PWG1: Technology

Technical Fact Sheet
Ad Hoc WG2

UNDERGROUND THERMAL ENERGY STORAGE (UTES) SYSTEMS FOR DISTRICT H&C

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Table of contents

1 Glossary

ATES: *Aquifer Thermal Energy Storage*. Storage system that employs an aquifer.

BHEs: *Borehole Heat Exchangers*. Pipes that allow the exchange of heat in the subsoil using a closed loop circuit.

BTES: *Borehole Thermal Energy Storage*. Storage systems employing heat injected/extracted by vertical BHEs.

CAES: *Compressed Air Energy Storage*. Storage systems employing compressed air produced using surplus power, through a rotary compressor.

CHS: *Chemical Heat Storage*. Storage systems consisting of thermo-chemical materials able to which store and release heat by reversible endothermic/exothermic reactions.

CTES: *Cavern Thermal Energy Storage*. Storage systems employing hot water in caverns or mines.

DHC*:* *District Heating Cooling*. Network systems for delivering heating, hot water, and cooling services from a central point of generation to the end users.

GSHP: *Ground Source Heat Pump* is a central heating and/or cooling system that transfers heat to or from the ground, by means of a heat pump between the ground and building heat exchangers.

HT ATES: *High Temperature Aquifer Thermal Energy Storage*. ATES systems storing water at >30° C.

LT ATES*:* *Low Temperature Aquifer Thermal Energy Storage*. ATES systems storing water at <30° C.

LHS: *Latent Heat Storage*. Storage systems which use phase change materials.

MD BTES: *Medium Deep Borehole Thermal Energy Storage*. BTES systems storing energy at medium depth (about 300-1000 m from the surface).

PTES*:* *Pit Thermal Energy Storage*. Storage systems, involving a pit filled by water or water/gravel.

SHS: *Sensible Heat Storage*. Systems based on the temperature change of a heat storage media (water or other).

STES: *Seasonal Thermal Energy Storage*. Storage system that enables thermal energy to be stored over at least one season.

TTES: *Tank Thermal Energy Storage*. Storage systems based on sensible heat, stored in thermally stratified water tanks (made of a concrete, stainless steel, or fibre reinforced plastic)

UPHES: *Underground Pumped Hydroelectric Energy Storage*. Storage system designed utilizing the gravitational potential energy of water, separated between a surface reservoir and a subterranean aquifer.

UTES: *Underground Thermal Energy Storage*. It is a kind of STES system that use the underground as an ideal medium to store heat and cold in large spaces and quantities, over several seasons.

2 Technological overview

Three main categories of STES can be defined based on the different storage mechanisms such as CHS, LHS and SHS applications. In particular, **SHS systems** comprise: i) TTES, and ii) UTES facilities. Focusing on geothermal applications utilising natural ground, **UTES systems** are considered.

The main features of Underground Thermal Energy Storage (UTES) systems are:

- **Capacity**: the amount of energy stored in the system; depends on the storage process, the medium and the size of the system;
- **Storage Efficiency**: the ratio of the energy provided to the user to the energy needed to charge TES. It accounts for the energy loss during the storage period and the charging/discharging cycle;
- **Storage period:** defines how long the energy is effectively stored in TES, i.e. hours, days, and months for seasonal storage;
- **Charge and discharge time**: the time needed to charge/discharge the system;
- **Cost Investment** (€/kW) **and Cost Production** (€/kWh): depends on the type of technology, size of TES, operating conditions, etc.

Currently, Geothermal energy (Fig. 1) can be used for baseload supply due to its low operational costs (OPEX). Typically, peak load systems are designed to have a low capital expenditure (CAPEX) with higher OPEX as they are designed to run for only a limited time. UTES can be used to reduce the amount of time peak load systems operate by using low OPEX energy (e.g., from geothermal or other local available renewable or recyclable heat sources). UTES can therefore be used to both fill peak demand loads as well as provide backup supply.

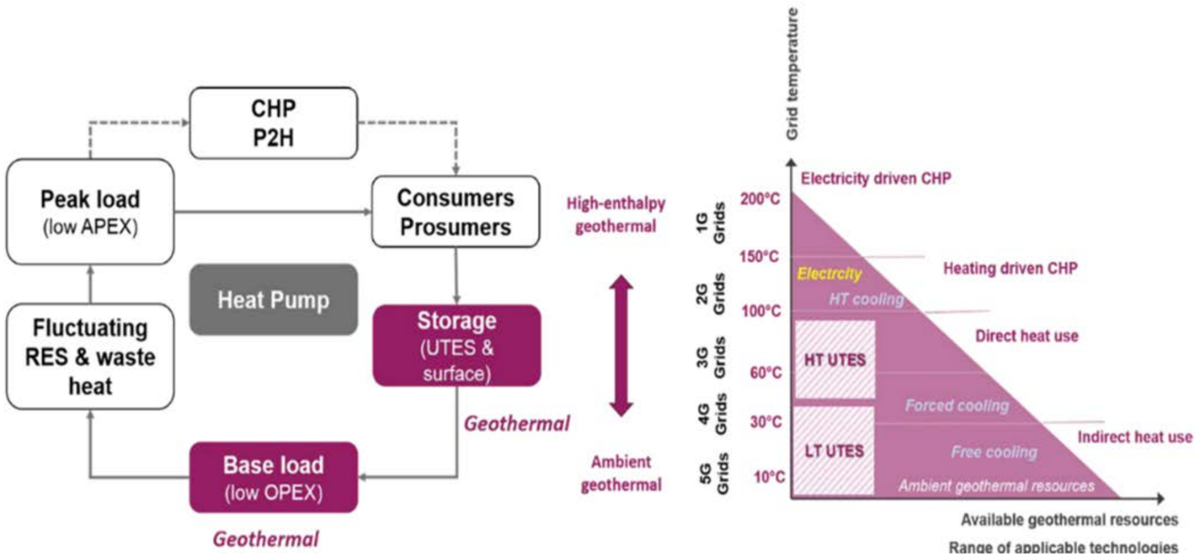

Fig. 1. Sketch of geothermal uses in district heating and cooling networks, from Goetzl et al. 2021.

