CHARACTERIZATION OF A LARGE LAB-SCALE LATENT HEAT STORAGE

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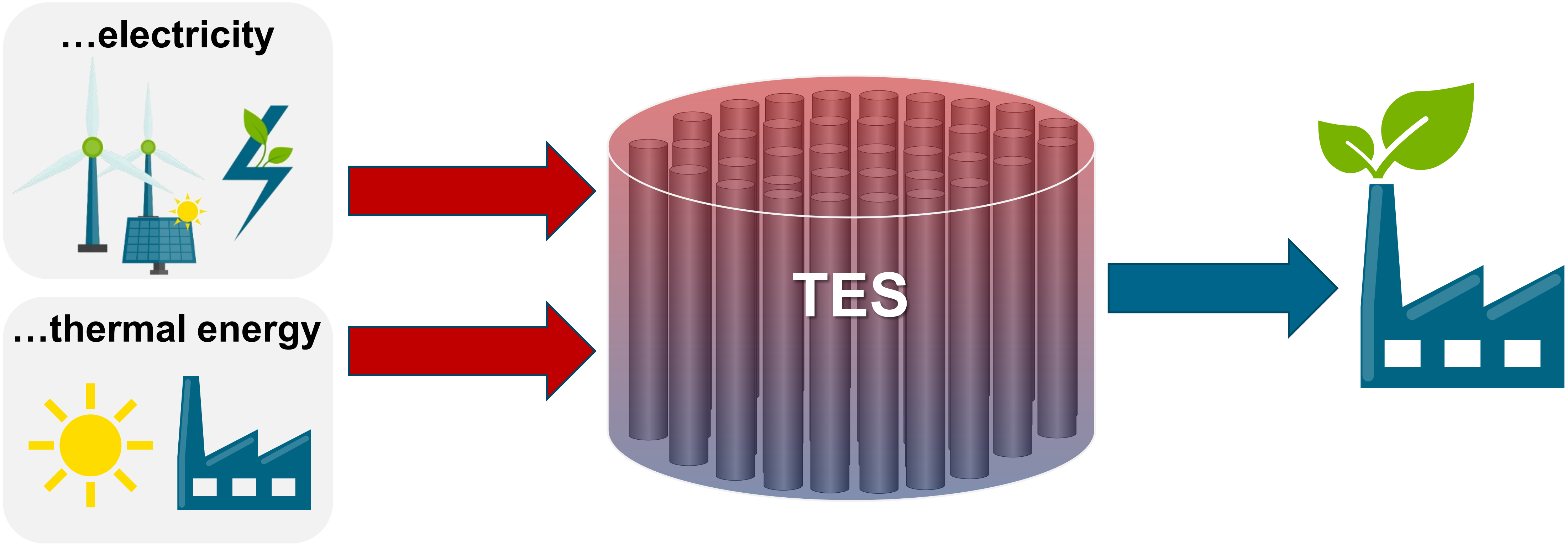
ISEC 2026, Graz, April 16, 2026

Supply of green process steam

Fluctuating… **Heat demand**



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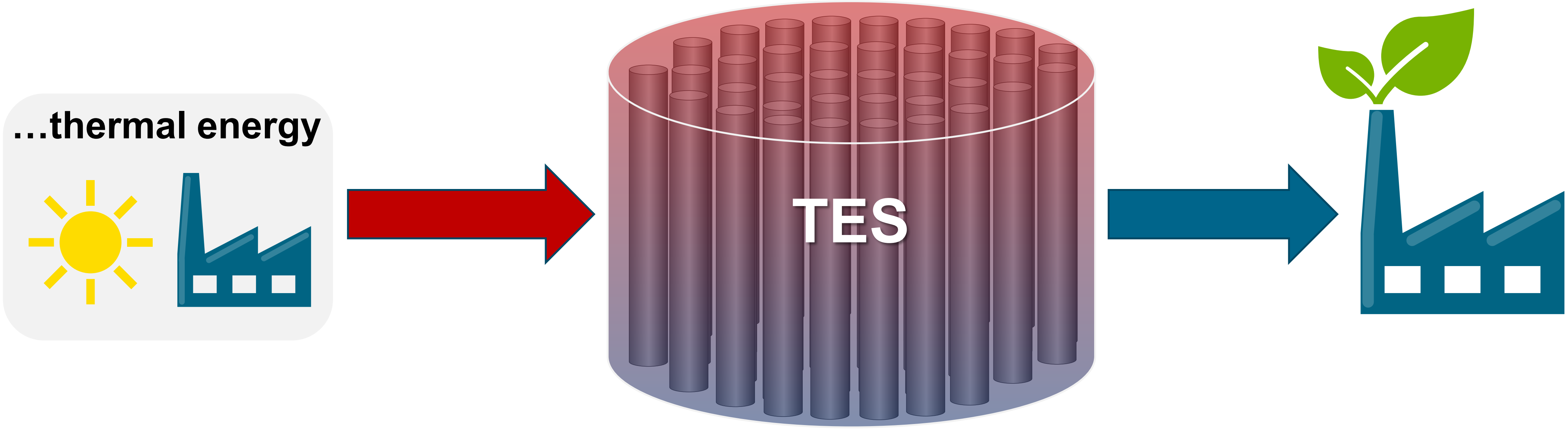
Converting the idea into integration

Fluctuating…

Heat demand



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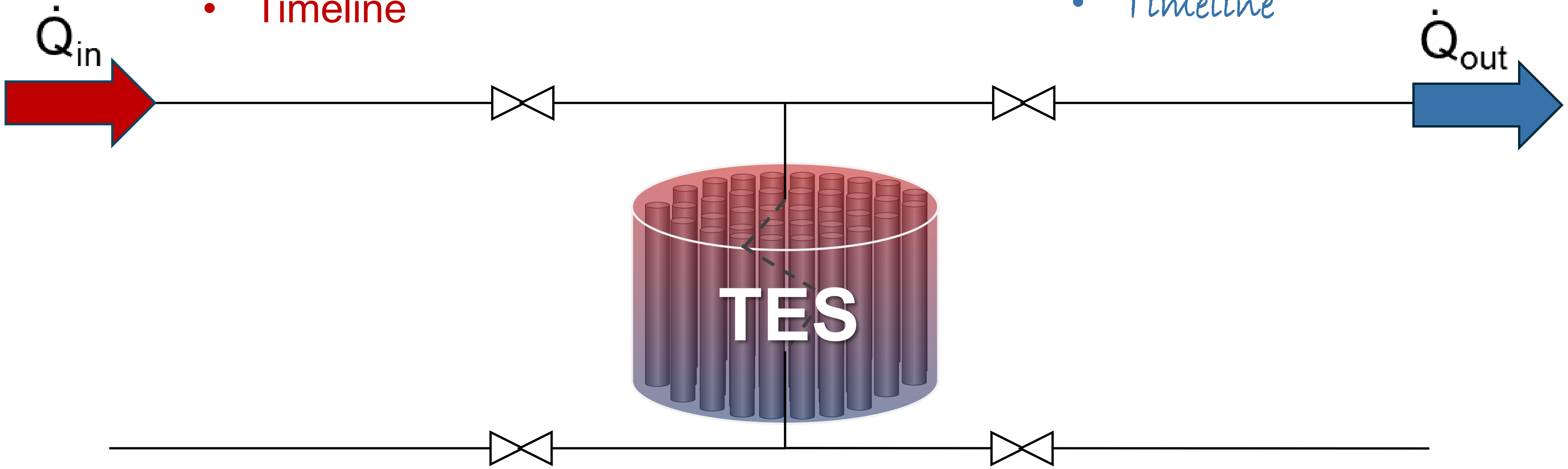
Converting the idea into integration – coupling the heat source and sink through a storage system

