GAS-SOLID REACTIONS FOR HEAT APPLICATIONS

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Outline

- Underlying principles of gas-solid reactions for heat application
  - Advantages
  - Challenges

- Current activities at the DLR
  - Direct heat transfer concept based on $CaO/Ca(OH)_2$
  - Process integration: Sorption system based on metal hydrides

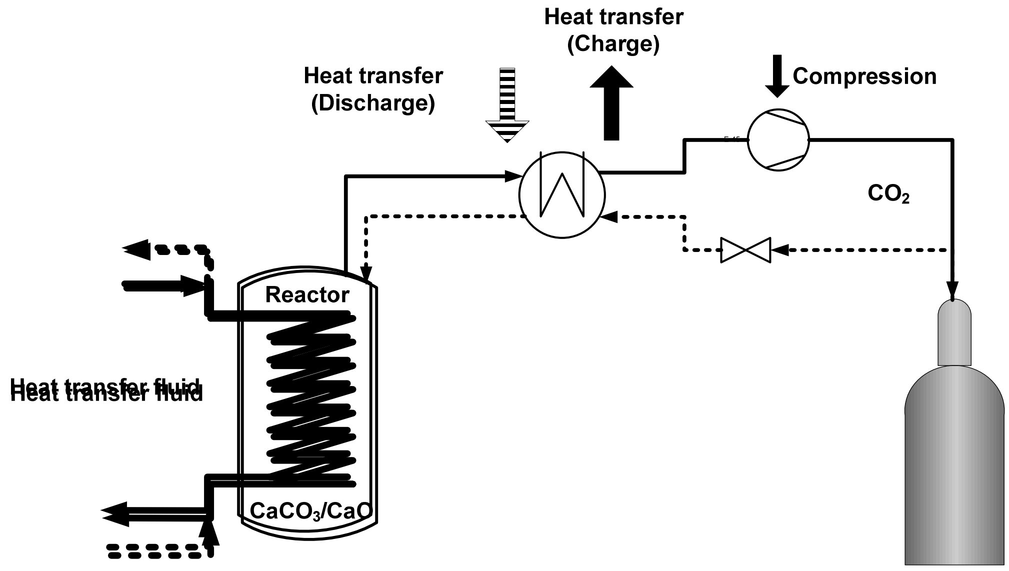
- Summary

Reversible Gas-Solid Reactions

Solid Reactant A + Gas ⇔ Solid Reactant B + ΔH

- Research Group „Thermal Energy Storage“ at DLR
  - Solid state hydrogen storage
    - Reactor development and modelling
    - Coupling to fuel cell
  - Themo-chemical heat storage
    - High storage density
    - Adaptability to different temperature ranges
    - Constant operation temperature
    - Long-term storage possible without losses => separation of reactants

Thermo-Chemical energy storage - system



- Complex system
  - Storage of gaseous reactant necessary
  - Additional energy required (for compression)

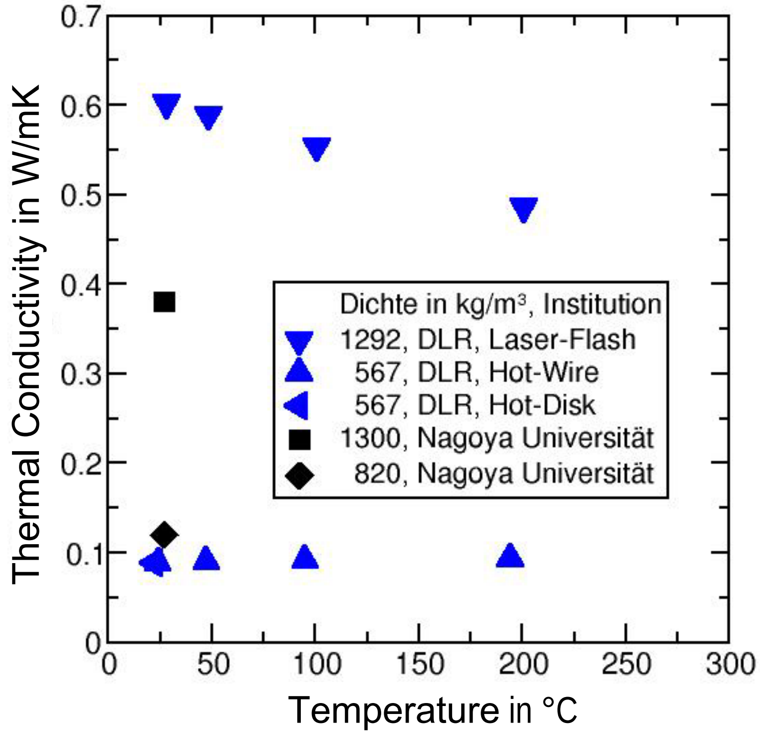
Thermo-Chemical energy storage - material