UTES can provide large-scale seasonal storage of cold and heat in the underground in different ranges of temperature. Commonly, literature refers to Low Temperature (LT) and High Temperature (HT) UTES. The main technical differences between them are:

- LT-UTES uses fluids at temperatures lower than ~25-30°C; it is usually coupled with geothermal heat pump systems and improves the overall efficiency. It is the most widespread UTES application.

- HT-UTES uses higher temperatures, up to >90°C, and typically deeper reservoirs; it can be easily coupled with traditional (higher temperature) and innovative district heating, with or without heat pumps to increase temperature.

Moreover, heat pumps at various temperature levels and positions inside the network can also help to modulate and stabilize the DHC network, and waste heat from providing cooling could be recycled through storage. These concepts could be applied to new networks but permit also upgrading existing heating networks, increasing their overall efficiency.

UTES technologies are divided in 4 main typologies, with the common feature of storing the surplus of heat and cold (usually in large quantities and over several seasons or years) thus bridging the gap between production and consumption.

The four UTES systems, depending on their requirement and designs (Fig. 2) as well as their Technological Readiness Level (Tab. 1), can be summarised as follows:

	tank-TES	**pit-TES**	**borehole-TES**	**aquifer-TES**
technology readiness level	8 – 9	up to 2GWh: 7 – 9 above: 3 – 4	8 – 9	5 – 6 (HT) 7 – 8 (LT)
storage depth	surface	surface to 30 m	30 - 1.000 m	10 – 1.000 m
temperature range	atmospheric: <100° C pressurized: >100° C	<100°C	up to 30°C for shallow and 100°C for deep systems	up to 20°C for shallow and 100°C for deep systems
specific thermal capacity	30-80 kWh/m³	30-50 kWh/m³	15-30 kWh/m³	30-40 kWh/m³
strengths	applicable in any place; low development risk	applicable in any place; low development risk	low development risk; small surface footprint	high efficiency rate; small surface footprint
weaknesses	high investment cost; visible landmark	high surface footprint; low efficiency rate	high investment costs; lower efficiency of thermal output	only applicable in aquifers; development risks

Tab. 1. Technological overview of different UTES systems

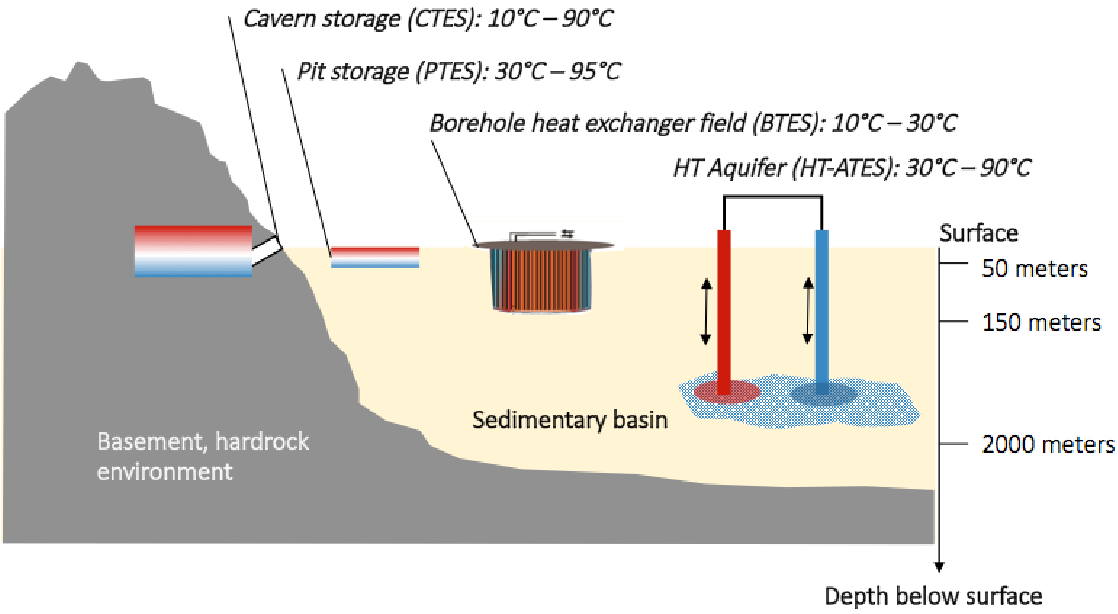

Fig. 2. Overview of the different UTES concepts regarding their position in an overall geological context. The graph also shows the depth and temperature interval of each application (Gregor Goetzl, personal communication).

- *ATES* uses naturally occurring groundwater bodies at depth between less than 30 meters and up to 2-3 kilometres. In general, all ATES concepts use at least two wells (well doublet) for the extraction and injection of groundwater. These wells are connected to a heat exchanger to transfer the heat between the geofluid loop and the user circuit. Depending on the maximum storage temperature, we distinguish between Low Temperature ATES (maximum storage temperature <30° C) and High Temperature ATES (storage temperature >30° C). For technical and physical reasons, storage temperature usually does not exceed 90°C.
- *BTES*. It can be considered as an improvement on conventional closed loop GSHP systems. Specifically, it consists of an array of vertical BHE, with a single or double U configuration, and installed in wells drilled at certain distances and depths depending on geological hydrogeological, and thermo-physical conditions of the underground. BHEs are designed in a way such heat or cold energy are stored or extracted seasonally from a cylindrical volume of soil or rock while, GSHPs, provide a simple dissipation of thermal energy into the subsurface.
- *CTES*. Here, thermal energy is stored as hot or cold water in an underground cavern. In such a system, a large volume of water is required in order to maintain a stratified temperature profile in the cavern. During summer, hot water is injected at the top of the storage volume of the cavern while, the colder one, is extracted from the bottom. The reverse cycle is applied during winter season. The CTES concept is mostly applied in hard rock environment. It often capitalizes on existing caverns resulting from abandoned mines.
- *PTES*. It consists of a water filled or water/gravel filled pit and is partially insulated on the sides and on the top with a watertight floating lid. It differs from the TTES because the construction is inside a natural material, rather than a fully manufactured one, and that pit storage is typically underground. Due to this, construction costs to store a unit of energy are much lower especially when large storage volumes are needed.

