Energy Storage

5th lecture

Heat storage

Heat Storage – Energy Storage?

- *DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU*
- *Chapter I, Article 2, point (59) : ‘energy storage’ means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier;*

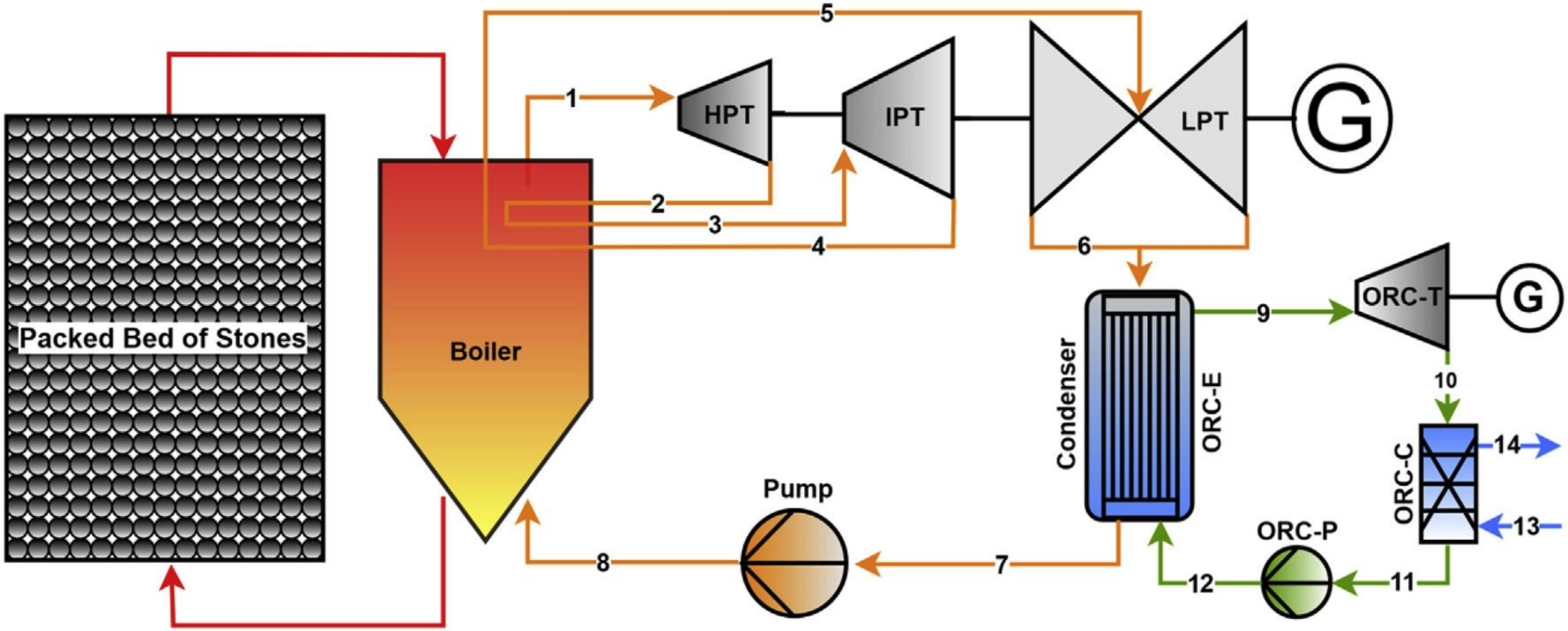
Red part is mostly for Power-to-Fuel applications. Officially, heat storage is NOT energy storage, except the Power-to-Heat-to-Power ones.

Heat Storage – Energy Storage?

Fireless Locomotive (Meiningen Steam Locomotive Works, Németország); using high presuure, high temperature water as “fuel”; can be used for smaller distances. Can be preferred, where fire or explosion could be expected (like coal mines, coal storages). Recently only a few of them are used, but formerly they were more popular. There are recent plans for steam-ferries working on similar way, connecting ports, where sufficient waste heat sources can be find to “fuel” them (for example iron forges).

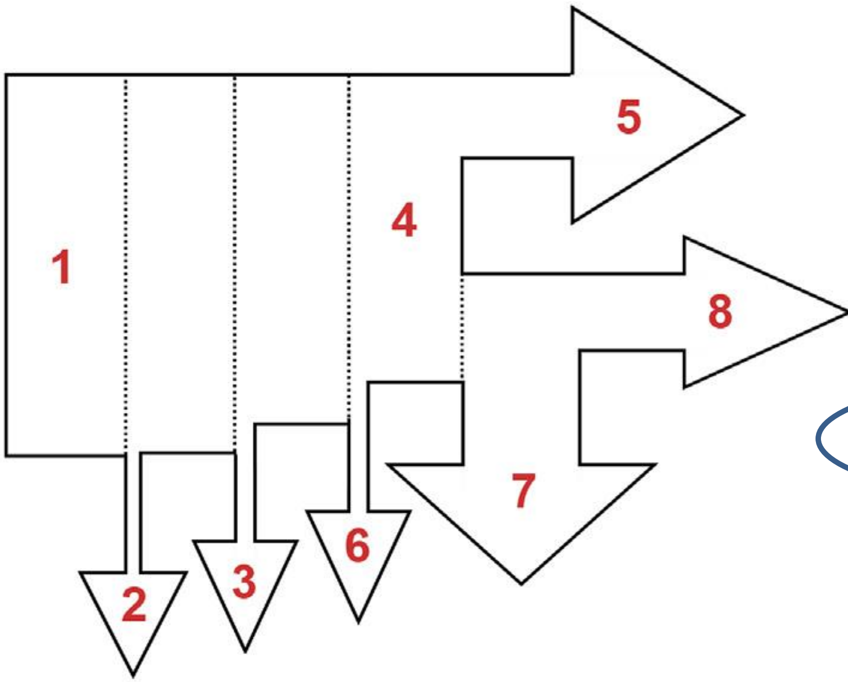
Here, the stored heat is fuel, therefore IF it was generated by power, then this would be real energy storage (by law). But when the heat is generated by an other way, officially it is NOT energy storage …. But one could feel, that this is pretty crazy!