- Medium
- Temperature
- Pressure
- Timeline

- *Medium*
- *Temperature*
- *Pressure*
- *Timeline*



- Control systems

→ Design limitations

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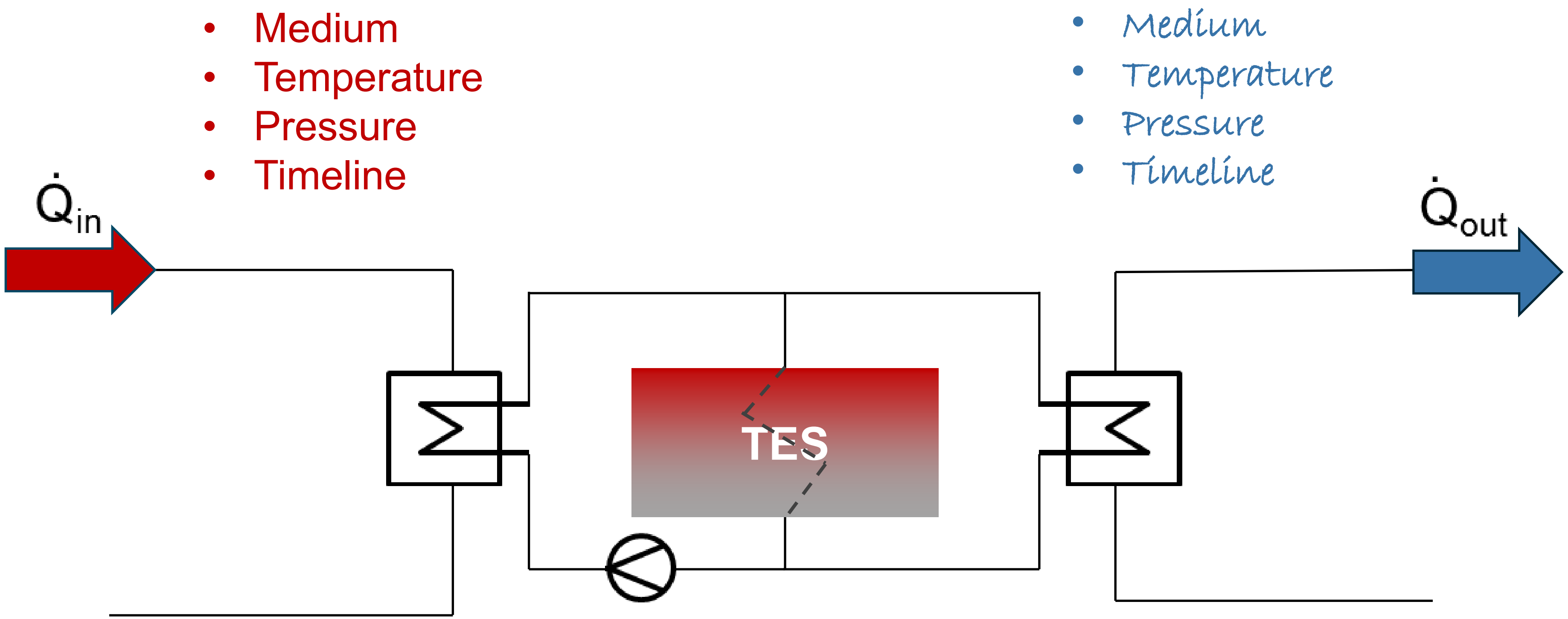
Converting the idea into integration – transferring <u>only heat</u> between two systems



- Control systems, simplified
- Increased system temperature gradients
- Design limitations

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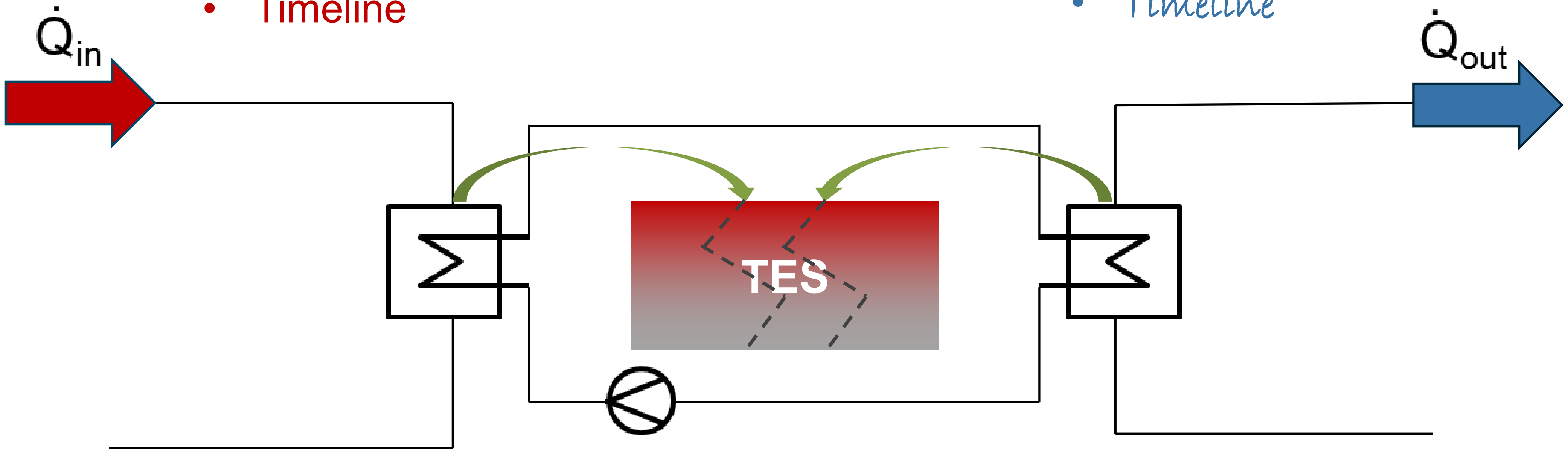

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Converting the idea into integration – simplifying the system