3 State of the art regarding the use in heating and cooling grids.

Optimizing the performance of a sustainable and renewable grid is becoming an increasingly important topic. Societal dependence upon energy has increased significantly in the last several decades. Air conditioning systems increased worldwide from about 4000 GW in 1990 to 11000 GW (and more) in 2016, and the energy consumption for space heating and cooling is expected to more than triple by 2050 (International Energy Agency, 2018). Since global energy demand for heating and cooling is growing rapidly, good economic and environmental performance are extremely important. Global energy demand is set to grow by more than a quarter to 2040 and the share of generation from renewables is projected to rise from 25% today to around 40%. This is expected to be achieved by promoting the accelerated development of clean and low carbon renewable energy sources and improving energy efficiency, as it is stated in the recent EU Directive 2018/2002 on energy efficiency. The European Commission has pledged to have 27% renewable energy production by 2030 (Menéndez et al., 2019). At present, buildings in Europe account for 41% of the final energy consumption, more than transport (32%), and industry (25%), hence the integration of renewable energy technologies is extremely necessary (Todorov et al., 2020).

Renewable heat generation, while coming from many sources and each having different characteristics, are less on-demand and often available either continuously or at opposite times than the demand, i.e., it is easier to generate renewable heat when it is hot and cold when it is cold. To overcome the temporal mismatch in demand and supply of thermal energy, storage facilities are needed.

UTES applications reveal a promising and effective technology to bridge the gap between energy demand and supply seasonally, for both district heating and cooling networks. This allows system's efficiency, techno-economic feasibility, and limited impact on the surrounding groundwater areas. Also, storage is currently the only way to use volatile renewables, like solar-thermal, and make use of waste heat to enhance the overall energy efficiency of the heating and cooling market, which is an EU goal.

On the other hand, space cooling demand for warm climates like Mediterranean areas is increasing. As incomes rise and populations grow, the use of air conditioners is becoming increasingly common, especially in commercial buildings and high-density residences of the hottest world regions, accounting for about a fifth of the total electricity in buildings around the world (International Energy Agency, 2019). Moreover, the HRE4 (Heat Road Map Europe) developed strategies and guidelines for 14 EU countries, accounting for 80% of heating and cooling demand (https://heatroadmap.eu). The growing air conditioning demand is mostly covered by various types of electrically driven vapor compression cooling systems. The most used cooling devices are vapor compression systems, which use electrically driven compressors to transfer energy. In this framework, low-carbon solutions can be a great possibility to improve this increasingly growing demand by ensuring clean energy without any form of pollution as well.

Approximately 1.4 million GWh could be saved and 400 million tons of GHG could be reduced annually by the application of TES in Europe (IEA ETSAP & IRENA, 2013).

Thermal energy storage includes several different technologies, each one with its own specific performance, application, and cost. For instance, TES systems based on sensible heat storage, offer a storage capacity ranging from 10-50 kWh/t and storage efficiencies between 50-90%, depending on the specific heat of the storage medium and thermal insulation technologies.

Various thermal energy storage systems can be easily integrated into a district heating system in centralized (mostly large capacity units) or decentralized (usually smaller scale units in public and office buildings or households) manner. The utilization of TES as a knot for coupling and integration of decentralized renewable energy heat sources contributes to the overall efficiency, flexibility, and response time of a district heating system. The coupling of local renewable energy subsystems and installations to the onsite thermal energy storage reduces the heat consumption of the district heating system, without any physical connection to the main DH network.

In the case of combined district heating and cooling systems, the cold storages are used. They might have common storage units with the heat storages (operating in seasonal modes) or be designed separately as cold water storages, ice storages, rock caverns, etc.

With regard to the *ATES systems*, these storage applications are one of the most promising technological options, due to their affordability and large storage capacities (Bloemendal and Hartog, 2018) They can provide sustainable heating and cooling energy for different building typologies and be well integrated at a district/urban level such as offices, airports, universities, shopping malls and hospitals. They require a suitable sub-surface which allows water to flow easily and can store water (an aquifer). Fleuchaus et al. (2018) reported that there were around 3000 ATES applications worldwide by 2017, mostly concentrated in Europe. They are mostly applied for single buildings and small building complexes in the Netherlands with over 2500 sites, and Nordic Countries such as Sweden and Denmark with 220 and 55 examples, respectively. A more limited number of examples are in Great Britain, China, Japan, Germany, North America and Turkey. The total amount of heat and cold produced by ATES is currently estimated to be 2.5 TWh per year, which equals the average thermal energy consumption of 150.000 households in Central Europe (Fleuchaus et al., 2018).

Among the 3000 ATES systems worldwide, 100 large-scale systems are integrated in district heating and cooling networks (Schmidt et al., 2018). This growing number and increasing attractiveness are mainly focused on LT ATES systems, and it is probably due to market incentive programs and the open-mindedness of certain Authorities to support these kinds of systems. Most of the LT ATES are in the Netherlands, are shallow and operate with well depths ranging between 25 and 250 m, with temperatures lower than 25 °C; while, in Germany, the current temperature threshold for these depths is at a maximum of 20 °C for heating and 5 °C for cooling. This last condition has led in the past, some problems with the integration of ATES systems. The Technology Readiness Level (TRL) of LT ATES can be placed between 7 and 8. The applicability of LT ATES in other European countries is high, based on the characterization of their subsurface. Despite this, the current level of implementation outside the Netherlands lags behind at European and worldwide level (Fleuchaus et al., 2018).

