Thermochemical Storage of Heat

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Content

- Potential and Challenges of Thermochemical Heat Storage
    - Reaction System and Storage Material
    - Reactor Concept

- The Calcium Hydroxide Reaction System (350 to 700°C)
    - Application for Storage in Concentrated Solar Power Plants

- The Calcium Chloride Reaction System (80 to 200°C)
    - Application for Heat Transformation of Industrial Waste Heat

- Summary and Outlook

Thermochemical Heat Storage

Principle and Potential

- Reversible gas-solid reaction
- Utilization of enthalpy of reaction
    - (1) Endothermal reaction – dissociation
    - (2) Separation of products
    - (3) Exothermal reaction – formation

endothermal

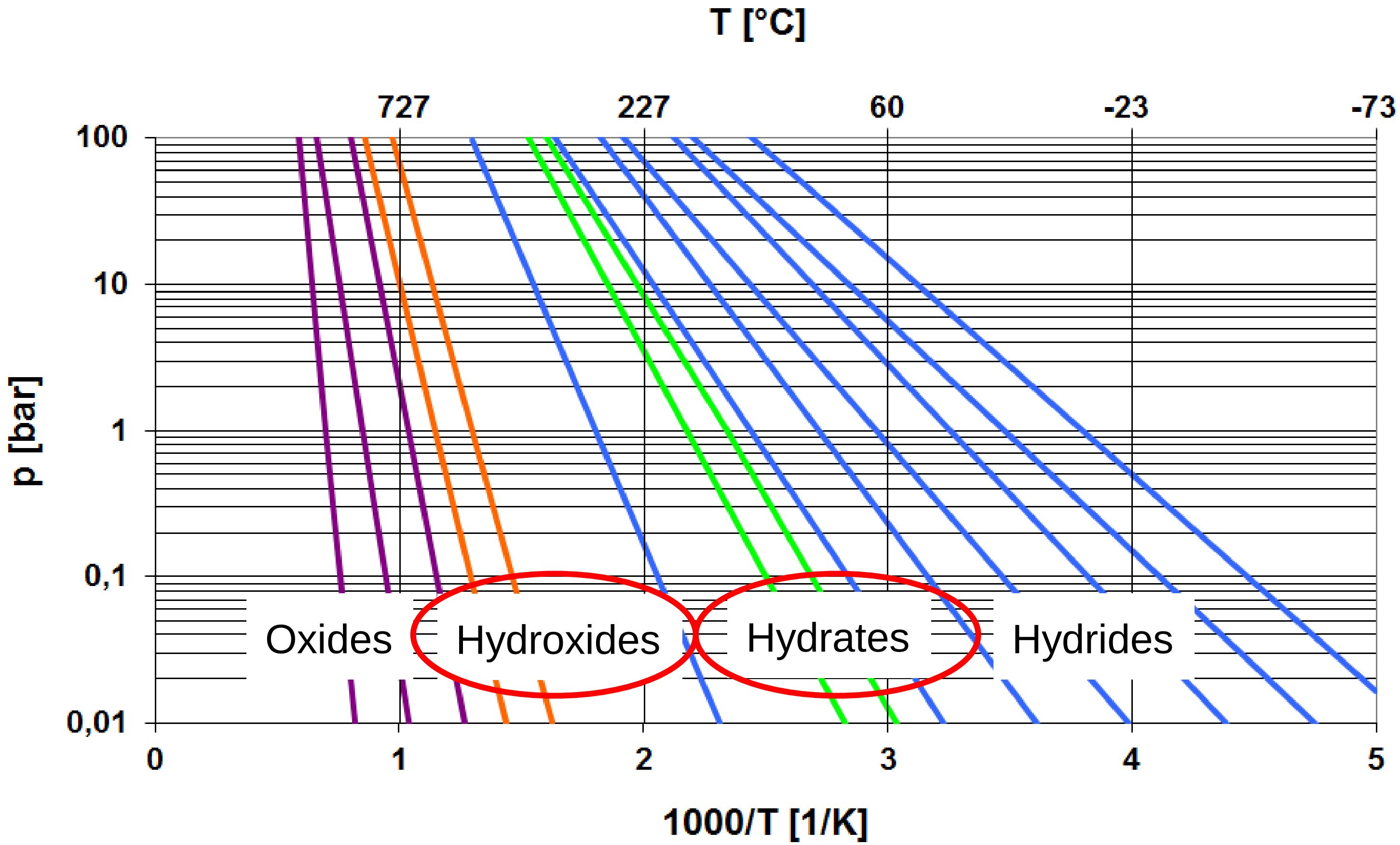
$$AB \rightleftharpoons A + B$$

exothermal

- High storage densities
- Loss-free and long-term storage
- Detachment of storage capacity and thermal power
- Possibility for heat transformation
- Application in a wide temperature range (below ambient up to 1000° C)

Gas-Solid-Reaction Systems

Application in a Wide Temperature Range

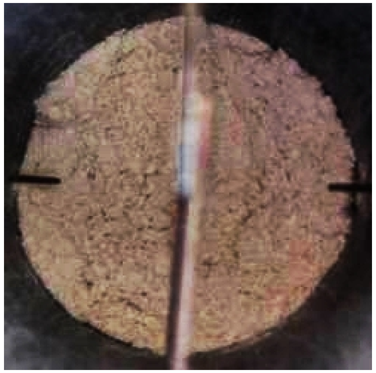


TCS Requirements for Reaction Systems

- High enthalpy of reaction
- Complete reversibility
- Cycling stability

- Thermodynamics and reaction kinetics
- Thermo-physical and mechanical properties

- High availability of material at low cost
- Positive LCA (sourcing, production, logistics, utilization, disposal)



