Picture courtesy of Olaf Kevin

High-temperature BTES in Switzerland: early lessons learned from pilots

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Shallow Borehole Thermal Energy Storage (BTES)

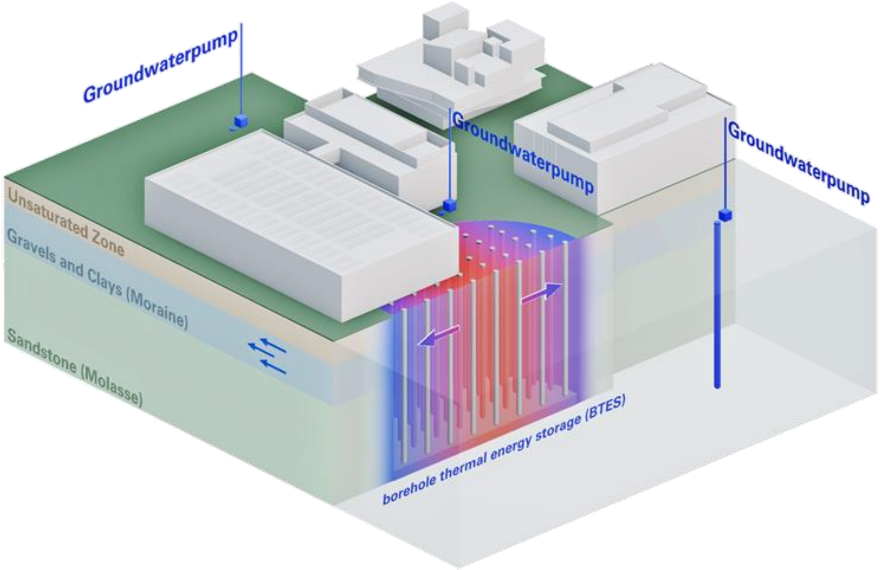


Figure from [Empa - Communication - ARTS Thermal Energy Storage]

Shallow (<200 m depth) BTES as seasonal thermal energy storage:

- **Heat injected in summer (excess), heat extracted in winter (demand)**

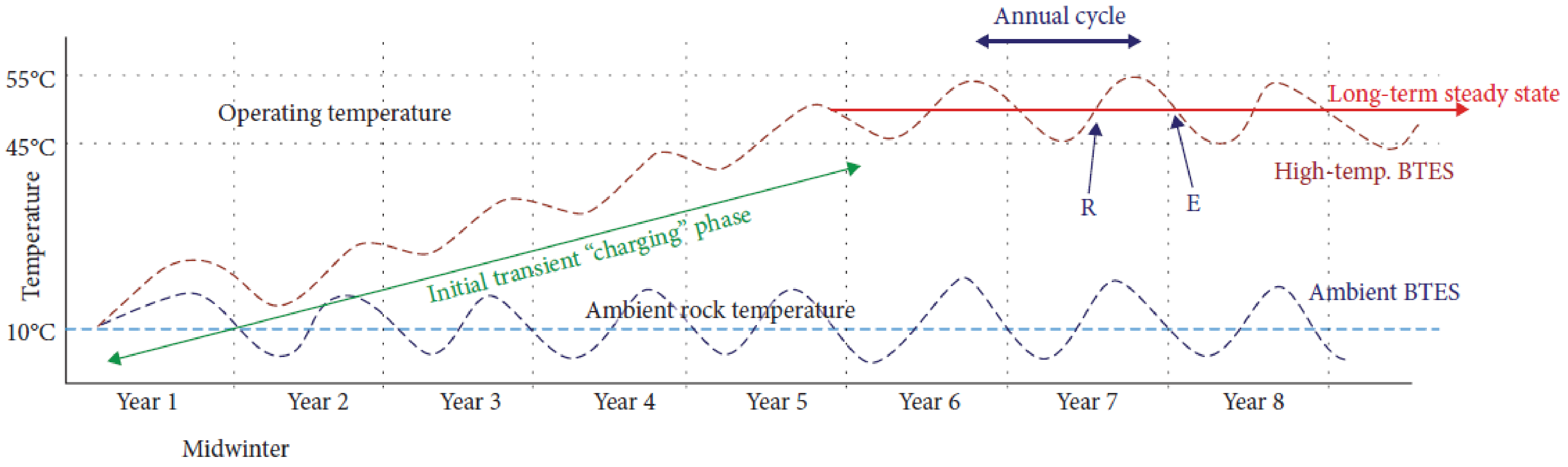
Cost-effective above ≈50,000 m^3 water equivalent [1] depending on geological properties and boundary conditions.

