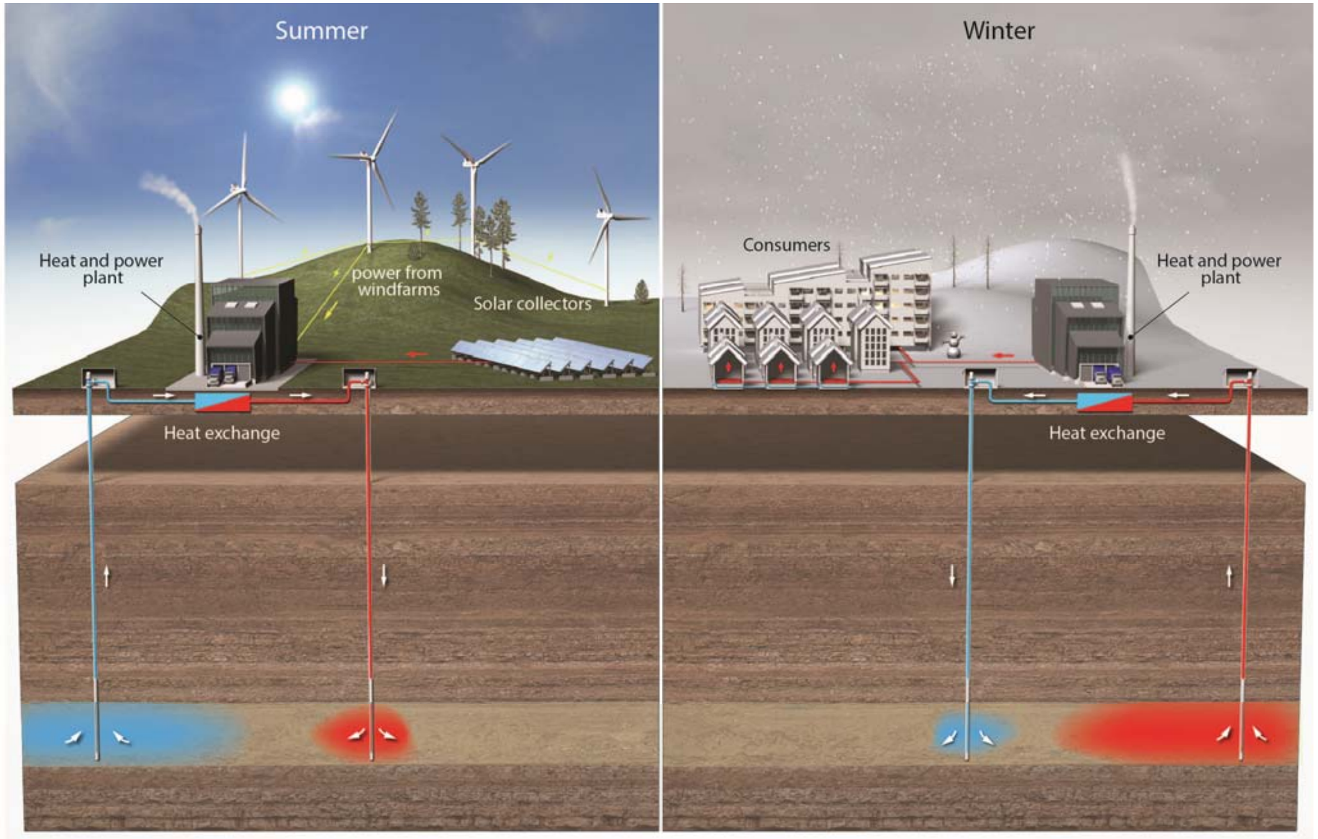
www.heatstore.eu

- EU Geothermica Era-Net co-fund
- 23 partners in 9 European countries
- Coordinated by TNO
- Close to 50% industry funding
- 6 demonstration sites, 8 case studies
- 16.3 MEUR total project budget

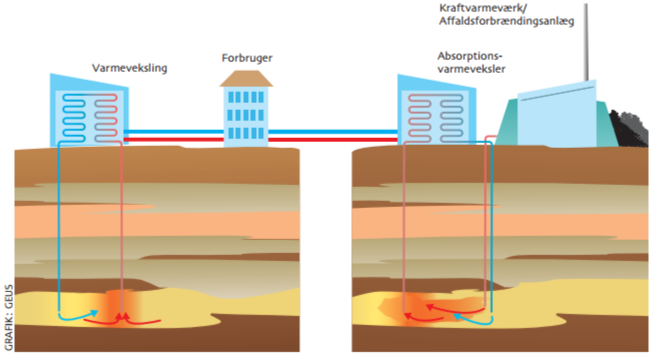
- Literature study
- Actual experience
- Partner know-how
- Relevant cases in and outside Europe