Limestone quarry Hahnstetten

Selected Reaction Systems

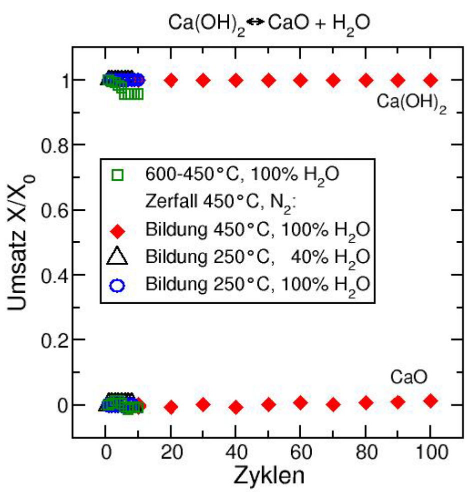
Calcium Hydroxide

$Ca(OH)_2 + \Delta H \leftrightarrow CaO + H_2O$

T_{eq} = 507°C at 1 bar

ΔH = 100 kJ/mol

Storage density*) = 410 kWh/m³



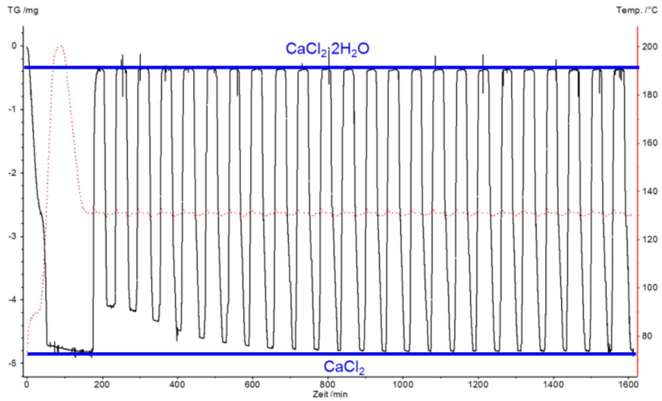
Calcium Chloride

$CaCl_2 \cdot 6\,H_2O + \Delta H \leftrightarrow CaCl_2 + 6\,H_2O$

T_{eq} = below 200°C at 1 bar

ΔH = 370 kJ/mol

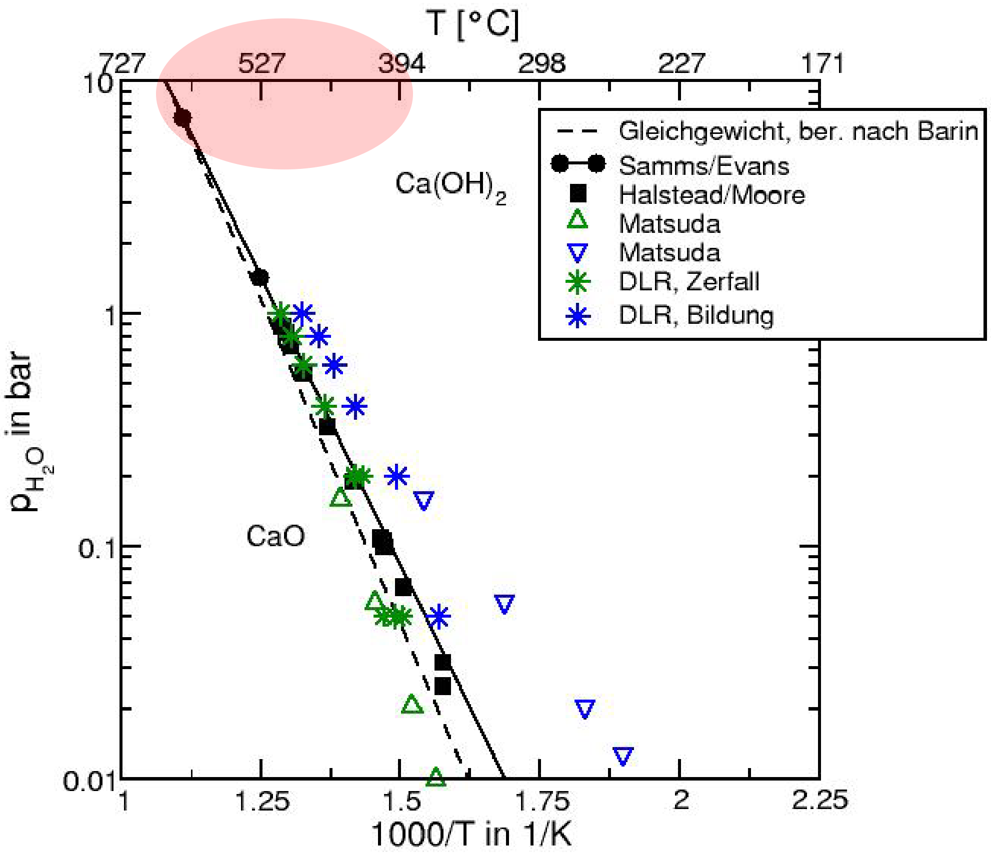
Storage density*) = 400 kWh/m³



*) bulk density 0.5

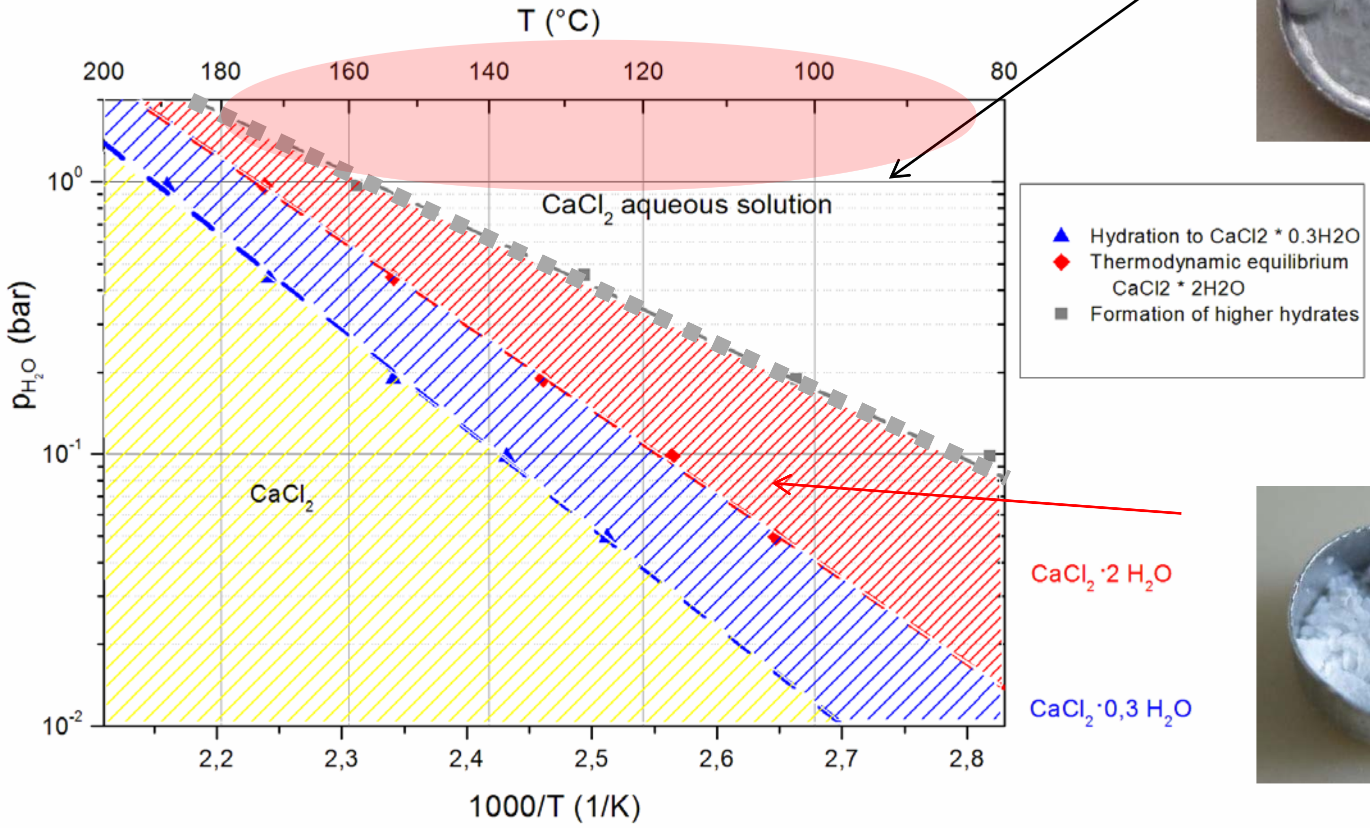
Evaluation of Thermodynamic Equilibrium

Calcium Hydroxide → 350 to 700°C



Evaluation of Thermodynamic Equilibrium

Calcium Chloride → 80 to 200°C

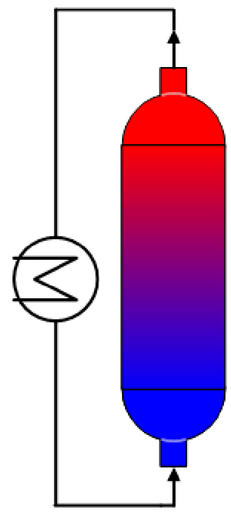
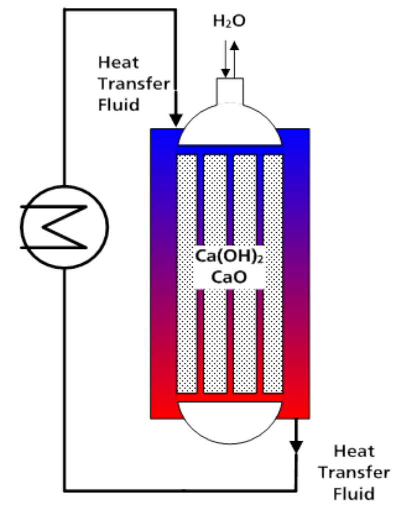


