SOLAR FUEL PRODUCTION BY THERMOCHEMICAL PARTICLE PROCESSES

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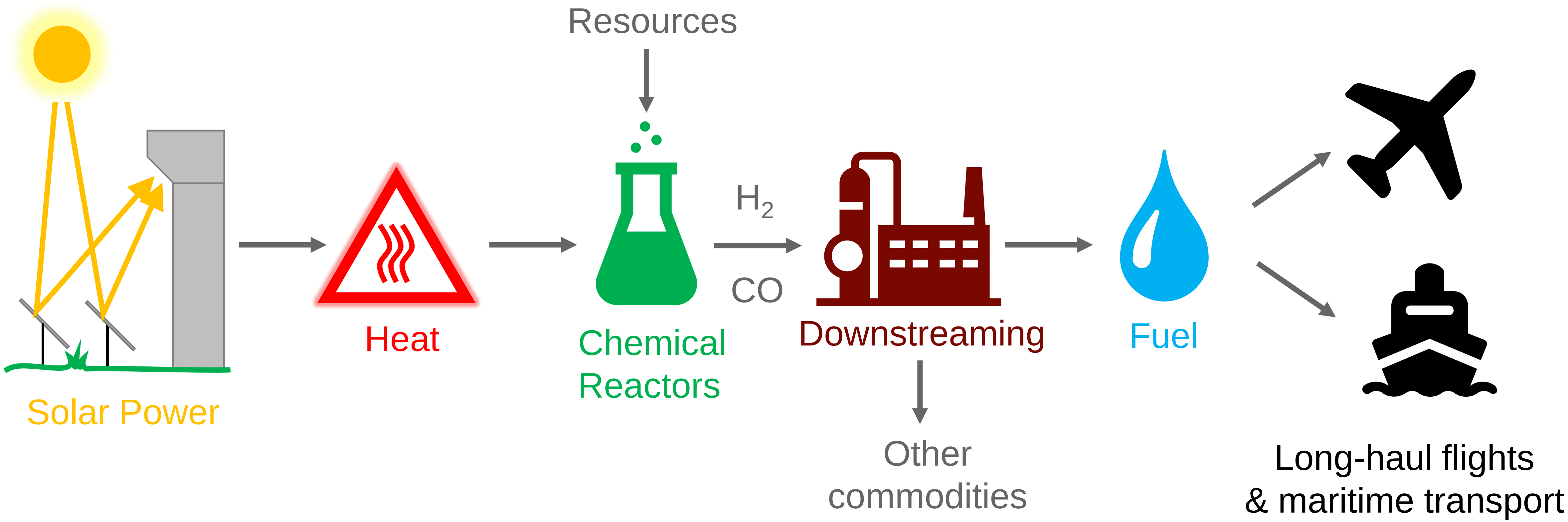
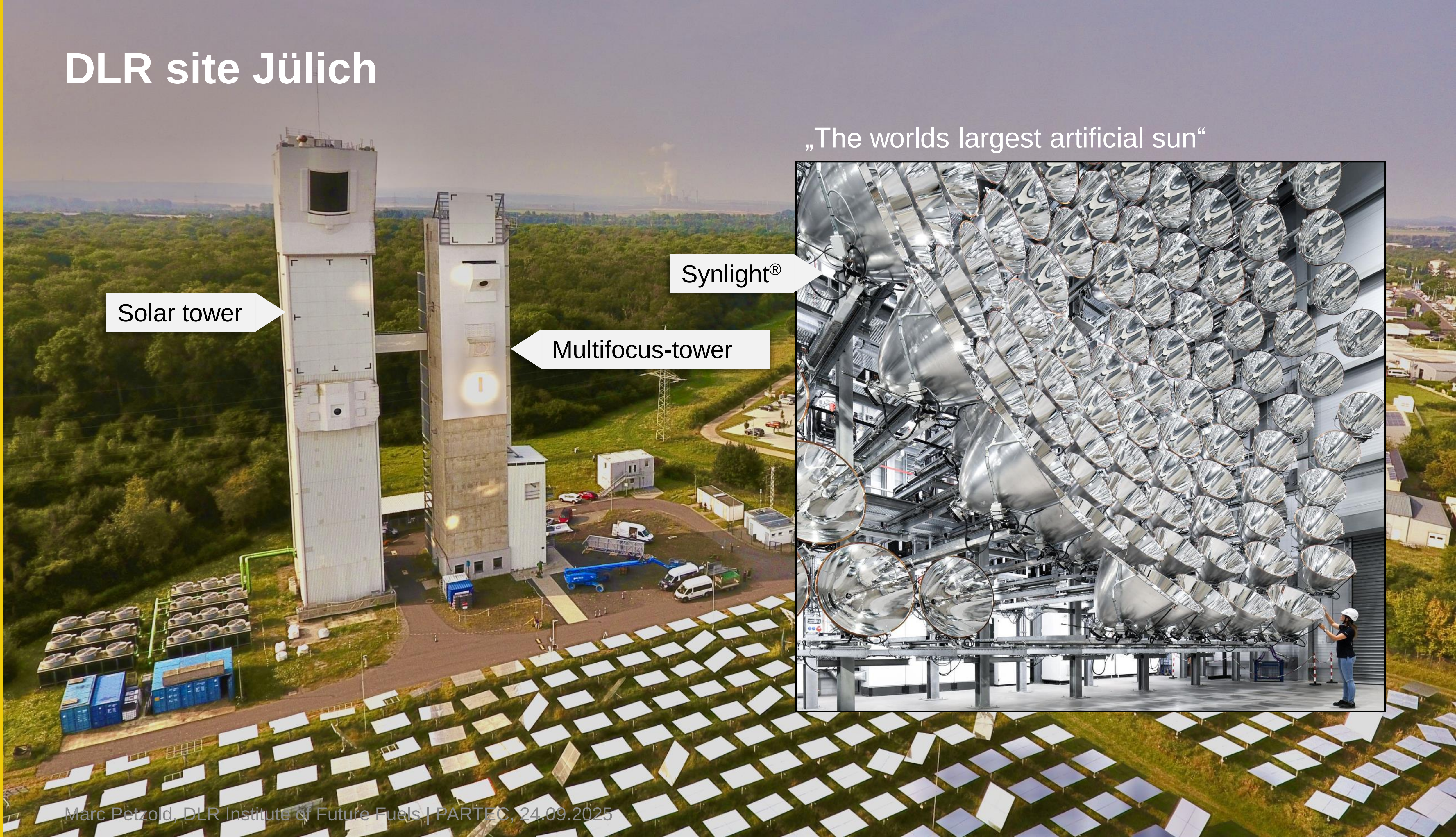
DLR