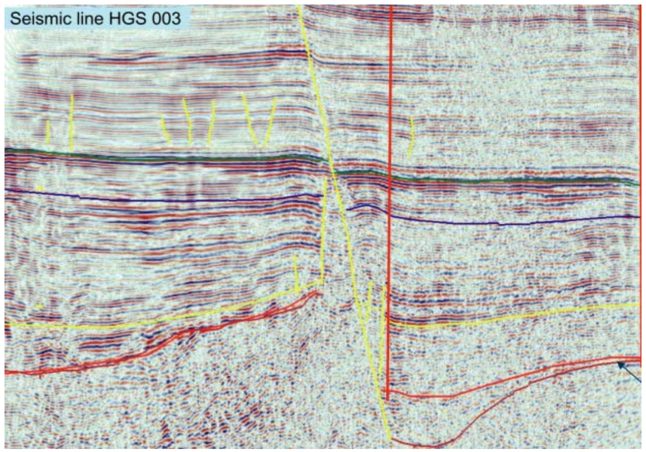
https://www.heatstore.eu/downloads.html

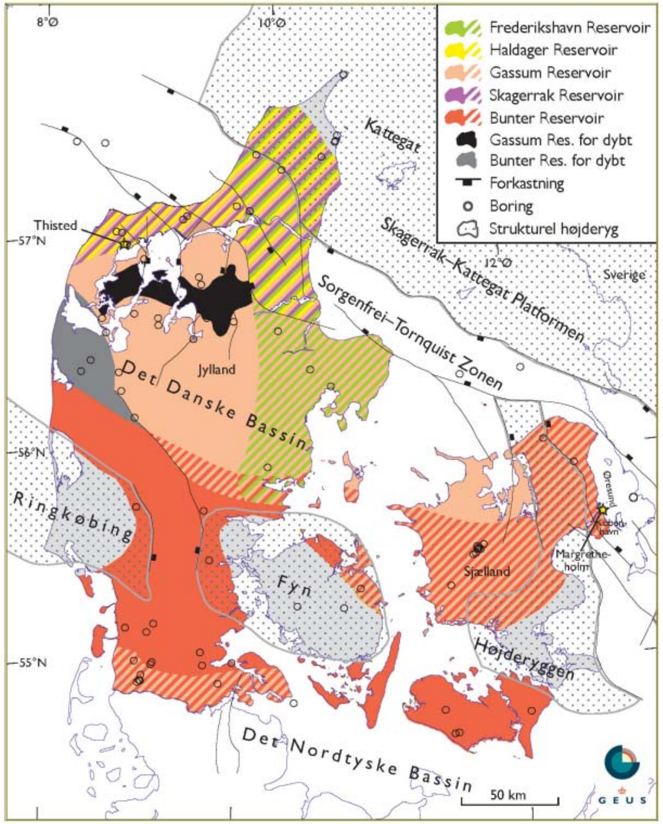
AQUIFER THERMAL ENERGY STORAGE (ATES)



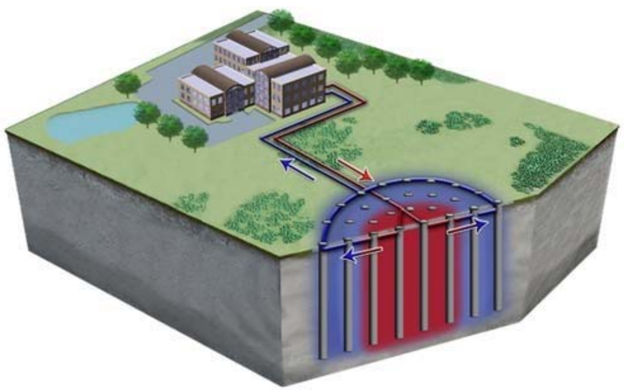
HIGH-TEMPERATURE ATES (HT-ATES)

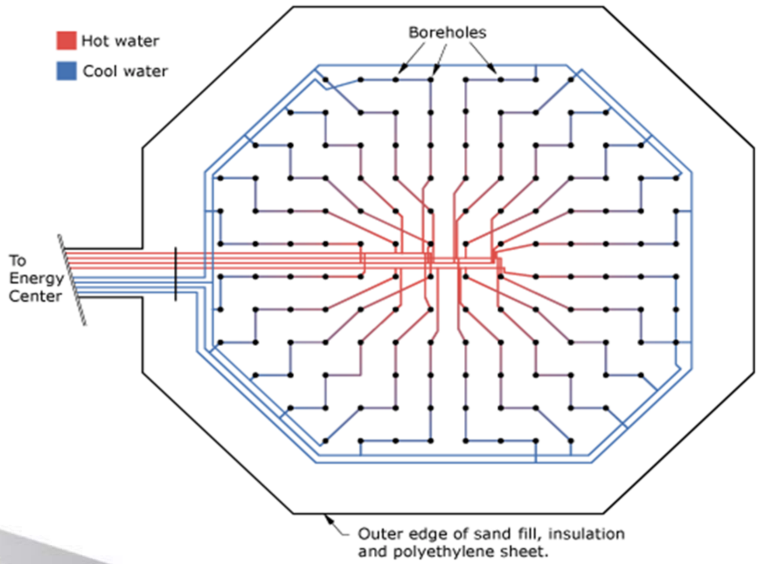


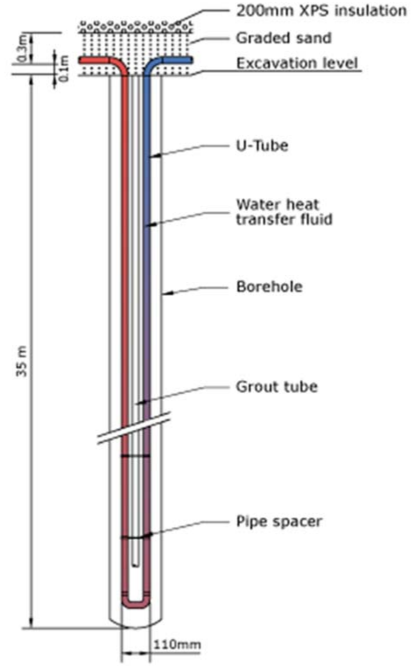


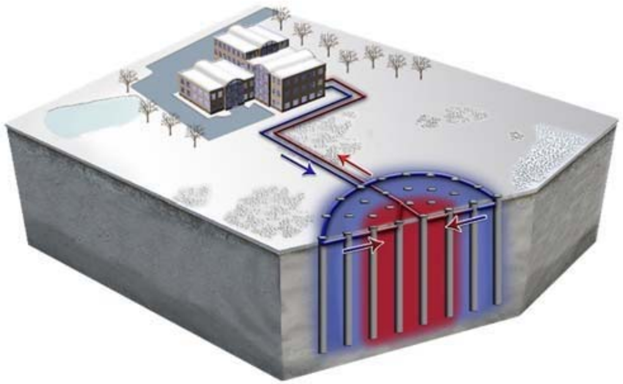


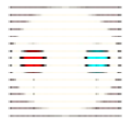
BOREHOLE THERMAL ENERGY STORAGE (BTES)