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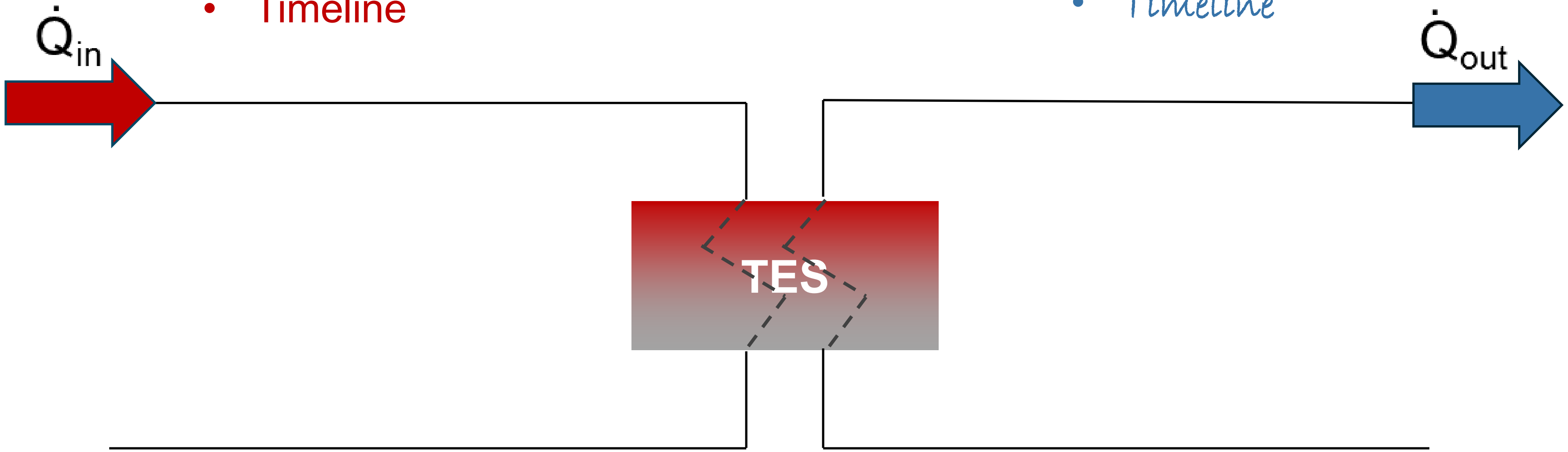
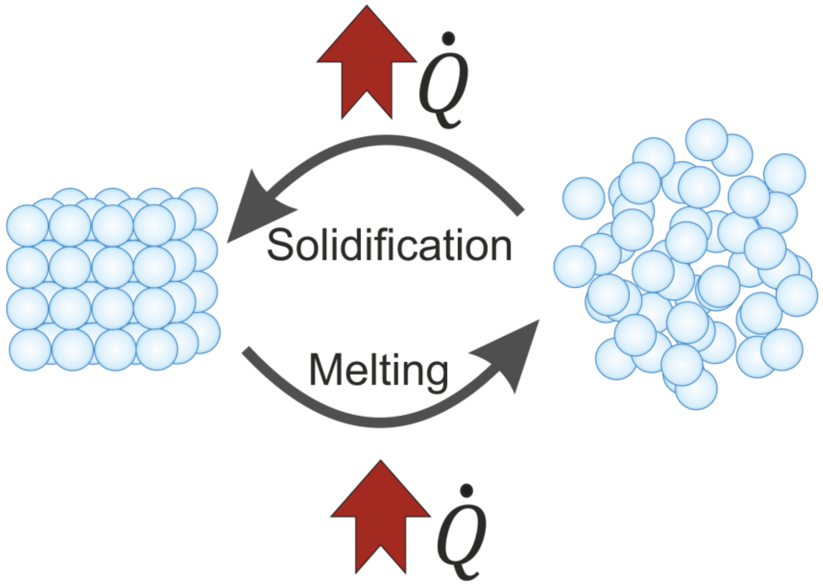


- Simplified system integration
- Heat exchangers in storage designed for heat source and sink

Latent heat thermal energy storage



$$Q_{latent} = \Delta h_m$$

Advantages

- High **energy density**
- Nearly **isothermal conditions**
  → Suitable for steam supply e.g.:
  - industrial processes
  - steam/organic Rankine cycle to generate electricity

Disadvantages

- Poor **thermal conductivity** of solid PCM

Finned-tube heat exchanger design

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Extruded aluminum fins

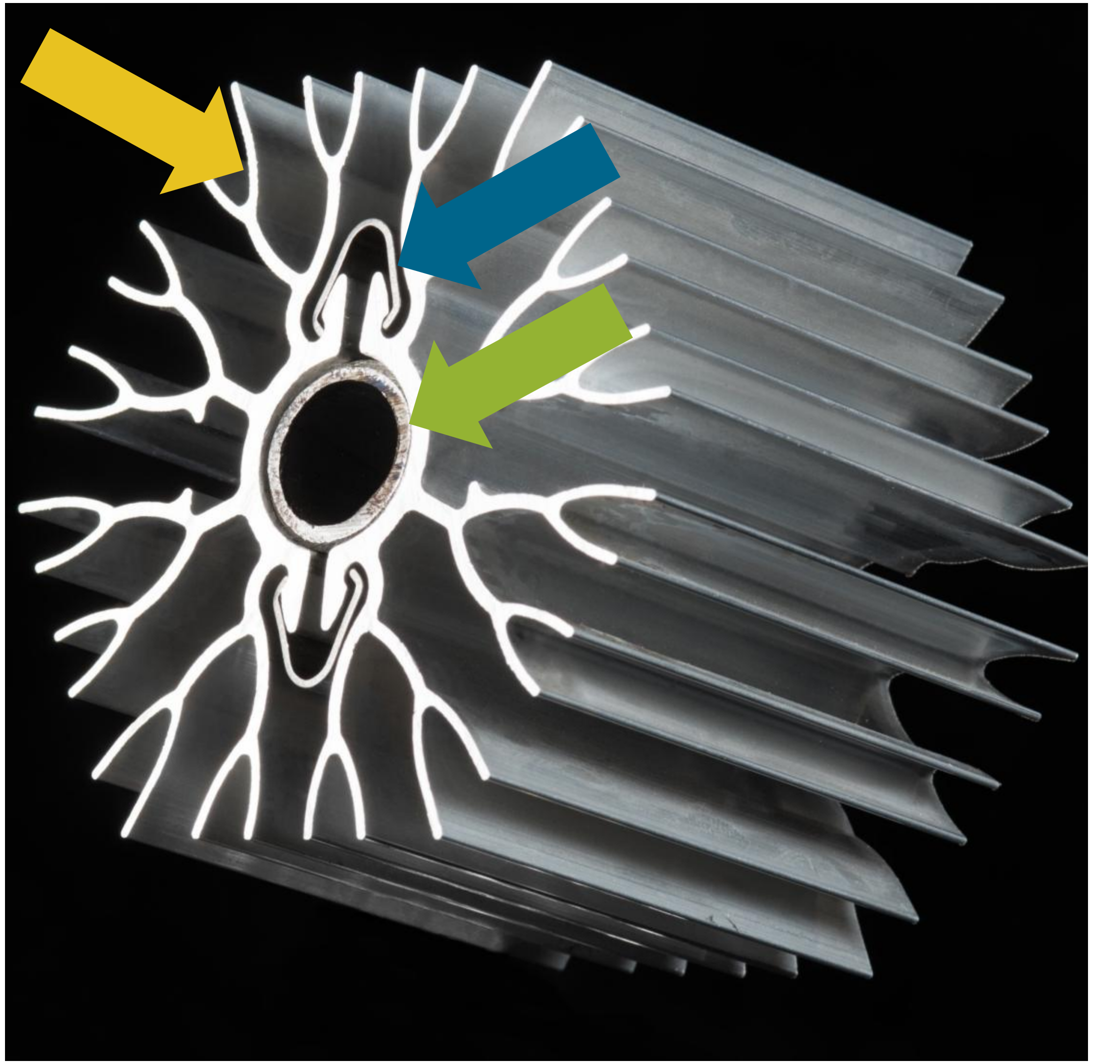
→ Increased heat transfer surface
→ Aluminum: high thermal conductivity
→ Power (and capacity) given by fin design