[1] Fiorentini et al, Applied Energy 2023

Operational temperatures

Conventional operation: **T_ground ≈ 10 degC**

High-temperature (HT) operation: **T_ground ≈ 45 degC**



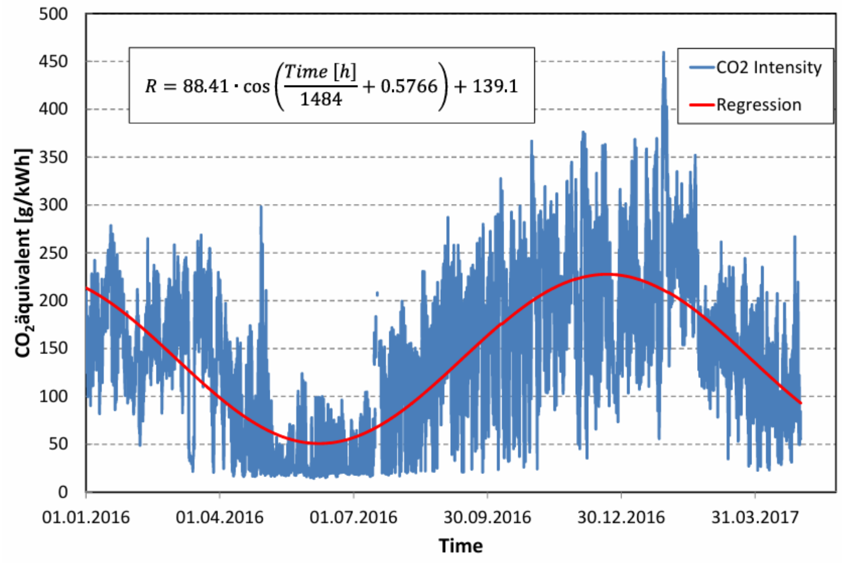
Skarphagen et al., Design Considerations for Borehole Thermal Energy Storage (BTES): A Review with Emphasis on Convective Heat Transfer, 2019

Why High-Temperature (HT)-BTES?

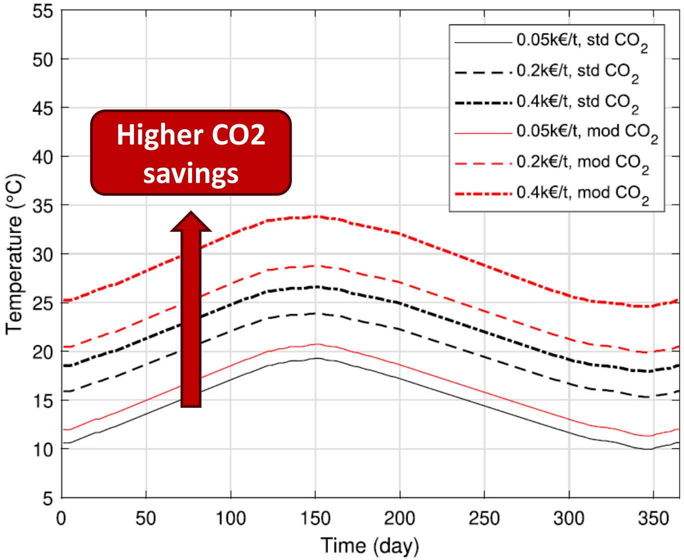
CO_2 intensity is **seasonal.**

HT lowers emissions in winter (higher heat pump COP), but increases heat losses → trade-off.

HT can increase available ΔT and thus increase energy density.

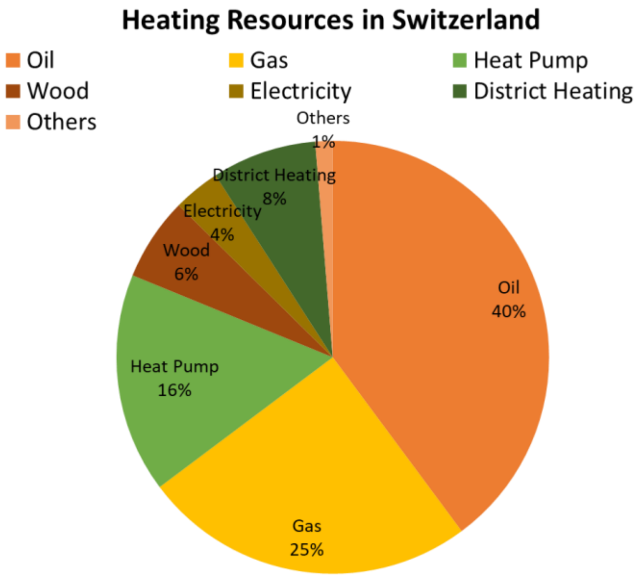


[1] Weber et al., Eurosun 2018 from Electricity Maps. Switzerland Carbon Intensity Data



[2] Fiorentini et al, Applied Energy 2023

Why HT-BTES in Switzerland?