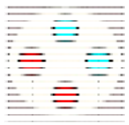


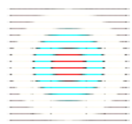




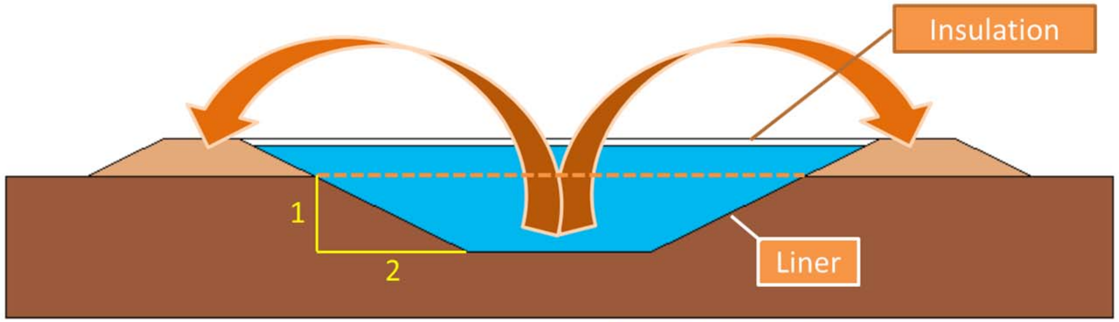



Single U-tube

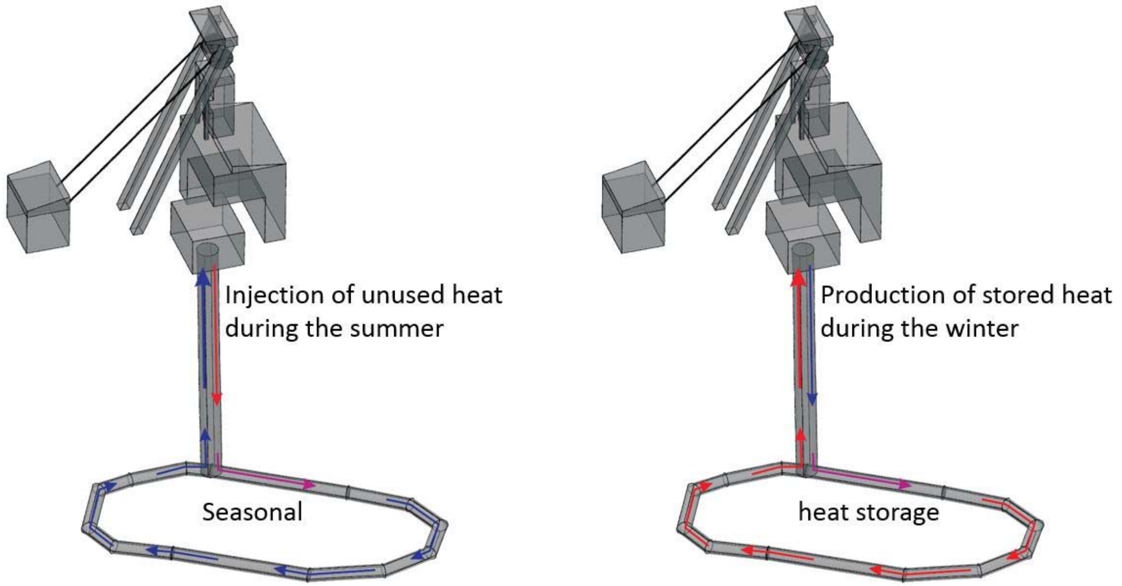

Double U-tube

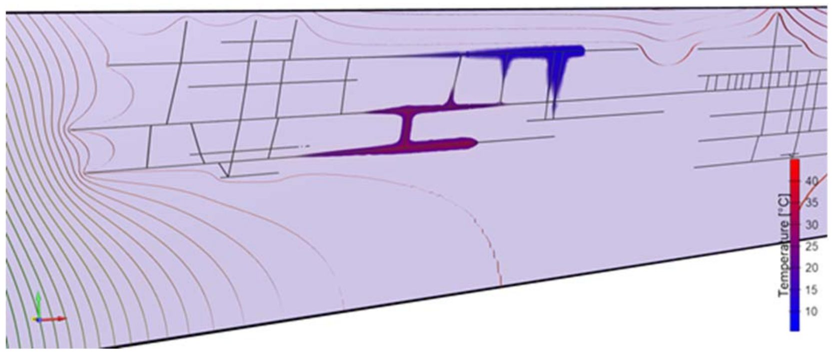

Co-axial

PIT THERMAL ENERGY STORAGE (PTES)