Reactor Concepts
Fixed Bed vs. Moving Bed

	Fixed Bed	Moving Bed
Reactor Types	Tube (Bundle) Packed Plate	Fluidized Bed Rotary Kiln Screw
Heat Transfer	🟡	🟢
Parasitics	🟢	🟡
Complexity	🟢	🟡
Material Requirements	🟢	🟡
Detachment of power and capacity	🔴	🟢

Reactor Concepts

Directly Heated vs. Indirectly Heated

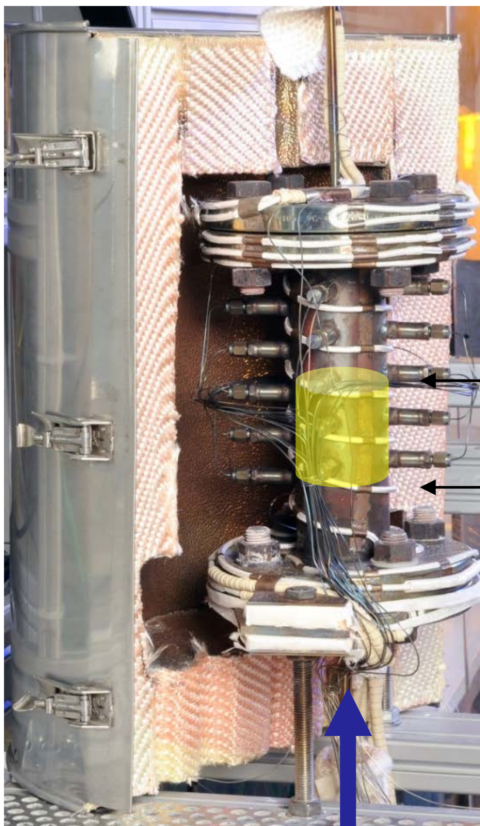
	Directly Heated	Indirectly Heated
Heat Transfer		
Parasitics (Δp)		
Storage Density		
Impact of HTF		
Operating Conditions		

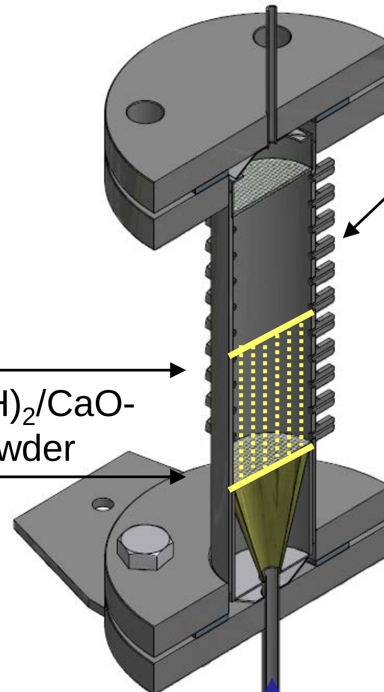
Reactor Concepts
Directly Heated vs. Indirectly Heated

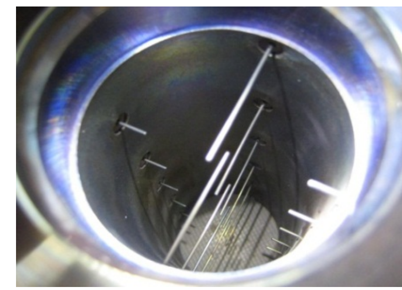
	Directly Heated	Indirectly Heated
Heat Transfer	🟢	🟡
Parasitics (Δp)	🟡	🟢
Storage Density	🟢	🟡
Impact of HTF	🟡	🟢
Operating Conditions	🟡	🟢

Directly Heated Reactor Concept
Lab-scale (100W)

