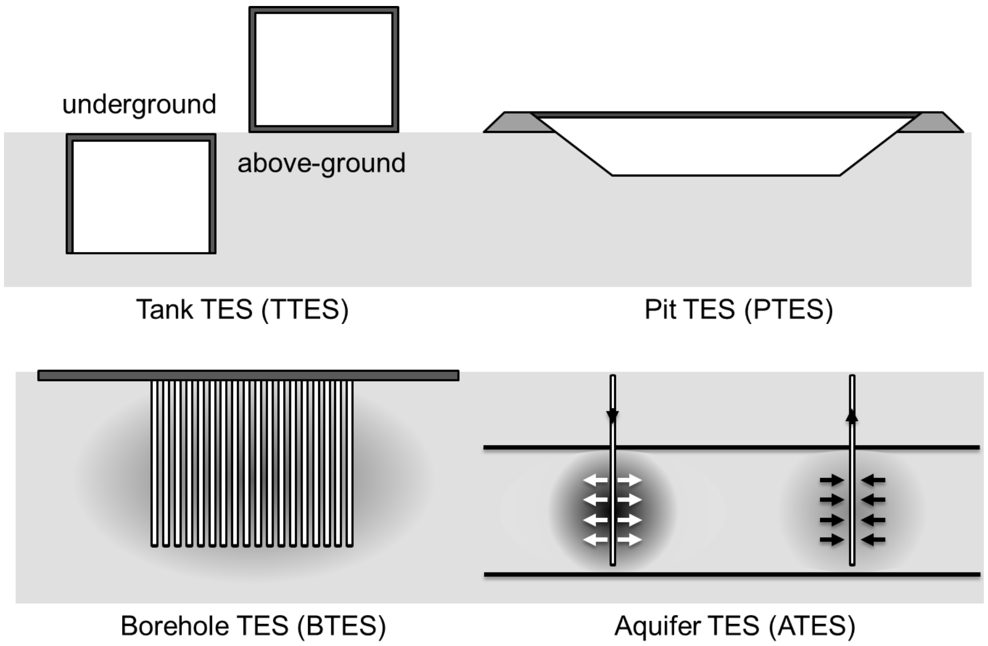
IEA-ES Task 39 brochure
Large Thermal Energy Storages for District Heating

Use Cases

PTES from Marstal district heating (photo: Aalborg CSP)

The purpose of this leaflet is to give technical **references** of Large Thermal Energy Storages (LTES) projects, in the form of **use cases** for all 4 kinds of LTES:



Sketch: Solites

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"IEA-ES" is the Technology Collaboration Program (TCP) from the International Energy Agency (IEA) focused on Energy Storage (ES)

energy storage
IEA Technology Collaboration Programme

IEA-ES Task 39 is the group of experts working on Large Thermal Energy Storages for District Heating (DH) within IEA-ES TCP

Tank Thermal Energy Storages Technology Summary

A TTES is a simple and low-tech TES solution, where the storage medium is water. It is a large tank filled with water, usually in a cylindric shape, insulated at the top and to the sides, and it is most of the time placed above ground, although it can also be underground, or even semi-buried

A TTES is built in 5 main steps (see illustration* below and next page)

1. **Build the foundation of the tank**

2. **Build the roof of the tank**, then build from top to bottom, one level at a time**

3. **Build diffusors at each corresponding level while building up the tank**

4. **Install insulation around and on top of the tank once the tank is built up**

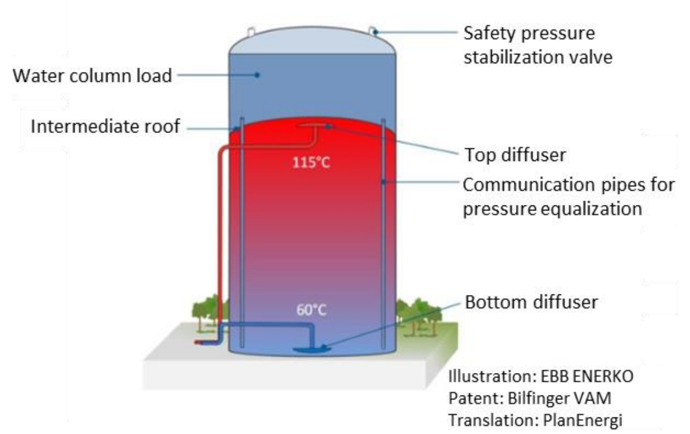
5. **Install cladding around the insulation to protect it from wind & rain, and decorate the tank**