Currently, there is a significantly lower implementation of HT ATES systems, partly due to lack of regulation and partially due to early test sites and pilot projects. In fact, according to Fleuchaus et al. (2018), only 5 HT ATES are in operation worldwide. The TRL is considered to be between 5 and 7. Generally, several market barriers in the energy market are often preventing the development of such a system in specific Countries, where this technology is not yet developed.

Focusing on *BTES applications*, the TRL can be placed between 8 and 9. They are becoming very popular because of their suitability for seasonal storage of thermal energy, thanks to slow thermal response and large storage capacities. They require only a small amount of space to tap into a large volume of subsurface rocks at relative low costs. These characteristics give them a great advantage with respect to the other kinds of storage technologies. Another selling point is that there is not exchange of groundwater like in ATES systems. Moreover, a literature review (Lanahan et al., 2017) reveals that energy storage of BTES is most effective when diurnal and seasonal storage are used in conjunction; BTES has also less geographical limitations than ATES system, and they have lower installation cost scale than other kinds of storage applications like TTES as well as they are more often used for heating than for cooling applications.

Furthermore, BTES consisting of grouped compact arrays of BHE representing suitable energy storage to combine with a DHC system, as they offer larger storage capacity.

As reported in Nilsson & Rohdin (2019), in recent years, experimental facilities have been used to better understand the underground thermal behaviour using these systems, where for example various charging and discharging strategies have been tested. Some research has also used numerical models to predict and investigate the performance of BTES for the storage of solar energy. Currently there are few BTES installations for the storage of industrial excess heat, and research on their potential it's at early stages and a thus, a future challenge.

CTES plants, have reached a TRL of between 5 and 7. CTES systems require a suitable natural or man-made cavern. Abandoned mines are often close to urban areas and can provide such a facility if the caverns are stable. There are more than one million abandoned mines worldwide. Depending on the geology and local groundwater conditions, polluted mine water may have to be perpetually treated becoming a long-term economic burden on current and future generations (Menéndez et al., 2019).

In Heating and Cooling (H&C) grids, geothermal will be a key energy source both in smart cities and smart rural communities in addition to supplying energy for industry, services, and agricultural sectors. This is thanks to its ability to supply not only heating, cooling, and warm water, but also to be a solution for smart thermal grids via UTES systems.

Existing housing infrastructure represents a considerable share of the low temperature H&C demand, that can be efficiently and sustainably supplied by geothermal heat pumps and geothermal district heating systems. New materials and designs of heat exchangers have also produced promising results to reduce costs and to increase efficiency, but here further work is needed. Furthermore, geothermal district heating will be increasingly targeted at existing buildings and old inner cities in dense urban areas. At the same time, the concept of UTES is attracting an increasing interest from industries, research institutions and public authorities. It is expected to gain acceptance and market uptake as it will provide a solution to partially replace the use of fossil fuels and to reduce the costs of heat storage. It will deliver the combination of geothermal energy with underground storage which will constitute a powerful tool in the context of sector coupling. Geothermal energy combined with small thermal grids systems is offering one of the most effective options for this market, both in terms of carbon footprint and economics.

Research and Innovation are two of the cornerstones for the further development of H&C geothermal technologies and their market uptake, in the context of the 2030 milestones (RHC, 2019). In addition, the European Parliament approved an Own Initiative Report on energy storage. The report highlights the role of geothermal as a provider of several energy storage and flexibility services, including seasonal thermal energy storage in the underground, batteries and generation of electricity from flexible renewable sources such as geothermal (https://www.europarl.europa.eu/doceo/document/A-9-2020-0130_EN.html).

4 Selected case studies

ATES systems

- **Delft**, the Netherlands. The ATES system is now being developed. Advanced development to realize a geothermal system to supply the heat, in which case the district heat system would be extended to part of city of Delft. For the time being the heat will continue to be delivered by the CHP plant. The HT-ATES will be developed on the campus property and because it will be a large system it has relatively low heat cost (Fig. 3).

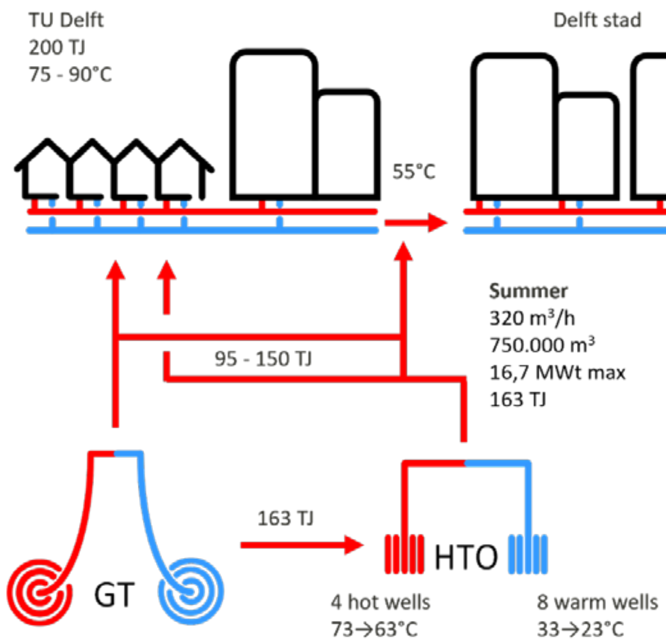

Fig. 3. HT-ATES example connected to the existing district heating network on TU Delft University, The Netherlands

- **<u>Reichstag of Berlin,</u>** Germany (Fig. 4) (Sanner et al., 2005). The system consists of two aquifers at different depth used to store cold (ca. 60 m) and heat (ca. 300 m), in Quaternary and Lower Jurassic sediments, respectively. The temperature may reach 70° C. The heat storage aquifer is overlain by a confining layer of about 140 m thickness, consisting of claystones/siltstones of the Upper Sinemurian (70 m thickness) and by the Oligocene Rupel clay (another 70 m). This confining layer prevents convective heat losses from the storage formation into the Tertiary sediments. Energy balance for cold ATES: cold retrieved in summer of 3950 MWh/a and cold stored in winter, 4250 MWh; energy balance for heat ATES: heat stored in summer of 2650 MWh and heat retrieved in winter, 2050 MWh.