Steel tube

→ High pressure systems
→ Easy welding processes

Clip mounting

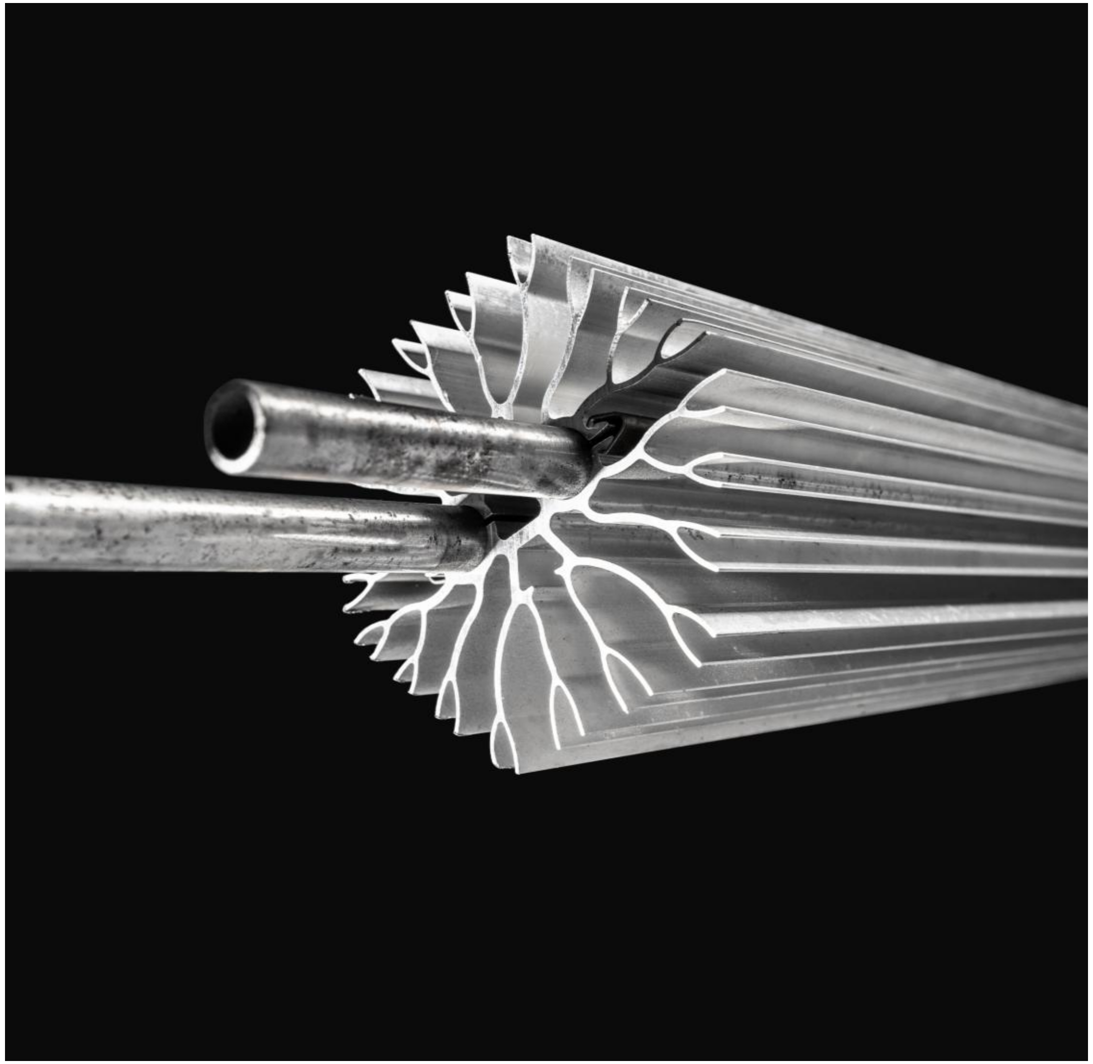
→ Decent thermal contact
→ Differential thermal expansion possible
→ Feasible assembly



Dual-tube finned-tube heat exchanger design

Decoupling charging and discharging

→ Two separate heat transfer fluids
→ No need of pressure equalization
→ Decent thermal contact between tubes



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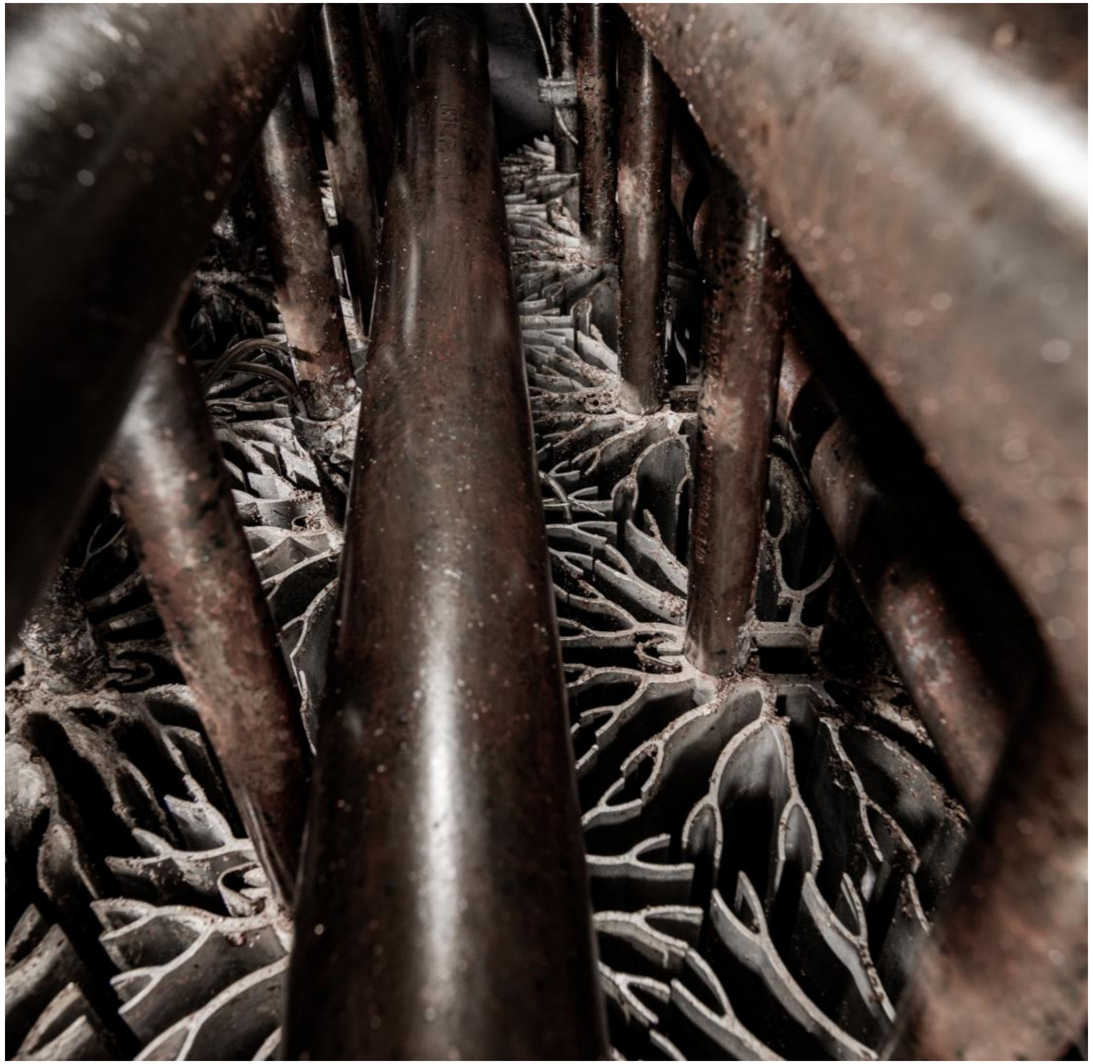
Storage design

