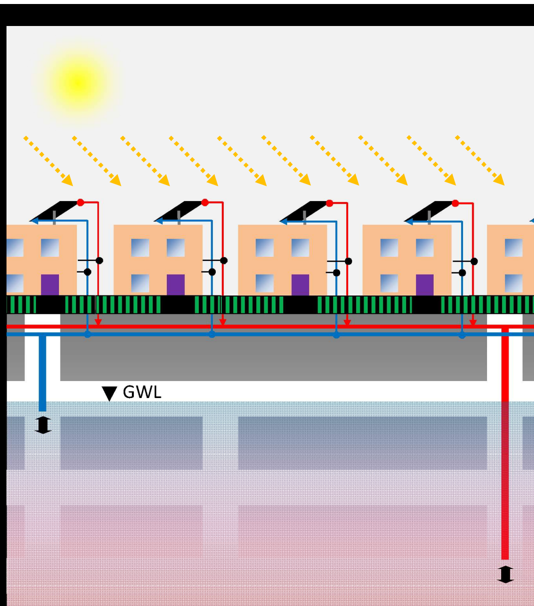
(ROCK) CAVERN THERMAL ENERGY STORAGE



For rock cavern thermal energy storage (CTES) systems, the most common scenario is the use of an abandoned, naturally flooded mine as a heat sink for the excess heat produced during summer (e.g. from solar collectors, industrial processes, deep geothermal, etc.). A thermal gradient is induced into the water contained in the cavity network. The stored heat is extracted during winter.

1 PROVEN CONCEPTS

FREELY CONFINED WATER

Although CTES is the least common one among underground thermal energy storage (UTES) systems, it represents the most appealing option from an operational perspective. In the end, it is "nothing more" than a large mass of water contained in a medium with low thermal loss (the underground), so the **heat exchanging rates are the highest compared to aquifer or borehole thermal energy storage (ATES and BTES, respectively) systems**. However, **the occurrence of sufficiently large cavities** (> 0.01 hm^3) is **neither common** (in the case of natural caves with no specific use restrictions), **nor economically feasible** (the cost of cavities excavated on purpose is one order of magnitude higher than that of an equivalent BTES system).

Therefore, CTES projects can only prosper in existing, human-made cavities, like **flooded old mines**. Not in vain CTES is also known as mine-thermal energy storage (MTES).

Besides thermal energy storage applications, mine water in flooded mines is used in many cases as **a low enthalpy geothermal resource**, given the large depth of extraction (500 - 1000 m), which provides between 10 and 30 °C extra degrees only due to the geothermal gradient (20 - 30 °C/km). **This should not be confused with a storage concept**.

A RESOURCE DIFFICULT TO SPOT

The **Lyckebo project** (Uppsala, Sweden) can be identified as the only operating CTES system based on an artificial cave that was specifically excavated for thermal energy storage purposes. In contrast, several old mines have been already reconverted in Germany, The Netherlands or Canada, most of them **oriented to district heating (DH) networks**.

The Lyckebo CTES system is based on an excavated volume of 0.1 hm^3, allowing an energy storage of up to 5.5 GWh/year with a storage temperature T_{in} between 60 and 90 °C. The heat source was originally a field of solar collectors, but now is the residual heat from a combined heat and power plant. The cost was about 45 €/m^3.

The project **Minewater 2.0 in Heerlen** (The Netherlands) is a representative example of an old mine re-utilisation. It started as a pilot plant back in 2008 for cool (16 °C, 250 m depth) and warm (28 °C, 700 m depth) mine water extraction from a flooded abandoned mine. In 2013, the pilot plant was upgraded to a cool and warm CTES system, combined with an intelligent DH network, where heat can be exchanged directly between buildings. The old mine is used in case of excess or shortage of heat and cold.

2 FUTURE CONCEPTS

FUTURE CONCEPTS: FUTURE PROJECTS

As seen in the previous paragraphs, the use of flooded old mines for CTES is not a new concept, but a concept yet to be exploited. Therefore, future concepts here mean "future projects". In the current context of coal phase-out, many coal-mining areas across Europe represent a vast potential. Some examples with an historic mining activity and comprising notorious urban areas are the Central England (UK) and the Ruhr region (Germany).

OIL RESERVOIRS WITH A GREEN FUTURE

In Kruunuvuorenranta, or Kronobergsstranden (Helsinki, Finland), it is projected to re-use **two caverns formerly used as oil reservoirs** (excavated in the 1970's) to store seawater during the summer and use it during winter as a heat source for a heat pump-based DH network. The total volume is 0.3 hm^3 and it is located between 20 and 50 m below the sea level. The idea is simple but powerful: **storing seawater when it is warmest into the underground (>20 °C in August)** is a straight way to store solar thermal energy, indeed.

3 GOOD EXISTING PRACTICES

In contrast to excavated caves, old abandoned mines consist of a 3D intricate network with tunnels and wells, which is **far from an optimised shape to minimise thermal losses**. Hence, a relatively low temperature difference (10 - 20 °C) compared to the undisturbed ground temperature will favour a low thermal loss scenario. Since the optimum temperature depends on many factors (hydrogeology of the location, volume of stored water and its 3D distribution), simulation becomes an essential tool to assess the actual storing potential.

Also because of the specific configuration of a mine, it might be justified to **allocate the warm reservoir at the deepest part of the mine**:

- **Buoyancy flow is limited** due to the twisted path that water must follow through the tunnel network.
- In cases where deep mine levels already exist (>500 m), significantly better conditions for heat storage will be achieved at the bottom **thanks to the geothermal gradient**.
- **Lower environmental risks** (temperature driven biological processes or thermal interaction with shallower aquifers).