The most technical/crucial elements of a TTES are:
- The inner shell
- The diffusors
- The insulation surrounding the TTES
- The nitrogen or steam systems preventing ambient oxygen diffusion into the tank water

A TTES can be decorated in many ways, to integrate it to an urban environment

TTES from Alperia Ecoplus, in Bolzano (IT)
5'600 m³ of water

TTES from Stadtwerke Heidelberg (DE)
19'980 m³ of water (two-zoned storage [*])



[*] A two-zoned TTES is a TTES that also works at atmospheric pressure but is divided into two zones: an upper zone, that is used to increase the pressure of the lower zone, and the lower zone is like a standard TTES (see illustration beside). This kind of TTES is more expensive than a "regular" atmospheric pressure TTES, but can store water temperatures above 100°C. This technology is however cheaper than a pressurized TTES

Technical Characteristics, TTES	
Size range, 1 tank [m³ water equivalent volume]	1'000 - 56'000***
Max thermal power [MW_{th}]	1 – 1'000
Response time [minutes] from 0 to full power	> 10
Technical lifetime [years]	> 25
Usage	Daily/weekly storage
Maturity	
Number of implemented full-scale projects by 2022	> 100
TRL	9

*Pictures from a project of F.W. Rørteknik of a 4'500 m³ TTES in Chile. See: https://www.fw.dk/references/4500-m3-heat-storage-tank-chile/ for more information

**Alternately, the roof can be built at the end of the process, once all levels have been built from bottom to top

***Upper bound valid for above-ground TTES. For underground TTES, current technology upper bound is at 100'000 m³

Tank Thermal Energy Storages
Use case Berlin (DE)

About the TTES

Technology: TTES (Storage medium: water)
Type of usage: daily storage of heat
Year commissioned: 2023

Technical details

Water volume: 56’000 m^3
Dimensions: Ø 43 m x h 45 m
Storage capacity: 2’750 MWh
Charge-discharge capacity: up to 200 MW_{th}
~70-120 cycles of charge/discharge per year
Max operational temperature: 98°C (atmospheric)
Static pressure holding function possible

Auxiliary equipment

Power-to-heat: 120 MW_{th}
Waste-water heat pump: 75 MW_{th} (planned for 2026)
Waste incineration: 99 MW_{th}

Increasing flexibility for the DHN of Berlin

This TTES is used in the conversion of the site from a coal fired CHP plant towards a multimodal energy hub in Reuter West. It is the largest TTES in the world in 2023 and is owned by Vattenfall in Germany

The main purpose of this LTES is to increase the fossil free heat share, while ensuring flexibility and security of supply of the Berlin DHN

Photo: Vattenfall

About the distribution DHN

Owner: Vattenfall Wärme Berlin AG (Germany)
Name: Berlin district heating
Type of ownership: private
Network length: > **2’000** km
Consumers connected: **1.4 Mio** household equivalents
Total heat production: **10.2** TWh/year
Total heat sold: **9.6** TWh/year

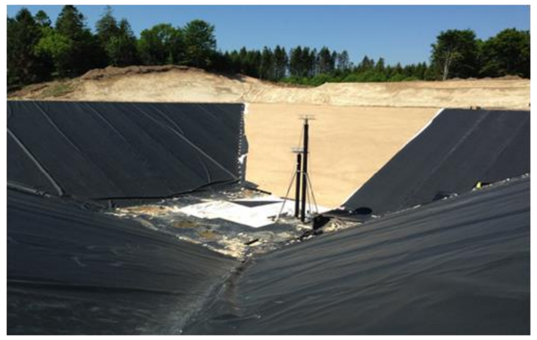
Pit Thermal Energy Storages Technology Summary

A PTES is a simple and low-tech TES solution, where the storage medium is water. It is a hole excavated in the ground, sealed with a liner, filled with water and insulated at the top such that the hot water inside is preserved to be used later

A PTES is built in 4 main steps (see illustration below and next page)

