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

Use Cases

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:

Tank TES (TTES)  Pit TES (PTES)
Borehole TES (BTES)  Aquifer TES (ATES)

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

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 Technology

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

Energy Storages Summary

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

Technical Characteristics, TTES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range, 1 tank [m$^3$ water equivalent volume]</td>
<td>1’000 - 56’000***</td>
</tr>
<tr>
<td>Max thermal power [MW$_{th}$]</td>
<td>1 – 1’000</td>
</tr>
<tr>
<td>Response time [minutes] from 0 to full power</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Technical lifetime [years]</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Usage</td>
<td>Daily/weekly storage</td>
</tr>
<tr>
<td>Maturity</td>
<td></td>
</tr>
<tr>
<td>Number of implemented full-scale projects by 2022</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>TRL</td>
<td>9</td>
</tr>
</tbody>
</table>

*Pictures from a project of F.W. Rørteknik of a 4’500 m$^3$ TTES in Chile. See: [https://www.fw.dk/references/4500-m3-heat-storage-tank-chile/](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 m$^3$
Tank Thermal Use case

About the TTES

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

Technical details

Water volume: 56’000 m³
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.

Energy Storages Berlin (DE)

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
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.**

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).

The most technical/crucial elements of a PTES are:
- The diffusors (see beside)
- The watertight liner
- The insulating cover/lid (see next page)

### Technical Characteristics, PTES

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range, 1 pit [m³ water equivalent volume]</td>
<td>20'000 – 1’000'000</td>
</tr>
<tr>
<td>Max thermal power [MWth]</td>
<td>10 – 1’000</td>
</tr>
<tr>
<td>Response time [minutes] from 0 to full power</td>
<td>30 - 60</td>
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<tr>
<td>Technical lifetime [years]</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Usage</td>
<td>Daily/weekly or seasonal storage</td>
</tr>
<tr>
<td>Maturity</td>
<td>7</td>
</tr>
<tr>
<td>Number of implemented full-scale projects by 2022</td>
<td>8.9</td>
</tr>
</tbody>
</table>

*IEA SHC FACT SHEET 55.C-D2*
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 m³
Lid dimension: 91 m x 91 m
Storage capacity: 5‘000-5‘500 MWh
Charge-discharge capacity: 27 MWₜₜ
2-2.5 cycles of charge/discharge per year
Max operational temperature: 85-90°C (only summer)

Auxiliary equipment
Solar field: 37‘500 m²
Solar fraction*: 41%
Air-water heat pump: 5.5 MWₜₜ (used on PTES during winter)
Auxiliary heat sources: bio-oil boiler (10 MW)
gas turbine & gas boiler (3.6 & 11 MW)

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
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 m³
Lid dimensions: 180 m x 62 m
Storage capacity: 3’300 MWh
Charge-discharge capacity: 30 MW
26-30 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

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
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.

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.

Technical Characteristics, BTES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range [m$^3$ water equivalent volume]</td>
<td>20'000 - 1'000'000</td>
</tr>
<tr>
<td>Max thermal power [MW$_{th}$]</td>
<td>2 - 50</td>
</tr>
<tr>
<td>Response time [minutes] from 0 to full power</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Technical lifetime [years]</td>
<td>&gt; 30</td>
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<tr>
<td>Usage</td>
<td>Seasonal storage</td>
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<tr>
<td>Number of implemented full-scale projects by 2022</td>
<td>4</td>
</tr>
<tr>
<td>TRL</td>
<td>8</td>
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</tbody>
</table>

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)
Borehole Thermal Use Case

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

Technical details

Boreholes configurations: 140 boreholes in a rectangular area to a depth of 150 m (see layout sketch beside)
Underground volume: 336,000 m³
Storage capacity: 3’800 MWh (for ΔT of 20°C)
Storage temperature: 60-40°C (design), 40-20°C (actual)

**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

Auxiliary equipment: heat pumps

- Nominal heating power: 480 kW_{th} (8×60 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 m²
- Total heat production: 2’200 MWh/year
  - Total heat sold: internal use only

**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
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

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

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.

### Technical Characteristics, HT-ATES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range, 1 pair of wells [m³ yearly pumped water vol.]</td>
<td>250’000 - 800’000</td>
</tr>
<tr>
<td>Max thermal power [MW&lt;sub&gt;th&lt;/sub&gt;]</td>
<td>5 - 15</td>
</tr>
<tr>
<td>Response time [minutes] from 0 to full power</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Technical lifetime [years]</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Usage</td>
<td></td>
</tr>
<tr>
<td>Maturity</td>
<td></td>
</tr>
<tr>
<td>Number of implemented** full-scale projects by 2022</td>
<td>4</td>
</tr>
<tr>
<td>TRL</td>
<td>8</td>
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</tbody>
</table>

*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

The most technical/crucial elements of an ATES are:

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

*Implementation steps. Pictures: IF Technology

**Number of implemented projects by 2022

Maturity

Seasonal storage
Aquifer Thermal Use Case HT-ATES

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 m³
Storage capacity: 28 GWh
Charge-discharge capacity: 10-8 MWth
1 cycle of charge/discharge per year
Max operational temperature: 85°C (infiltration temperature); 85-50 °C abstraction temperature

Auxiliary equipment
The HT-ATES is connected to 2 heat exchangers
Groundwater is treated with CO₂ dosing to prevent calcite precipitation
The well heads are controlled with N₂ to prevent oxygen from entering the system
Heat is used by the greenhouse directly (without extra heat pump)

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

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

Energy Storages Middenmeer (NL)

ATES can be used as a geothermal heat source or as a thermal storage
The experts of IEA-ES Task 39

This leaflet is intended as a toolkit for policy makers, project developers 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/