Thermocouples







$Ca(OH)_2/CaO$-powder

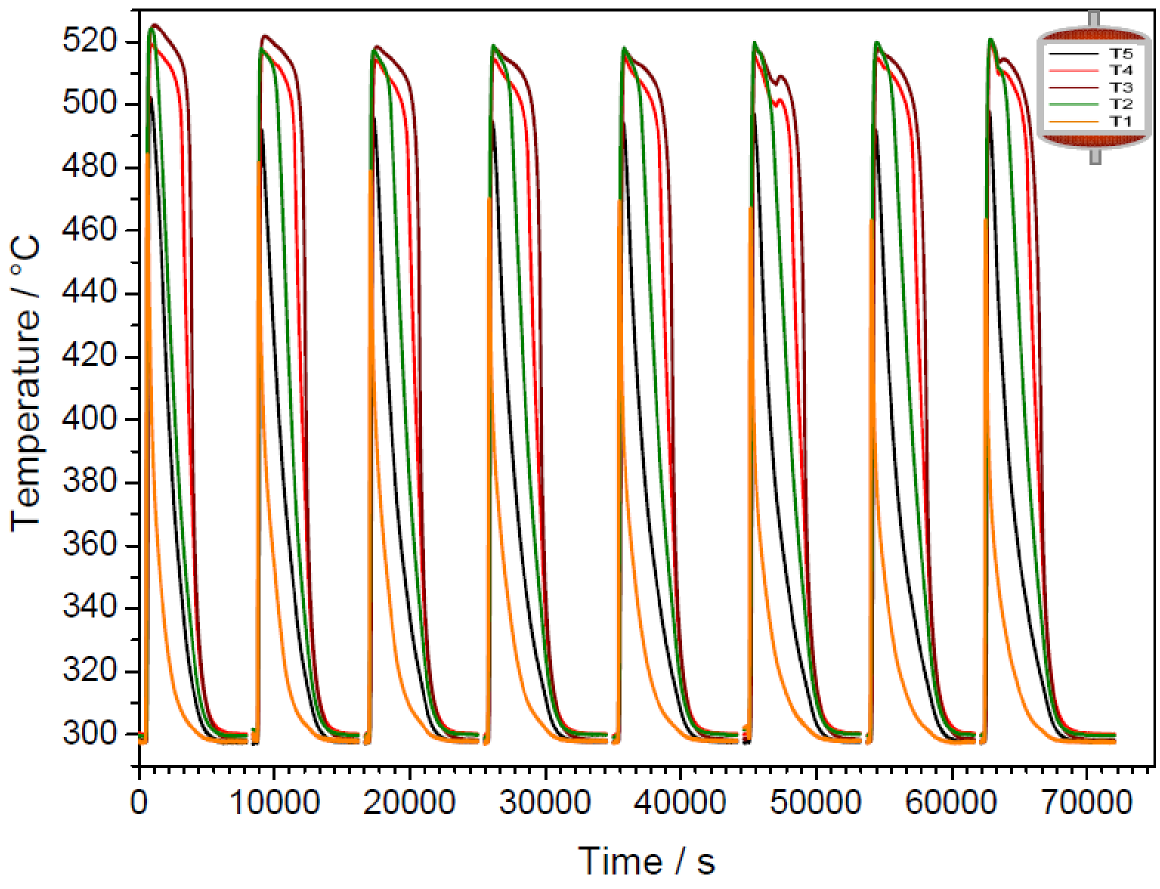
gas mixture (N_2+H_2O)

