The TCSPower Project
Thermochemical Energy Storage for Concentrated Solar Power Plants

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Outline

- Overall concept and Targets of the TCSPower Project
- Reaction System and Storage Material
- Reactor Concepts
- Thermochemical Storage System
- Summary and Outcome of the Project

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Key Data

- Starting date	November 01, 2011
- Duration	42 months
- Overall budget	4.253 Mio €
- EU contribution	2.849 Mio € requested

Overall Target

- Development and proof-of-principle in 10 kW-scale of a thermochemical storage reactor for integration with a direct steam parabolic trough or molten salt tower CSP plant and a volumetric air receiver, respectively
- Techno-economic evaluation of a commercial-scale TCS system

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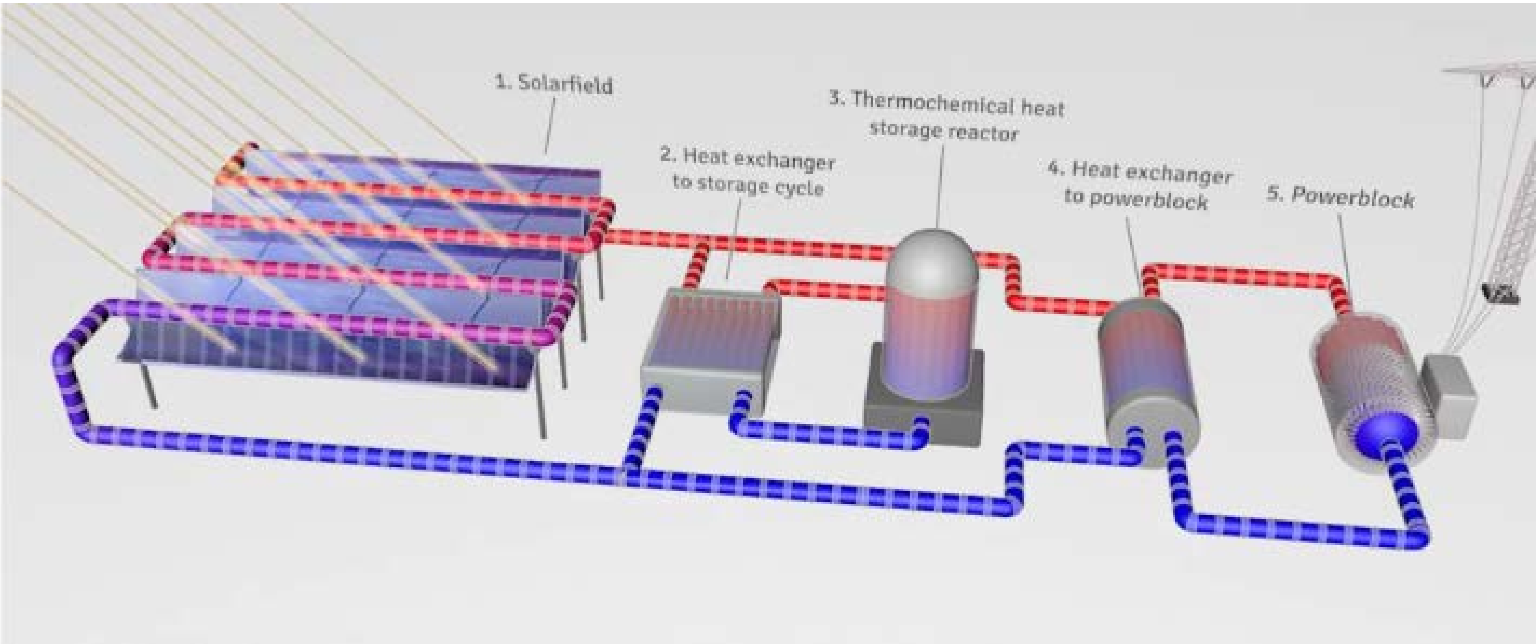
CSP Plant with Thermochemical Storage