Low thermal conductivity of powder bed

- Thermal power?
- Reactor design

Material costs

- Amount of „useful“ cycles determines the amortization periode
  - Seasonal storage
  - Day / Night storage
  - Continuous operation (sorption system)



F. Schaube et al., High Temperature TC Heat Storage for CSP using Gas-Solid Reactions, Proceedings of SolarPaces 2010, Perpignan, France (2010)

Key factors: Development of reactor systems
Process integration

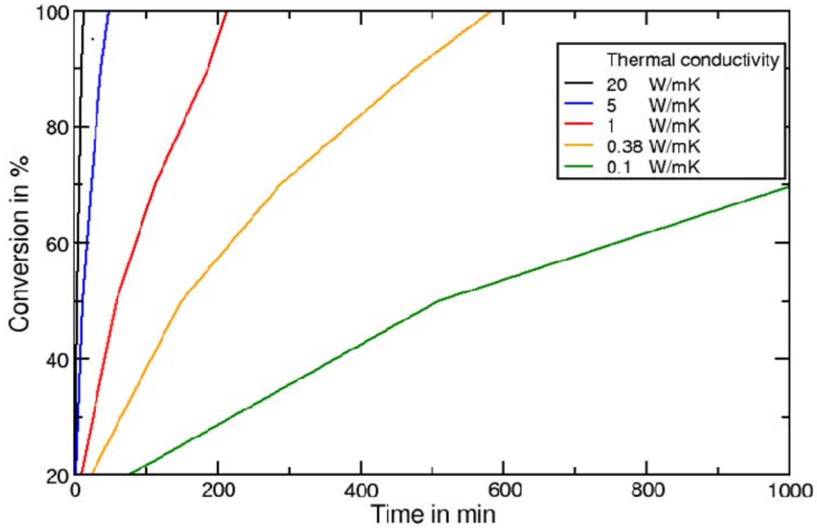
Current activites on Gas-Solid Reactions for heat applications at DLR:

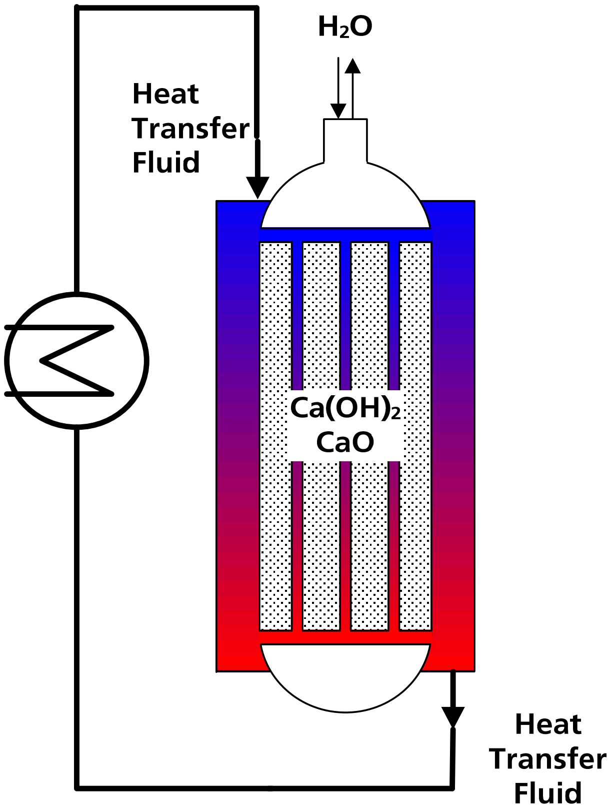
- **Development of reactor systems:**
  - Concept of direct heat transfer
  - $CaO/Ca(OH)_2$

- **Integration into an existing process:**
  - Hydrogen driven cars with compressed hydrogen tank and FC
  - Sorption system based on metal hydrides

CaO/Ca(OH)$_2$ system

- Temperatur range: 400 – 600 °C
  - CSP plants
- Bed with **low thermal conductivity**