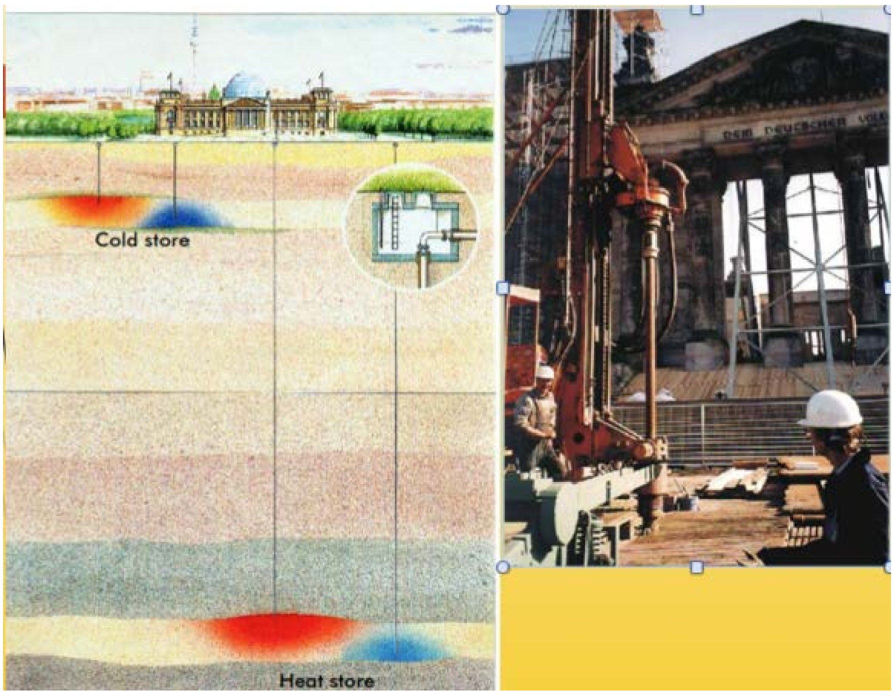

Fig. 4. Sketch of the ATES system at the Reichstag Berlin, Germany

BTES systems

- **Emmaboda, Sweden,** (Skarphagen et al., 2019). High Temperature BTES system installed and in operation since 2010. Stored around 10 GWh of industrial waste heat (with source temperatures ranging from 58 to 90° C but supplied to the BTES at up to 55° C) in a 10×14 array of 140 boreholes, spaced at 4 m, drilled to 150 m deep in a predominantly granodiorite bedrock. BTES has reduced the amount of bought district heating by approximately 4 GWh/year.

- **Braedsturp, Denmark** (Fig. 5), (Miedaner et al., 2015 ; Baser et al., 2019). It was installed in 2007, it supplies heat from 18.000 m^2 of solar thermal panels to an array of 50 boreholes, 47-50 m in depth, and with a distance of 3 m (the minimum safe distance for drilling) installed across 15 m wide area. This system provides 20% of the heat to 14.000 homes. Also, 6 boreholes are connected in series in a string from the center of the storage towards the periphery resulting in a total of 16 parallel flow strings. During the charging phase, the storage hot water flows through the strings from the center towards the periphery while when discharging, cold water circulates in the opposite direction.

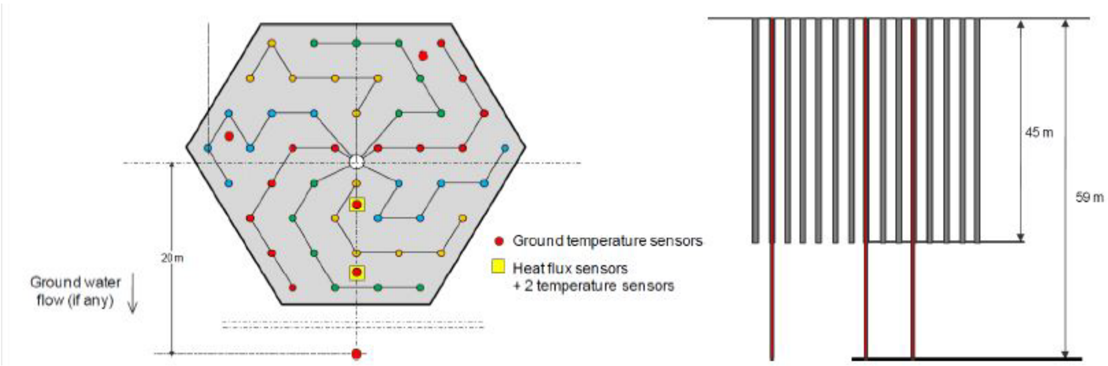

Fig. 5. Sketch of the BTES system at Braedsturp, Denmark.

- **Crailsheim Hirtenwiesen, Germany** (Fig. 6) (Miedaner et al., 2015). 7300 m^2 of solar thermal flat plate collectors provide 50 % of the heat for a housing area with 260 units. Heat is stored in two water tanks (100 and 480 m^3) and in a seasonal 37.500 m^3 borehole storage. For the second phase, a collector area of 9.700 m^2 (6,8 MWh) and a 75 800 m^3 borehole storage were foreseen. A 489 kWh high temperature heat pump transfers heat from the larger buffer storage to the smaller one when necessary, so there is always hot water at 70° C available.