1. **Excavate a pit in the ground and put excavated soil around the edges.**

2. **Add a watertight liner at the bottom and sides of the pit.**



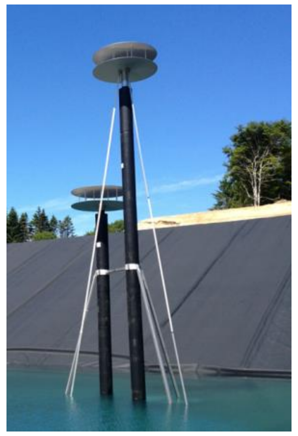
3. **Fill the pit with water.**

4. **Add an insulating floating cover on the top.**

PTES in Dronninglund, main implementation steps. Pictures: PlanEnergi

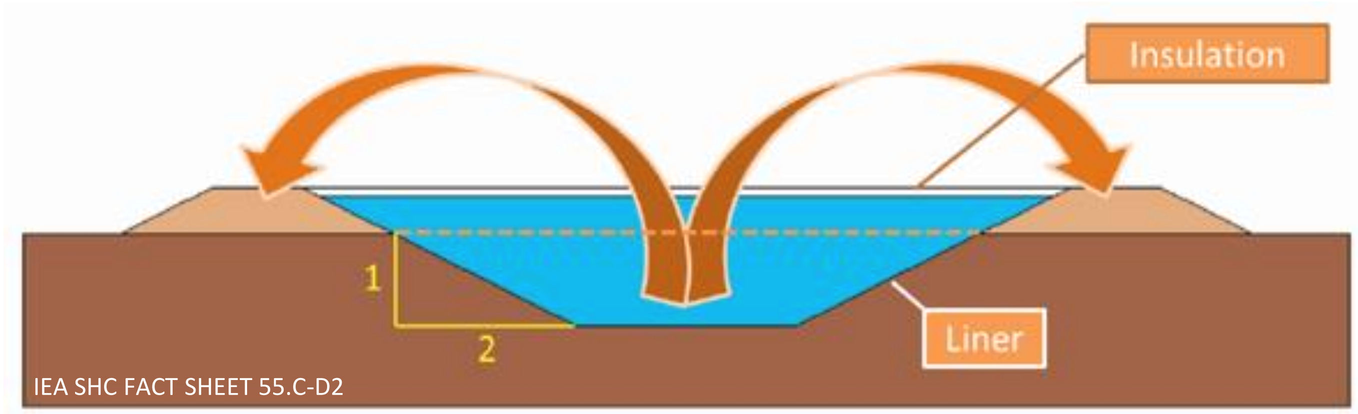
The most technical/crucial elements of a PTES are:

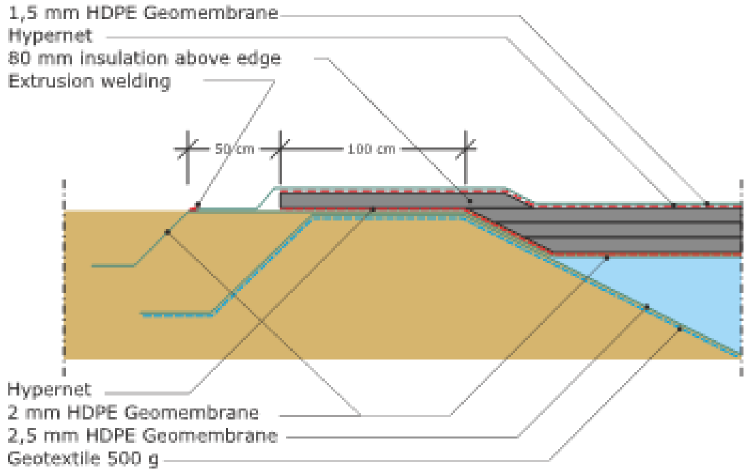
- The diffusors (see beside)
- The watertight liner
- The insulating cover/lid (see next page)



PTES diffusors in Dronninglund.
Picture: PlanEnergi

Reuse of the soil to build up the sides of the pit is important to minimize the costs of soil handling, and the simplest shape is an upside-down truncated pyramid (see illustration below)





Cross-section sketch of the original lid design in Dronninglund (adapted from Sunstore 3 – Phase 2 final report). "Geomembrane" is the technical term for the liner

Technical Characteristics, PTES	
Size range, 1 pit [m^3 water equivalent volume]	20'000 – 1'000'000
Max thermal power [MW_{th}]	10 – 1'000
Response time [minutes] from 0 to full power	30 - 60
Technical lifetime [years]	> 20
Usage	Daily/weekly or seasonal storage
Maturity	
Number of implemented full-scale projects by 2022	7
TRL	8-9