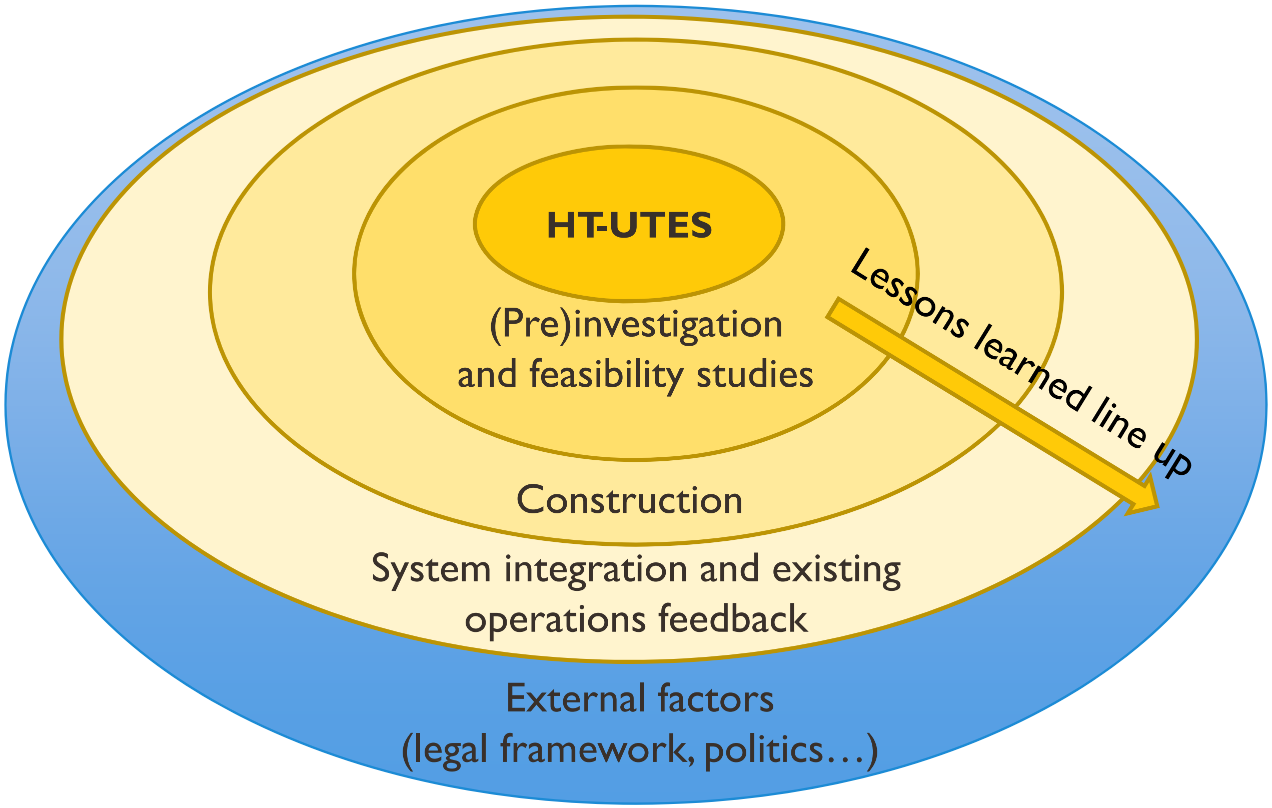


MINE THERMAL ENERGY STORAGE (MTES)

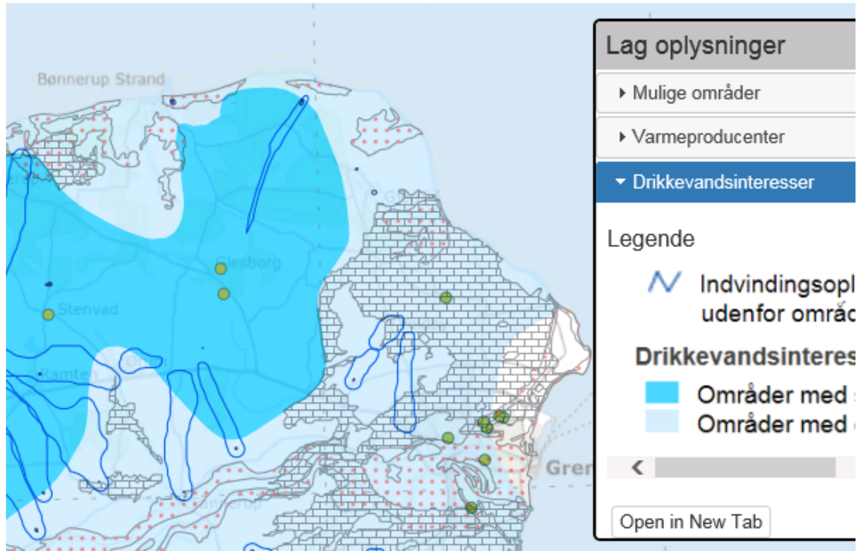




HT-UTES – LESSONS LEARNED FROM DIFFERENT PHASES



(GEUS screening tool, 2019)



- Screening for geographical parameters is essential
  - Geological conditions
  - Surface activities
  - District heating networks
- Modelling of entire energy system
- Socio-economic factors
- Legal/regulatory barriers

KNOWN HIGH-TEMPERATURE ATES PROJECTS

Year	Location/project	Status	Heat source	Aquifer depths	Storage temperature	Storage capacity	Test period
1976	Auburn University, Mobile/AL, USA	E/C	Hot waste water	41-61 m	55°C	2.235 MWh/år	-
1982	SPEOS, Lausanne-Dorigny, Switzerland	C	Waste water treatment	-	69°C	-	-
1982	Hørsholm, Denmark	D/C	Waste combustion	10 m	100°C	-	-
1982	University of Minnesota, St. Paul, USA	E/C	-	180-240 m	115°C (150°C)	9.000 MWh/år	< 3 år
1987	Plaisir Thiverval-Grignon, France	E/C	Waste combustion	500 m	180°C	20.000 MWh/år	< 3 år
1991	Utrecht University Netherlands	D/C	Combined Heat and Power	220-260 m	90°C	6.000 MWh/år	8 år
1998	Hooge Burch, Zwammerdam near Gouda, Netherlands	D/C	Combined Heat and Power	135-151 m	90°C	2.250 MWh/år	10 år
1999	Reichstag, Berlin, Germany	D/O	Combined Heat and Power	300 m	70°C	-	
2004	Neubrandenburg, Germany	O	Combined Heat and Power	1,250 m	75-80°C	-	-
2009	Geostocal, France	E	Waste combustion	1460 m	95°C	-	-
2015	Duiven, Netherlands	FS	Waste combustion	-	>140°C	-	-
Planned	BMW, Dingolfing, Germany	FS	-	500-700 m	130°C	-	-
2019 -	**HEATSTORE pilot (ECW), Netherlands**	D	Surplus geothermal heat	300-400 m	90°C	20.000 MWh/år	
2019 -	**HEATSTORE pilot, Geneve, Switzerland**	FS/D	Waste combustion	1100 m	>50°C	~ 4 MW (effekt)	
2019 -	**HEATSTORE pilot, Bern, Switzerland**	FS/D	Surplus heat	200-500 m	120°C	~ 1,7 MW (effekt)	