- → 56 dual-tube pairs
- → PCM: 4.4 tons of KNO_3/$LiNO_3$(eu)
- → Nominal storage capacity: 160 kWh



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Operation

→ Initial: ORC/HTHP (ISEC 2024)
→ Secondary: Extensive parameter testing using in-house rig and single tube

CHESTER
Compressed Heat Energy Storage for Energy from Renewable sources

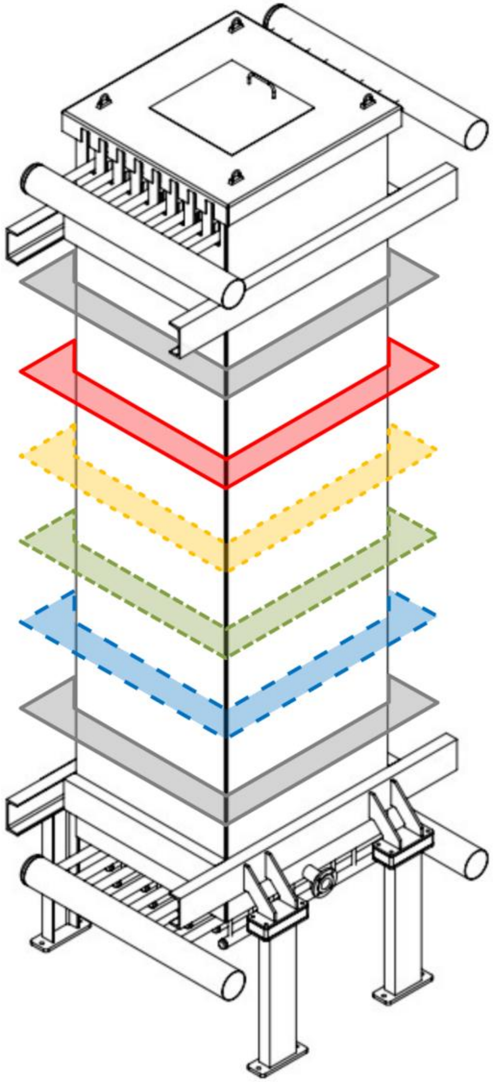
Secondary test rig
Organic fluid test rig for charging and discharging

Rig parameters

- Refrigerant: **R1233zd(e)**
- Temperatures: **110 - 145 °C**
- Pressures: **14 - 40 (20 °C) bar**
- Mass flow rates: **0.3 - 0.7 kg/s**

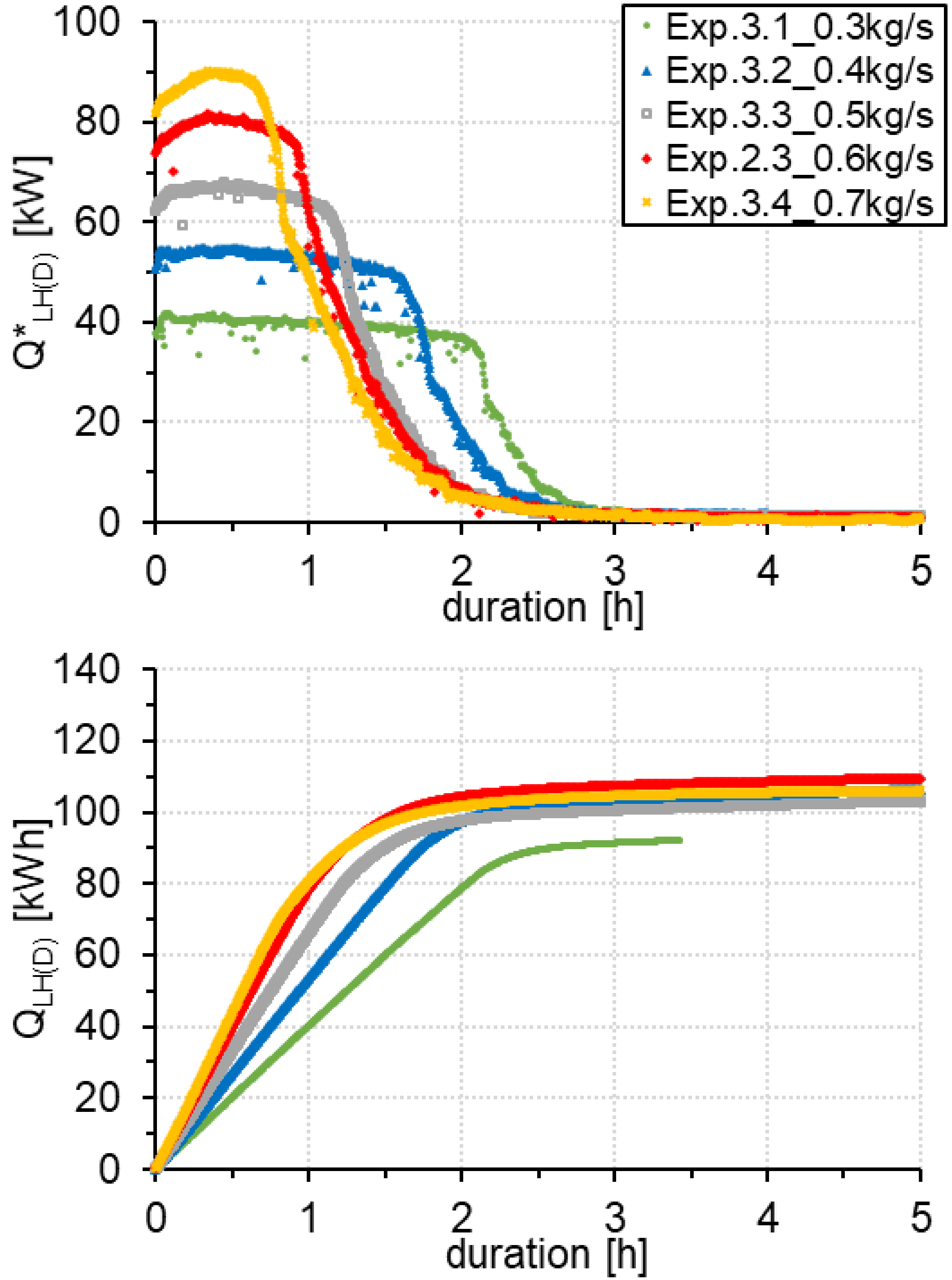
Measurement points

Measurement	Location/Type
Temperature, PCM	10*6 type K thermocouples with measurements in 6 levels
Temperature, HTF	Inlet and outlet, PT100
Mass flow, HTF	Coriolis, separate for charging and discharging
Pressure, HTF	Inlet and outlet



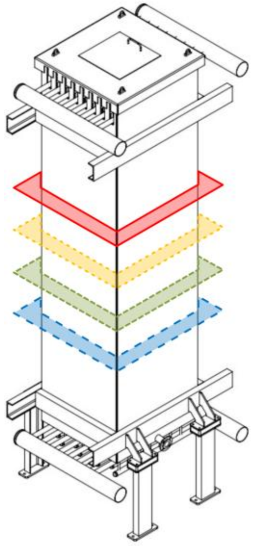
Mass flow variation
Heat flow rate and duration

- Increase in mass flow rate
  - →Increase in maximum heat flow rate
  - →Decrease in duration of phase change
- Low mass flow rates may lead to uneven distribution across the headers
  - →Average flow rate in tubes for 0.3 kg/s
    - → 0.04 m/s (liq.)/0.58 m/s (gas.)