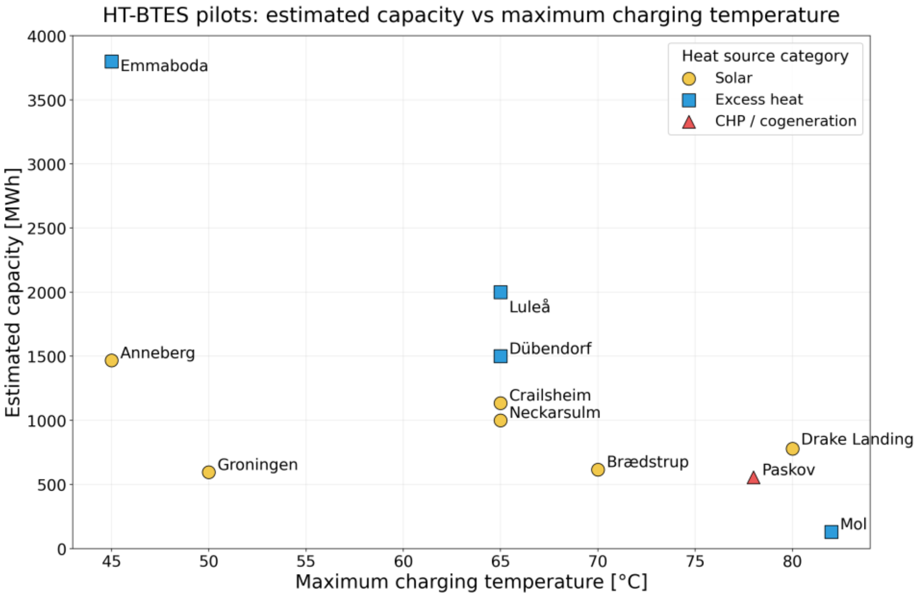
Sources: FSO - Federal Population Census, Buildings and Dwellings Statistics

The **Swiss heating sector needs to be decarbonized:**

- **2 out of 3 people** are heated by **Fossil Fuels** (58% of residential buildings)

Land is expensive: HT can increase available ΔT and thus incrase energy density.

Needs for pilots → the Dübendorf HT-BTES pilot



Pilots are key to de-risk. Long-term monitoring to evaluate ground response.

According to [1], 12 HT-BTES installations worldwide, of which only 8 are well documented.

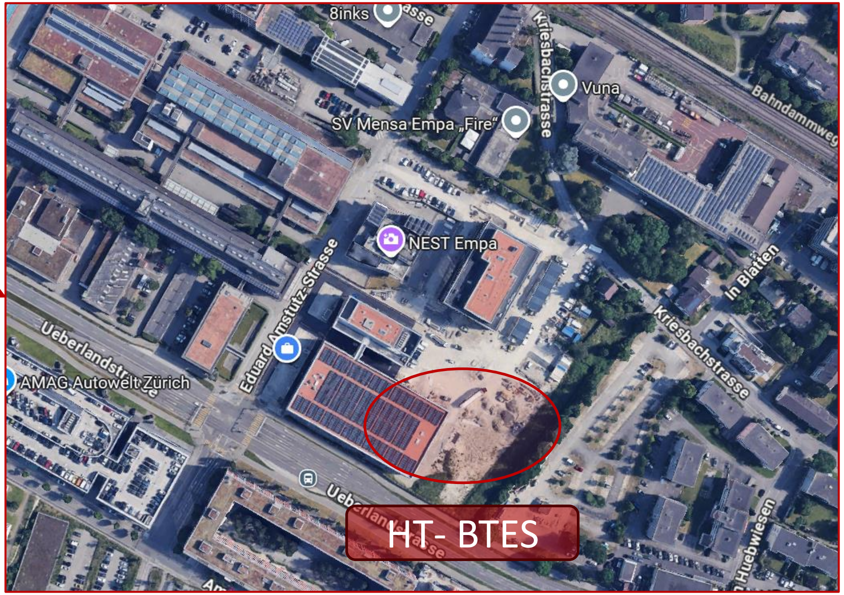
The **Dübendorf HT-BTES pilot** addresses:

- Waste heat from cooling
- Multi-temperature network
- Retrofit constraints

[1] Underground Thermal Energy Storage (UTES) – state-of-the-art, example cases and lessons learned, 2019