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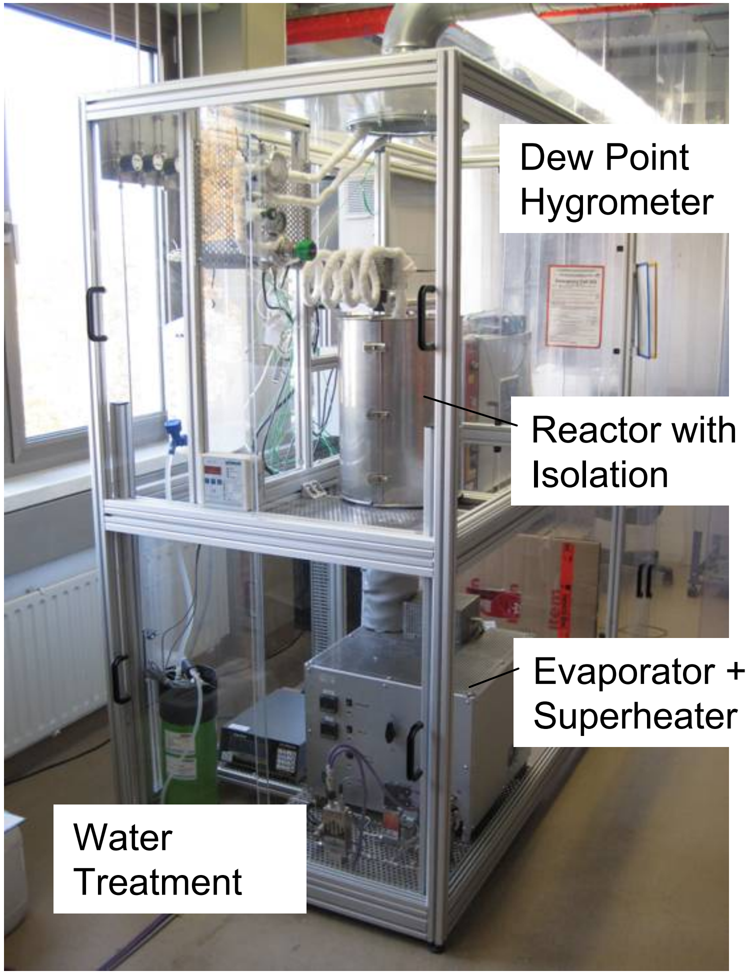
$CaO/Ca(OH)_2$ system

- **Direct** heat transfer concept

⇒ Heat transfer **not limiting**

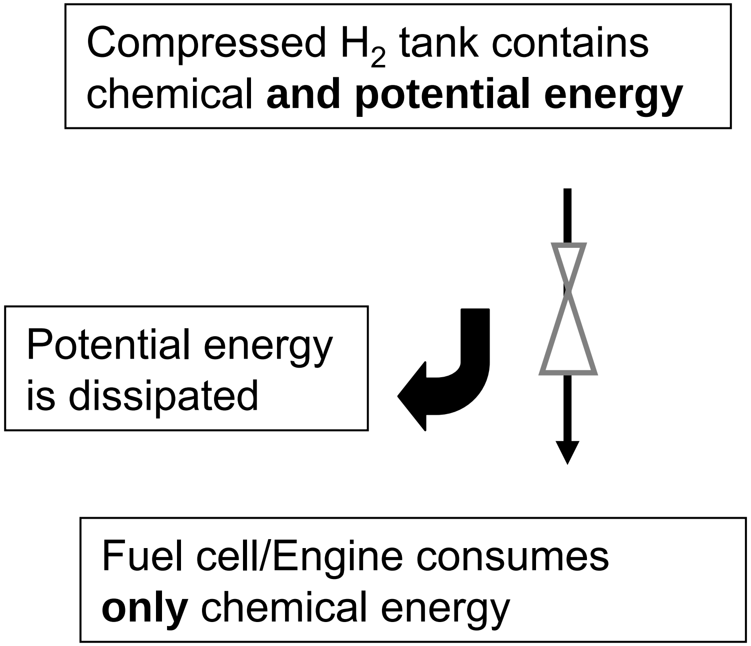
⇒ Operation with **N_2/H_2O mixture** (sensitivity of current powder)



F. Schaube et al., High Temperature TC Heat Storage for CSP using Gas-Solid Reactions, Proceedings of SolarPaces 2010, Perpignan, France (2010)