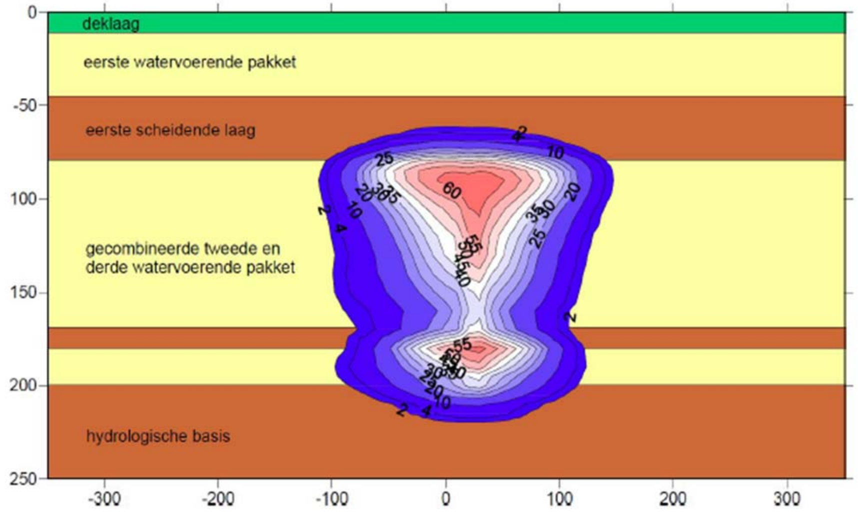
D = demo site, E = Explorative, C = Closed, FS = feasibility study, O = in Operation

- Open system using aquifers as storage media
- 11 known projects, first pilot in 1976
- 4 planned/under construction in 2019
  - 3 in HEATSTORE
- Heat sources:
  - Waste combustion
  - Waste water
  - Combined Heat and Power
  - Surplus heat (geothermal, industry, datacentres etc.)
- Storage temperatures from 50°C to 150°C
- Storage depths: < 100 m to > 500 m
- Most ATES systems worldwide are low-temperature (LT) systems
- Extensive LT-experience in the Netherlands
  - Low-temperature storage (< 30°C)
  - Medium-temperature storage (30-60°C)
  - **High-temperature storage (>60°C)**
- Known technology/well testet, good business cases for LT
- Need for further research and demonstration of new technology and materials to go from low-medium storage temperatures to high storage temperatures

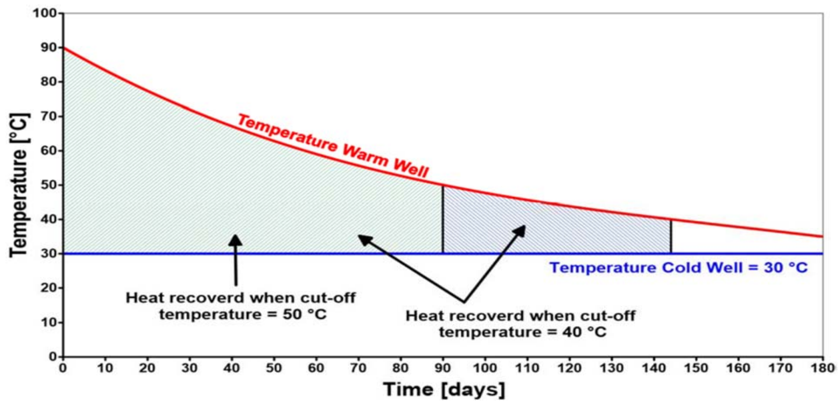
HIGH TEMPERATURE ATES – LESSONS LEARNED

- **Screening** for availability of aquifer/reservoir, infrastructure and potential conflicts of interests is a prerequisite
- **Test drilling** including pumping tests and water samples
- Hydro-geochemical **modelling** to assess need for water treatment
- Calculate thermal efficiency with **3D heat transport models** (3D geological and hydrological model)
- Well construction and **choice of materials** (pumps, casing and screens) depend highly on temperatures and water/sediment geochemistry
- Well capacity (and **declining well capacity**) needs to be evaluated and not overestimated
- On one hand, **permeability** is required for efficient production/injection, but too high hydraulic conductivity may cause **density driven groundwater-/heat flow and/or thermal breakthrough** between wells
- **Water treatment** should be considered at temperatures >50°C
  - Clogging of **fines** and **calcite scaling** are known problems
  - **Ca/Na ion exchanges** can be used to prevent precipitation of $CaCO_3$, but may cause **clay swelling**
  - **HCl-treatment** is effective, but expensive and subject to public acceptance

HIGH TEMPERATURE ATES – LESSONS LEARNED



(IF Technology)



(IF Technology)

- Careful **monitoring** is highly recommended in order to **diagnose and optimize the system**
- Repeated **re-generation of wells** should be implemented in the maintenance budget
- Do **visual inspection** of well heads, valves, transmitters and heat exchangers for leakage and corrosion as preventive maintenance
- **Thermal losses** are higher for smaller systems and for higher storage temperatures
  - Storage volume of **at least 300.000 m^3** of water is recommended
  - Demand side requirement of minimum **5 MW thermal power** is recommended
- Most efficient if used as **base load** during unloading
- Very important that the entire **energy system** is fitted to possible temperature ranges in the ATES system
  - The lower the usable **(cut-off)** temperature from the storage, the better
- Maximum **injection temperature** (20-25°C) in the regulation in some countries a serious limiting factor