Power-to-Heat-to-Power: Carnot battery



Heat storage in packed bed of stones, up to 600 Celsius (ore even above that). This can replace the boiler for a steam- or organic Rankine cycle. When the stored heat was generated by electricity (hopefully from cheap surplus one), it is a nice way of high-capacity daily energy storage (charged during daytime from PV and discharged during night). Efficiency is around 25-30 % (direct heating) or 80-90 % (plan, with heat pump based heating)(Journal of Cleaner Production 247 (2020) 119098).

Köves kőtározó, mint pszeudo-kazán



1. 1 Unit of Power Given to the Heat Storage
2. 0.7% Heat Losses from the Packed Bed of Stones
3. 1.9% Losses of Inefficiencies in the Steam Cycle
4. 63.2% Heat Rejection from the Steam Cycle Condenser
5. 34.2% Power Output of the Steam Cycle
6. 1.5/1.5/1.6% Losses of Inefficiencies in the ORC Cycle with R123/R134a/R124
7. 53.1/51.8/50.9% Heat Rejection from the ORC Cycle Condenser with R123/R134a/R124
8. 8.6/9.9/10.7% Power Generation by R123/R134a/R124 ORC Units

For Power production!

For heating/hot water!

Carnot battery

Siemens Gamesa, Hamburg: 1000 tons of basalt, 750 Celsius, can store 130 MWh_{th}/week (but used for daily storage) . Presently charging power is 1 MW, discharging is 250 kW, heated by direct electric heating (planned to do it with special, high-temperature heat pumps

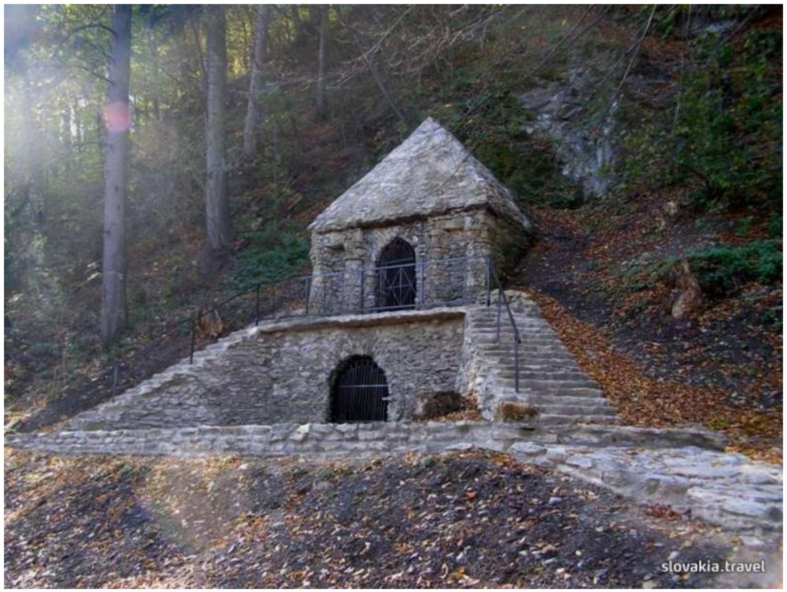
Carnot battery

- For daily storage, but high power and high capacity.
- Using “common” materials (no Litium, Vanadium, etc.), so each country can use it.
- For discharging: Steam Rankine above 20 MW, organic Rankine below that value.
- Old, even closed coal power plants can be refitted; the boilers will be replaced by the packed stone storage system.