The HT-BTES of the Empa and Eawag campus

The Empa and Eawag campus



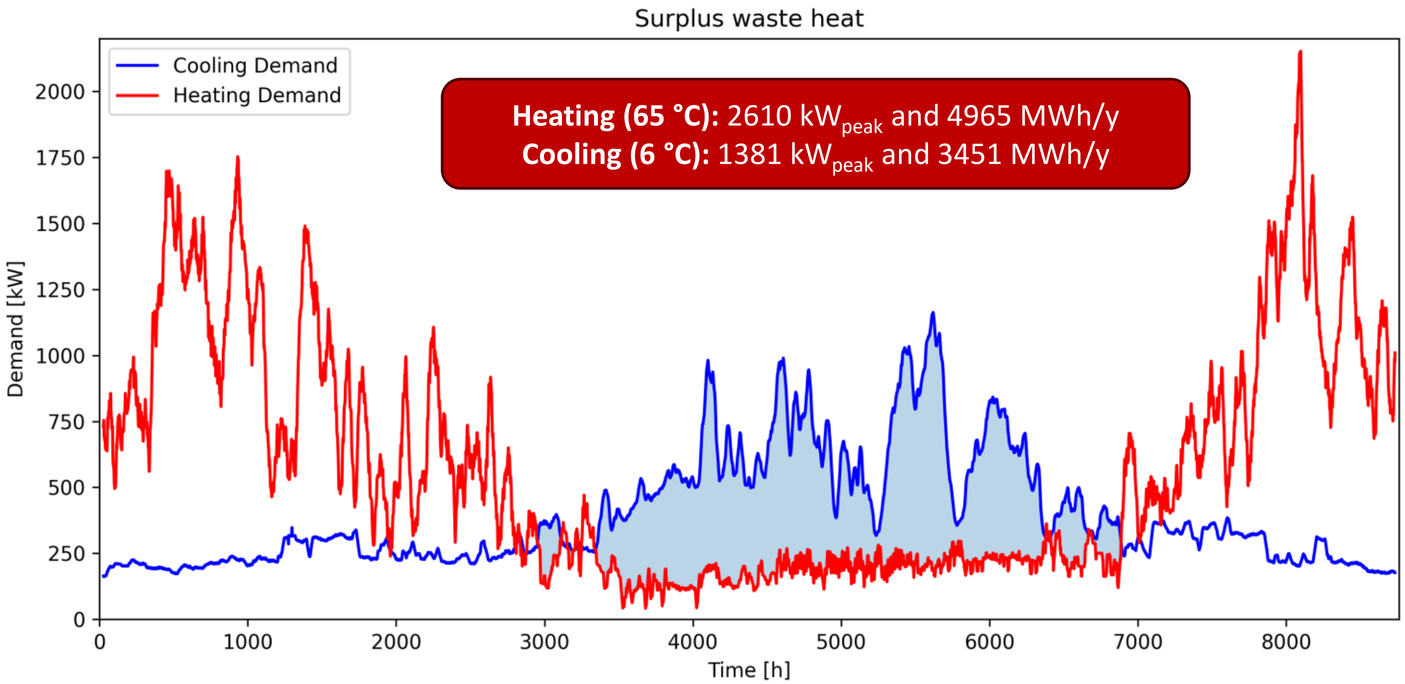
Pictures from [Spotlight on Switzerland | Nature]

Pictures from Google Maps

Why? Seasonal unbalance and waste heat potential

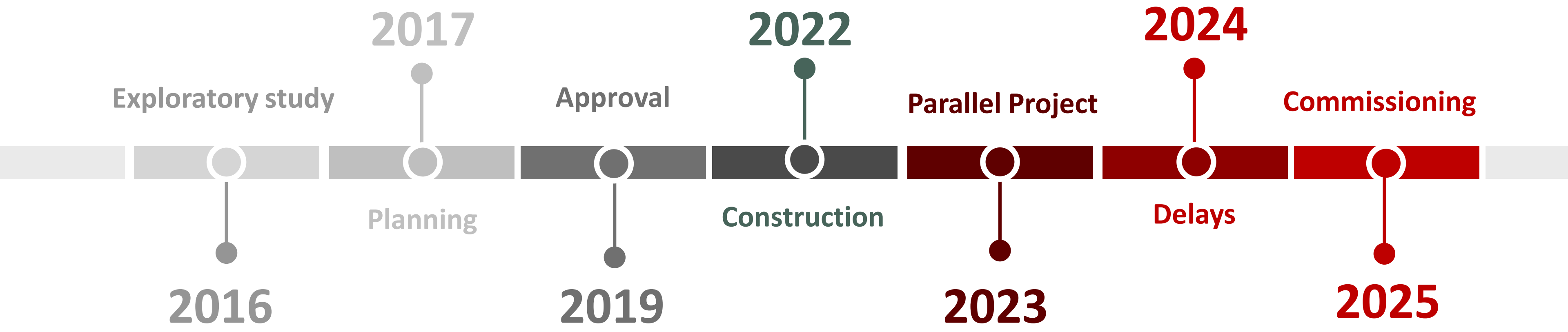
Heating-dominated demand with waste heat from chillers available in summer;

However, the potential is lower than the heat demand in winter.



Heating and cooling demands for the Empa campus (40ish buildings) in 2023

History of the pilot



Lessons learned from the planning phase:

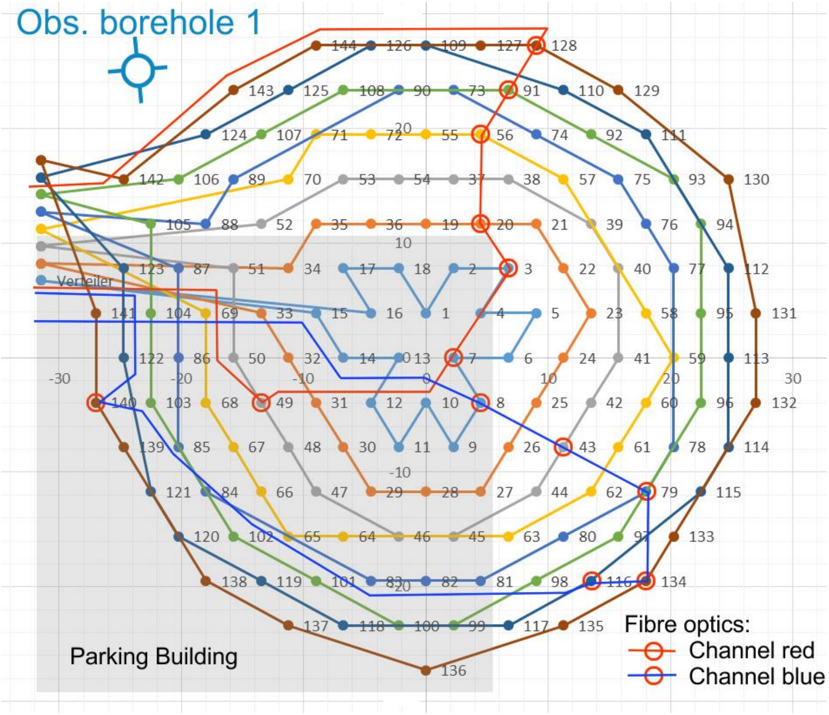
1. <u>Underestimation of Cooling demand growth:</u> +30% assumed for 2030 reached already in 2023;
2. <u>Coordination with parallel construction is critical</u>: BTES tightly coupled to new lab construction;
3. <u>Operational fallback is essential</u>: HT system was designed to allow conventional operation;
4. <u>Material properties must be validated:</u> Backfilling conductivity lower than specified in 1/3 of the borefield;
5. <u>Research-construction communication needs clear structure:</u> Communication gaps impacted planning efficiency;
6. <u>Early design verification reduces commissioning risks:</u> Some component failures and incidents could have been avoided.

