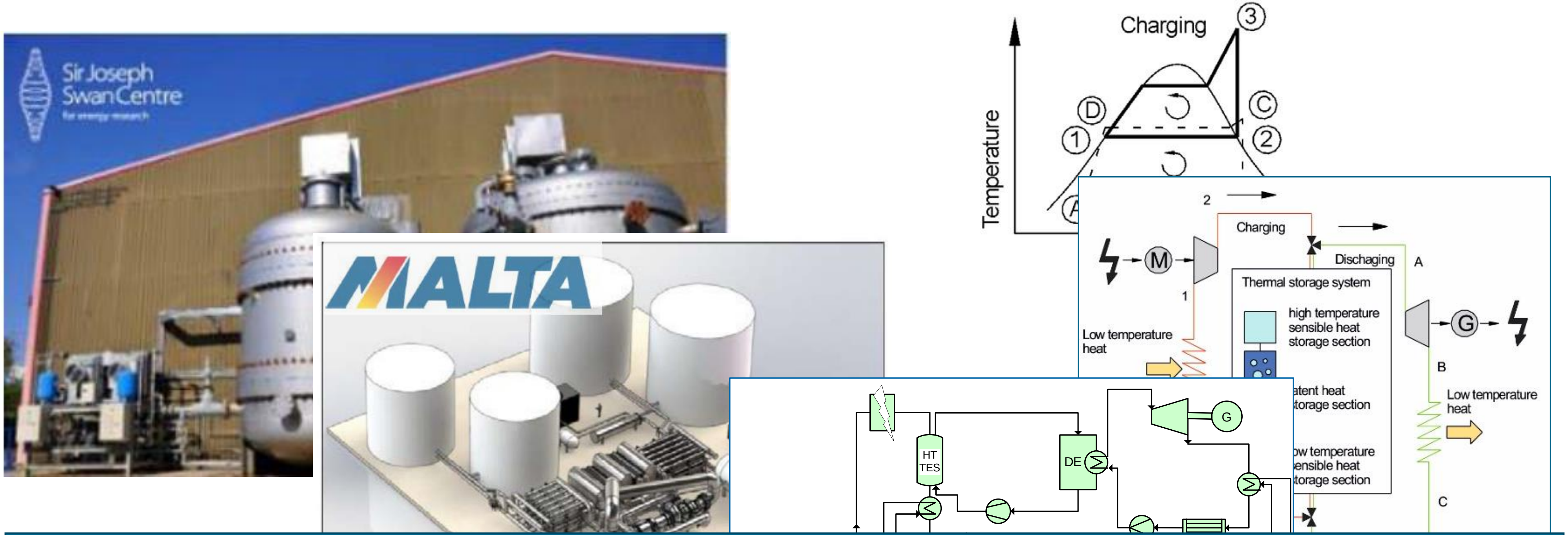
THERMAL STORAGE - THE CENTERPIECE OF EVERY CARNOT-BATTERY

A unique solution for each Carnot Battery Concept

What is the optimal thermal storage for a Carnot Battery?



- Optimally matched to the process cycles
- Low Cost
- High energy density

Institute of Engineering Thermodynamics

Thermal Process Technology

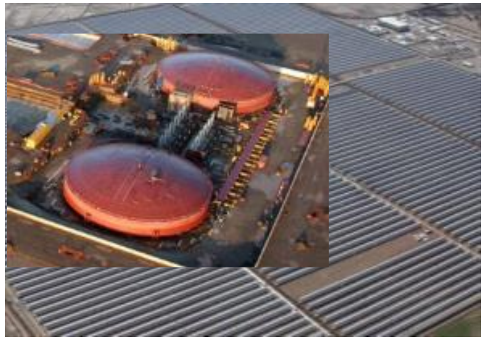
Prof. Annelies Vandersickel

Thermal Power Plant Components	Thermal Systems for Fluids	Thermal Systems with Phase Change	Thermo-chemical Systems
Dr. Stefan Zunft	*Dr. Thomas Bauer*	*Dr. Andrea Gutierrez*	*Dr. Marc Linder*
			
Regenerator and solid state storage **High temperature heat exchangers**	**Molten salt storage**	**Latent heat storage** **PXP storage**	**Thermochemical Storage** **Chemical Heat Pumps**

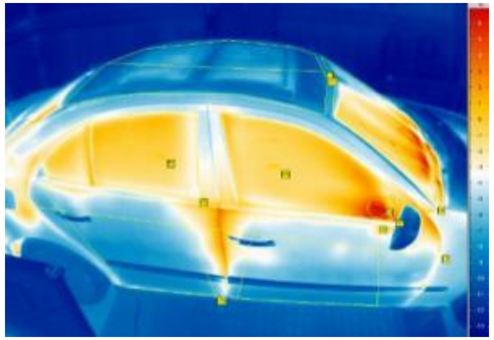
About 60 people located in Stuttgart & Cologne

Application Areas

- Improved flexibility of conventional power plants and industrial processes
- Storage technologies for solar thermal power plants (CSP/PV)
- Utilization and management of industrial process heat up to 1000 ºC
- Power-to-Heat(-to-Power) for high temperature applications and electrical storage (Carnot Batteries)
- Compressed air energy storage for grid stabilization
- Thermal management for vehicles