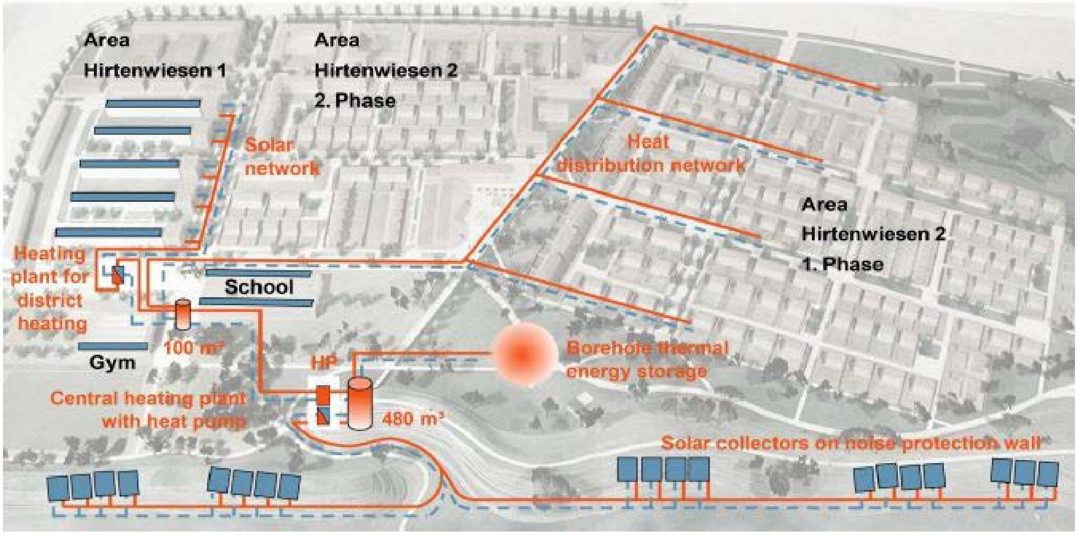

Fig. 6. Sketch of the solar district heating system in Crailsheim Hirtenwiesen equipped with a storage system made by water tanks and a BTES technology.

CTES systems

- **Heerlen town, the Netherlands** ("Minewater 3.0 Project"). It is un upgrade from the first project called "Minewater 1.0 Project" designed as a low-temperature district heating system launched in 2008, and being one of the most successful of the Netherlands. Here, the extraction wells supply heat and cold from the minewater. Surplus of heat and cold can be stored in the mine water reservoir through the hot and cold injection wells. (https://www.mijnwater.com/?lang=en).

- **Fraunhofer IEG Bochum, Germany** ("Heatstore" sub-project, Fig. 7). It is a fully functional high temperature mine thermal energy storage (HT-MTES) pilot plant, for the energetic reuse of an abandoned coal mine. The seasonal unutilized surplus heat during the

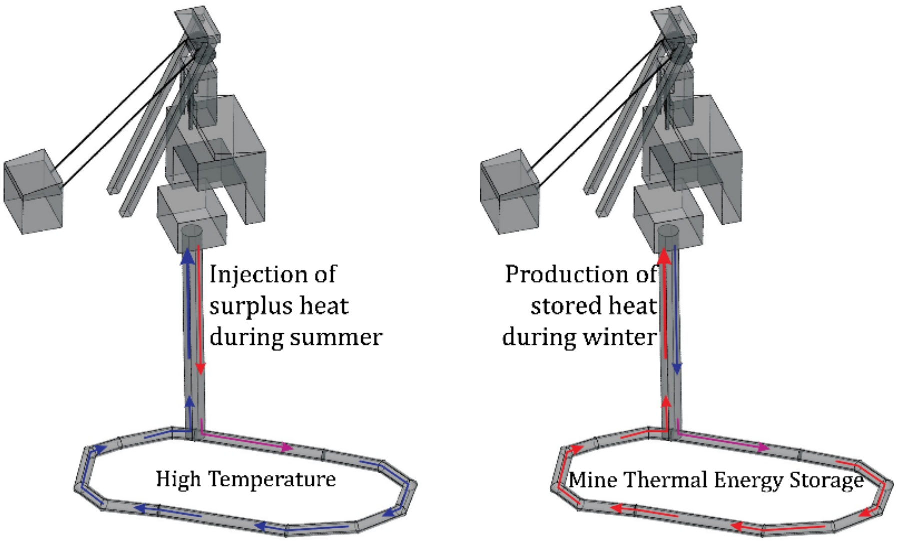

Fig. 7. Conceptual model of the H-MTES plant in Bochum, at Fraunhofer IEG.

the summer is stored from solar thermal collectors within the mine layout, and it is used during the winter season, for heating purposes of the institute buildings of the "Fraunhofer

Institut für Energieinfrastruktur und Geothermie" (IEG). (https://www.heatstore.eu/national-project-germany.html)

- **Lyckebo, Uppsala district heating system, Sweden** (Fig. 8) (Hellström, 2012; Bergensund et al., 2015). The Lyckebo system was built in the 1980's and consisted of a solar field, an electrical boiler, and a cavern for storage of excess heat. Currently, the only change is about the solar field which has been substituted with two pellet boilers. On the whole, the volume of cavern is of 104.300 m^3, while its storage capacity of 5,5 GWh and the store temperature ranges between 60 and 90° C.

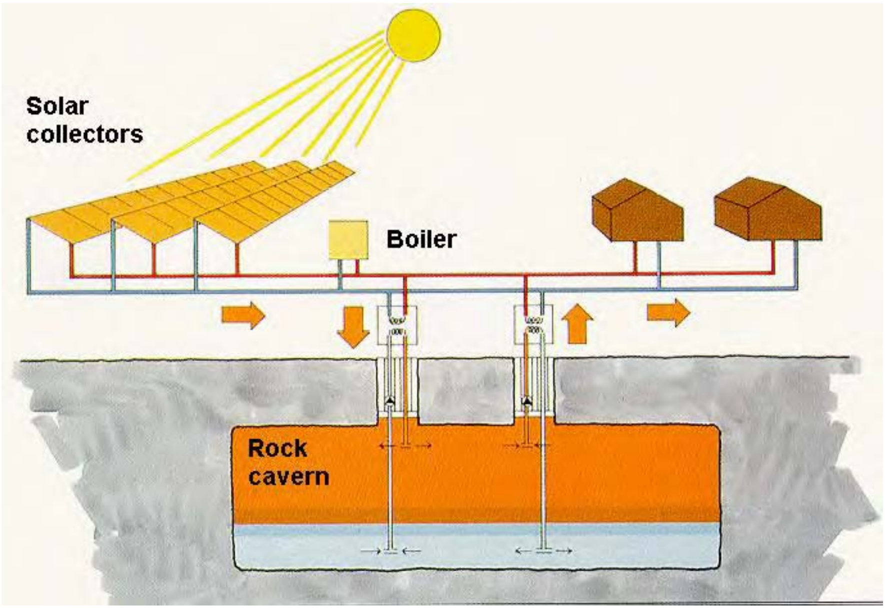

Fig. 8 Sketch map of the integrated solar district heating system and CTES plant in Lyckebo, Sweden.