- Charging of thermochemical storage reactor



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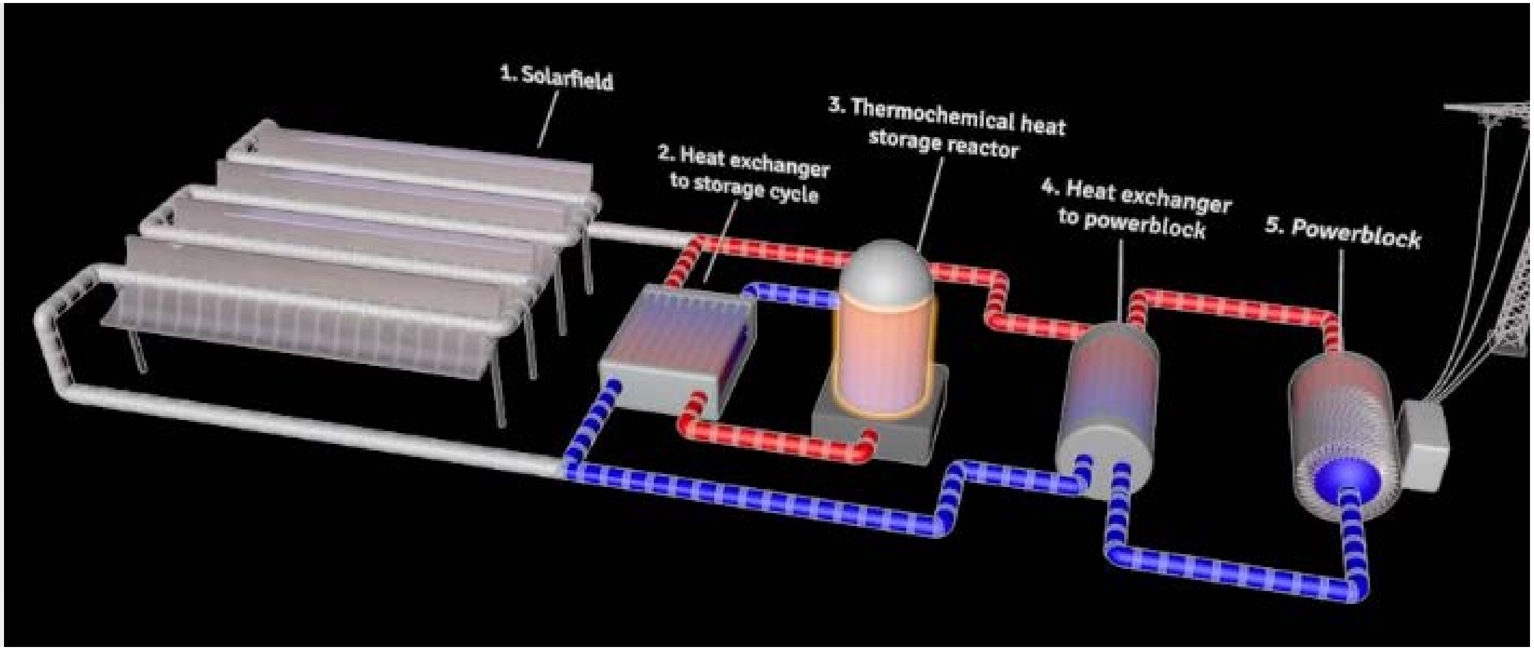
Electricity Production from Storage

- Discharging of thermochemical storage reactor



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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)

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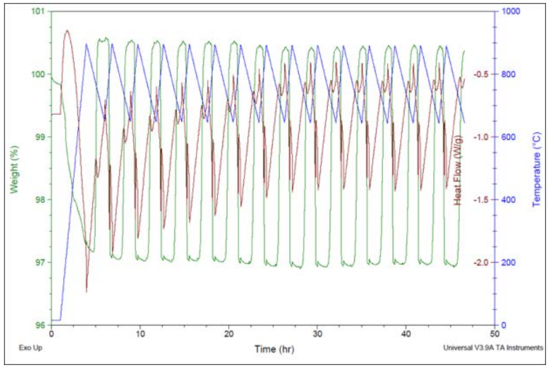
Requirements for TCS Reaction System and Storage Material

- High enthalpy of reaction
- Complete reversibility and cycling stability
- Suitable thermodynamics and sufficient reaction kinetics
- Long-term stable and superior thermo-physical and mechanical properties