The mine water level should not be excessively deep (< 100 m). An excessively high hydraulic head implies a too high pump power, reducing overall coefficient of performance and endangering economic profitability. However, there are several variables driving this decision. Given a certain heat-exchanging rate, different configurations of pumping flow and temperature difference (ΔT) leads to large differences in efficiency (see Figure 1).

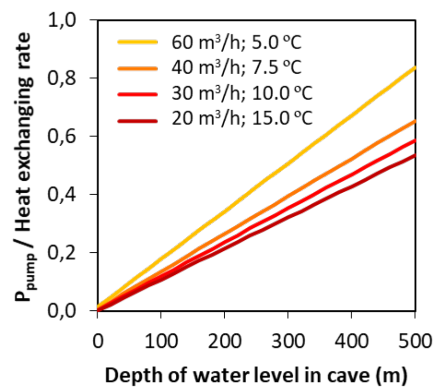


Figure 1. Ratio between pumping power and heat exchanging rate vs. depth of water level below the surface. Different pump flow and ΔT configurations are compared. Heat exchanging rate is ~350 kW_{th} in all cases. Pump power is calculated for pure water flowing through $Ø_{ID}$=6" steel pipes and $\eta_{e\text{-}m}$=40%.

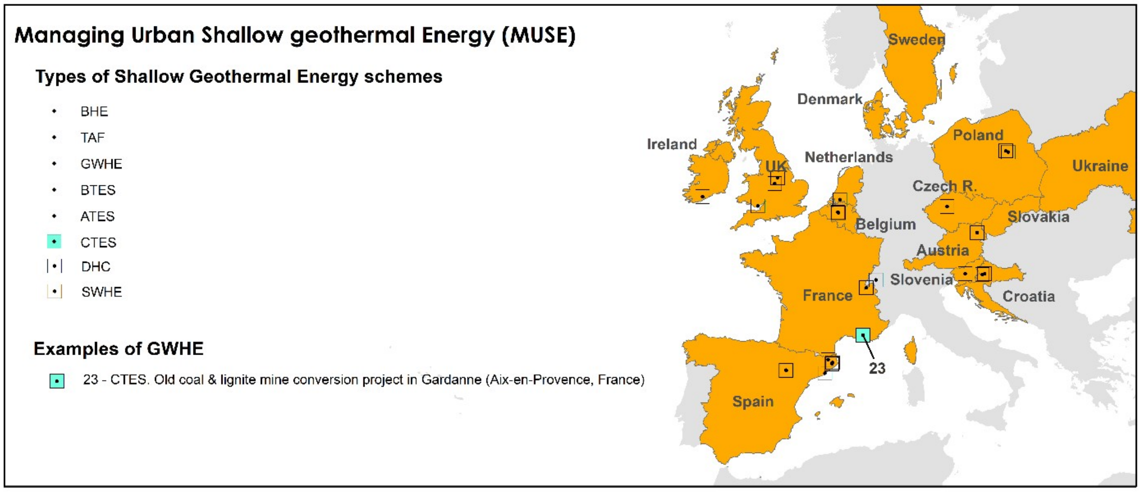
4 LESSONS LEARNED

When new UTES are conceived, subsidence events related to old mining areas must be considered. Hence, **geotechnical studies and further ground monitoring installations should be implemented**.

Those abandoned mines where a water pumping infrastructure remains active for environmental reasons (for example, in order to avoid mineralised mine water mixing with shallower aquifers) should receive special attention. The cost of this pumping is an externality, so it makes sense at least to **compensate this energy expenditure by the energy that could be stored or extracted in/from the mine water**.

Existing operative mines should receive probably as much attention as old ones. The exploitation of many of these caverns across Europe might get to an end in the next 5-10 years. From a practical point of view, an **early resource assessment** when the mines are still accessible will surely help to a smarter and more efficient transition in its use.

5 EXAMPLES



CTES-1. Old coal & lignite mine conversion project in Gardanne (Aix-en-Provence, France)

GARDANNE PILOT AREA

Location (WGS84 coordinates): N 43.451893 E 5.448345

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1476	272

Maximum flow [m^3/h]: 50

Initial $T_{gw\text{-}cool\ season}$ [ºC]: No data

Initial $T_{gw\text{-}warm\ season}$ [ºC]: No data

Depth of extraction [m]: 330

Depth of injection [m]: 1100

Reservoir volume [m^3]: 65000

	Heating	Cooling
Capacity installed [kW]	500 (simul.)	500 (simul.)
Demand [MWh]	2.1 (calculated)	1.3
Seasonal performance (SPF_{H2})	no data available	no data available

The utilization of the minewater from the old mine is part of a large project for the conversion of this obsolete installation within the project "Pôle Yvon-Morandat". The minewater is pumped at 330 m of depth and re-injected at 1100 m, creating a loop where heat is exchanged in a titanium heat exchanger. At the other side of the heat exchanger, water is circulated and deposited in 2x50 m^3 storage tanks, from where a temperated water network will be used for heating and cooling (depending of the season) multiple buildings by using heat pumps. Photovoltaic solar panels will provide 100% renewable electricity to the buildings, and excess power will be used to pump the water from the extraction well. The storage tanks favours low thermal losses and an optimized utilization of photovoltaic solar panels. The balance between extracted and injected heat into the minewater reservoir is expected to be null.