Pit Thermal Energy Storages Use Case Dronninglund (DK)

About the PTES

Technology: PTES (Storage medium: water)
Type of usage: seasonal storage of heat
Year commissioned: 2014
Main heat source: Solar thermal
Owner: Dronninglund district heating (Denmark)

Technical details

Water volume: 60’000 m^3
Lid dimension: 91 m x 91 m
Storage capacity: 5’000-5’500 MWh
Charge-discharge capacity: 27 MW_{th}
2-2.5 cycles of charge/discharge per year
Max operational temperature: 85-90°C (only summer)

Auxiliary equipment

Solar field: 37’500 m^2
Solar fraction*: 41%
Air-water heat pump: 5.5 MW_{th} (used on PTES during winter)
Auxiliary heat sources: bio-oil boiler (10 MW)
gas turbine & gas boiler (3.6 & 11 MW)

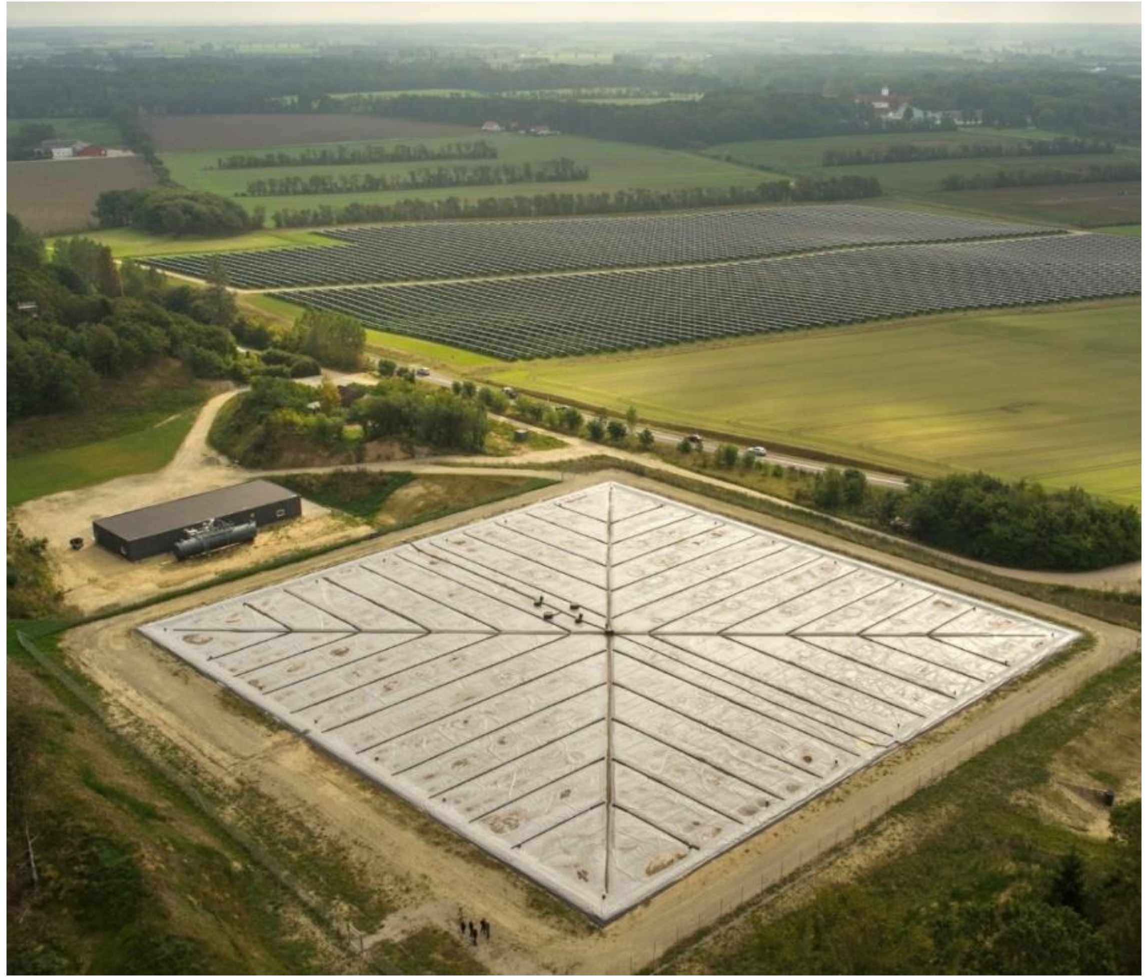


Photo: PlanEnergi

About the distribution DHN

Name: Dronninglund district heating
Type of ownership: consumer-owned (& non-profit)
Network length: **46** km
Consumers connected: **1’450** buildings/households
Total heat production: **38** GWh/year
Total heat sold: **28** GWh/year