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

Limestone quarry Hahnstetten

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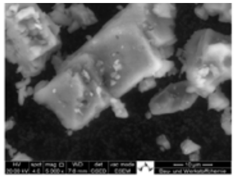
Selected Reaction Systems



Calcium Hydroxide

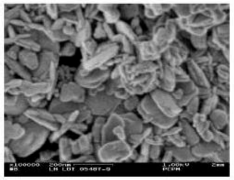
$Ca(OH)_2 + \Delta H \leftrightarrow CaO + H_2O$

$T_{eq} = 507°C$ at 1 bar

$\Delta H = 100$ kJ/mol

Storage density*) = 410 kWh/m³

Manganese Oxide

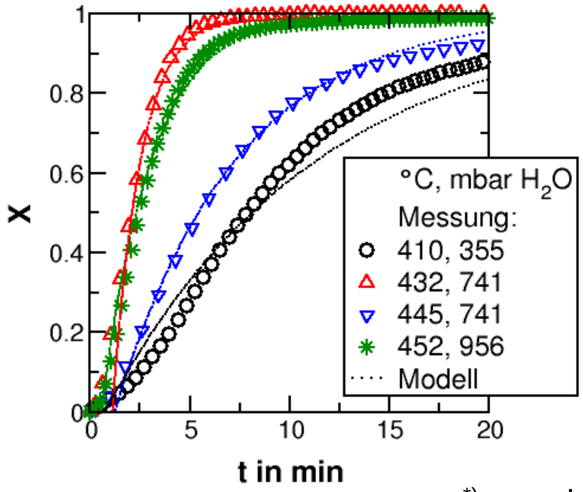


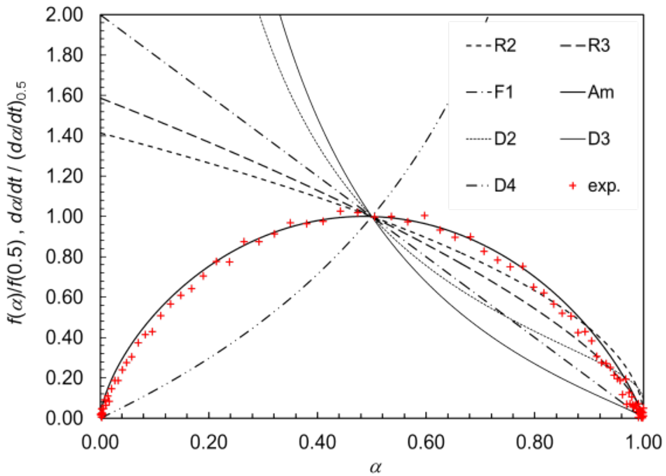
$6\, Mn_2O_3 + \Delta H \leftrightarrow 4\, Mn_3O_4 + O_2$

$T_{eq} = 980°C$ at 1 bar

$\Delta H = 31.8$ kJ/mol

Storage density*) = 126 kWh/m³





*) open loop, bulk porosity $\varepsilon = 0.5$

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Range of Operation of Reaction Systems

Hydroxide

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

Oxide

$6\ Mn_2O_3 + \Delta H \leftrightarrow 4\ Mn_3O_4 + O_2$

Trough Tower (Salt)	TCS Parameters	Tower (Air)
410 ↔ 590	Reaction temperature in °C	780 ↔ 980
0.1 – 5	Partial pressure reaction gas in bar	0.01 - 1
H_2O / N_2	Reaction Gas / HTF	O_2 / Air
ca. 270 kg	Amount of storage material 100 kWh_{th}	ca. 1800 kg

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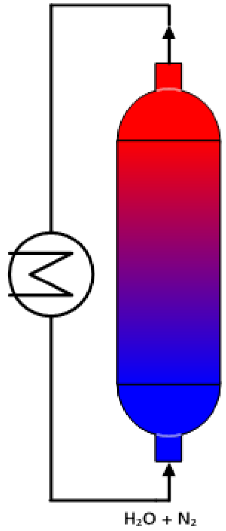
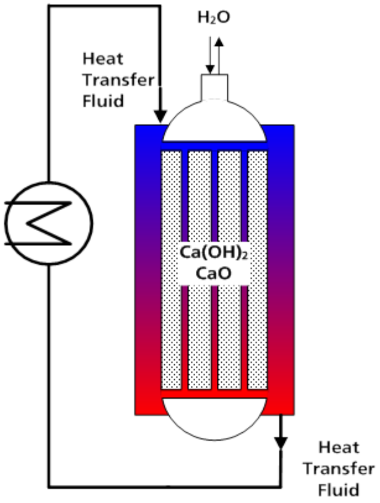
Reactor Concepts
Directly Heated vs. Indirectly Heated