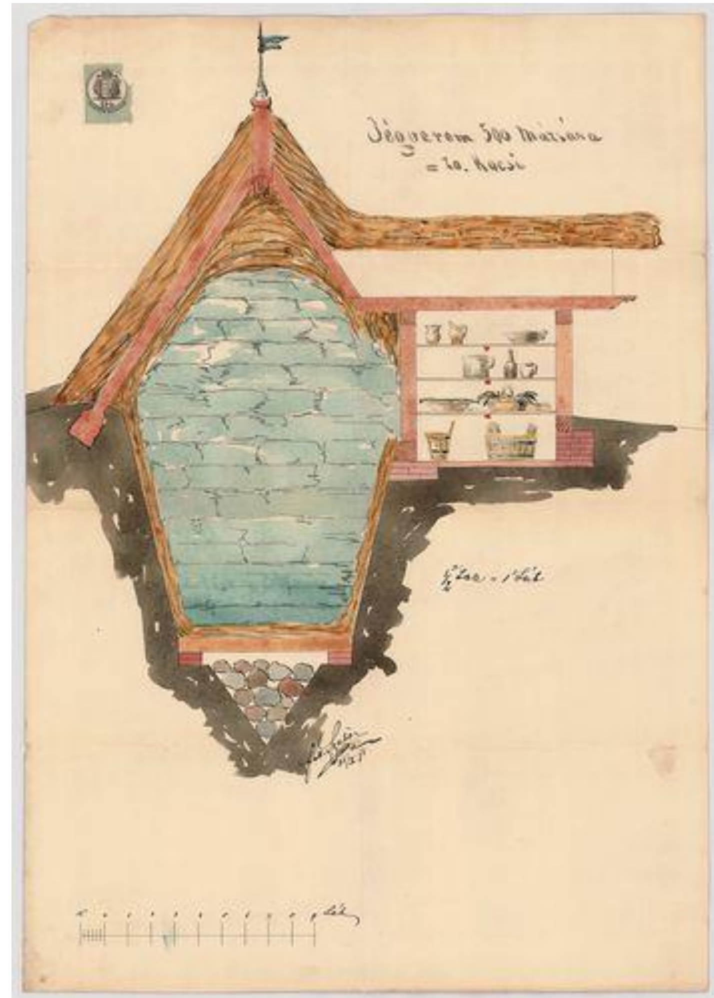
Therefore….

…yes, heat storage can be energy (power) storage, but usually it might be better to utilize the heat directly. So, how can we store heat?

…long ago is …



Ice stack (Vlachovo, Slovakia)



Design of an ice stack

Types of the heat storage systems

- according to storage temperature: cold (below room/ambient temperature), low temperature (below 100 °C), medium temperature (between 100-400 °C), high temperature (above 400 °C)
- According to the method: without phase change, with phase change and with thermochemical processes
- according to the heat transfer method: with heat transfer or with heat exchanger
- According to storage time: short storage (storage from a few hours to a few days), long storage (weekly, annual)
- According to centralization: local or centralized storage
- According to mobility: mobile or localized (fixed) ones

Without phase change

The heat is stored in sensible form, i.e. charging and discharging are associated with temperature change:

$Q = c_V * m * \Delta T$ $\left(Q = \int_{T_1}^{T_2} c_V(T) m dT\right)$

In most case, volume is more important than mass, therefore m often replaced by rho*V.

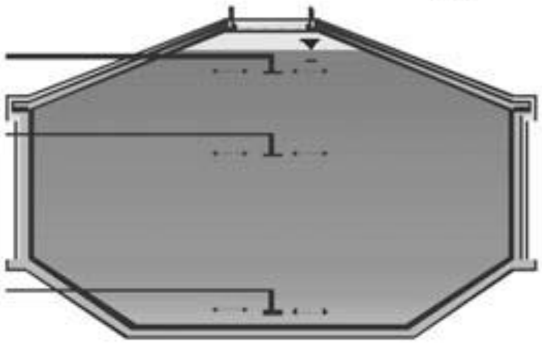
Heat storage capacity and available temperature ranges for various materials

Material	Temperature range (°C)	Volumetric storage capacity (kJ/m^{3}K)
water	0–100*	4175
Sand, gravel	0–800	1278–1420
Gravel+water	0–100*	2904
concrete	0–500	1672–2074
Thermo-oil	0–400	1360–1620
granite	0–800	2062
Molten salt	150–450	1970–1725
iron	0–800	3655