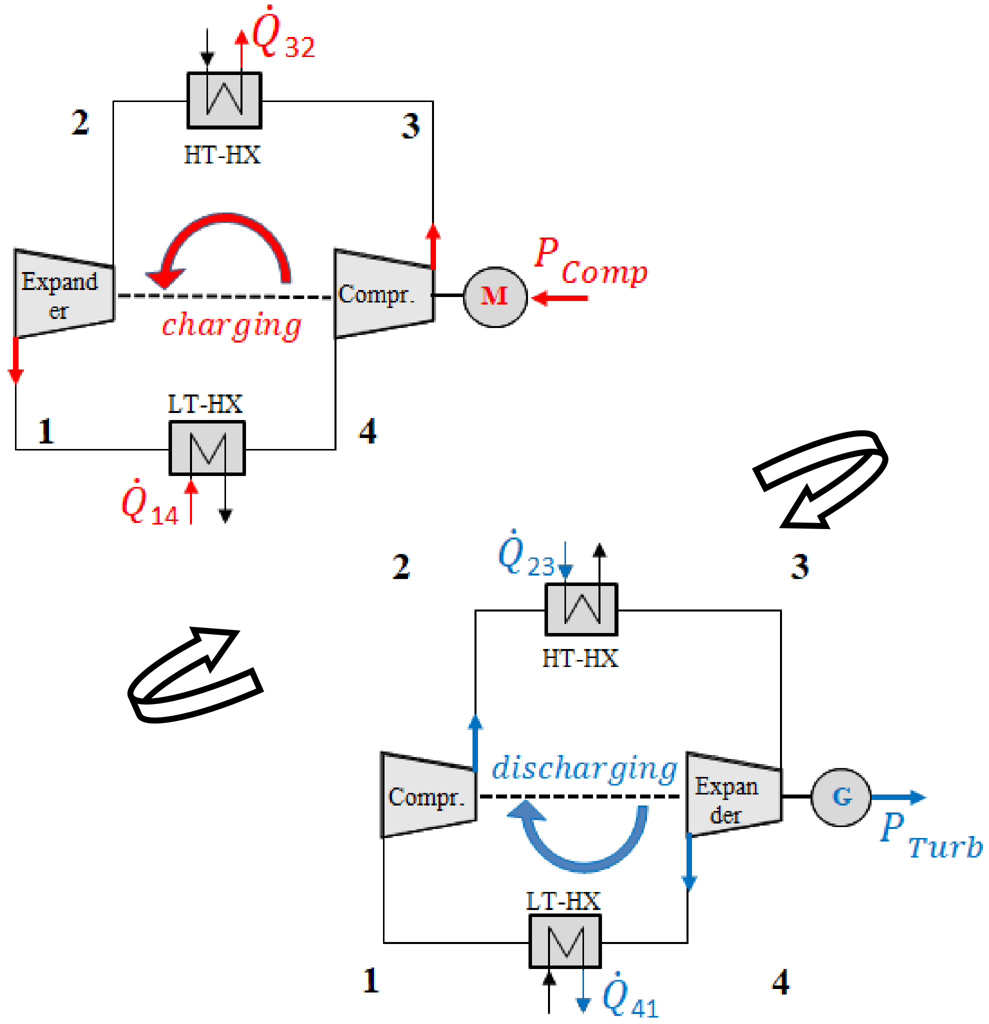




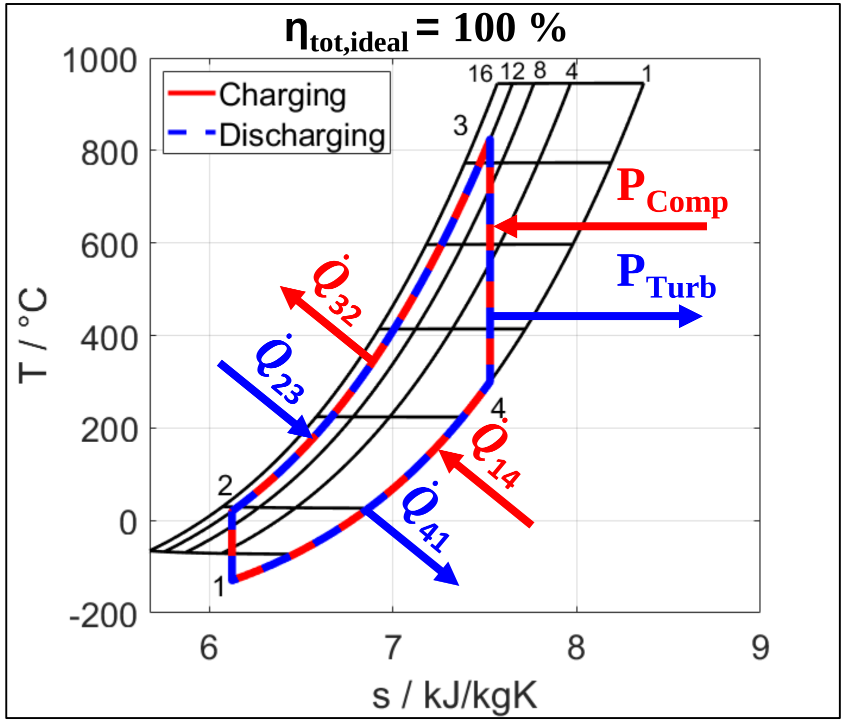
Agenda
> 10 Years of Carnot Battery related Research

- Regenerator Storage & E-Heater for Brayton Batteries
- Molten Salt Components for Brayton Batteries
- Phase Change Storage for Rankine Batteries

Brayton Battery
Working principle, with gas as a working medium



Idealized cycle



Objectives:

- Total efficiency: > 60%
- CAPEX: < 300 €/kWh$_{el}$
- Power output: > 10 MW$_{el}$ (> 7h)

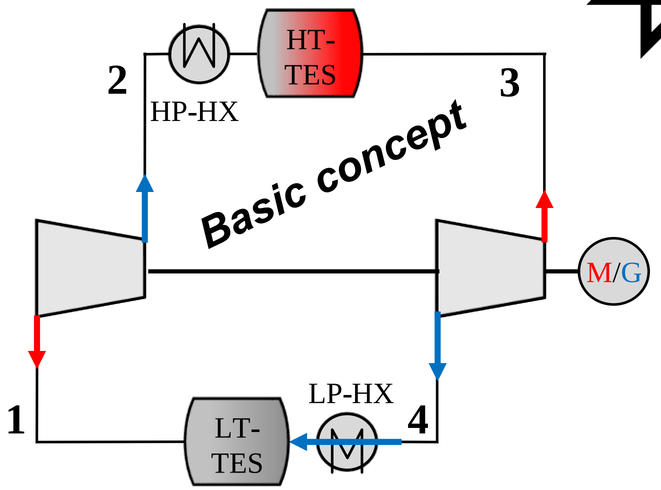
Sensible storage – regenerator
Potential and challenges