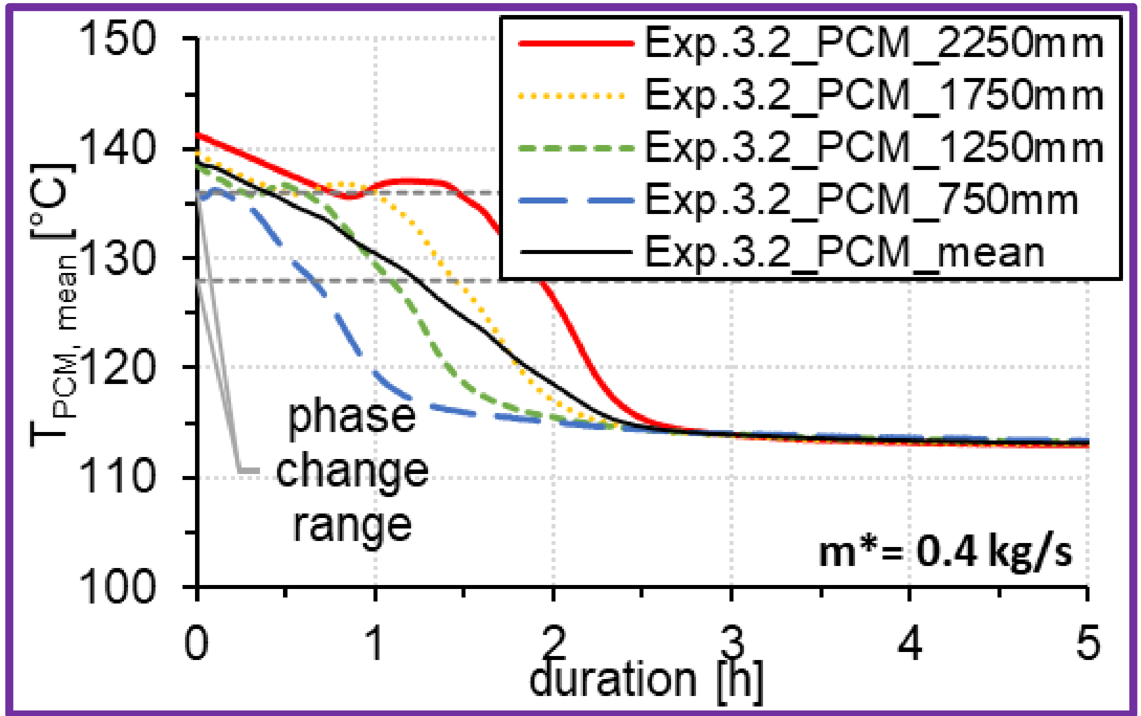


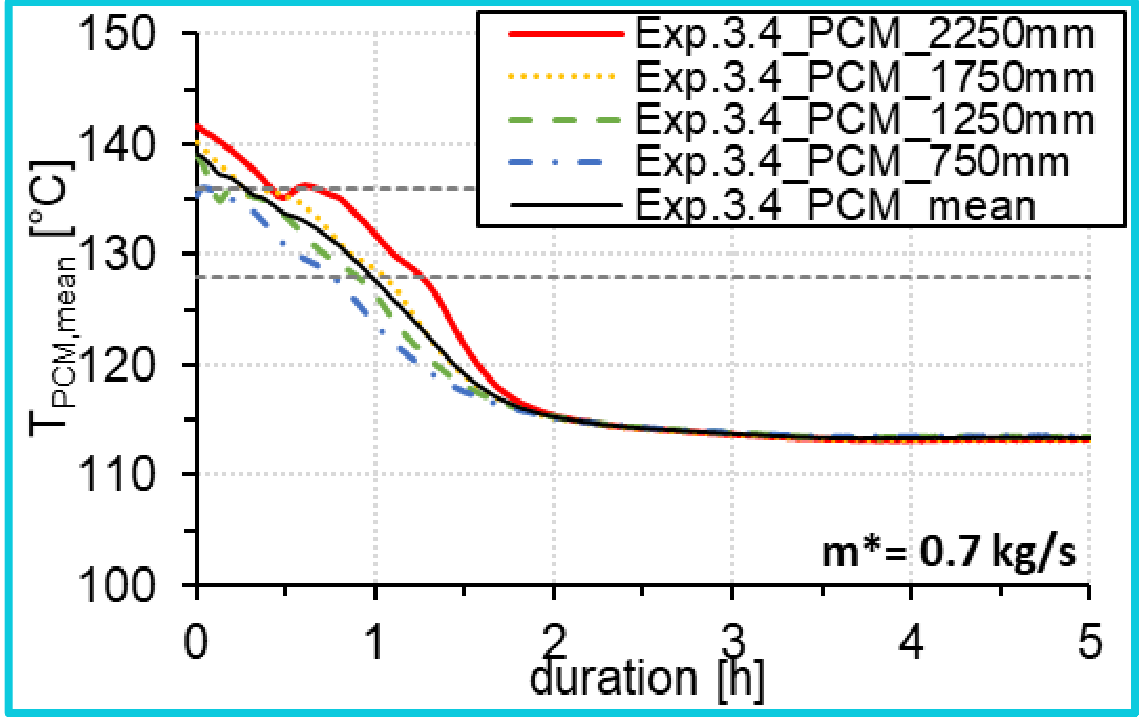
Diagrams from Theologou et al., doi: 10.1016/j.est.2025.117841.

Mass flow variation over height of the storage



- Comparison of 0.4 and 0.7 kg/s
  →4 measurement levels, averaged temperature
- Phase change front
  - Low mass flow → high temp. difference
    - Phase change over height
  - High mass flow → low temp. difference
    - Phase change through fins
  - Confirmed by work published by L. Dietz et al, doi.org/10.1016/j.est.2024.111709