More information about the PTES in Dronninglund can be found in the final report of SUNSTORE 3 (phase 2) on PlanEnergi’s website https://planenergi.eu/

* Solar fraction = share of the heat production covered with solar heat

Pit Thermal Energy Storages Use Case Høje Taastrup (DK)

About the PTES

Technology: PTES (Storage medium: water)
Type of usage: weekly storage of heat
Year commissioned: 2022
Main heat source: transmission DHN
Owners: VEKS & Høje Taastrup (Denmark, respectively transmission & distribution DHN operators) 50%/50%

Technical details

Water volume: 70’000 m^3
Lid dimensions: 180 m x 62 m
Storage capacity: 3’300 MWh
Charge-discharge capacity: 30 MW_{th}
25-30 cycles of charge/discharge per year (design figure)
Max operational temperature: 90°C (all year)

About the transmission DHN

Name: VEKS
Type of ownership: joint local-authority-owned (& non-profit)
Network length: **135** km
Consumers connected: **150’000** households
Total heat production: **2’500** GWh/year

Photo: Ioannis Sifnaios

About the distribution DHN

Name: Høje Taastrup District Heating
Type of ownership: consumer-owned (& non-profit)
Network length: **279** km
Consumers connected: **7’900** buildings & industries
Total heat production*: **350** GWh/year
Total heat sold: **306** GWh/year

This project is a first-of-its kind: it is the first PTES in the world not coupled to a solar thermal plant
For more information about this project please visit https://www.veks.dk/en/publications

*Including heat bought from transmission grid & self-production from Høje Taastrup District Heating

Borehole Thermal Energy Storages Technology Summary

A BTES is a TES where the heat is stored directly in the ground: the storage medium is soil or rock. It is a series of boreholes where heat exchangers are inserted in order to transfer heat to the surrounding ground

A BTES is built in 3 main steps (see illustration below)

1. **Dig the boreholes.**

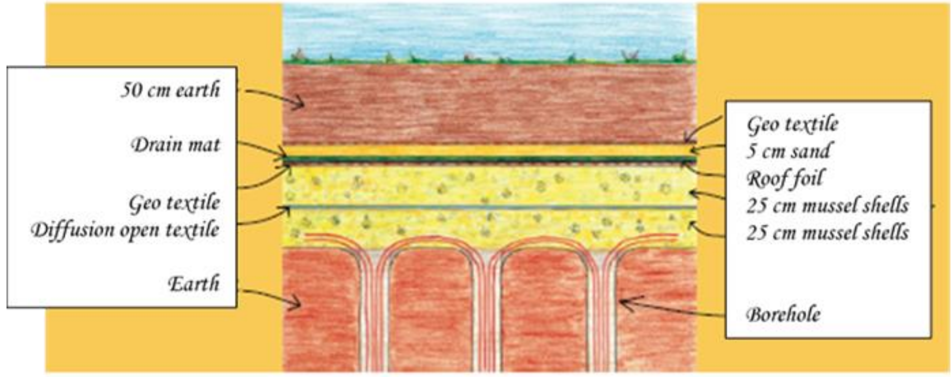
2. **Insert and connect the heat exchangers inside the boreholes.**