The HT-BTES of the Empa campus

HT- BTES

Pictures from Olaf Kevin

HT-BTES Configuration



Charged **up to 65 °C**. Estimated storage capacity ~1.6 GWh [1];

8 Rings with 18 probes each (144 in total):

- **Zone 1** (inner 3 rings) → **T up to ~65°C**
- **Zone 2** (outer 5 rings) → **T up to ~40°C**

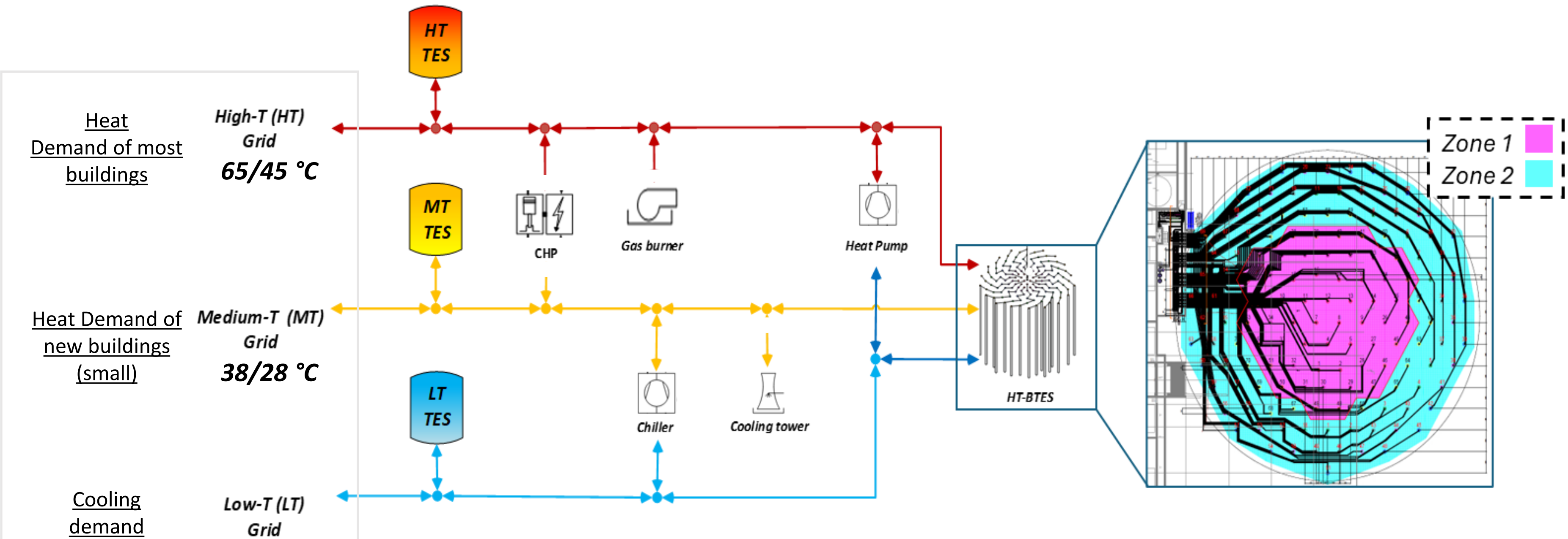
Rings can be operated **in series and in parallel**;

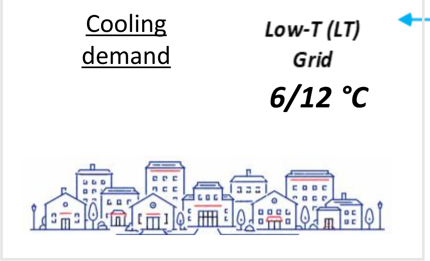
Several probes are equipped with **fiber optics** for temperature measurement;

Y-shaped measurement points were also installed to quantify the potential **influence of underground flow.**

[1] Weber R, Baldini L. High Temperature Seasonal BTES for Effective Load Shifting and CO2 Emission Reduction 2019:1–9. https://doi.org/10.18086/eurosun2018.13.04.