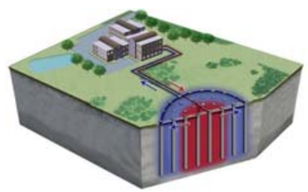
heatstore High Temperature Underground Thermal Energy Storage

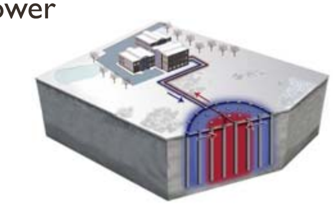
GEUS GEOTHERMICA

KNOWN BTES PROJECTS

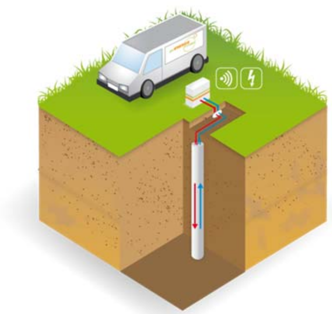
Country	Location	Energy source	Application	Start of operation	Borehole depth (m)	Max. Temp. (°C)	Estimated capacity (MWh)	Storage efficiency	Soil type
Canada	Drake Landing	Solar	Domestic (52 homes)	2006	35	80	780	50%	Sand silty, clayey
Sweden	Luleå	Industrial	n/a	1983	65	65	2000	45-55%	Crystalline rock
	Emmaboda	Industrial	Office buildings	2010	149	45	3800	n/a	Crystalline rock
	Anneberg	Solar	Domestic (50 homes)	2002	65	45	1467	46%	Crystalline rock
Czech Republic	Paskov	CHP	Test site	2011	60	78	555	n/a	Clay/miocene rocks
Germany	Neckarsulm	Solar	Domestic (300 homes, shops)	1997	30	65	1000	n/a	Clay
	Crailsheim	Solar	School buildings	2008	55	65	1135	n/a	Mudstone/ Limestone
	Attenkirchen	Solar+ hybrid	Domestic (30 homes)	2002	30	n/a	77	n/a	n/a
Denmark	Brædstrup	Solar	District heating	2013	45	70	616	61%	Clay/till
Belgium	Mol	Wast heat	Building	2002	30	82	130	n/a	Sand saturated
Netherlands	Groningen	Solar	Domestic (96 homes)	1985	20	50	595	n/a	Sand, clayey
Finland	Kerava	Solar+ hybrid	Domestic (44 homes)	1983	25	50	n/a	n/a	Soil and bedrock
Switzerland	Wollerau	Heat pump-Gas	Office buildings	1998	120	n/a	350	n/a	n/a
	Root Lucerne	LTN-heatpumps	Office buildings	2003	160	n/a	n/a	n/a	Sandstone
	Suurstoffi	Building cooling	District heating and cooling	2012	150	n/a	n/a	n/a	n/a
	Oberfeld	PVT	Domestic (100 homes)	2012	125	n/a	n/a	n/a	n/a
	Blatten Belalp	Solar	Residential	2014	120	n/a	n/a	n/a	n/a
France	**Heatstore pilot, Chémery**	Solar	Office buildings	2020?	-	-	-	-	-

- Closed loop system using soil volume as storage media
  - 18 known projects in 10 countries
  - 1 in HEATSTORE
  - 4 in crystalline bedrock
- Storage temperatures from 45°C to 80°C
- Storage capacities from 100 to 3800 MWh
- Storage efficiencies from 45% to 60%
- Heat sources:
  - Solar
  - Waste combustion and industrial waste heat
  - Combined Heat and Power





BTES – LESSONS LEARNED



(www.geoenergie-konzept.de)

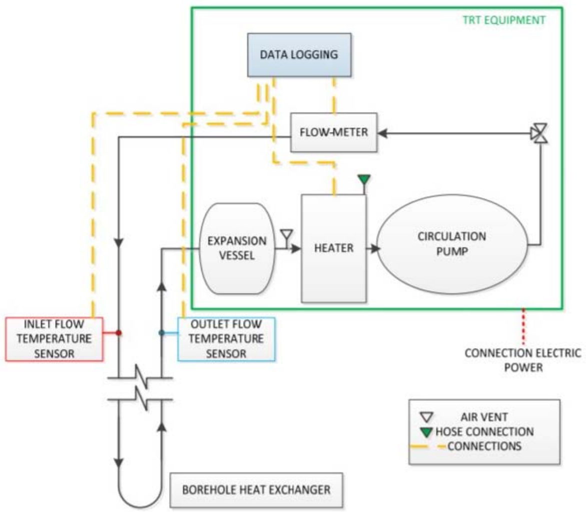
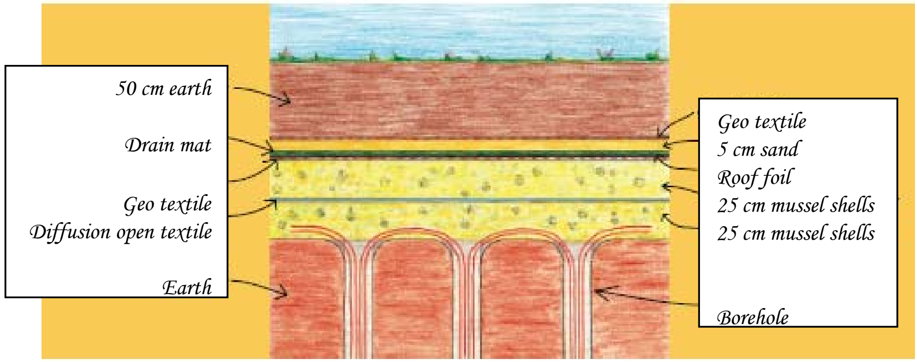


Diagram of thermal response test equipment



Top insulation at Brædstrup BTES (Brædstrup Fjernvarme)