3. **Cover the boreholes with an insulation material and then with soil.**

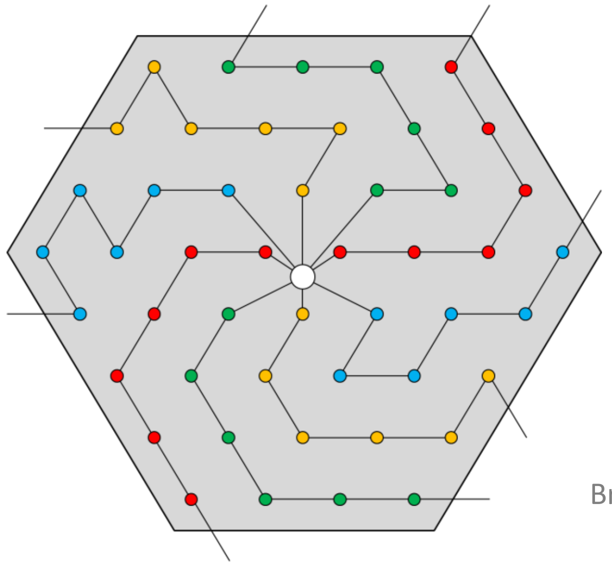
BTES in Brædstrup, main implementation steps. Pictures: PlanEnergi

The most technical/crucial elements of a BTES are:
- The borehole heat exchangers (see illustration beside)
- The insulating cover/lid (see illustration beside)
- The auxiliary heat pump (if necessary)
- The charging/discharging power management system

The BTES lid is usually covered with soil after implementation, which means that the surface can thereafter be used for other purposes



Cross-section sketch of the lid design original plan in Brædstrup (extract from Boreholes in Brædstrup final report)



Top view of the 48 boreholes from the BTES in Brædstrup and how they are connected (extract from Boreholes in Brædstrup final report)

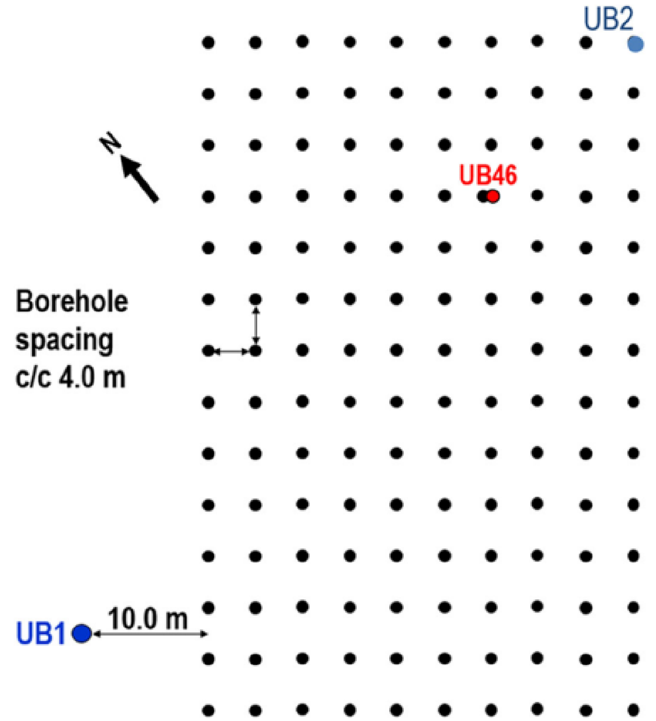
Technical Characteristics, BTES	
Size range [m^3 water equivalent volume]	20'000 - 1'00'000
Max thermal power [MW_{th}]	2 - 50
Response time [minutes] from 0 to full power	60 - 120
Technical lifetime [years]	> 30
Usage	Seasonal storage
Maturity	
Number of implemented full-scale projects by 2022	4
TRL	8

Borehole Thermal Energy Storages Use Case Emmaboda (SE)

About the BTES

Technology: BTES (Storage medium: rock)
Type of usage: seasonal storage of heat
Year commissioned: 2010
Main heat source: Industrial waste heat
Owner: Xylem Water Solutions AB

Picture showing the piping and manifolds of some sections of the BTES in Emmaboda during installation in 2010



Sketch of the 140 boreholes (black dots) and monitoring boreholes (colored dots)

Technical details

Boreholes configurations: 140 boreholes in a rectangular area to a depth of 150 m (see layout sketch beside)
Underground volume: 336’000 m^3
Storage capacity: 3’800 MWh (for ΔT of 20°C)
Storage temperature: 60-40°C (design), 40-20°C (actual)

Location of the BTES at the Xylem manufacturing site at Emmaboda

Auxiliary equipment: heat pumps

- Nominal heating power: 480 kW_{th} (8x60 kW_{th})
- Temperatures* (nominal conditions): T_{evap}=0°C, T_{cond}=35°C
- Nominal COP**: 6.5