PTES systems

- **Marstal, Braedsturp, and Dronninglund (Denmark), (**Fan et al. 2017). Successfully implemented in solar district heating plants in Denmark. Authors monitored temperature data at different levels of the water pit storage, and at different depths of the ground around the storage. A simulation model of the pit storage was also conducted to investigate thermal behaviour in and around the storage. It consists of 75.000 m^3 pit heat storage with 98×98 m excluding the dam around the storage, and water level at 16 m depth.

5 Outlook until 2050

One of the major challenges for the future energy systems is to overcome the mismatch between supply and demand through the development of energy managements tools achieved thanks to new information and communication technologies and a new smart energy system approach.

Underground Thermal Energy Storage Systems can allow the integration of renewable energy in power generation, industry, and buildings. Between the most important outlooks until 2050, the International Renewable Energy Agency (IRENA) shows the key attributes of UTES technologies (IRENA, 2020), identifying priorities for ongoing research and development such as:

- investment to drive technological development and measures needful in enhancing a market pull, together with well-defined and favourable energy policies aimed at scaling up the use of geothermal energy in the district heating and cooling sector also combined with other renewables.
- UTES systems which can contribute to the energy transition investment package available to Countries for post-COVID recovery. This can strengthen health and economic infrastructure and align the energy development with global climate and sustainability goals.

On the other hand, the RHC and EGEC Agenda (RHC/EGEC, 2020) shows some outlook technologies showing how the well-established, low temperature heat pump supported applications, energy produced from low temperature air source, water source and solar thermal energy could be stored underground and used for heating and cooling purposes. Based on what reported in this Agenda, these systems could become an important provider for heating and cooling for individual houses, industry, and utility buildings, but also with district heating and cooling.

Stakeholders in the district heating and cooling projects such as developers, local authorities, utilities, consumers, and housing associations can be disheartened in investing in UTES technologies despite their technical feasibility has been widely proven.

Investment mechanisms, clear guidelines, and regulations for planning, building standards and environmental protection, can contribute to accelerating the deployment of UTES projects in the district heating and cooling context (IRENA, 2020).

Policy makers should work to removing unnecessary barriers to project progress by ensuring robust planning procedures and assisting potential stakeholders. This stresses the need to implement the current EU Strategy (European Commission, 2016) that aims to have flexible procedures in the district heating and cooling market, but still have special planning for UTES technologies.

The important work of policy makers in this field, can be also linked to funding R&D and demonstrations to prove the system benefits as well as to promote media campaigns encouraging consumer uptakes. Price support mechanisms are one of the important pillars between the main outlook until 2050: they can help drive competitiveness of decarbonizing district heating and cooling overall, helping to increase demand for thermal storage as well.

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7 Appendix A:

7.1 Further UTES Systems with TRL between 6 and 9

ATES systems

- **Rostock, Germany** (Fig. 1). (Schmidt et al., 2004). The system supplies a multifamily house with a heated area of 7000 m² in 108 apartments with heat for space heating and domestic hot water preparation. On the roof of the building 980 m² of solar collectors are mounted. The ATES operates with one doublet of wells and is located at a depth of 15 to 30 m below ground surface. The store works as a seasonal heat store to overcome the gap between high amount of solar energy in summer and highest heat demand of residential buildings in winter. For monitoring reasons, seven additional boreholes have been drilled to be able to place more than 50 temperature sensors into the storage volume.