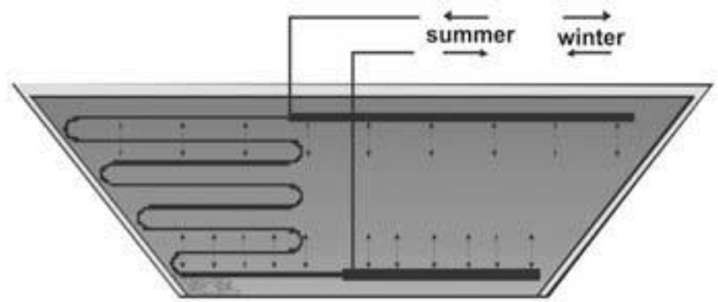
*: can be increased by pressurization

methods

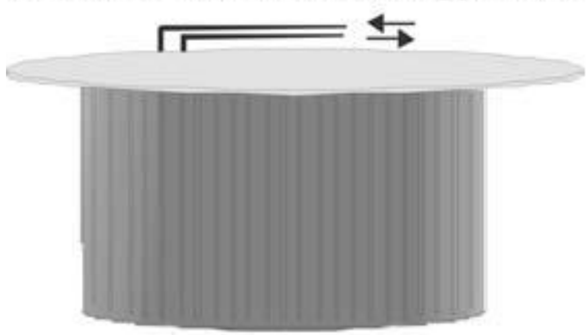
Hot water thermal energy store



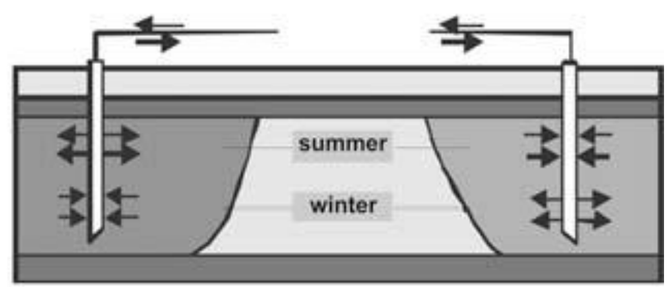
Gravel-water thermal energy store



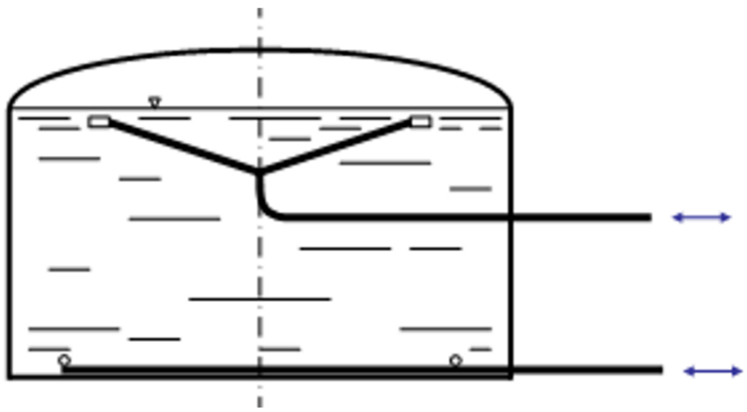
Borehole thermal energy store



Aquifer thermal energy store



Storagy by hot water



Storage thank for district heating (also used in oil industry), 10 000–120 000 m^3 volume 1:2 height/diameter, steel. Two in/outlet, one down at the bottom (for high density cold water), the other(s) just above the top level (for low-density hot water). Insulated from every side.

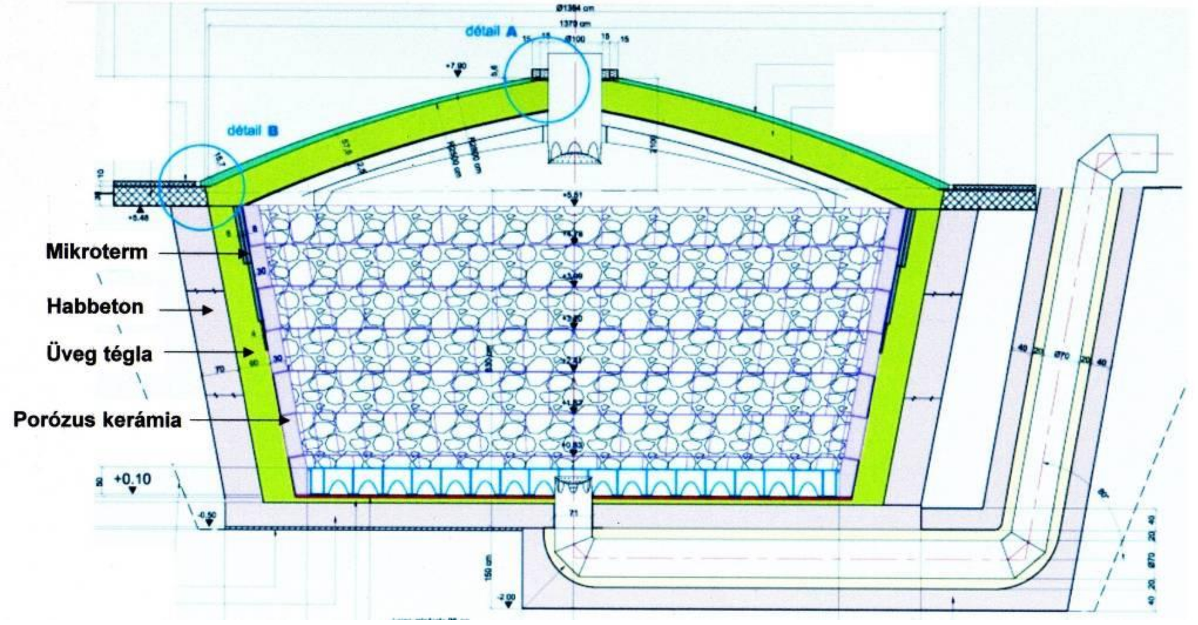
Important: Charging/discharging is NOT only for the heat, but also for the carrier material. Charging (with hot water) from the top), discharging (from colder water, but still hot one) from the bottom). Hot/cold water are layered; extra prevention for mixing by lamellaes. Efficiency can reach 98%.

„Ground-heat" storage

The ground can be heated/cooled through boreholes (few to few tens of meters). It can work without charging (ground can store heat/cold)

Packed bed thermal storage – medium T

Filled with gravel+water, can store up to 90 Celsius.



Can be heated with solar heat or waste heat. Provides district heating.

Examples

2006, Münich, Germany, 7500 m^3 , 2900 plane solar collectors, serving 300 flats (heating and hot water)

(http://www.solites.de/download/literatur/07-Mangold_ESTEC%202007.pdf)

Examples

Steinfurt (1998)

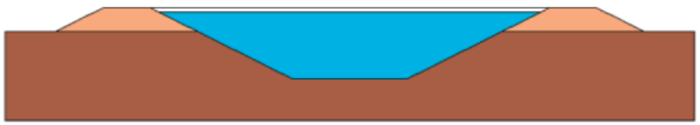
510 m²
flat plate coll.,
1.500 m³
Pit
(gravel / water)

District heating for 42 flats (3800 m^2), underground storage.