	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	🟡	🟢

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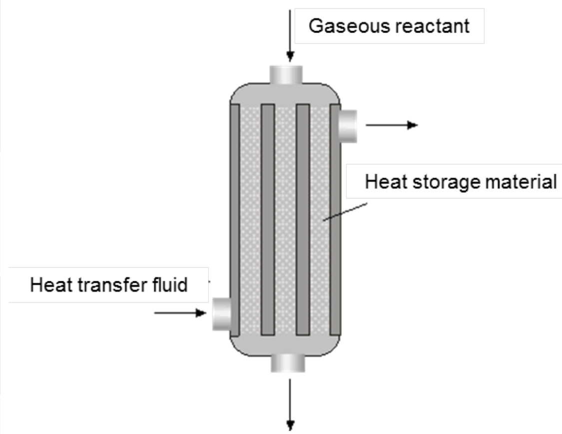
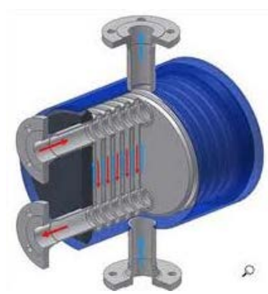
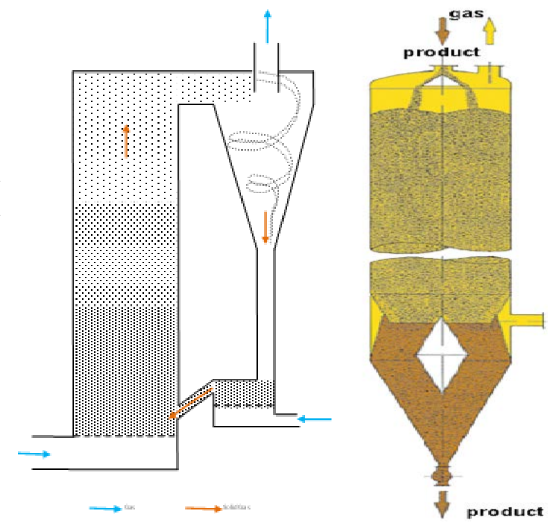
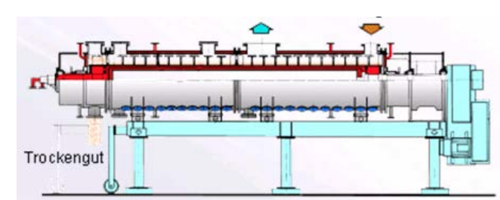
Reactor Concepts
Fixed Bed vs. Moving Bed

	Fixed Bed	Moving Bed
Reactor Types		
Heat Transfer		
Parasitics		
Complexity		
Material Requirements		
Detachment of power and capacity		









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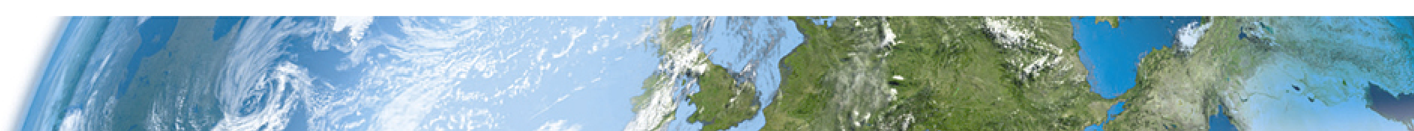
Reactor Concepts
Fixed Bed vs. Moving Bed

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



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Requirements for Operation of TC Storage Reactor