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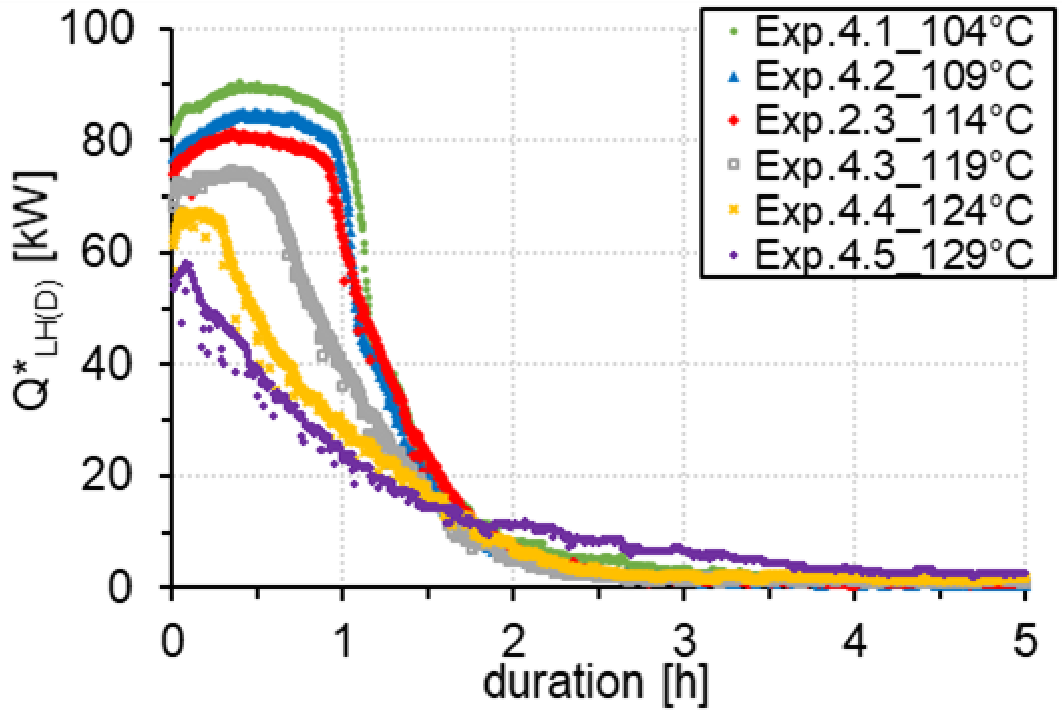
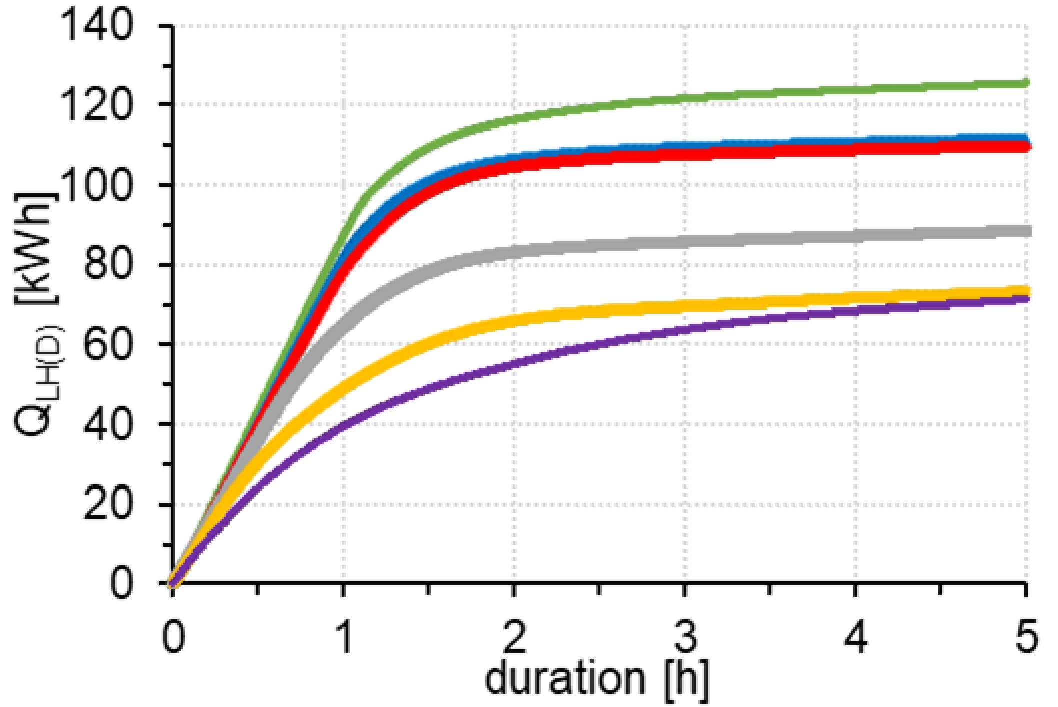
Evaporation temperature variation

Effect of driving temperature difference

- Mass flow rate 0.6 kg/s
- Varying evaporation temperature in HTF
- Higher HTF ↔ PCM driving temperature difference → increased heat flow rate
  - →Above 119 °C (low dT) → curve characteristics change
- Overall heat transferred directly related to sensible heat transferred
  - →Deviation to theoretical values likely due to rig characteristics





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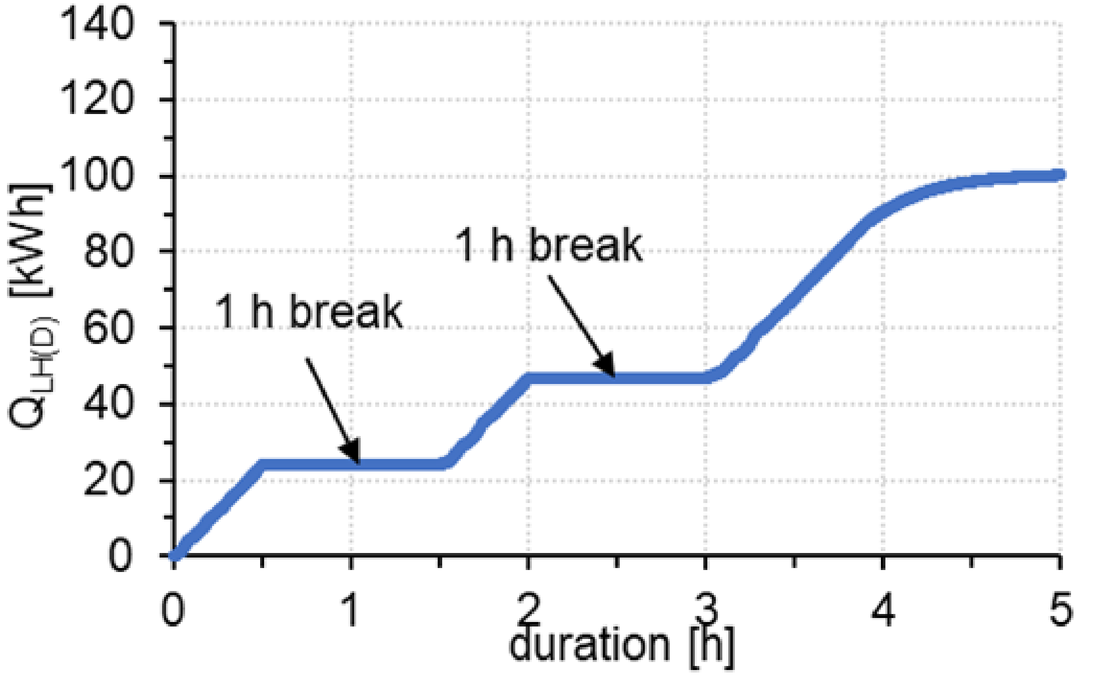
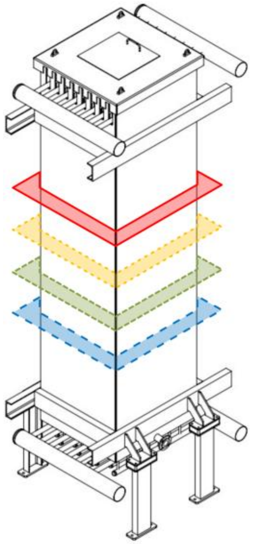
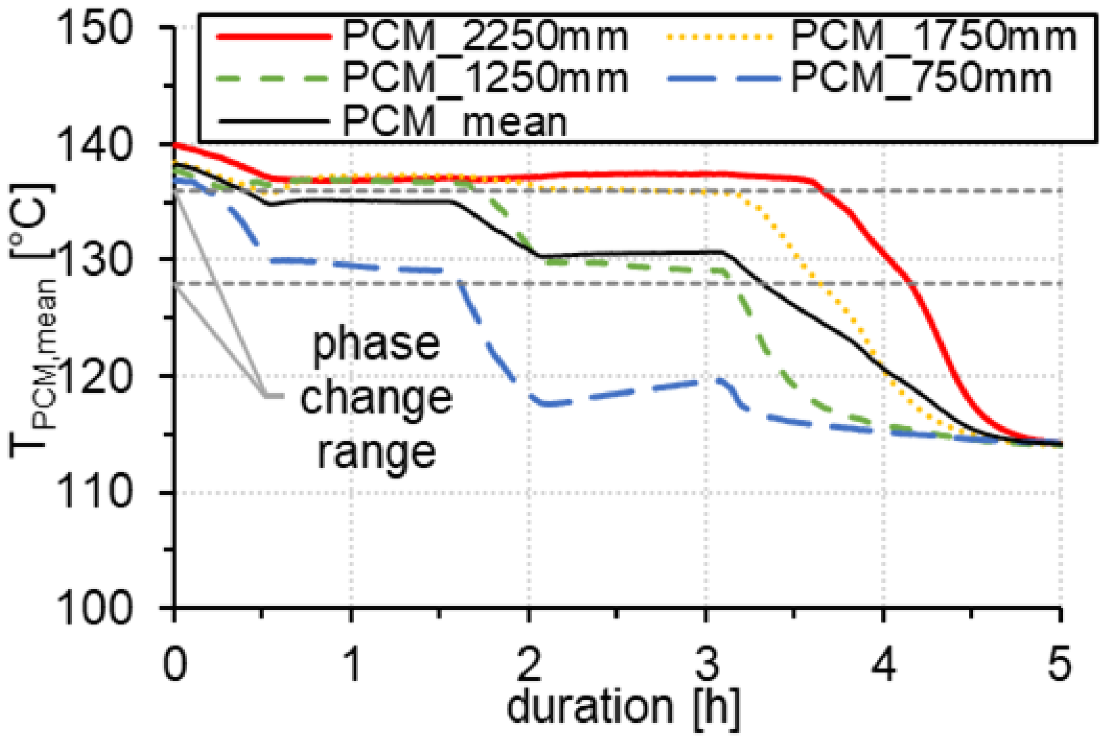
Sequential discharging