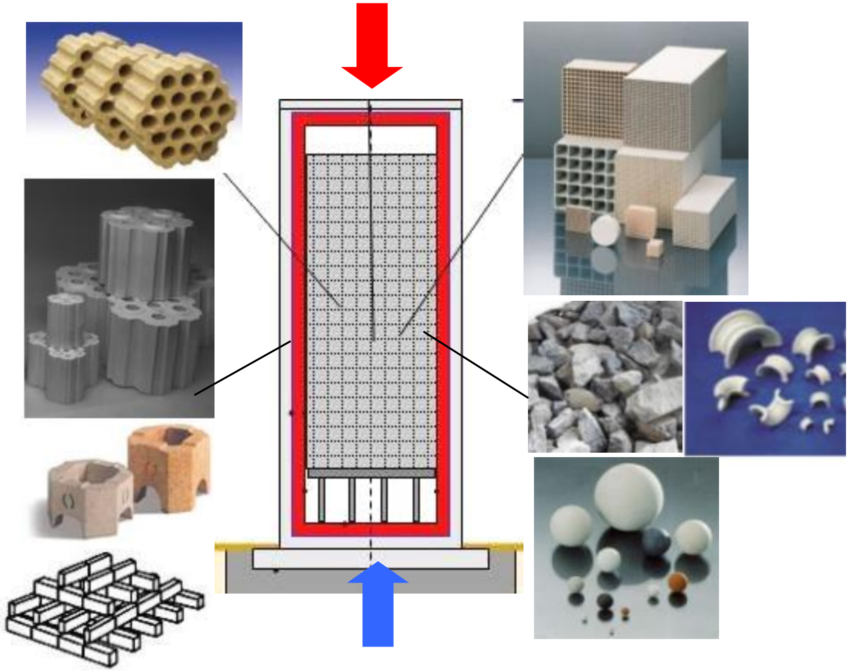
Advantages

- Direct contact between storage material and gaseous heat transfer fluid
- High temperatures & temperature flexibility
- Wide choice for possible materials, cost reduction potential

Challenges

- Vessel design (pressurized)
- Thermo-mechanical aspects (packed bed design)
- Flow aspects

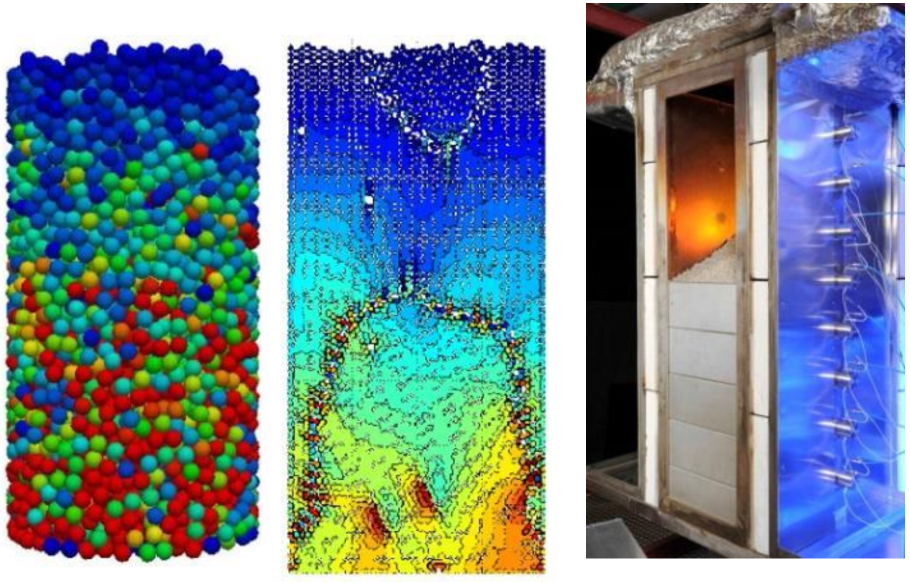




Sensible storage – regenerator
Mechanical forces in packed bed

Prediction of thermally induced mechanical loads

- Development of particle-discrete models
- Parameterization of continuum mechanics model for simulation of large TES structures
- Experimental validation of simulation models for time-varying forces



To quantify local contact forces & mechanical stress

To develop protections measures

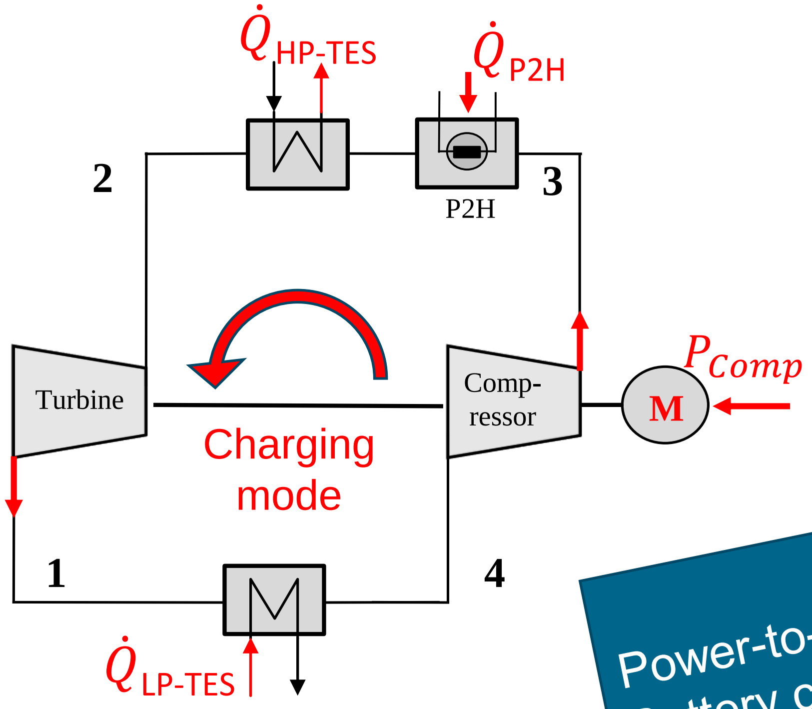
HOTREG test facility
Pilot-scale validation of concepts