Reaction Zone

- Fixed bed with Ø 54 mm and height ~60 mm
- 100 g of material

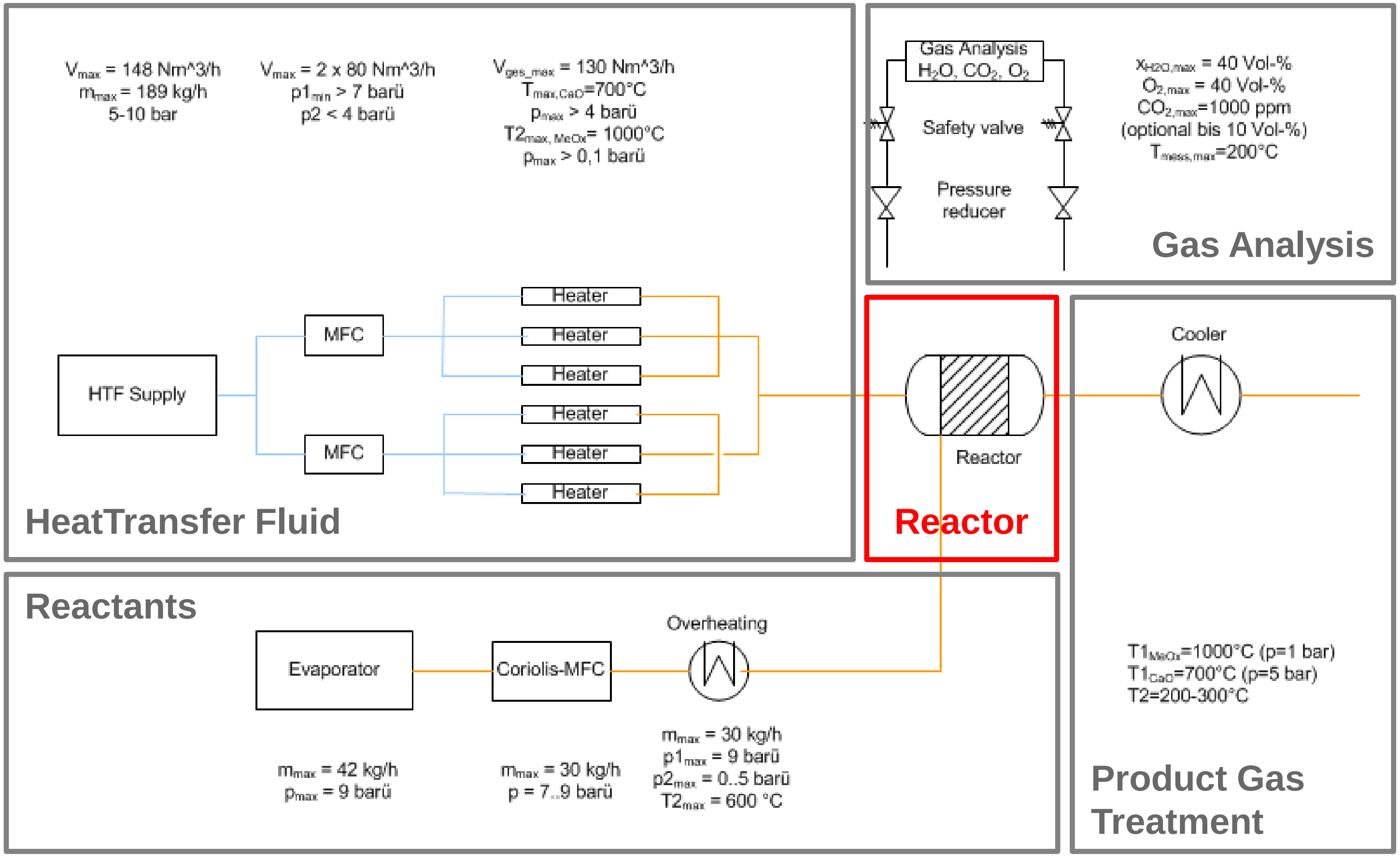
Directly Heated Reactor Concept

Hydration of CaO – 8 Cycles



Pilot-scale Test Facility

10 kW Power Output, T_{max} = 1000°C



Pilot-scale Test Facility

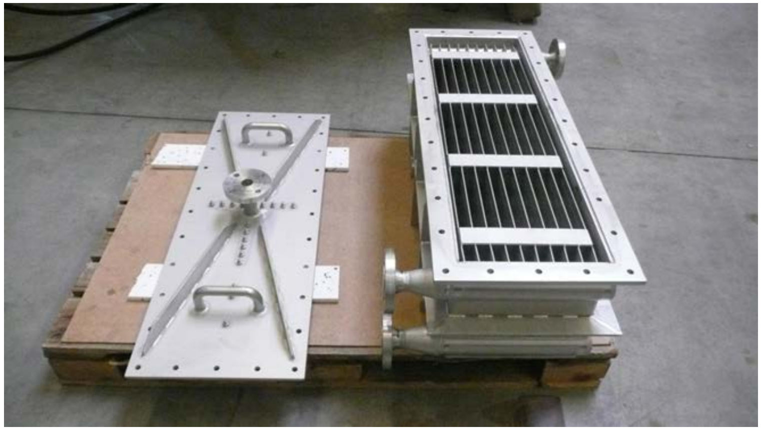
10 kW Power Output, T_{max} = 1000°C

Indirectly Heated Reactor Concept

10 kW

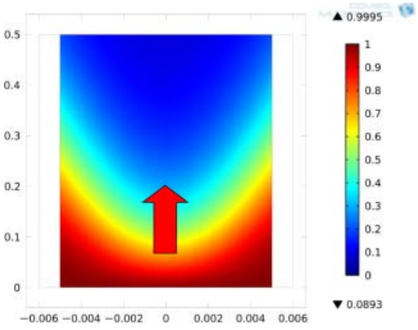
Operation Principle

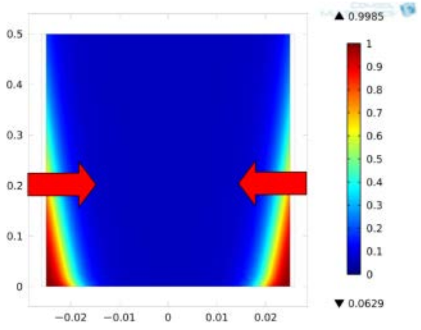
- Plate heat exchanger
- Separation of reactant and HTF
- Cross flow of reactant and HTF
    - Short distance steam (reactant)
    - Long distance (HTF)



Modes of operation

- High peak power (long reaction front)
- Constant power (sharp reaction front)

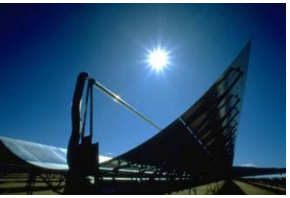




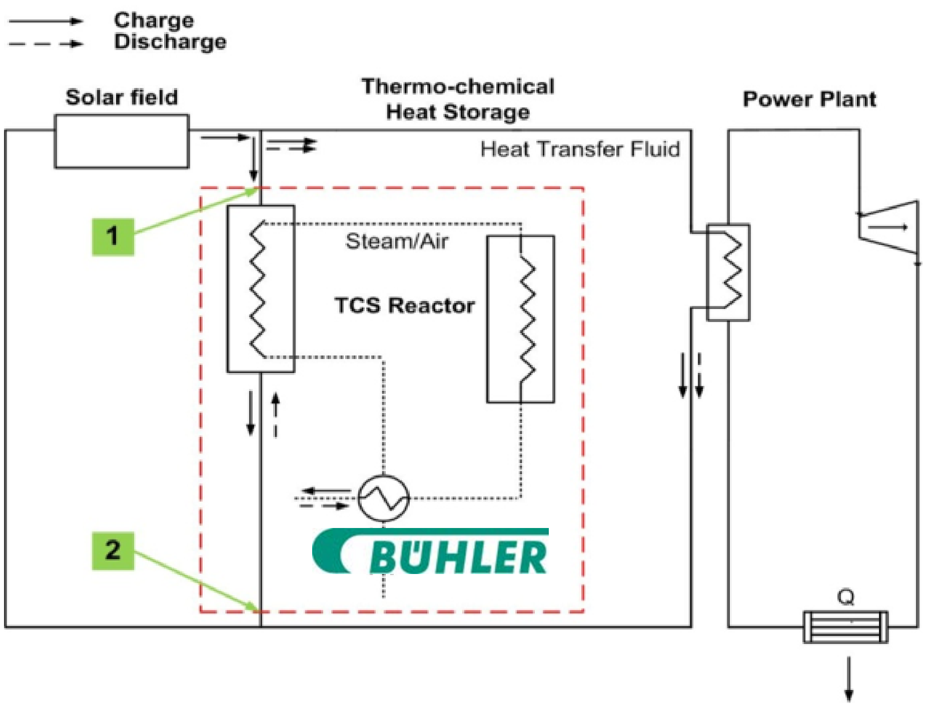
Application for Concentrated Solar Power Plants

The TCS Power-Project

TCS Power
thermochemical energy storage



SIEMENS



EU- FP7: 11/2011– 04/15

- Material development
- Development of reactor concepts
- Lab-scale testing
- Built-up of 10kW pilot-scale reactor and testing
- Process integration and economic evaluation

Development and demonstration of a 10kW pilot-scale storage reactor

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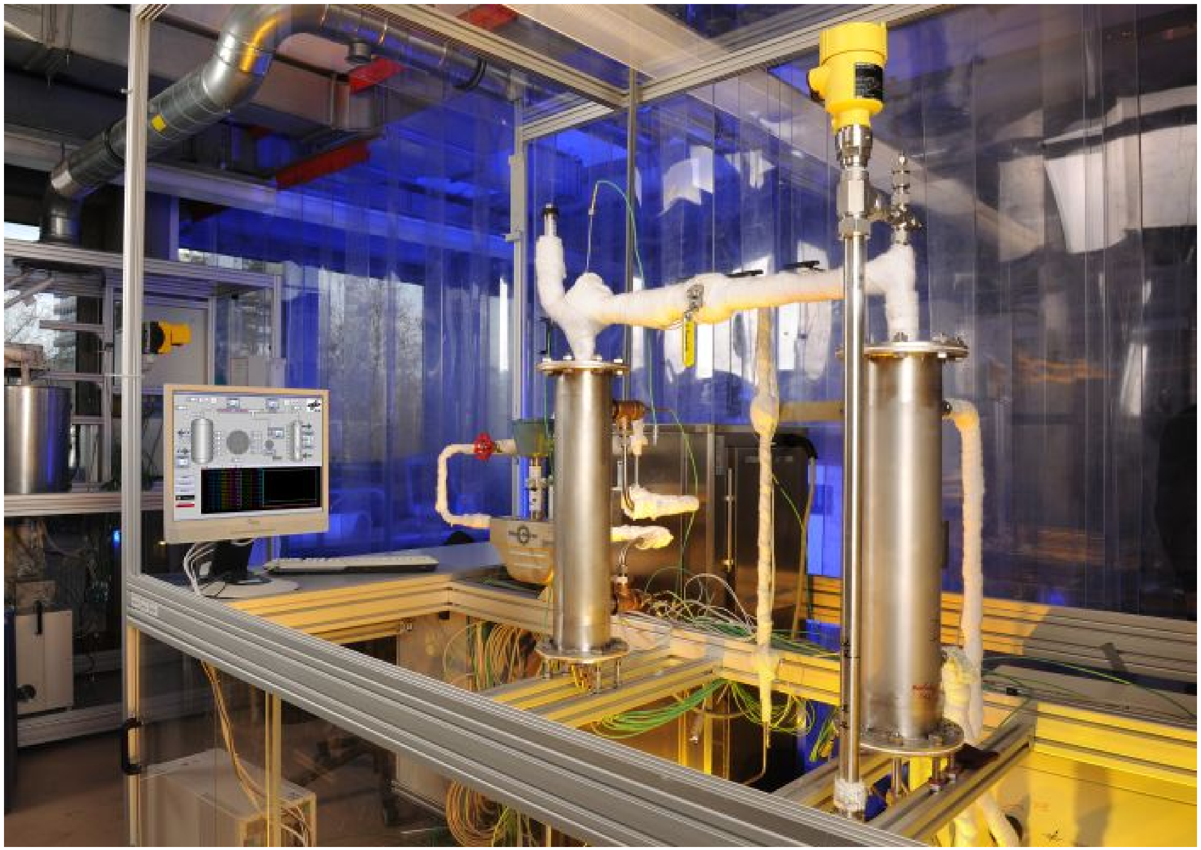
Test Bench for Calcium Chloride