System integration





Supply units	***Size [kW]***
Heat pump	500
Gas boiler	900 + 2000
Chillers	3 x 630
CHP (gas)	577

Learnings from commissioning

Lessons learned at the pilot level

I. One heat exchanger was identified as undersized and replaced.

II. Bypasses for the HT and LT heat exchangers were added, while a bypass for the MT heat exchanger was recommended but not yet implemented.

III. The selected insulation is predicted to be sufficient for both MT and HT charging, but requires validation against measurements.

IV. Temperature compatibility with material resistance for borehole rings 4–8 must be monitored.

V. The first year of operation should focus on MT-level charging to gradually increase BTES temp.

Generalization of lessons learned

I. Design verification enables robust component sizing, especially in non-standard systems.

II. Hydraulic and operational flexibility should be systematically embedded in system design.

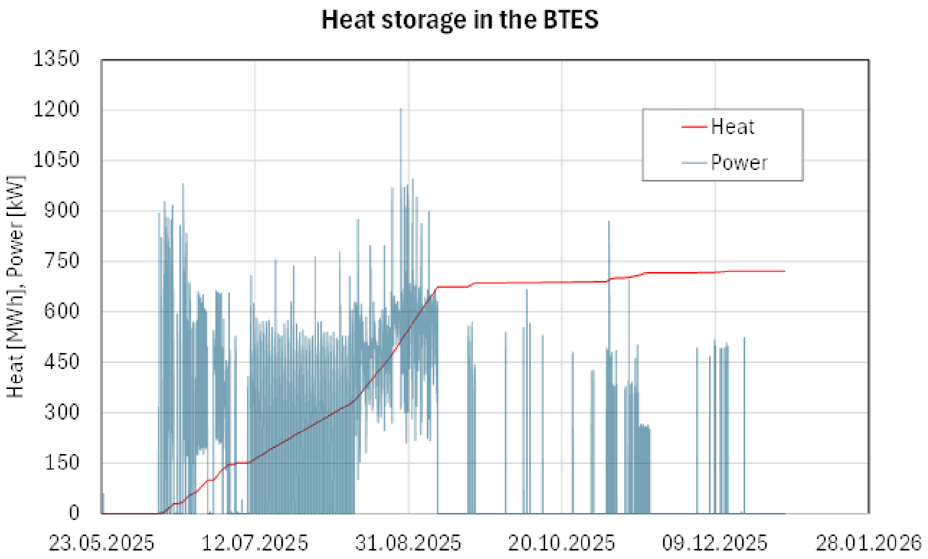
III. Standard pipe insulation seems sufficient for HT-BTES operation; however, validation with operational data is still needed.

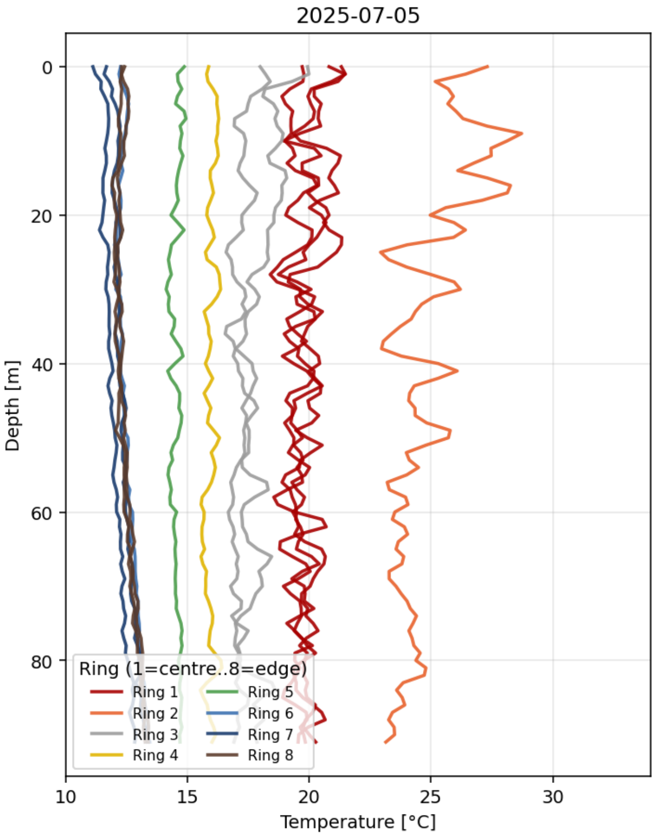
IV. Material temperature limits need to be explicitly included as operational constraints in models.