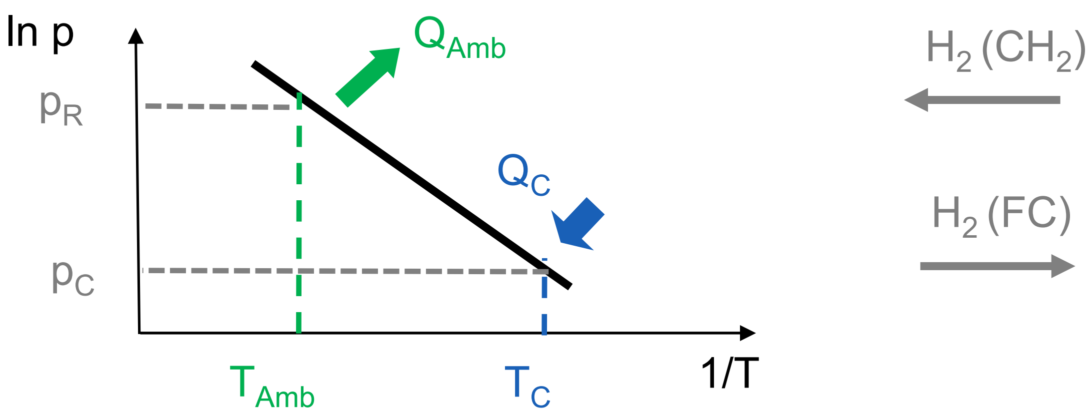
Process integration:
Sorption system for Hydrogen driven cars

Manufacturer	Type of Car	**H_2-Storage**
Daimler	B-Klasse F-CELL	**700 bar**
Ford	Ford Focus FC	**350 bar**
GM/Opel	Hydrogen 4	**700 bar**
Honda	FCX Clarity	**350 bar**
Hyundai/Kia	Borrego	**700 bar**
HyTruck	Fuel cell truck	**350 bar**
Toyota	FCHV adv	**700 bar**
Volkswagen	HyMotion	**350 bar**
Daimler	Citaro FC-Hybrid Bus	**350 bar**



Cars at the „Ride & Drive Event“ of the WHEC 2010

Sorption system - generation of cold



- Regeneration at ambient temperature
- Generation of cold by means of desorption
- Continuous operation possible with constant hydrogen current (two alternating reactions)