Examples – the BIIIIIG one

Denmark (Marstal, Dronninglund, Gram), solar collectors, plus pellet and biomass heating. Summer: 80-85°C, Winter 10-15°C (still can serve heatpumps); by heatpumps, the 10-15°C raised up to 30-40°C , enough for contact heating.

Examples (still Marstal)

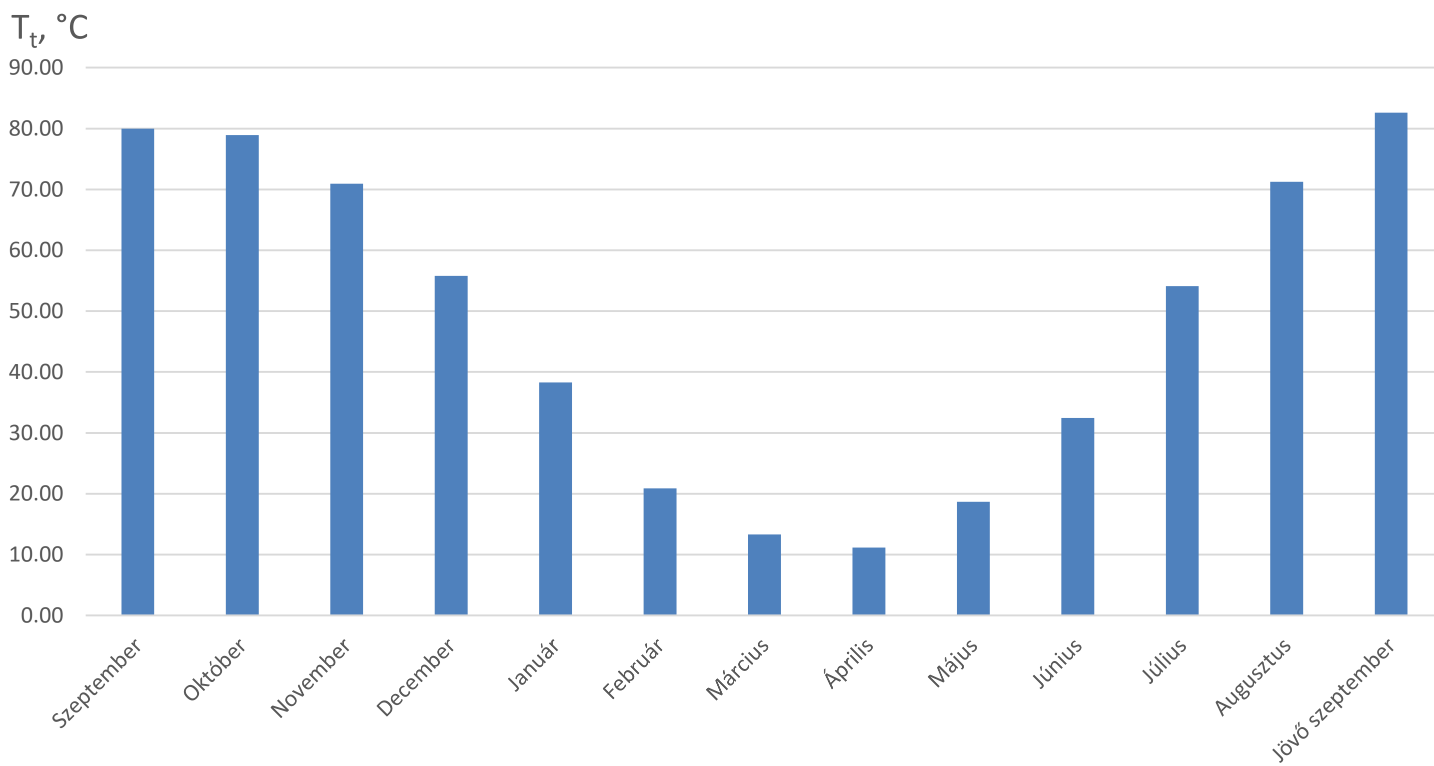


33,300 m^2 solar collectors, 75,000 m^3 volume (with total surface of 10,000 m^2 ; 1.5-2 bigger than a football-field).