V. Commissioning strategies for HT-BTES should include gradual temperature ramp-up phases.

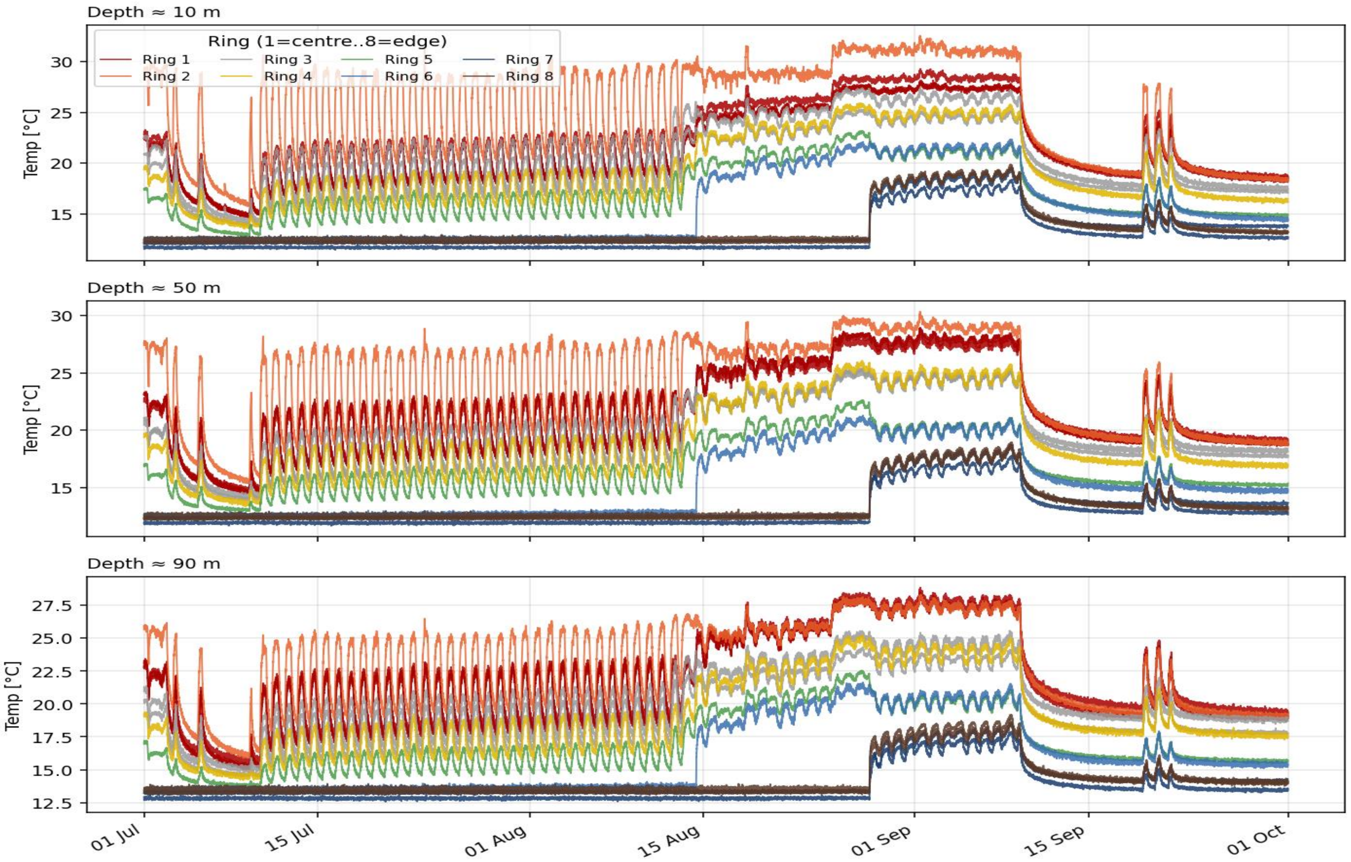
Measured performance (2025)

- ~0.6 GWh of MT heat injected (~38 °C)
- Undisturbed ground temperature: mean ~12.9 °C





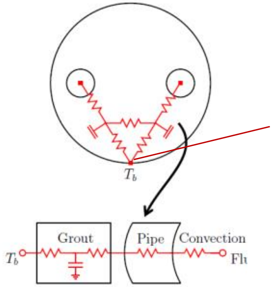
Measured performance (Q3 2025)