Maximum Power of 1 kW



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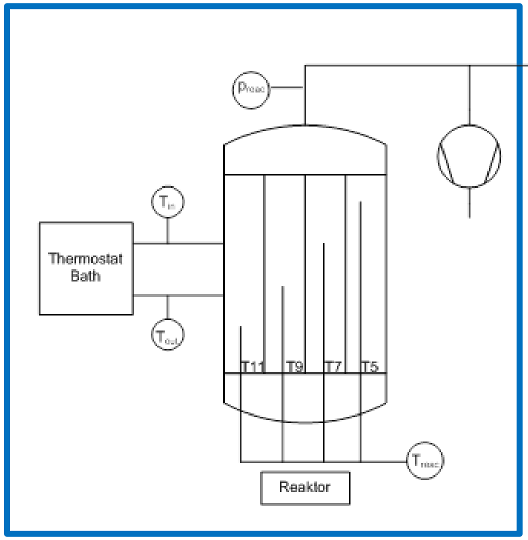
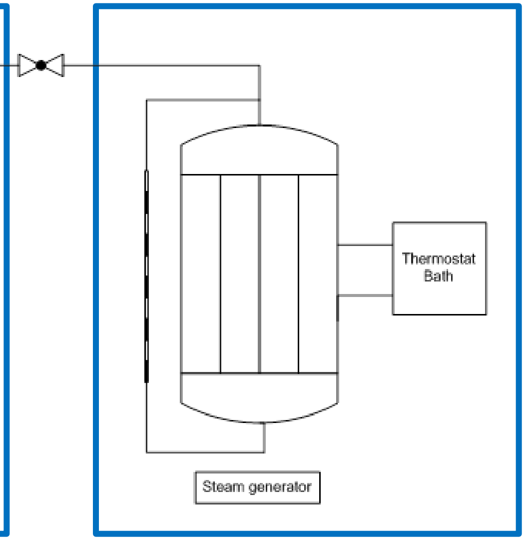
Test Bench for Calcium Chloride