Technical data, Marstal:

Heat production technology / fuel / heat capacity / year of installation:	• 18,300 m^2 solar system + 15,000 m^2 solar system • 8.3 MW bio-oil boilers • 2,100 m^3 steel tank water storage • 75,000 m^3 pit heat storage • 4.0 MW wood chip boiler producing thermal oil for ORC. Heat output 3.25 MW, η(heat) 82%, η(el) 18% • 750 kWel ORC (Organic Rankine Cycle) • 1.5 MWth heat pump using CO_2 as refrigerant, COP 3.4
DH network:	• 19.5 km distribution • 17.7 km service pipes
Consumers / total annual heat sales	• 1,481 consumers • 296,378 m^2 connected floor area • 32,000 MWh heat produced • 24,640 MWh heat sold
Variable heat price Total heat price	• 107 EUR/MWh • 2,525 EUR/year (standard house 18.1 MWh; 130 m^2 incl. VAT

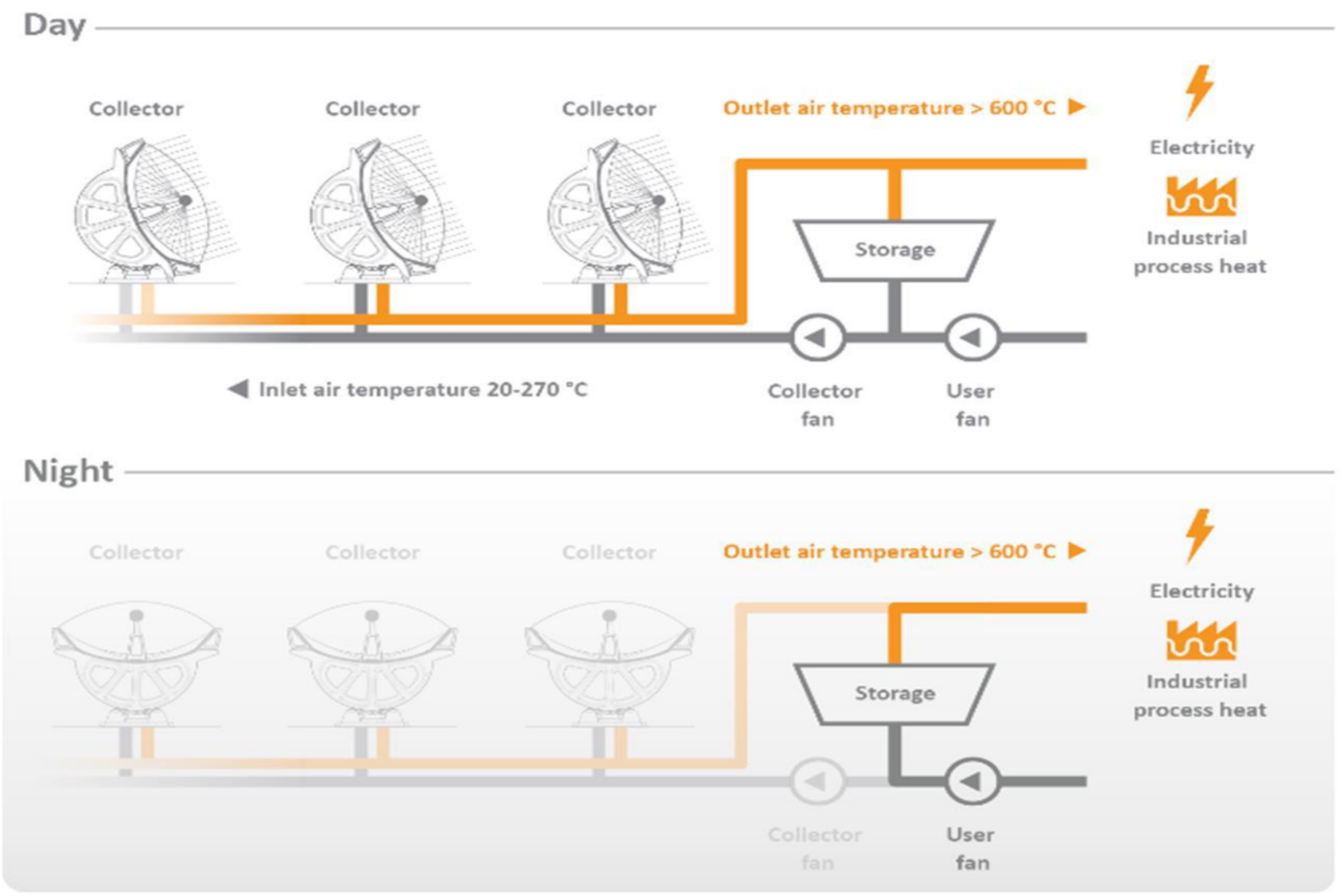
Examples (for a stand-alone house)



200 m3 storage tank, house: 100 m2, 4 persons, heating and hot water. Change of annual temperature. Between November-January, it can be used even without heat pump!. Problem: cost!

Packed bed thermal storage – high T

Morocco, Ait Baha (3 TWth), charged by solar heat, discharging medium is air ; max. gravel temperature is 650 Celsius. The hot air can be used to provide industrial process heat (for a concrete factory).

