Danish Energy Agency

Technology Brief

New chapter on Carnot batteries and high temperature thermal energy storage in the Technology Catalogue (Feb 2025)

The Danish Energy Agency has published a new chapter on Carnot batteries and high temperature thermal energy storage as part of the energy storage Technology Catalogue.

Carnot batteries are systems that convert electricity into heat, store the heat in thermal energy storages, and convert it back into electricity. This is shown in simplified form in Figure 1.

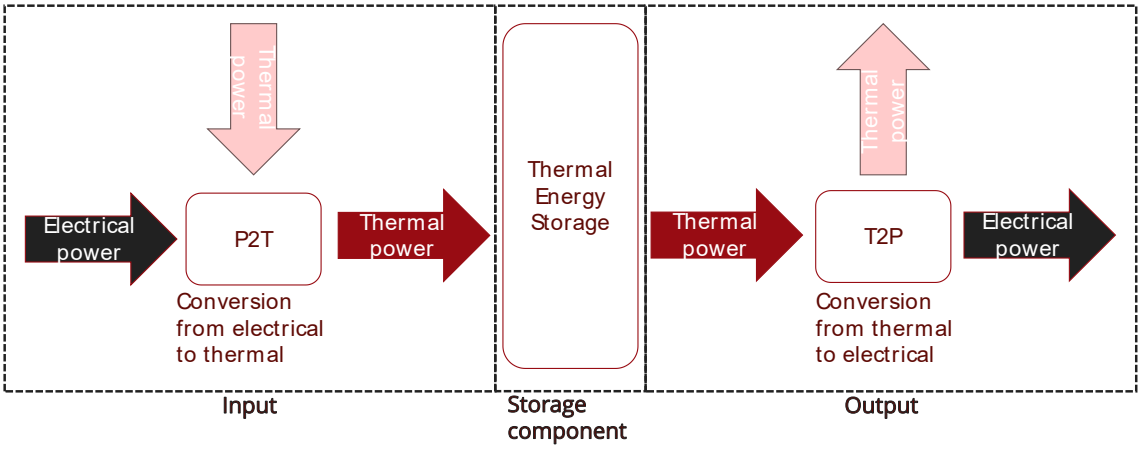

Figure 1 Typical Carnot battery

The focus of the chapter was on Carnot batteries with the following three characteristics:

- Input conversion using resistive electrical heating.
- Sensible heat storage using molten salt or hot rocks to store at >200 °C.
- Output conversion using steam generators and Rankine cycle for power generation.

In addition the chapter also describes the possibility of using the steam for process heat instead of electricity generation. This use case is not a Carnot battery but instead a high temperature thermal energy storage. This focus reflects the Danish commercial solutions and the status of the most advanced pilots and demonstration plants in Denmark in autumn 2024. These are centered on replacing gas consumption for industrial applications by electrification of steam production.

Danish Energy Agency

Carsten Niebuhrs Gade 43
1577 København V

T: +45 3392 6700
E: ens@ens.dk

www.ens.dk

Molten salt vs hot rock based storage

Two storage media are described in the data sheets, molten salt based and hot rock based. One large difference between the two media is the storage temperature, molten salt Carnot batteries reach much higher temperatures (upwards of 600 °C). This higher storage temperature directly affects the maximum power-to-power efficiency of the Carnot battery. Round trip efficiency (power-to-power) for a molten salt based Carnot battery is 30% (as described in the datasheet) while for hot rock based it is only 10%.
This large discrepancy between the round-trip efficiencies is outweighed by a similarly pronounced difference in the storage investment cost – the cost of an MWh of storage capacity for hot rocks is 1/7 of the price of molten salt based on the gathered data.

Nascent technology

Carnot batteries and high temperature thermal storage in molten salt and hot rocks are nascent technologies with projects mostly in the pilot and demonstration phase. Molten salt has been used for concentrated solar power and nuclear technologies, but Carnot batteries are a newer use case. Carnot batteries are essentially an exercise of system integration of the three major components: Input conversion, thermal energy storage and output conversion. Here input conversion (resistive heating) and output conversion (Rankine cycles) are technically mature technologies, while the implementation of thermal energy storage (molten salt and hot rocks) is still under technical development. Uncertainty regarding costs is mainly found on the thermal energy storages themselves, where initial cost estimates need to be verified when going to large-scale commercial deployment, and thus the cost estimates should be considered as subject to significant uncertainty.

Perspectives for Denmark

The economic feasibility of **Carnot batteries** is dependent on the ability to provide energy arbitrage. In other words, large fluctuations in power prices are needed that enable to charge the battery during low prices and discharge at high prices. In addition, Carnot batteries can be located such that low temperature steam from the output turbine can be valorized in district heating systems, thus increasing the total energy efficiency of the system. This is especially relevant in a Danish context with widespread district heating.

High temperature thermal storage on the other hand is relevant for electrification of process steam used in the industry, making it possible to take advantage of low electricity market prices in times of high production from renewables.