- Capacity of 2 h up to 12 h of discharge at nominal power level,
- Average 5.5 h of charging per day,
- Charging possible at 10 to100 % nominal power,
- Discharging possible at 0 to 100 % nominal power
- Charging to discharging ratio $0.1 < \eta < 3$
- Short switching times (seconds – minutes) between different operation modes,
- Parasitics shall be chosen to minimize LCOE

- CAPEX (of commercial system) shall be targeted at 25 to 40 €/kWh

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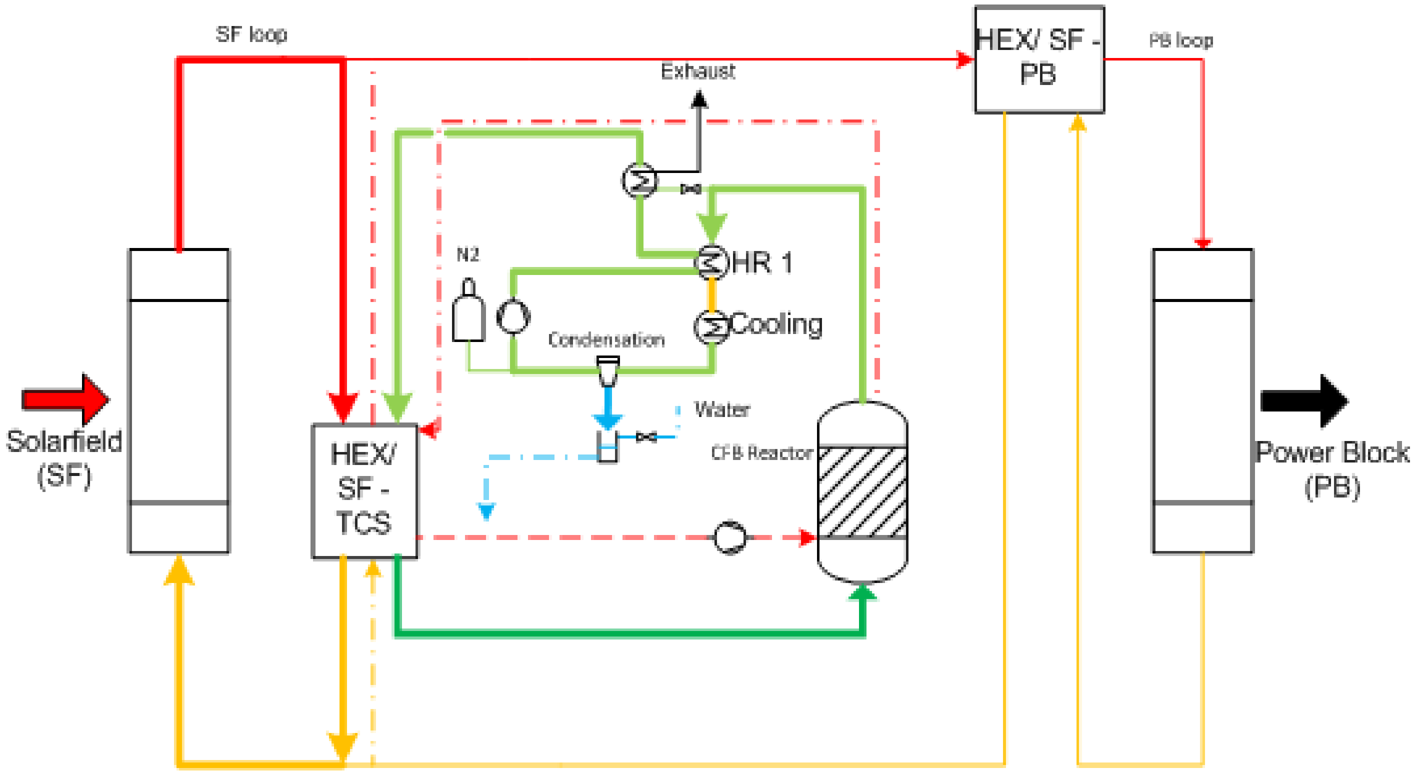
TCS System – Closed Loop Operation
Hydroxide System