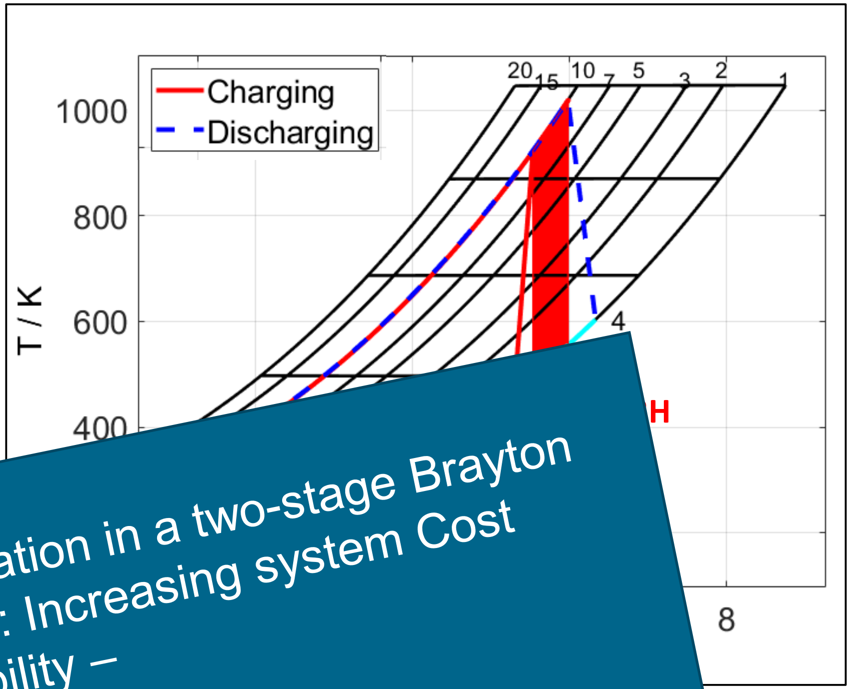
- Validation of storage arrangements
- Validation of simulation models
- Removable inner chamber allowing for quick exchange of test setups
- Broad variability of test parameters

Test bed HOTREG Specifications
- Inventory mass: 3-5 tons
- Mass flow rates: 220 – 800 kg/h
- Max. heat rate: 180 kW
- Inlet temperatures
    - Charging: 600 – 830 °C
    - Discharging: 100 – 400 °C
- Max. pressure: 11 bar
- Optionally: Humid air operation

Power-to-heat integration in a Brayton Battery

Cost reduction through power-to-heat integration





Power-to-Heat integration in a two-stage Brayton Battery configuration: Increasing system Cost Efficiency and Flexibility – Sergej Belik, DLR

Integration of electrical heating capacity (P2

- Higher energy density in HP-TES and system
  → potential for cost savings (CAPEX↓) vs. roundtrip efficiency
- Lowered outlet temperature for HT-compressor → short-/medium-term feasibility

Test facility HOTREG-P2H/KindLE
Qualification of P2H-concepts in pilot-scale

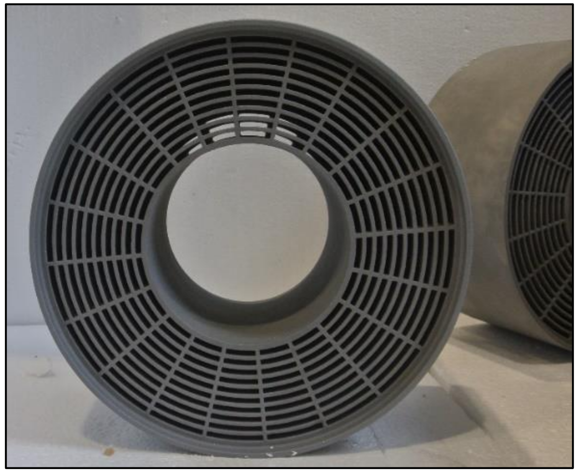
Test bed for power-to-heat technologies for solid media storage using gas as HTF

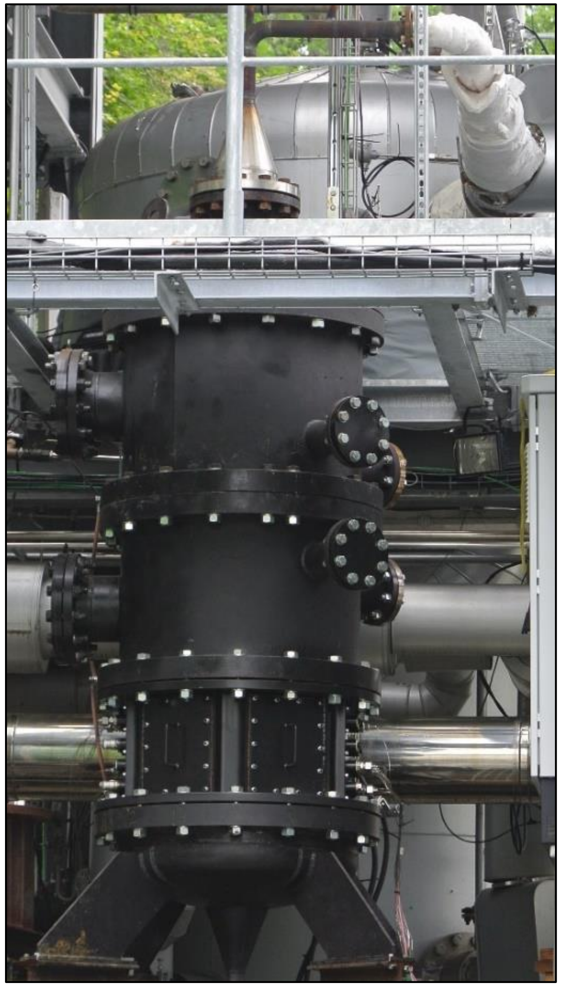
- Operating temperatures up to 1000 °C
- Power level ~100 kW
- Aims at use with Carnot batteries & industrial process heat

Objectives:

- Development of P2H technology based on radiation-heated ceramic elements

➔ Demonstrated up to 95 kW





SiC-Waben: 3D-Druck (190 m^2/m^3 & 42 %)

Test facility HOTREG-P2H/KindLE
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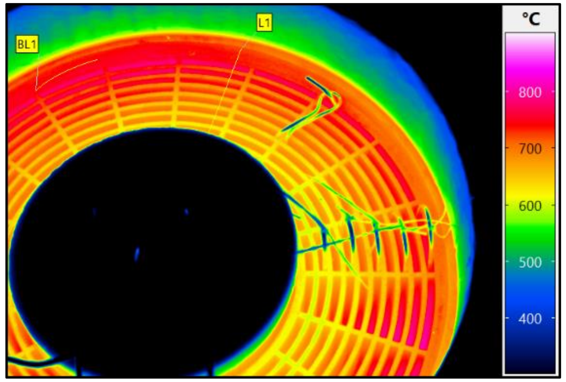
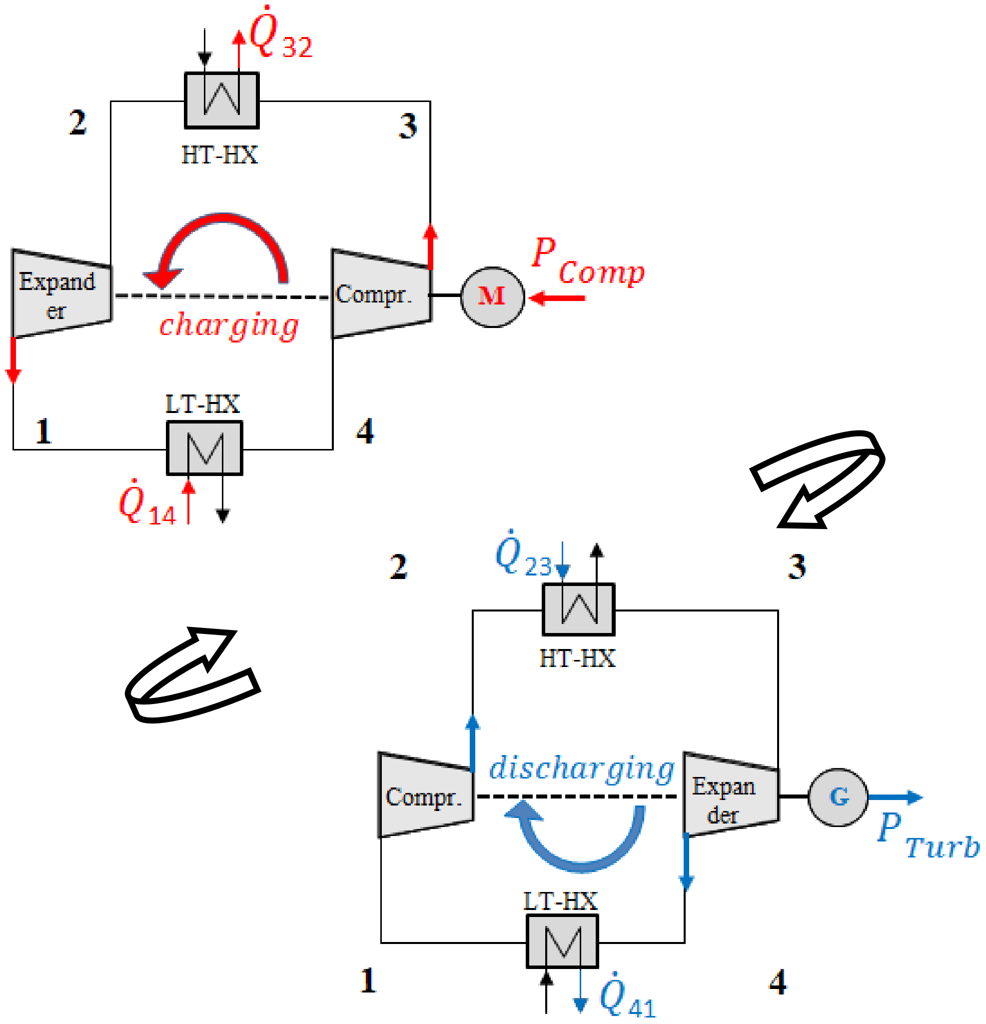
- Operating temperatures up to 1000 °C
- Power level ~100 kW
- Aims at use with Carnot batteries & industrial process heat

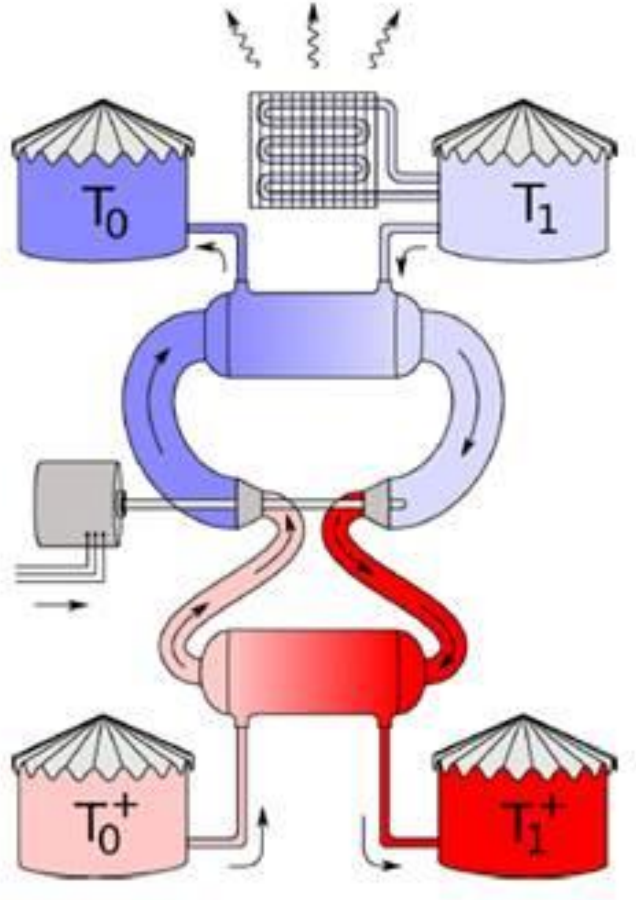
Objectives:

- Development of P2H technology based on radiation-heated ceramic elements
- Experimental testing of a ceramic induction air heaters & proof-of-concept



Brayton Battery
Working principle, with gas as a working medium





Laughlin, R. B. (2017), Pumped thermal grid storage with heat exchange, Journal of Renewable and Sustainable Energy 9(4), DOI: 10.1063/1.4994054.