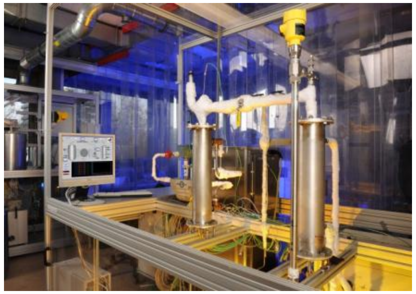
Maximum Power of 1 kW



Reactor

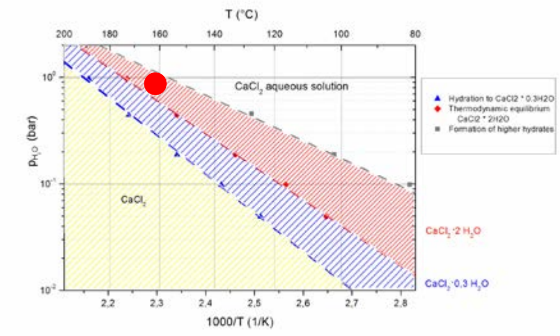


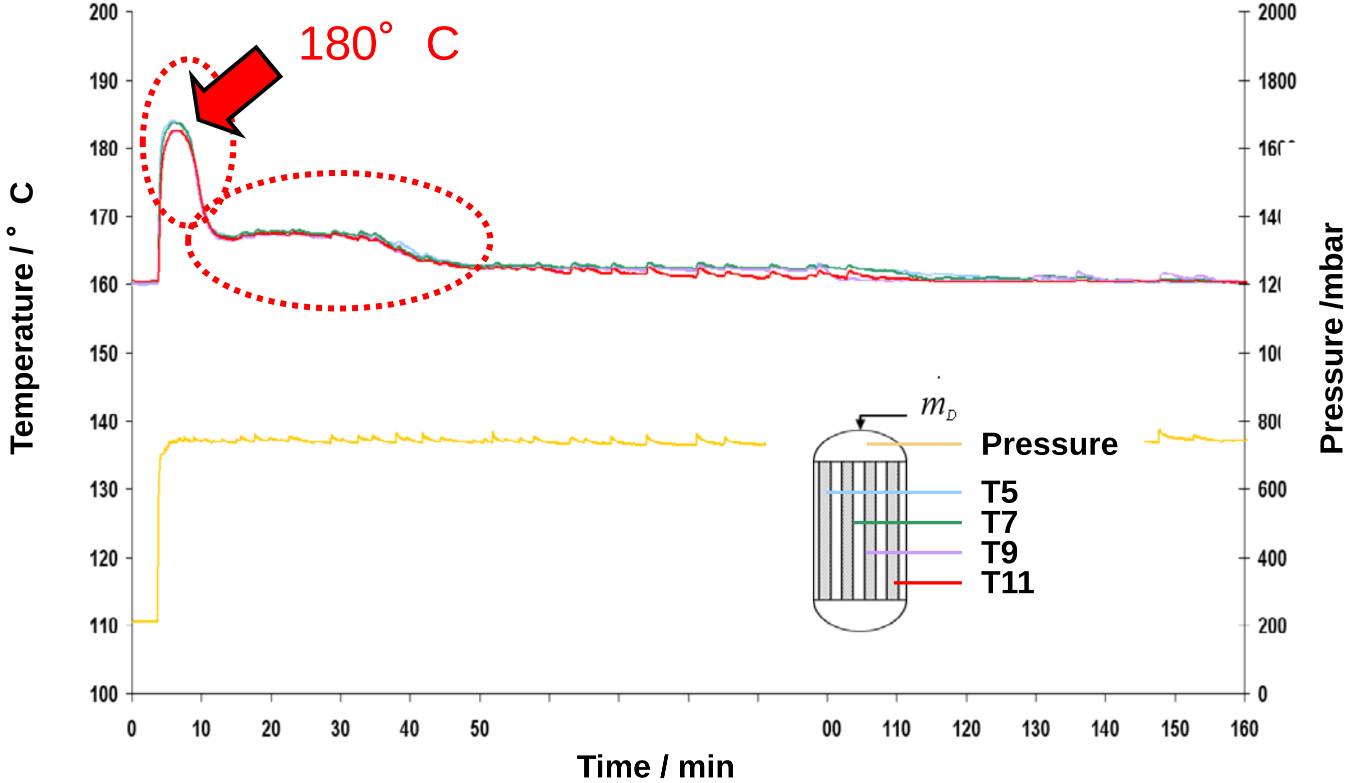
Steam Generator



Hydration – Thermal Discharging

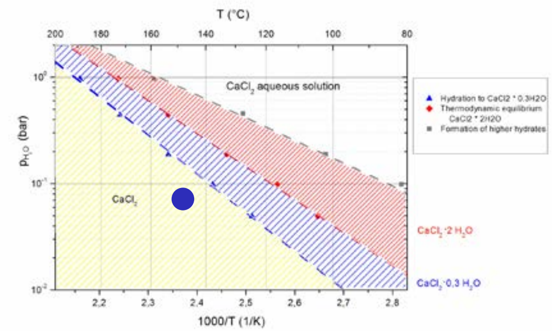
Calcium Chloride

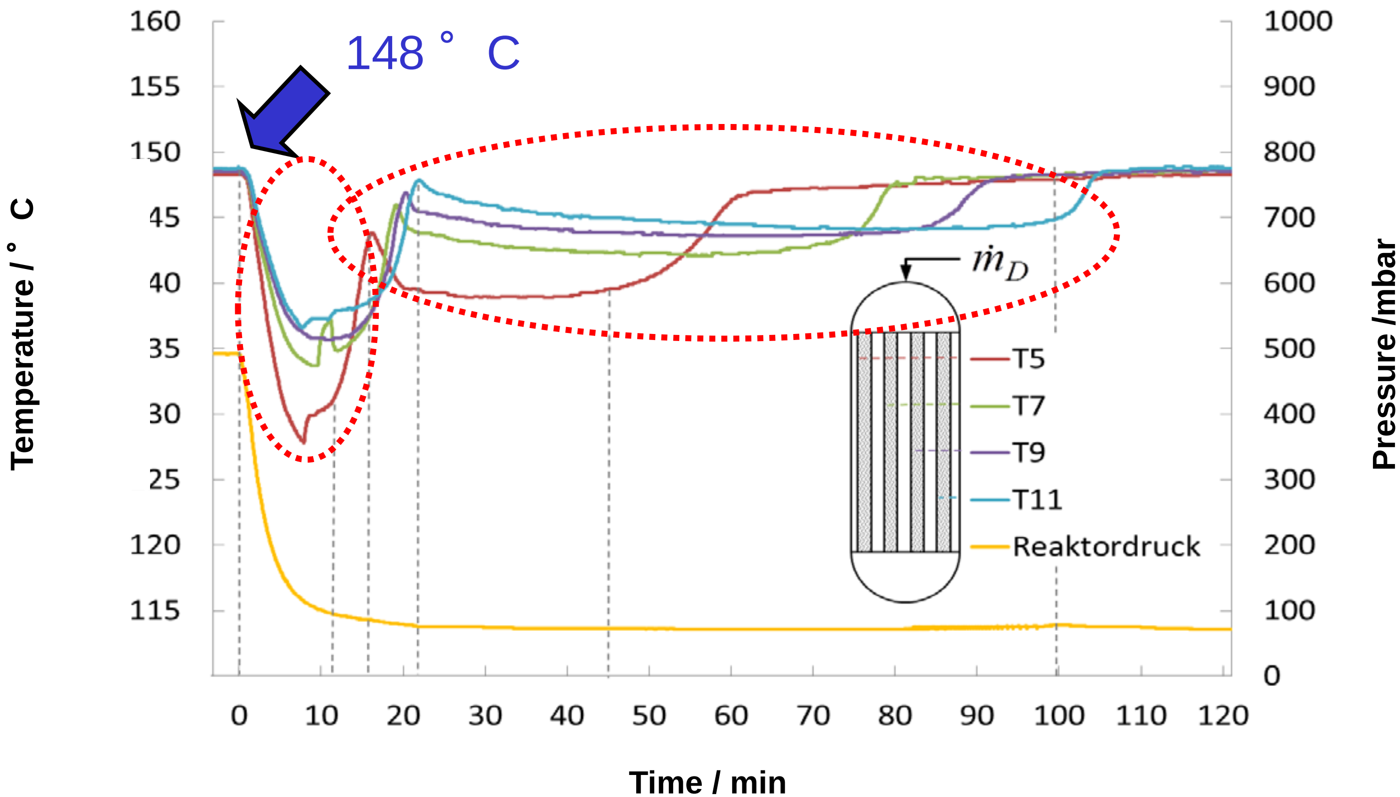




Dehydration – Thermal Charging

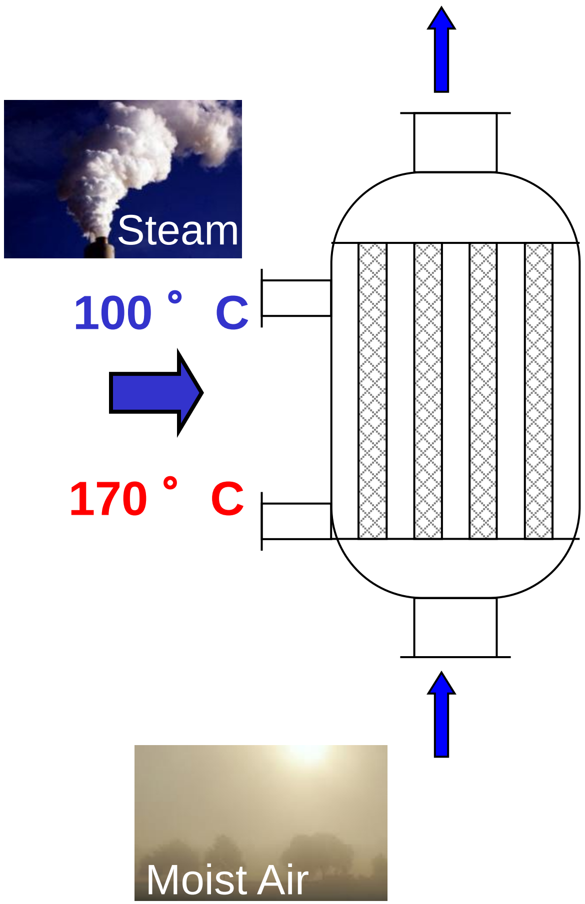
Calcium Chloride

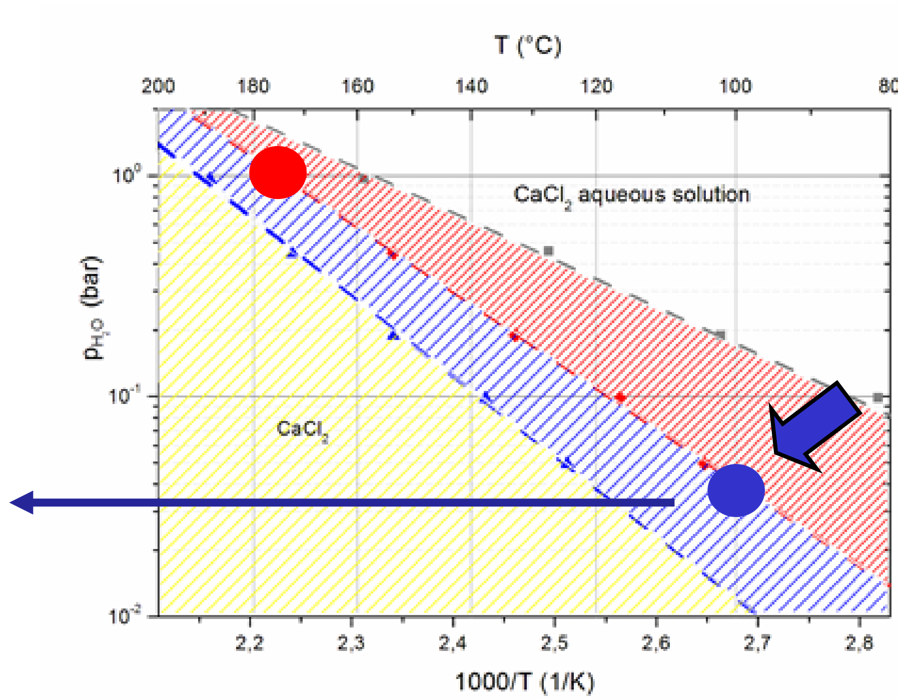




Heat Transformation

Utilization of Excess Steam (~ 100°C)





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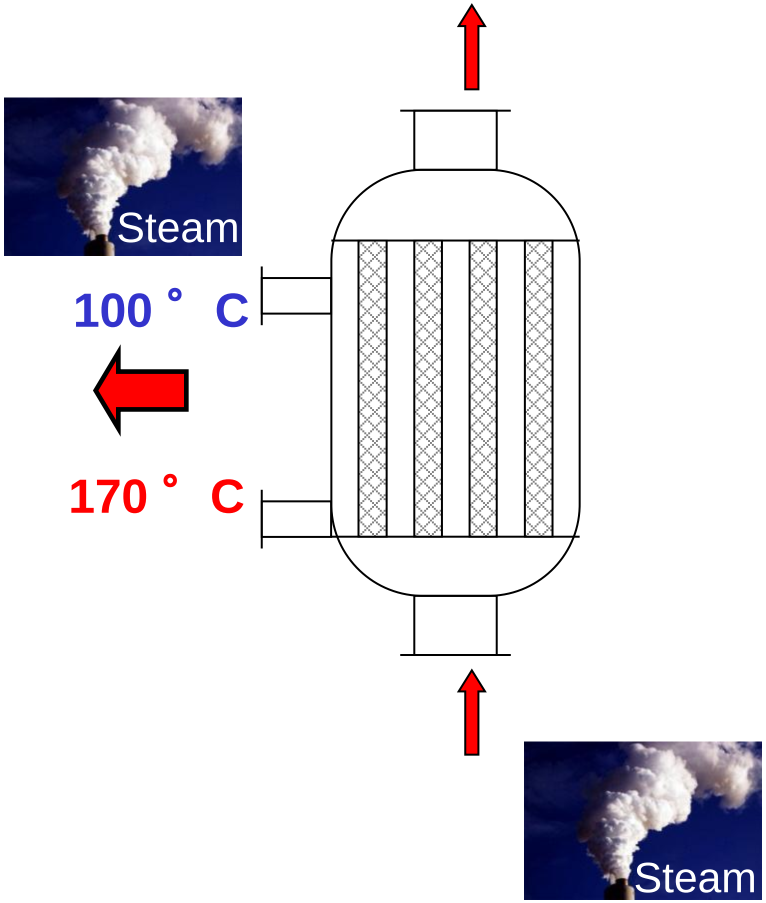

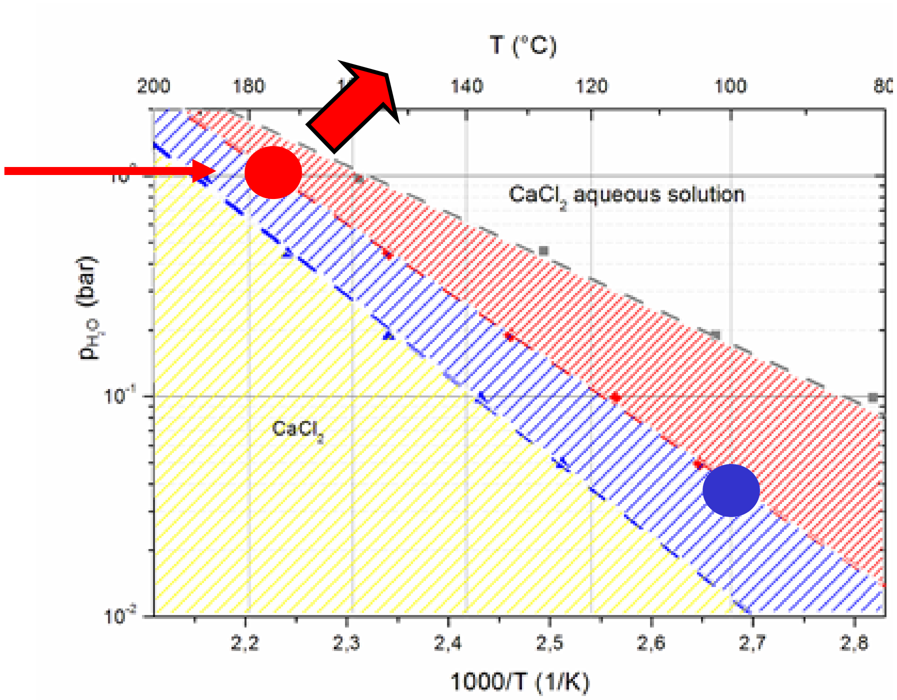

Summary and Outlook

- Thermochemical heat storage has significant potential in regard to
  - Achievable storage density
  - Modulation of operating temperature
  - Detachment of storage capacity and charging/discharging temperature
- Calcium hydroxide reaction system
  → very cheap material, high storage density, CSP and process heat
- Calcium chloride reaction system
  → heat transformation by utilization of excess steam
- Reactor design and system integration need to be adjusted for specific application

- The learning curve in the last 5 years has been steep and will continue to be like this…

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CWS
Chemische Wärmespeicherung

Federal Ministry of Economics and Technology

SIT
Thermochemical Energy Storage

Federal Ministry of Education and Research

CeraStorE ®

Ministerium für Innovation, Wissenschaft, Forschung und Technologie des Landes Nordrhein-Westfalen
NRW.

TCS Power
thermochemical energy storage

SEVENTH FRAMEWORK PROGRAMME

Thank you!

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