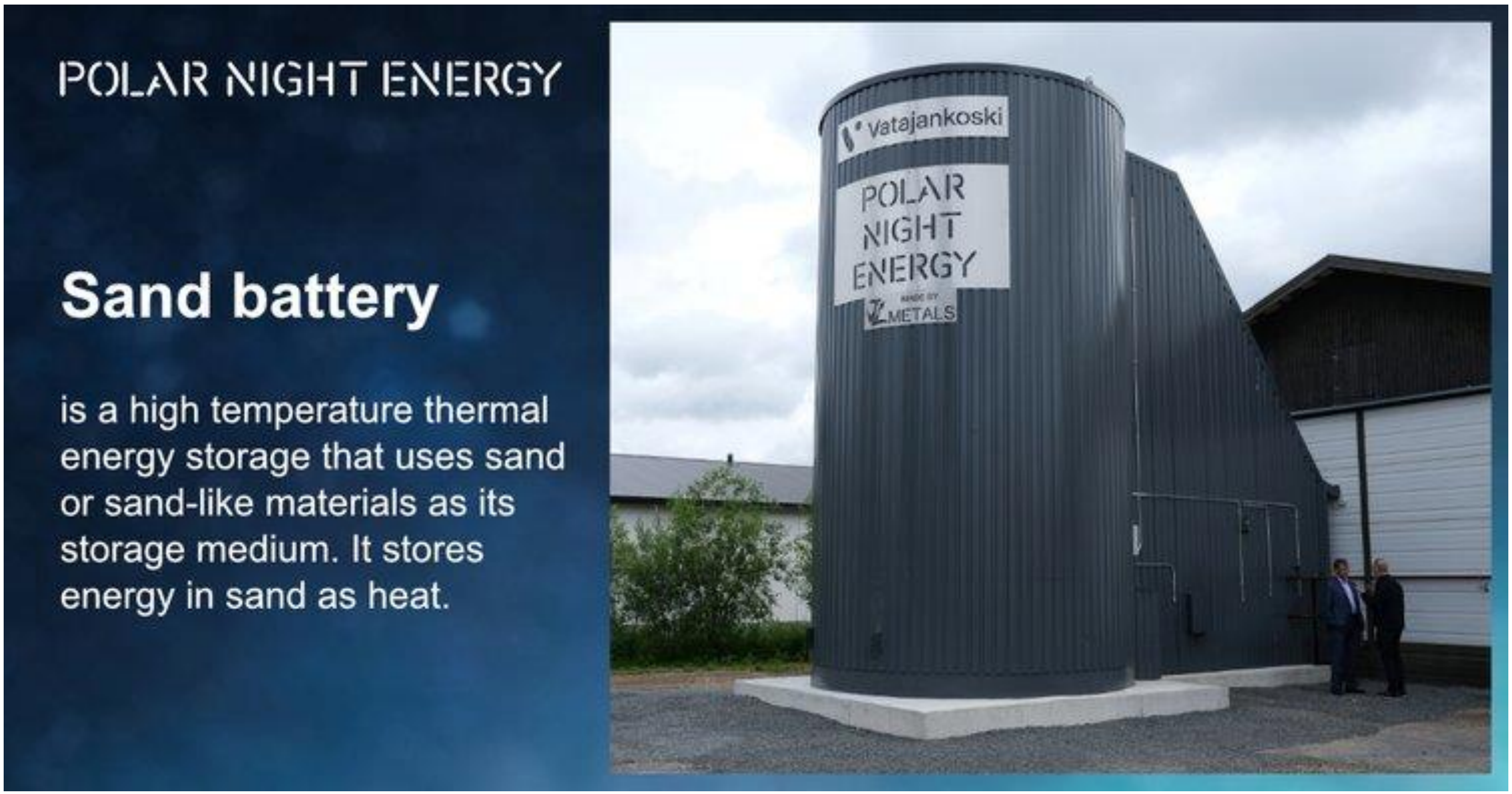


Sand battery

Sand Battery

- Sand heated above 500-600 Celsius; stored in the immediate vicinity of the heatable house. No underground storage (leaking).
- Summertime heating by electricity (direct; heating coils), power from PV.
- With proper size, it is enough for the whole heating season.
- How to discharge the 500-6000 Celsius heat? Definitely not with water. Even oils can be problem. Air??? Plus heat fans (after diluting hot air with cold one)?
- Safety! No leakage of water in; no entrance of undiluted hot air to the house, etc.).

Sand battery



Storage with phase change

Upon phase change (boiling/condensation or freezing/melting), relatively high amount of heat can be released or absorbed (LATENT heat) without the change of temperature.

Boiling/condensation is not good (high vapour volume); freezing/melting OK!

Storage with phase change

Pros

- Relatively high heat density (1 kg of water can absorb 333,55 kJ heat upon melting; with this amount of heat, one could heat up that 1 kg from zero to approx. 333,55/4,19=79,6 Celsius)
- Constant temperature for the heat source (easier to design and maintain)

Contra(s)

- For a given material, usually just one available temperature (for water, it is 0 Celsius). In some “family”, it can be solved (like alkanes, by changing the chain length; for example for triacontane - $C_{30}H_{62}$ – is is 66 Celsius, good for traditional heating)

Thermochemical storage

Using a reversible chemical or physico-chemical (like sorption) process, which is exothermic in one direction and endothermic in the other. Usually they can used in a relatively narrow temperature range; outside of that range, one of the direction will be dominant.

Thermochemical storages

Water of Crystallization water out/in

- From dry NaOH, by adding water, endothermic (cooling!) reaction occurs around 50 Celsius; for the re-charging, drying is needed. Efficiency can reach 60%, lifetime is several month, although even humid air can damage it!