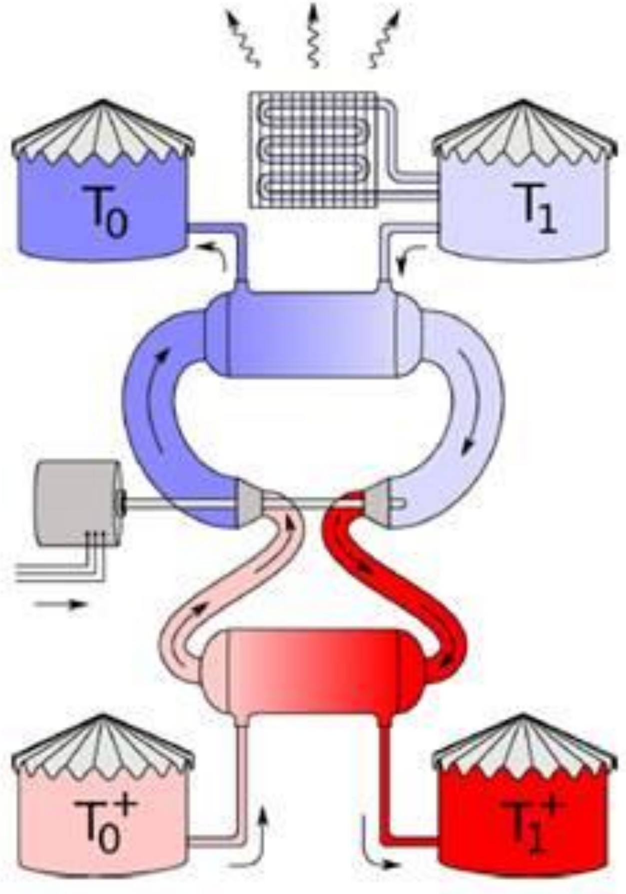
Molten Salt Storage
Potential and challenges

Advantages

- Experience from CSP
- No need for pressurised storage

Challenges

- Need for Air/Salt HXGer
- Limited Temperature range (efficiency)
- High Material Cost



Laughlin, R. B. (2017), Pumped thermal grid storage with heat exchange, Journal of Renewable and Sustainable Energy 9(4), DOI: 10.1063/1.4994054.

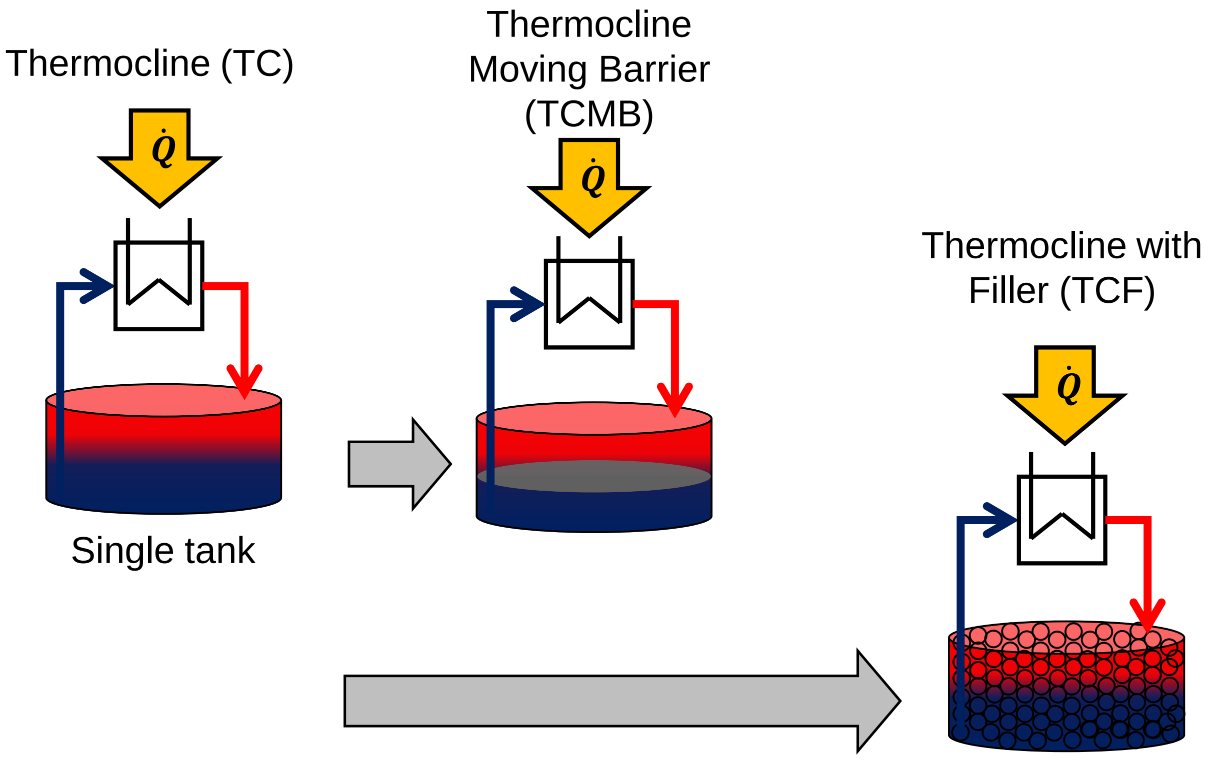
Pushing temperature through increased understanding
Molten Salt Material Research

Objectives:

- Increase max. Operating temperature from 565°C to 620°C
- Supress corrosion to allow use of standard steels
- Design components (tanks, E-Heater, HXGer) minimising local decomposition

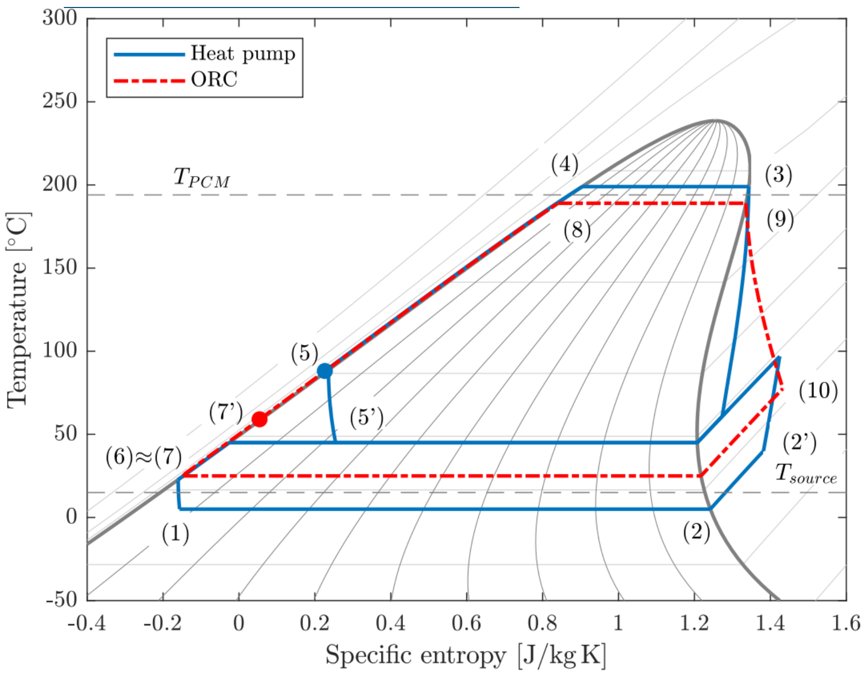
Testing key components for Carnot batteries in molten lead and **molten salt at elevated temperatures** –
Klarissa Niedermeier, Karlsruhe Institute of Technology & Thomas Bauer, DLR

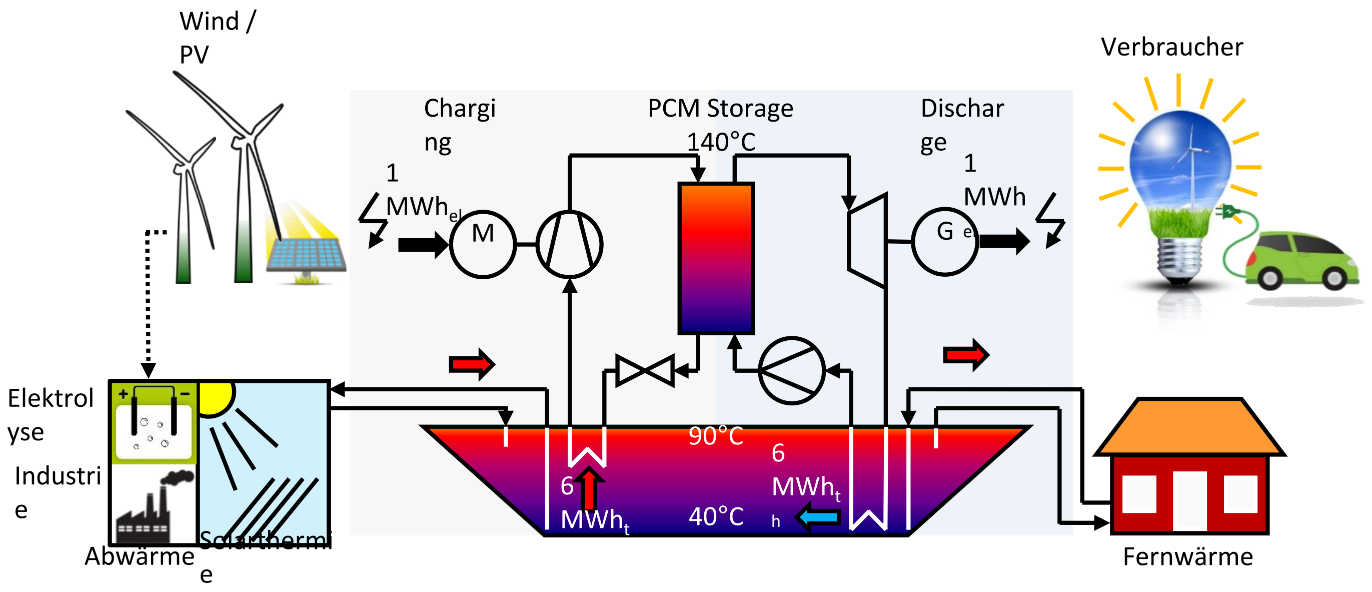
Single Tank Storage
Cost reduction through packed bed storage




DLR Test facility for thermal energy storage in molten salts (TESIS) – 100 ton scale

Carnot Battery
Working principle, Rankine cycle





Design, built and initial operation of the **CHESTER-system**
– *Dan Bauer, DLR / HFT Stuttgart & Maike Johnson, DLR*

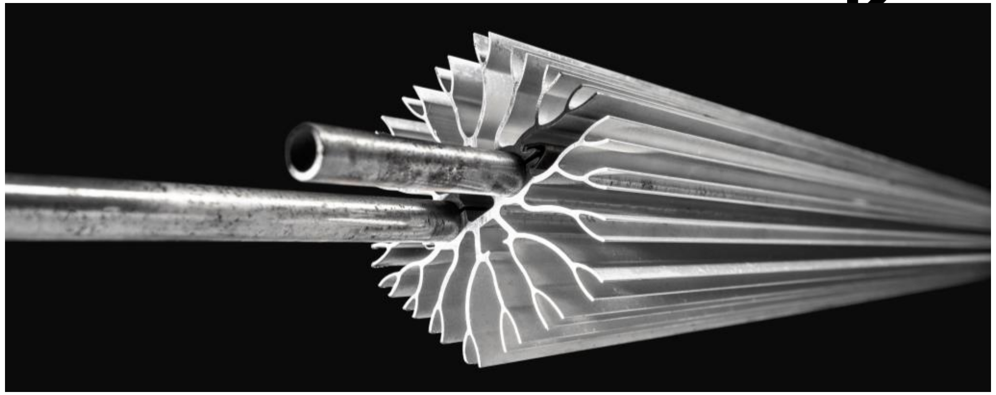
Phase Change Storage
Potential and Challenges