- Potential energy is used to generate cold, e.g. for air-conditioning

Sorption system – test bench

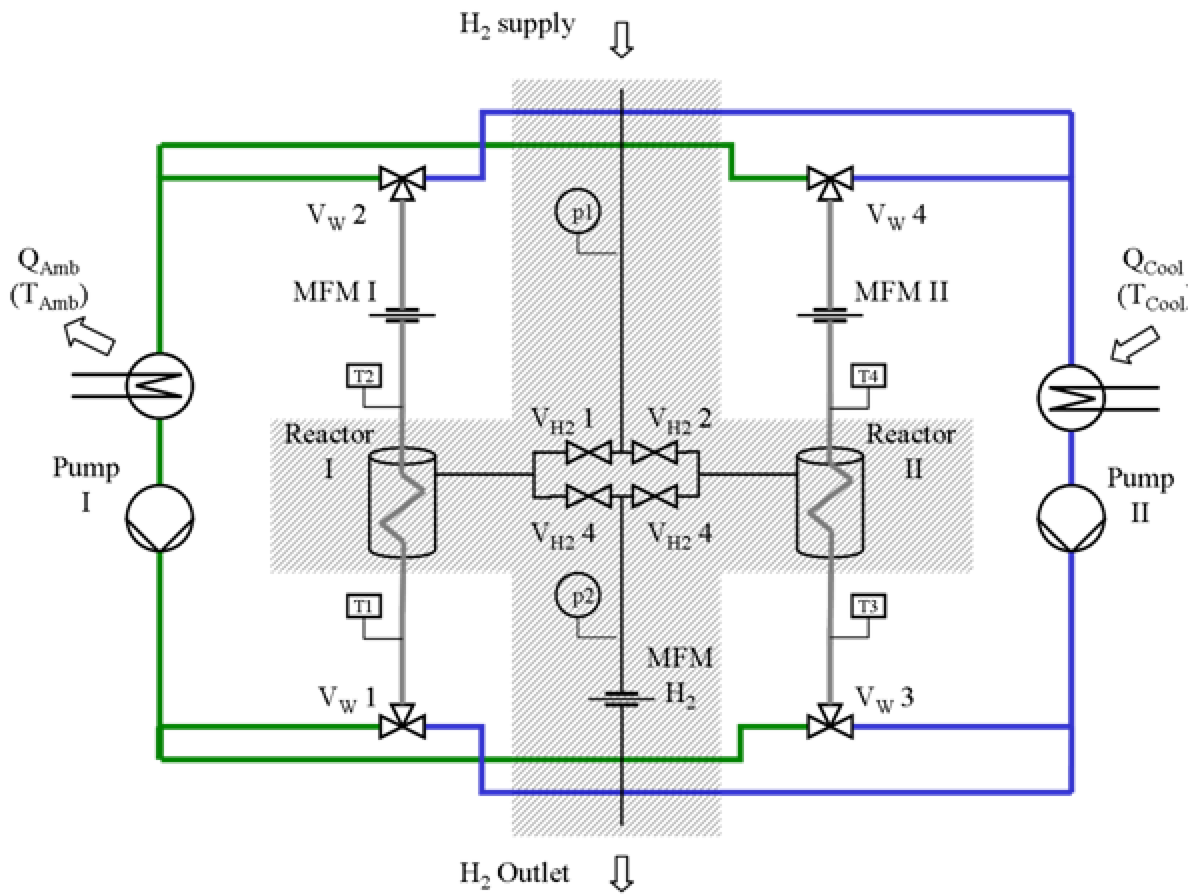
Hydrogen inlet
Max. 55 bar

↓

Sorption system

↓

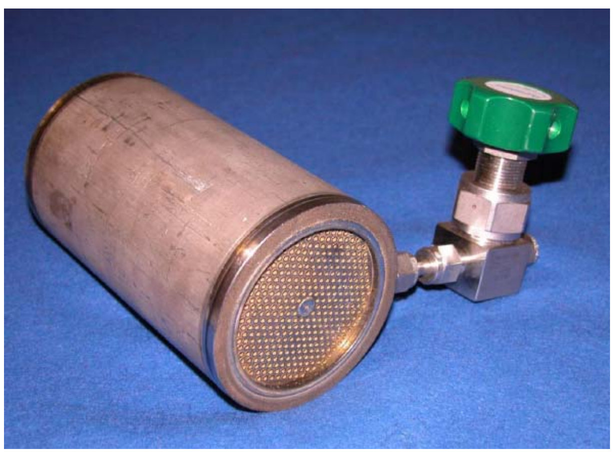
Hydrogen outlet
Min. 6 bar



Sorption system - reaction beds

Fast reaction kinetics are necessary (high thermal power)

- Sufficient heat management
- Hydrogen distribution



Linder et al., Experimental analysis of fast metal hydride reaction bed dynamics, Int. J. Hydrogen Energy 35, 8755-8761, 2010