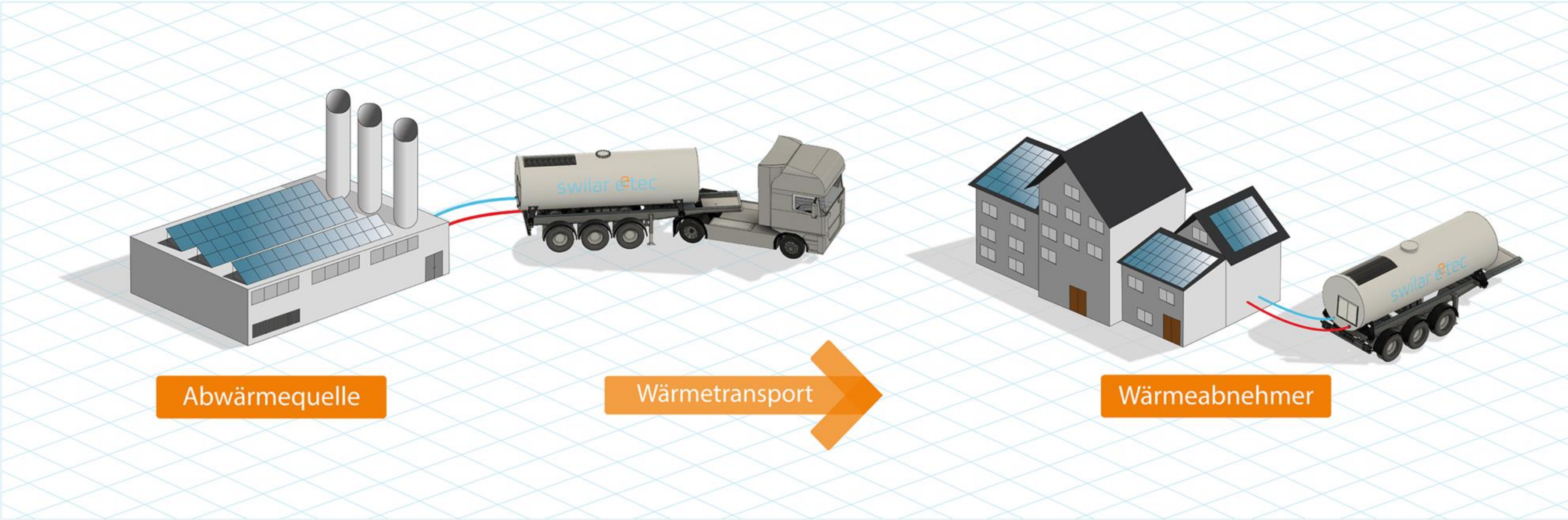
- Other materials, see small warming pads (for hand).
- Extreme example: thermal cracking of water (charging by heat) then burning the hydrogen (discharging it).

Transportation

Often the location of the heat release differs from the location of heat usage; transport needed.

Figure 22: Railway wagon with a latent heat storage system (Source: TransHeat GmbH)

Transportation



Transportation

Conclusions....

Stored heat can be used to generate work/kinetic energy....

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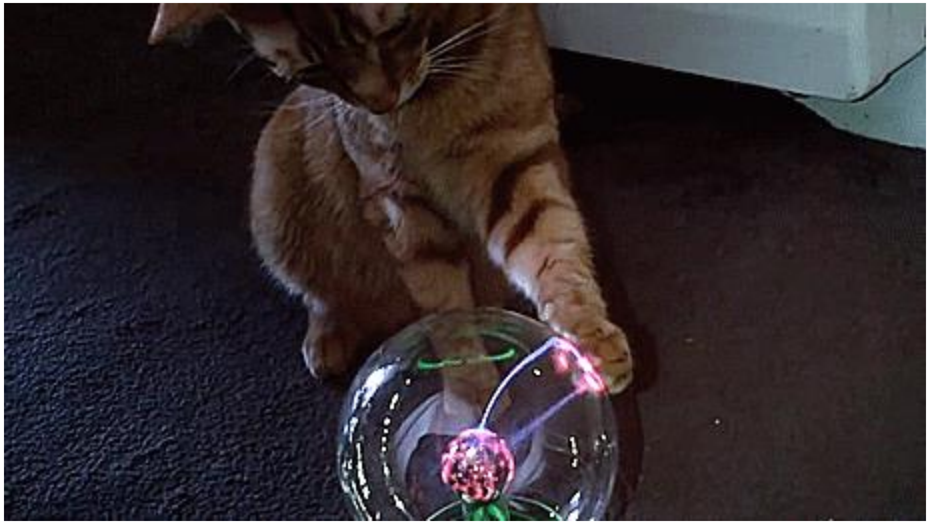
Stored heat can be used to generate work/kinetic energy....

...and from that, only one small step is electricity



A bit more seriously

Heat can be stored, the loss is determined by temperature and storage time.

If heat is stored in and heat is extracted (for heating), it is the easy way.

If you store in electricity or heat and want to extract electricity, it is more difficult because at low temperatures the efficiencies would be quite low! (but there is a solution, especially for storage of no more than a few hours).

Next weeks

- Project consultations, project reports (3-5 pages/person, can be done in groups), project reports (5 minutes/person, can be done in groups).

Projects

Power-to-ammonia: the present status

Power storage by heat: the Carnot batteries

Heat storage by phase change materials

- for a house
- transportable version for industrial vaste heat

Energy Vault : a tower for energy

Estimation for fueling the transportation of a country entirely with green hydrogen (from PV or wind)

…or anything else!

Thanks for your attention