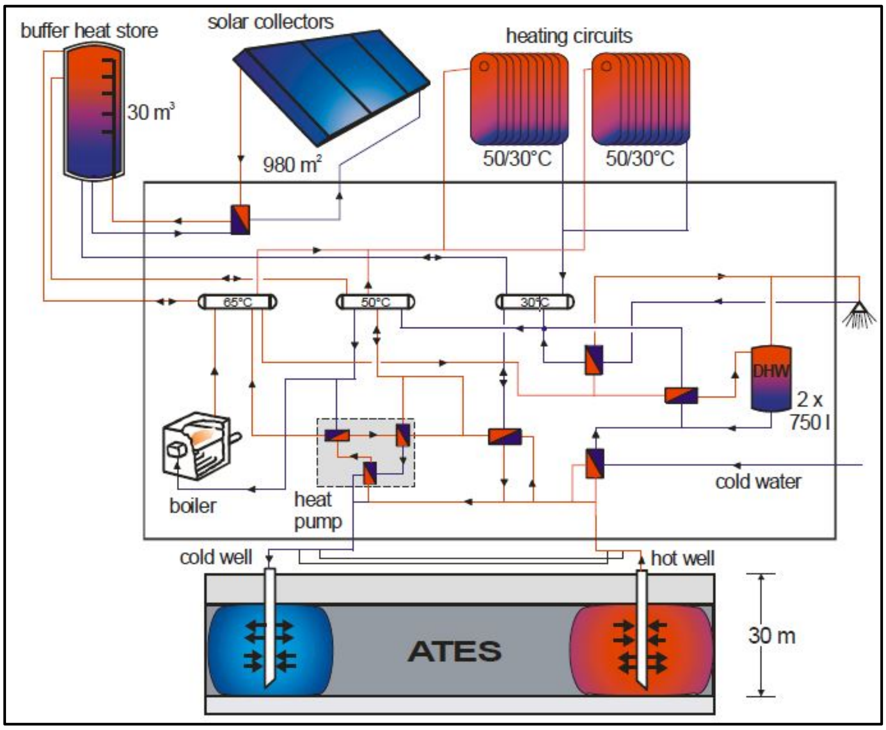

Fig. 1. Sketch map of the heat supply and of the ATES system in Rostock, Germany

BTES systems

- **Drake's Landing, Okotoks, Alberta, Canada** (Fig. 2). (Baser et al., 2019). Provides 100% of the heat demand of 52 homes with annual steady-state efficiency of heat extraction overheat injection of 27% via solar panels installed on garage roofs, to an array of 144 boreholes in a 35 m deep and wide grid. The solar energy is captured year-round by 800 panels mounted on all the garages in a large array. Both seasonal and Short-Term Thermal Storage (STTS) systems allow the storage of solar energy in the summer for use in space heating in winter. The Borehole Thermal Energy Storage (BTES) system acts as an in-ground heat sink for seasonal energy storage, as well. The city of Okotoks is located at 1084 m elevation, and it is characterized by winter low temperatures around -33°C, and summer high temperatures around 28°C. Drake's Landing won the 2011 Energy Globe World Award, represented by more than 40 nations at the Energy Globe World Award Ceremony in Wels, Austria.

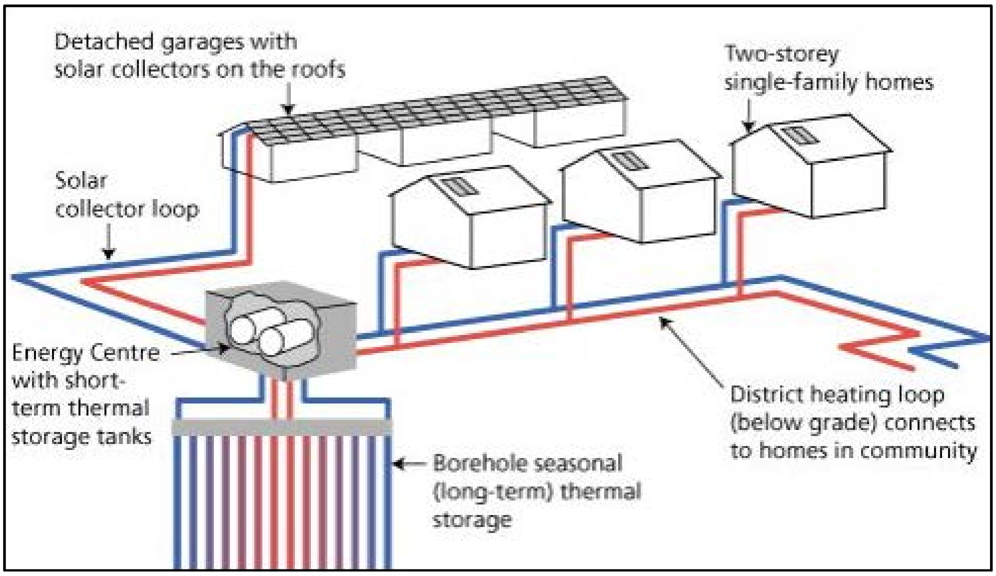

Fig. 2. Sketch map of the BTES system in Drake Landing, Okotos, Alberta, Canada.

CTES systems

- **<u>Barredo Colliery, Mieres, Asturian Central Coal Basin, Spain</u>** (Fig. 3) (Hunosa-Sepi, 2019). The project involves the development of a District Heating with a unique Generation Plant with two heat pumps in the own facilities of Barredo Colliery. The heat pumps benefit by heat exchangers using the temperature of the water pumped from the main shaft of the mine at 23° C. Subsequently it feeds, using an underground pipe network, two public buildings and a total of 245 dwellings, at a maximum distance of 900 meters. The energy supply may be set at different working temperatures. The network has a power capacity of about 2 MW supplying energy to the buildings heating systems and for the domestic water. It keeps the previous natural gas boilers out of service most of the time, with a total installed capacity of 6.274 kW.

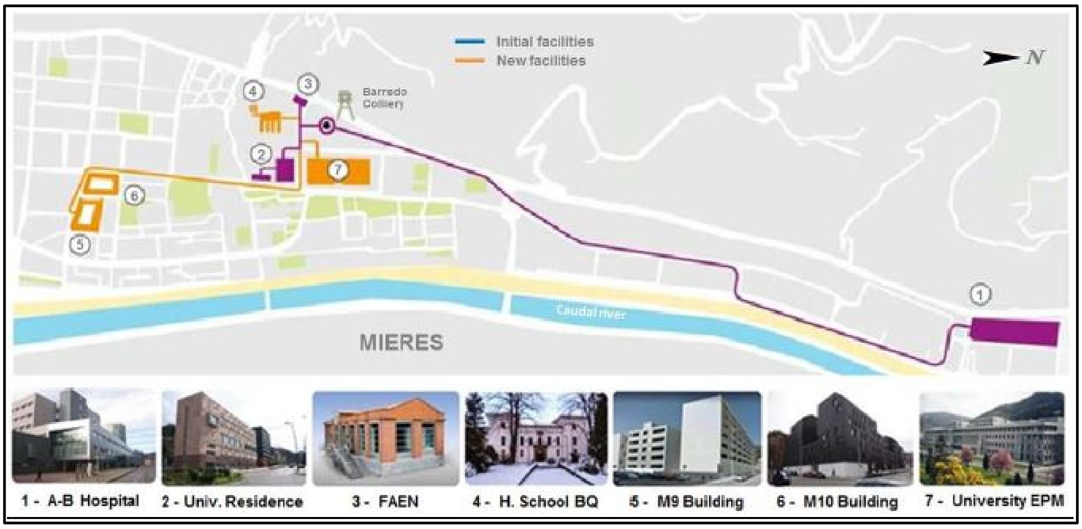

Fig. 3. Sketch map of the district heating in Barriedo Colliery.

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