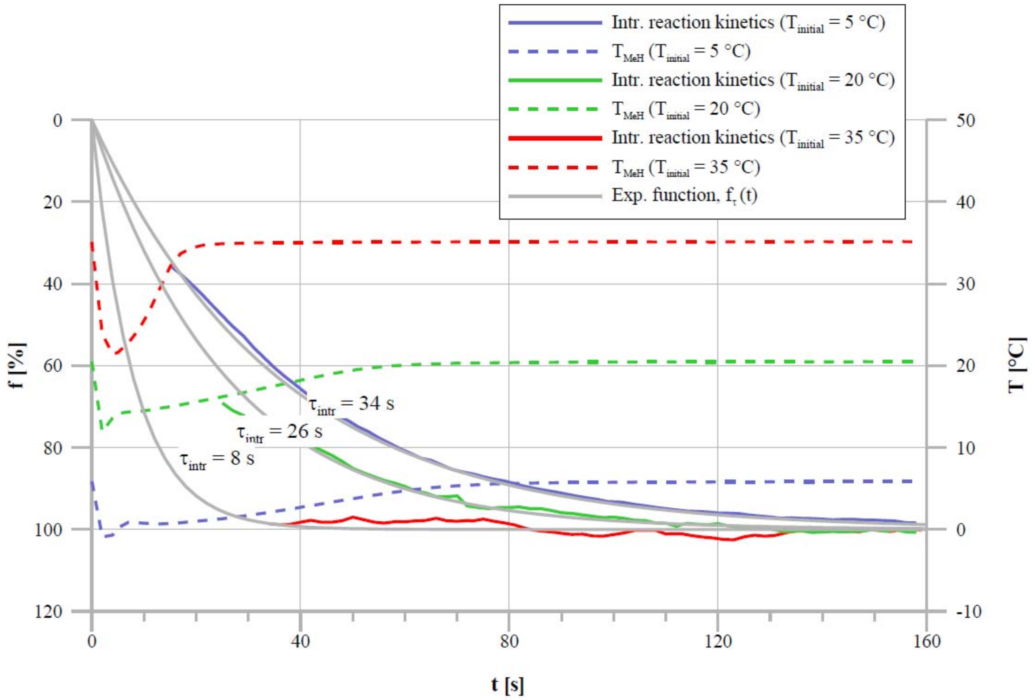
Sorption system – metal hydride

- **Low temperature metal hydride** with a high equilibrium pressure (around 10 bar @ 5 °C, desorption)

⇒ Adaptation to fuel cell requirements

- **Fast reaction kinetics**

⇒ 80 % H_2 desorbed within 60 s @ 5 °C



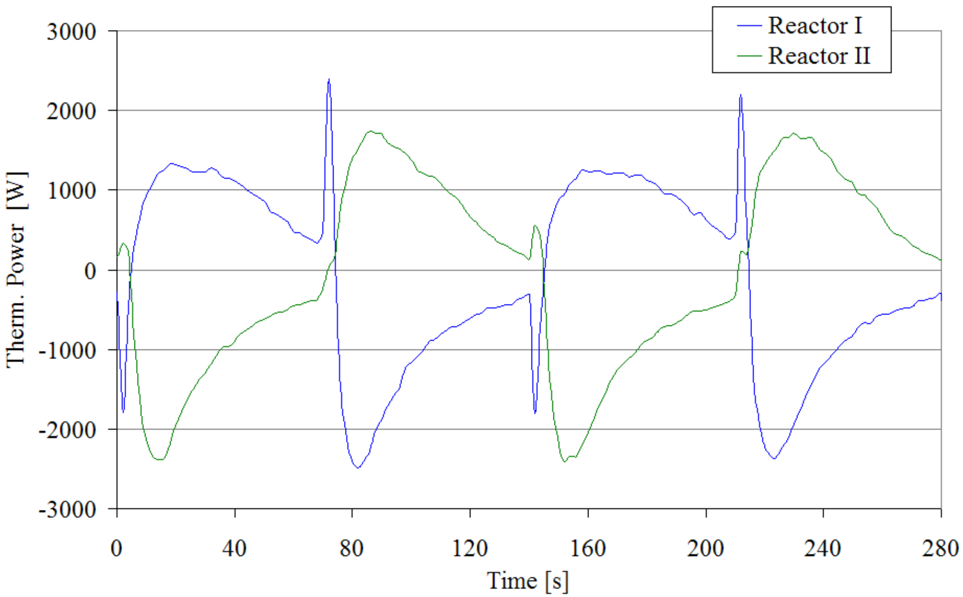
Sorption system – measurement results

- Two alternating reactions (regeneration and cooling effect)

- Regeneration at
  50 - 53 bar
- Cooling at
  6 – 10 bar

- Ambient temp.: **> 30 °C**
- Cooling temp.: **< 12 °C**

- Cooling power: **~ 900 W**



Linder et al., An energy-efficient air-conditioning system for hydrogen driven cars, Int. J. Hydrogen Energy, Article in Press

Sorption system – general comments

Main idea:

- No additional fuel consumption => partial **re-use of compression work**
- No additional refrigerant necessary

System weight and volume (MeH part, extrapolated to 2 kW system)

- Weight: **~ 12.5 kg**
- Volume: **~ 3 l**

Operation principles => **Dependency on hydrogen consumption**

- $P_{Cool} \sim 0.2 * P_{el,\ FC}$
- Bypass for higher flow rates

Summary

Thermo-Chemical Energy storage

- **offers several advantages** like
  - potential high storage density,
  - lossless long-term storage
- but **the crucial points are**
  - **adapted reactor systems and**
  - **process integration**

Reactor development:

CaO/Ca(OH)2 with direct heat transfer

Integration into an existing process:

Sorption system for onboard cold generation

Thank you for your attention !

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