Charging of Thermochemical Storage System



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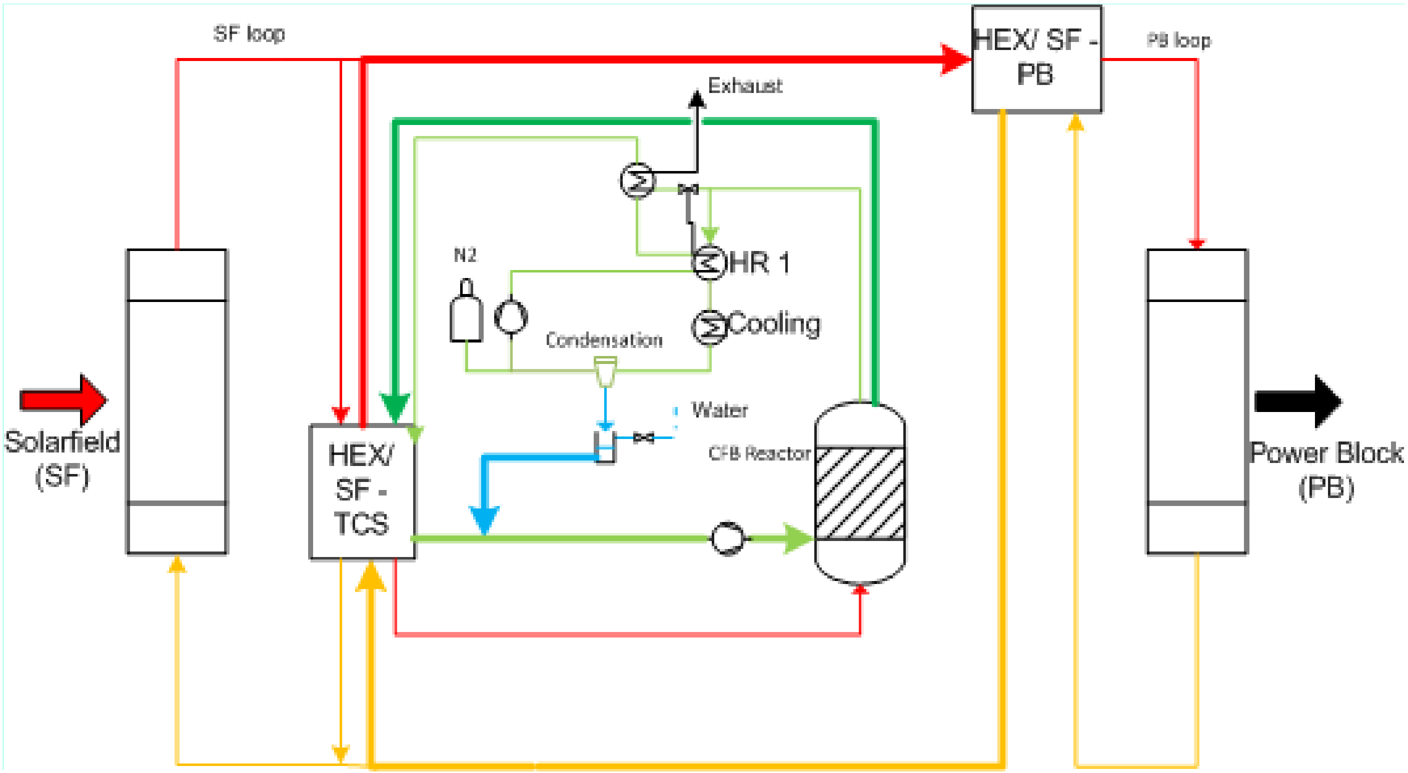
TCS System – Closed Loop Operation
Hydroxide System

Discharging of Thermochemical Storage System



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TCS System – Operation Modes

Closed Loop vs. Open Loop

	Closed	Open
Gas Separation	🟡	🟢
Reaction Gas Purity	🟢	🔴
Reaction Gas Consumption	🟢	🟡
Auxiliary Devices	🟡	🟢
Process Efficiency	🟡	🟢
Process Economics	🟢	🟡