- **Screening** for geology, groundwater flow, thermal properties, infrastructure etc.
- Perform a **test drilling** to verify the ground conditions and the estimated drilling costs and include a **thermal response test** to verify the thermal properties of the site
- A low **thermal conductivity** increase the recovery efficiency, but decrease the rate of charging/discharging
- In soft sediments **grout sealing** of the boreholes is always recommended (and often required) in order to protect groundwater resources and to obtain thermal conductivity in unsaturated conditions
- The **drilling cost** may account for approx. 50% of the total construction costs
- A **top insulation** of the BTES is necessary to reduce the heat loss and may account for 25% of the total construction costs
- A BTES **reacts slowly** during charging and discharging and normally a buffer heat storage like a water tank is necessary, especially if the heat source is solar

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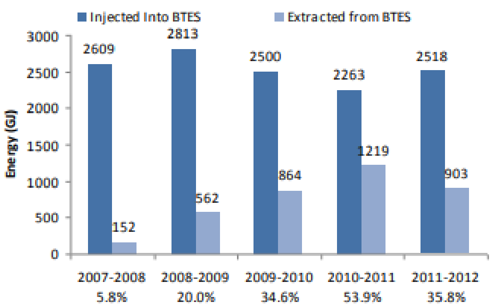
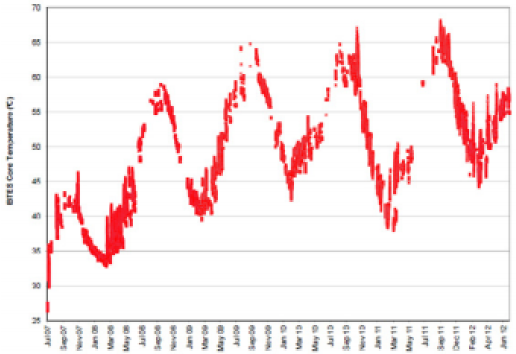
GEUS GEOTHERMICA

BTES – LESSONS LEARNED



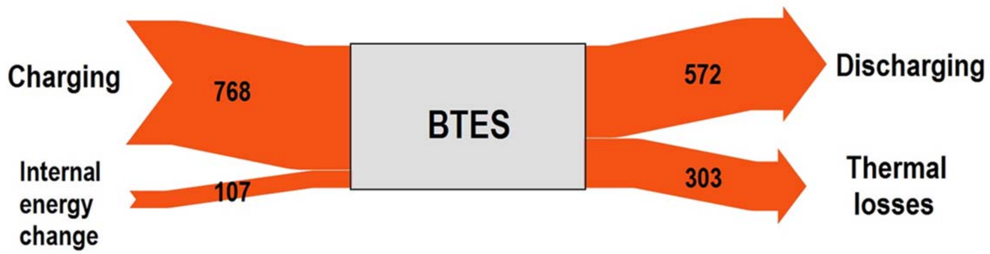
Drake Landing BTES, Canada

Injected and extracted energy 2007-2012.



Average BTES temperature 2007-2012.

(Reused from https://doi.org/10.1016/j.egypro.2012.11.097 with permission by Elsevier Ltd. under Creative Commons license CC-BY-NC-ND https://creativecommons.org/licenses/by-nc-nd/3.0/)



Heat balance for Brædstrup BTES in MWh for the period 2014-2017 (SOLITES)

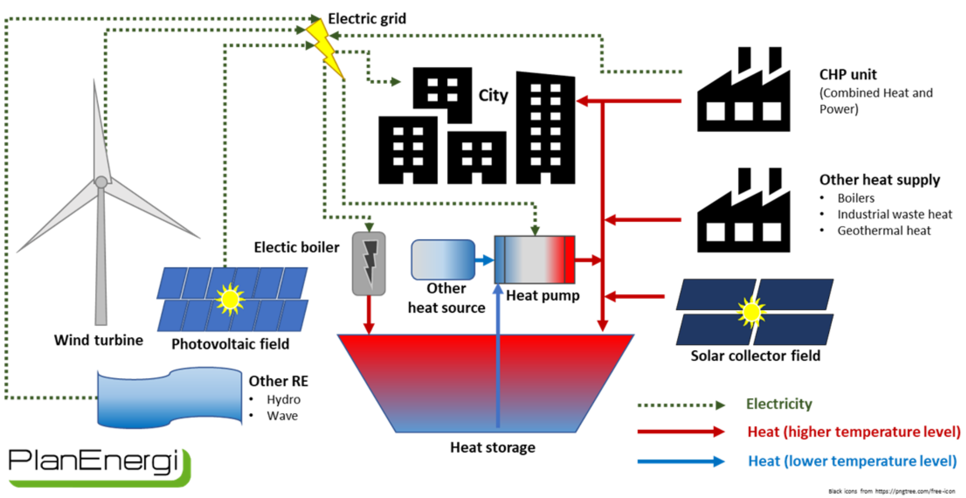
- High quality **cross-linked high density polyethylene (PEX)** tubes are normally used as they are strong, chemical resistant and can withstand high pressures and high temperatures
- **Double U-tubes** are found to be more efficient than single U-tubes, but co-axial tubes are theoretically best
- The **storage efficiency** (where known, **45% - 60%)** is often lower than expected/modelled
- In general a **start-up period of a few years** should be expected to heat up the storage and the surroundings
- the specific costs drops significantly with increasing storage size and in general BTES systems **larger than 20,000 m^3 of storage volume** are recommended
- A **clear regulative framework** is missing in many countries
- **Initial investments costs** are relative high
- Risks of **not** getting a permit and/or a **long permit procedure**

KNOWN PTES PROJECTS

Year	Location/Project	Storage volume	Storage temp.	Capacity
2003/2011	Marstal, Denmark	75.000 m^3	Up to 90°C	6.000 MWh
2013	Dronninglund, Denmark	60.000 m^3	Up to 90°C	5.600 MWh
2014	Gram, Denmark	122.000 m^3	Up to 90°C	10.000 MWh
2015	Vojens, Denmark	203.000 m^3	Up to 90°C	12.000 MWh
2017	Toftlund, Denmark	85.000 m^3	Up to 90°C	6.900 MWh
2019 – planlagt	Høje Taastrup, Denmark	70.000 m^3	Up to 90°C	3.300 MWh