Potential

- Constant temperature allows for low entropy generation

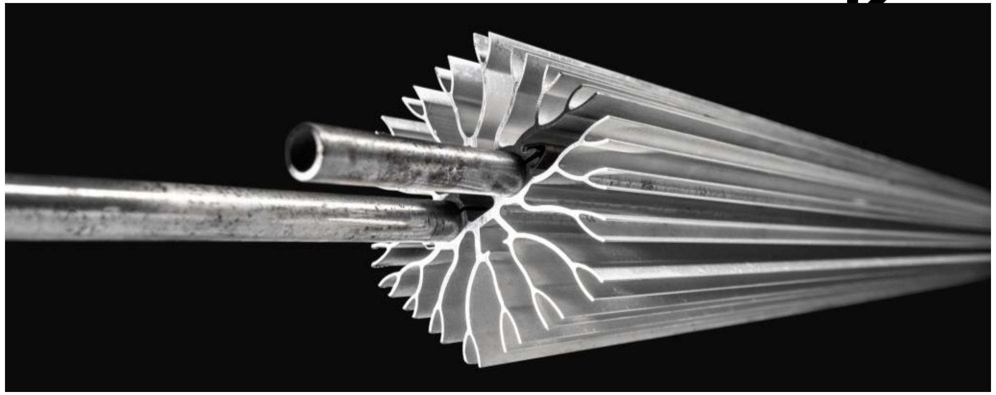
Challenges

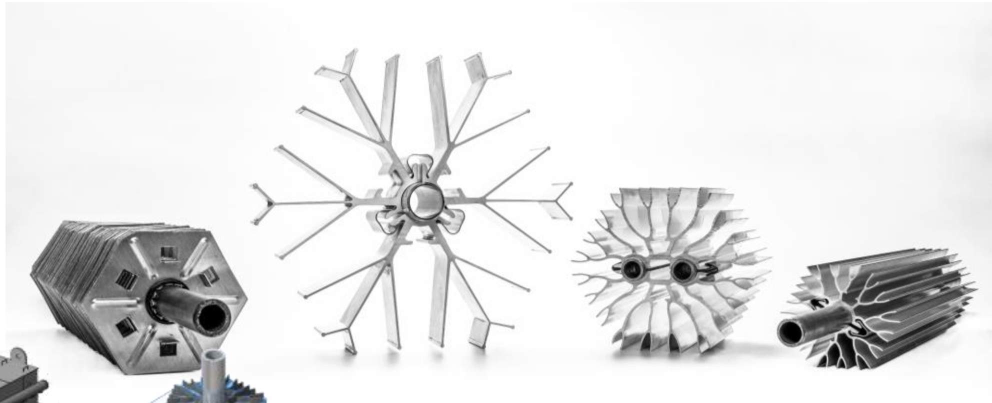
- Low HTF coefficient

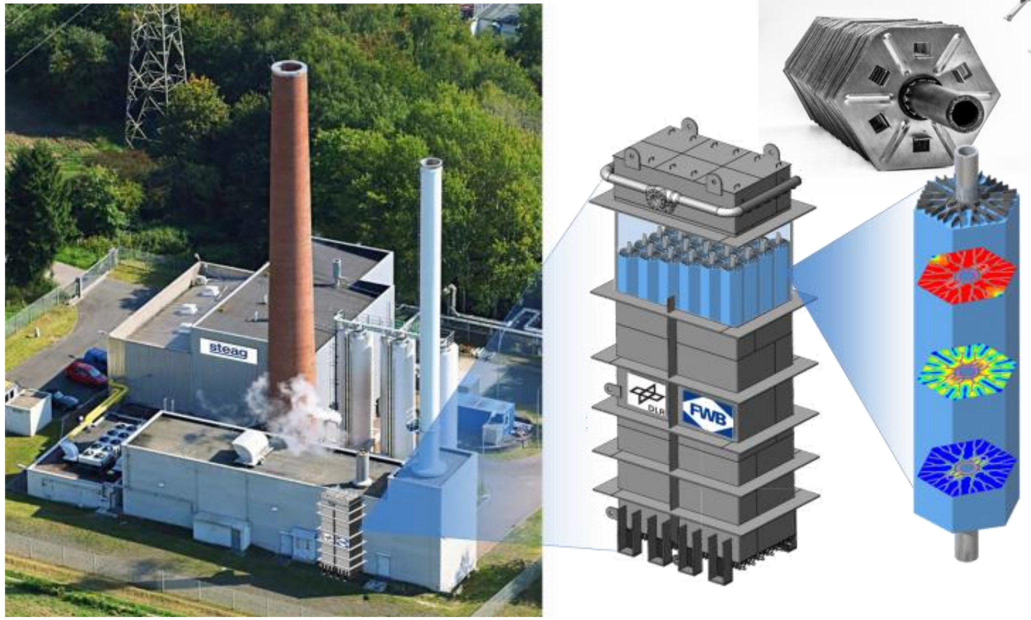


Phase Change Storage
Heat Exchanger Design for scalability

- Finned tube storage concept demonstrated:
  - Graphite fins / horizontal tubes for T < 250 ºC
  - Aluminum fins for T < 350 ºC
    - Radial / vertical tubes
    - Extruded / vertical tubes
- Large-scale storage tested:
  - 6 MW, 1,5 MWh







300 °C, 26bar, 8t/h, 15min

Conclusion

DLR has wide expertise in component and cycle design for Carnot Batteries

… we are happy to support any other institute/ industry with specific design & look forward to collaborations…