- Mass flow rate 0.4 kg/s
- Interrupted discharge
  - 0.5 h discharge
  - 1 h break
  - 0.5 h discharge
  - 1 h break
  - complete discharge
- Compared to no interruptions…
  - Transferred heat in same range
  - Active heat transfer duration comparable
- Homogenization occurs in sensible phase







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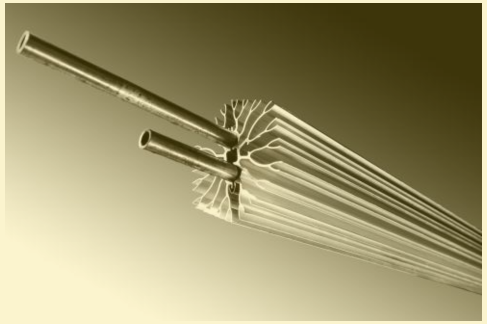
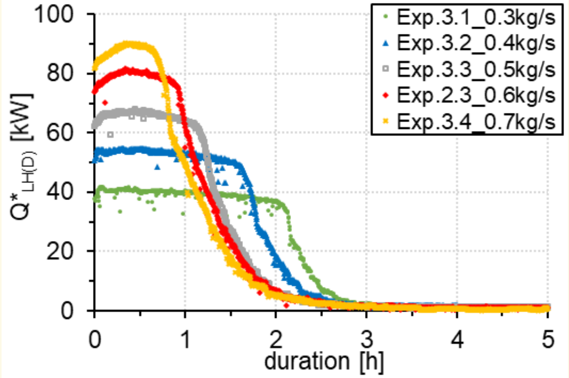
Conclusions and outlook

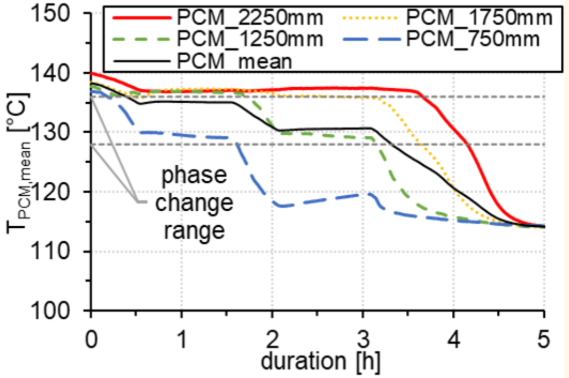
- Dual-tube storage system demonstrated
  - Different heat transfer fluids and parameters with low temperature gradients
  - Simplified integration → Avoiding additional valves or heat exchangers, simple control systems
  - Reduces hurdles for industrial integration

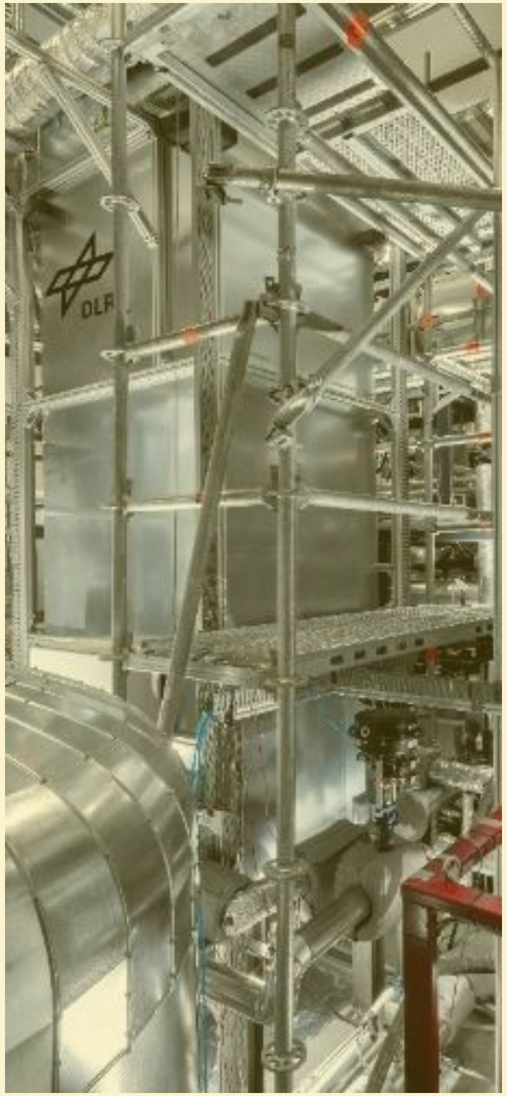
- Experimental testing
  - Extended testing with heat flow up to 90 kW and storage capacity of 124 kWh (dT 35 K) measured
  - Adjustment of mass flow rate can be used to control degree of superheating and heat flow rate
  - Interrupted operation possible, allowing for flexible integration in industrial systems

- Outlook → Two dual tube storages under construction!
  - Lab-scale for testing with T_m=222 °C, MDM for charging and water/steam for discharging → CHASE
  - Industrial integration with T_m=222 °C, electrical resistance charging and water/steam discharging → PCM-Grid









Questions & Discussion

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Imprint

Title: Characterization of a large lab-scale latent heat storage

Date: April 16, 2026

Author: Dr. Maike Johnson

Institute: Institute of Engineering Thermodynamics

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