- Pit storage is using water as storage media
  - 5 existing systems in Denmark
  - 1 planned in 2019-2020
- Storage temperatures up to 90°C
- Storage capacities from 3000 to 12.000 MWh
- Storage efficiency may be up to 90%
- Effective for both short- and long term storage
- High charge- and discharge capacity
- Heat sources:
  - Solar
  - Waste combustion and industrial waste heat
  - Combined Heat and Power

PTES – LESSONS LEARNED



(PlanEnergi)

- **Soil properties/geotechnical parameters** must be checked in order to utilize the excavated soil as banks
- **Groundwater flow** is unwanted in order to prevent heat loss from sides and bottom and avoid bank instability
- Relatively high **space demands**
- The top of the banks must be **levelled** and the excavated soil must be **compressed** when rebuilt into the banks
- **Plastic liners** keeping the banks and bottom tight must be double welded and the material must be temperature resistant (good experience with HDPE plastic)
- The **insulating lid** is a critical element for the performance
  - A **floating lid** is the cheapest, but most sensitive option
  - Must be **tight** and dry and with **no air pockets** below and rain water must be **drained** from the top

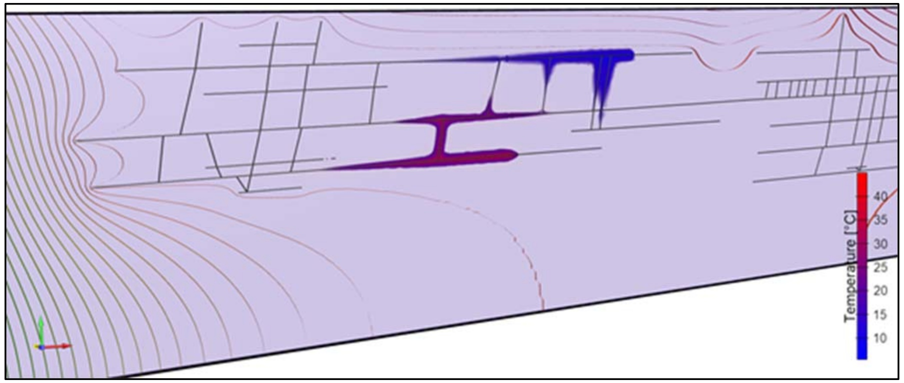
PTES – LESSONS LEARNED

(PlanEnergi)

- **Temperature monitoring** from bottom to top in the storage is necessary for optimization of operation
- **Water quality** must be checked and **filters cleaned** at regular intervals
- Check the construction by **diver inspection** and **check for leakage** by monitoring "water consumption"
- Check regularly for **wet insulation** to avoid heat loss
- **Environmental Impact Assessment** - Screening is required
  - Permission for seepage of groundwater drainage and drainage water from lid-top is necessary
  - Permission for seepage/drainage of (salty) return water from softening unit when filling storage
  - Permission for new water supply drillings for water to fill storage (can be very time-consuming)

MINE THERMAL ENERGY STORAGE

- **Mine water** of abandoned and flooded mines has until now only been used as **low-temperature energy source** for heating buildings and a few plants exist in Germany and the Netherlands:
  - The Mijnwater-project in Heerlen (Netherlands), 28°C
  - The School of Design in Essen (Germany), 28°C
  - Robert Müser colliery in Bochum (Germany), 20°C
  - Seven operational mine water utilization plants in Saxony (Germany) works as shallow geothermal reservoirs



(GZB, 2019)

- No **mine water heat storage** has been realized so far
  - 1 Pilot project in HEATSTORE, in the abandoned **Markgraf II** coal mine in Bochum
- A **large mine water volume**, safe and close to a district heating network is needed
  - Information on **mine layout**
  - Depth and **condition** of the mine
  - **Mine water analysis** including temperatures
- Modelling of the **hydraulic and thermal impacts** on a regional scale is recommended (finite element code SPRING can be used)
  - Discretization of **mine drifts**
  - Modelling of **layered aquifer systems**
  - Coupling the mine hydraulic and thermal behaviour to the surrounding **rock mass and aquifers**
- Within the Ruhr area, abandoned and flooded mine infrastructures in combination with available surplus heat from power plants and industry provides a vast potential for large scale heat storage
- Further technology development and pilot demonstrations

COMPARISON OF HT-UTES CONCEPTS

	HT-ATES	HT-BTES	PTES
Storage medium	Groundwater/sediments	Sediments/groundwater	Water
Subsurface requirements	XXX	XX	X
Required pre-investigation	XXX	XX	X
Maximum storage capacity	XX(X)	X	XXX
Storage volumes	XXX	XX	XX
Space requirements	X	X	XXX
Peak load response	X(X)	X	XXX
Investment costs	X(x)	XX	XXX
Maintenance	XXX	X	X(x)
Environmental interaction	XXX	XX	X

High: XXX	Medium: XX	Low: X

*** MTES – first of its kind, not included*

THANK YOU FOR YOUR ATTENTION

HEATSTORE (170153-4401) is one of nine projects under the GEOTHERMICA – ERA NET Cofund aimed at accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximise geothermal heat production and optimise the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe. The three-year project will stimulate a fast-track market uptake in Europe, promoting development from demonstration phase to commercial deployment within two to five years, and provide an outlook for utilisation potential towards 2030 and 2050.

This project has been subsidized through the ERANET cofund GEOTHERMICA (Project n. 731117), from the European Commission, RVO (the Netherlands), DETEC (Switzerland), FZJ-PtJ (Germany), ADEME (France), EUDP (Denmark), Rannis (Iceland), VEA (Belgium), FRCT (Portugal), and MINECO (Spain).