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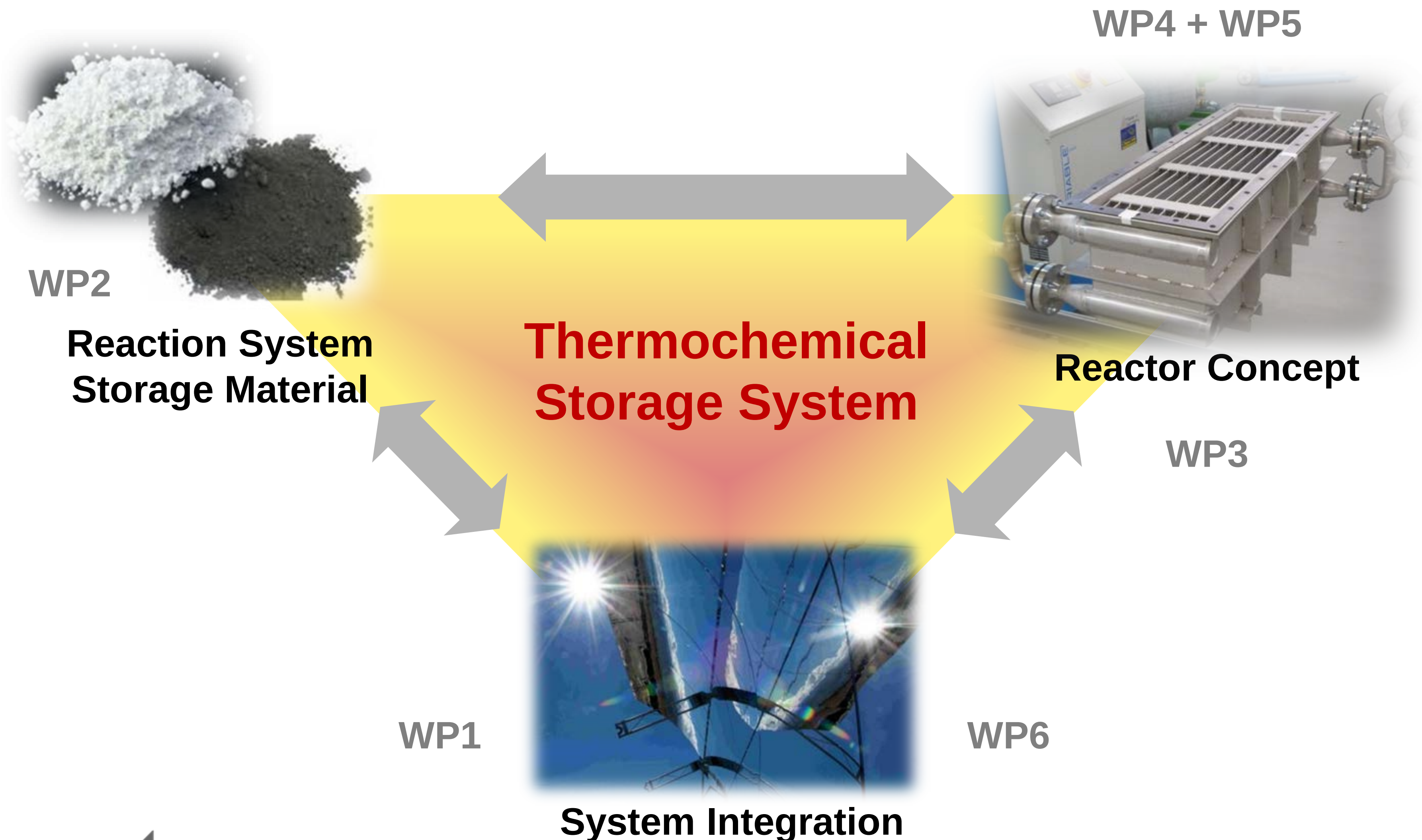
Work Plan and Summary



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Outcome of the TCSPower Project – 2015

- **Storage materials** with improved functionality in regard to reaction kinetics, thermo-physical and mechanical properties
- **Dynamic simulation tool** for the design of a TCS reactor with improved performance (heat and mass transfer, charging/discharging behaviour)
- Suitable **reactor concept** being experimentally proven and evaluated in laboratory scale
- Proof-of-principle **pilot-scale thermochemical reactor** (10 kW, 100 kWh)
- **Overall process concept** for the integration into the CSP plant,
- **Strategy for up-scaling** to commercial scale and **techno-economic evaluation** of thermochemical storage systems

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Thank you!

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