About the distribution DHN

- Name: Xylem heating & cooling grid
- Type of ownership: Industrial company
- Network length: **local grid**
- Consumers connected: industrial buildings, approx. 110’000 m^2
- Total heat production: **2’200** MWh/year
- Total heat sold: internal use only

*T_{evap} is the temperature at the inlet of the evaporator of the Heat Pump (HP), and T_{cond} the temperature at the outlet of the condenser

**The COP is the “Coefficient Of Performance”, and it is the ratio between thermal energy output of the HP and the energy input to the HP. For T_{evap}=20°C & T_{cond}=55 °C, the total thermal output of the HP is 740 kW_{th} & the COP is 5.2

Aquifer Thermal Energy Storages Technology Summary

A HT-ATES is a TES where the heat is stored directly in an aquifer: the storage medium is groundwater and soil/ground. The basic system consist of a medium temperature well for “cold” water abstraction and a hot well for the injection of the charging heat

An ATES is built in 4 main steps (see illustration beside & below)

1. Drill the well pair(s)

2. Install the well tubes

3. Install Submersible Electric Pumps (ESPs)

4. Install well heads with injection units

HT-ATES in Middenmeer, main implementation steps. Pictures: IF Technology

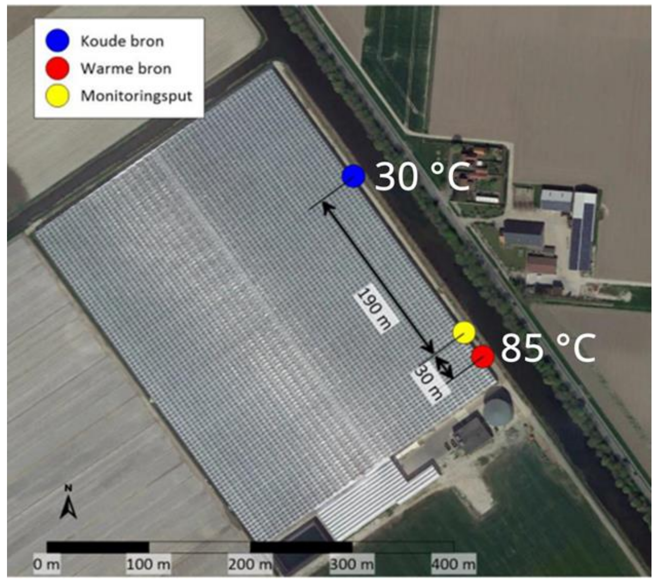
The most technical/crucial elements of an ATES are:

- Hydro-geological investigations
- Drilling & well development
- Water treatment*
- Use of ESPs

The ATES surface can be used for other purposes after implementation, only 2 well heads remain

When heat is required, water is abstracted from the hot well and re-injected in the medium temperature well. Heat exchangers are used to exchange the heat from the groundwater to the district heating network and vice versa

- Cold well
- Monitoring well
- Hot well



Top view presenting the location of the wells of the HT-ATES of ECW

Technical Characteristics, HT-ATES	
Size range, 1 pair of wells [m^3 yearly pumped water vol.]	250’000 - 800’000
Max thermal power [MW_{th}]	5 - 20
Response time [minutes] from 0 to full power	60 - 120
Technical lifetime [years]	> 30
Usage	Seasonal storage
Maturity	
Number of implemented** full-scale projects by 2022	4
TRL	8

*Together with the selection of materials & components, resistant to high temperature, corrosion & expansion

**1 of the HT-ATES projects is now decommissioned, and another is used as a geothermal heat source

Aquifer Thermal Energy Storages
Use Case HT-ATES Middenmeer (NL)

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About the ATES

Technology: ATES (Storage medium: groundwater)
Type of usage: seasonal storage of heat
Year commissioned: 2021
Main heat source: geothermal heat of 90 °C from 2’400 m
Owner: Ennatuurlijk Aardwarmte

Technical details of the LTES

Water volume: 440’000 m^3
Storage capacity: 28 GWh
Charge-discharge capacity: 12-10 MW_{th}
1 cycle of charge/discharge per year
Max operational temperature: 90°C (infiltration temperature);
85-50 °C abstraction temperature

Auxiliary equipment

The HT-ATES is connected to 2 heat exchangers
Groundwater is treated with CO_2 dosing to prevent calcite precipitation
The well heads are controlled with N_2 to prevent oxygen from entering the system
Heat is used by the greenhouse directly (without extra heat pump)