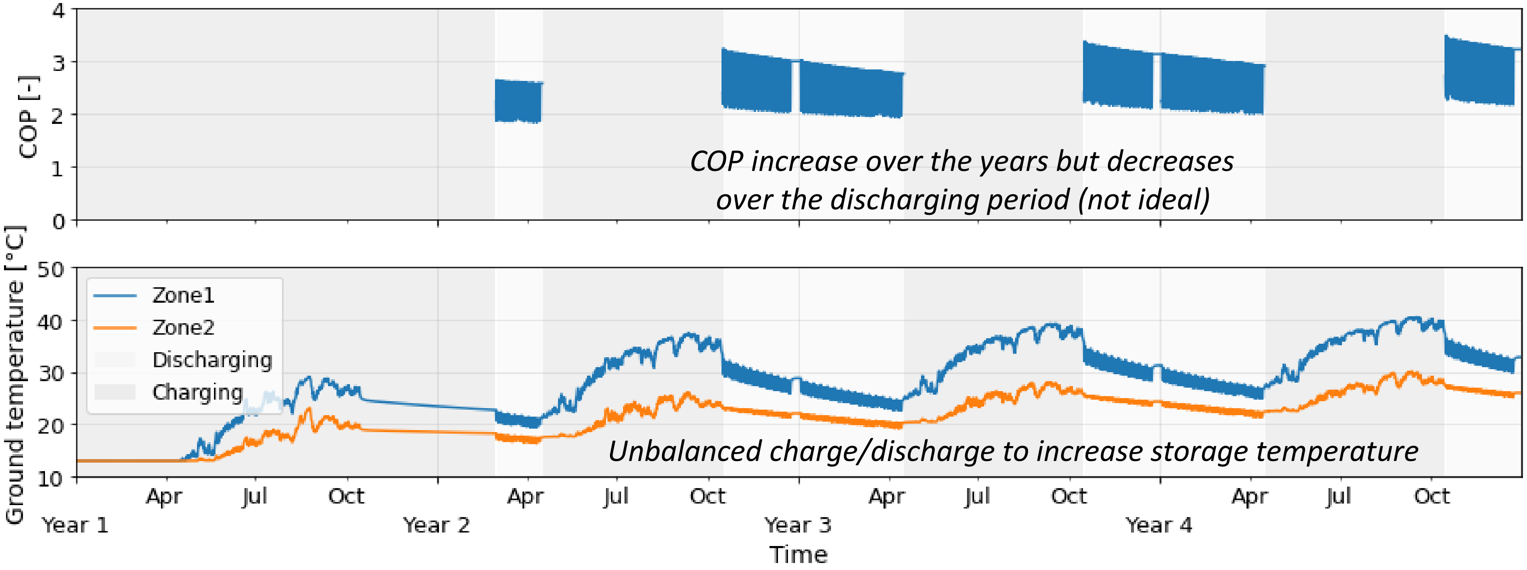


Next steps

First year of HT charging is ongoing; measured data are not yet available.

Experimental data will be used to calibrate numerical models (modelica and surrogate models for optimization), <u>optimal planning/operation is still an open task.</u>





Simulation results

Challenges for HT-BTES deployment in Switzerland

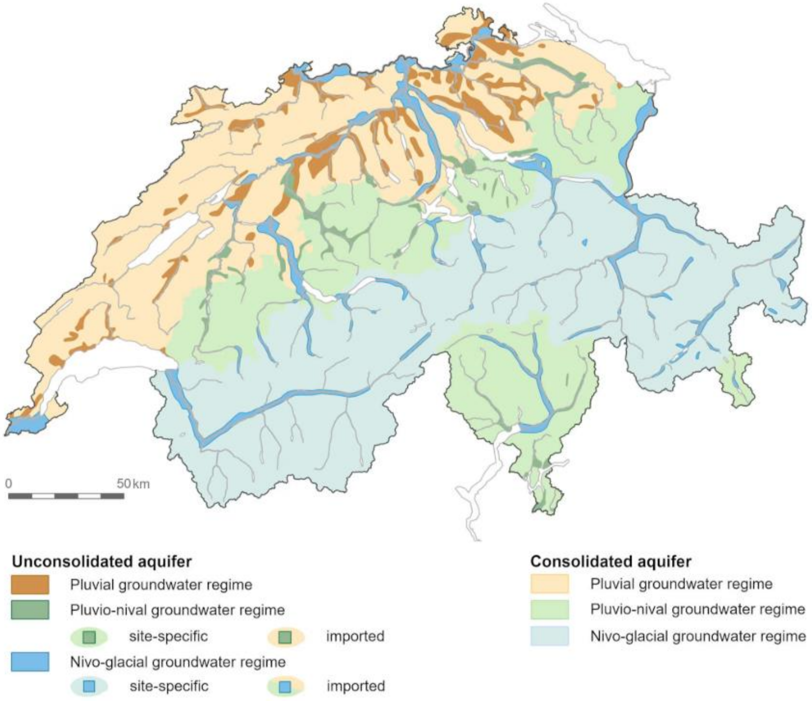


figure from [Groundwater regimes]

Low-temperature borehole systems are established.

HT-BTES is often treated as an environmental risk to be justified, not yet as a standard decarbonization infrastructure.

Regulation is cautious:

- The **±3 K rule** for groundwater temperature protects how much groundwater can be heated up/cooled down at a distance of 100 m, → possibly the strictest value in Europe.
- Discussions to change regulations are ongoing.

Prof. Dr iur. Andreas Abegg, presentation for SwissTES symposium 2025

Ongoing projects and next steps

- **GOES project:** tools for rapid design and verification following the Platform-Based Design (PBD) framework
- **UnlockTES project:** design guidelines for high-temperature BTES under the Swiss regulations constraints.
- **ARTS project:** Studying the impact of HT-BTES on the subsurface.

GOES
GEOTHERMAL-BASED OPTIMIZED ENERGY SYSTEMS

ARTS
Aquifer Reaction to Thermal Storage
Open database

Thank You!
Questions?

Gabriele Humbert (*), Robert Weber, Florian Ruesch, Krisztina Kelevitz, Robin Mutschler, Matthias Sulzer.

(*) Scientist, Urban Energy Systems Lab, Empa, Switzerland.

We are open for collaboration and feedback!

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