ATES can be used as a geothermal heat source or as a thermal storage

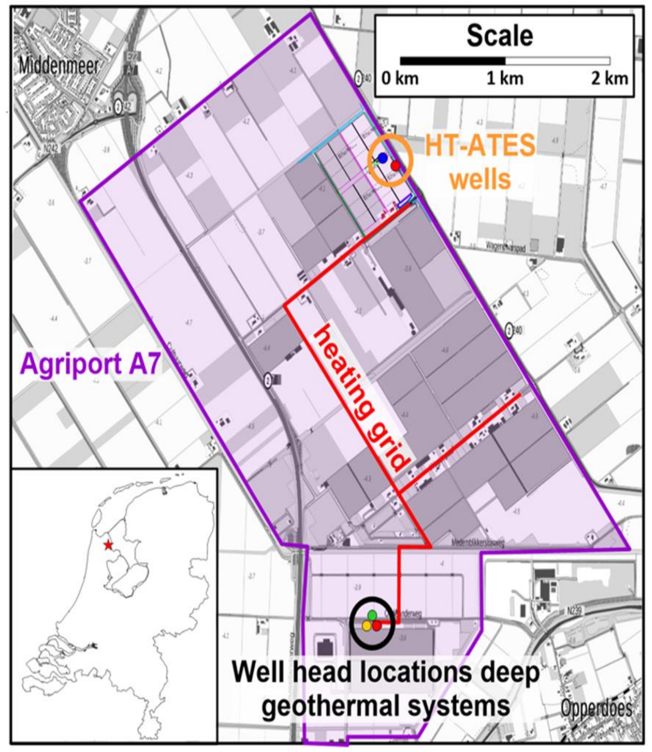
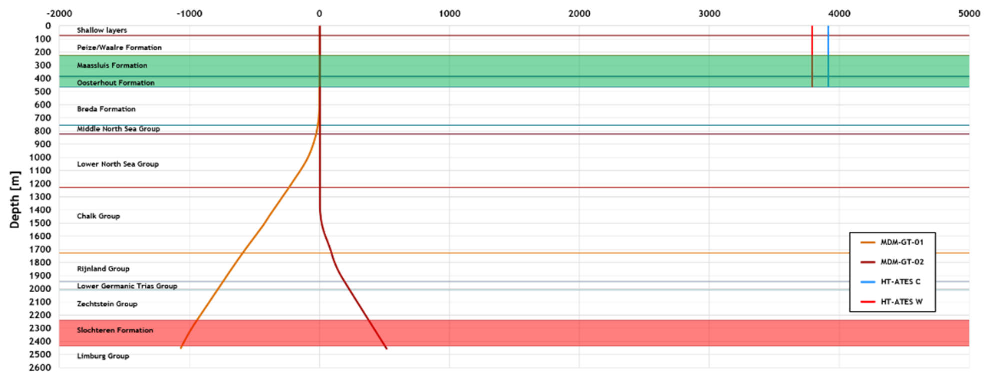


Figure beside: top view presenting the location of the wells of the HT-ATES (blue and red dots at the top of the sketch) as well as the deep geothermal wells (yellow, green and red dots at the bottom of the sketch) of ECW, as well as the location of the greenhouse in the Netherlands (bottom left corner of the sketch), in the city Middenmeer

Figure below: cross-section presenting the wells of the HT-ATES (blue and red lines at the top-right of the sketch) as well as the deep geothermal wells (orange and dark-red lines at the left of the sketch) of ECW, together with key facts about respective reservoirs



HT-ATES Aquifer (~400 m depth)
- ~ 25 m thick Aquifer
- Unconsolidated sand
- Between thick clay layers

Geothermal Reservoir (> 2km)
- Sandstone
- Slochteren Formation

About the user

Name: Helderman
Type of ownership: Greenhouse
Network length: directly connected
Consumers connected: paprika greenhouse

The experts of IEA-ES Task 39

This leaflet is intended as a toolkit for policy makers, project developers, researchers and engineers (main stakeholders of LTES projects). It is made such that the main information about LTES is available in one place: definitions, project examples, guidelines & references

For more information, you can visit the homepage of IEA-ES Task 39:
https://iea-es.org/task-39/