Introduction
Concentrated Solar Power for high temperature processes



- Use concentrated solar power (CSP) to produce CO_2-neutral fuels
- Some industries cannot be electrified and rely on liquid fuels

DLR site Jülich



„The worlds largest artificial sun“

Thermochemical redox cycle

Water / CO_2 splitting

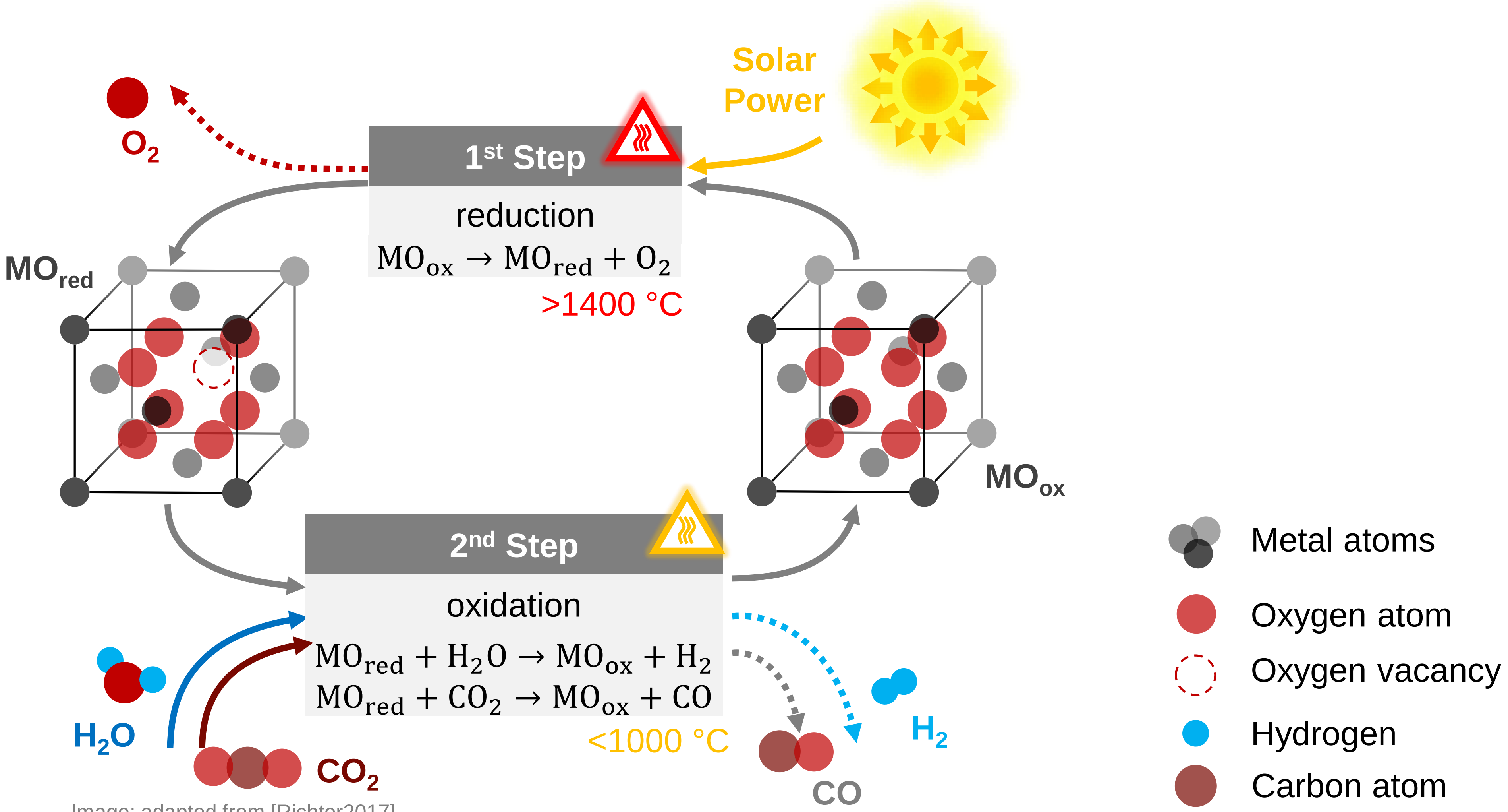


Image: adapted from [Richter2017]

- Cycle between low and high temperature / reduction and oxidation atmosphere

Thermochemical fuel production I

State of the art: Batch reactors with fixed irradiated monolithic structures

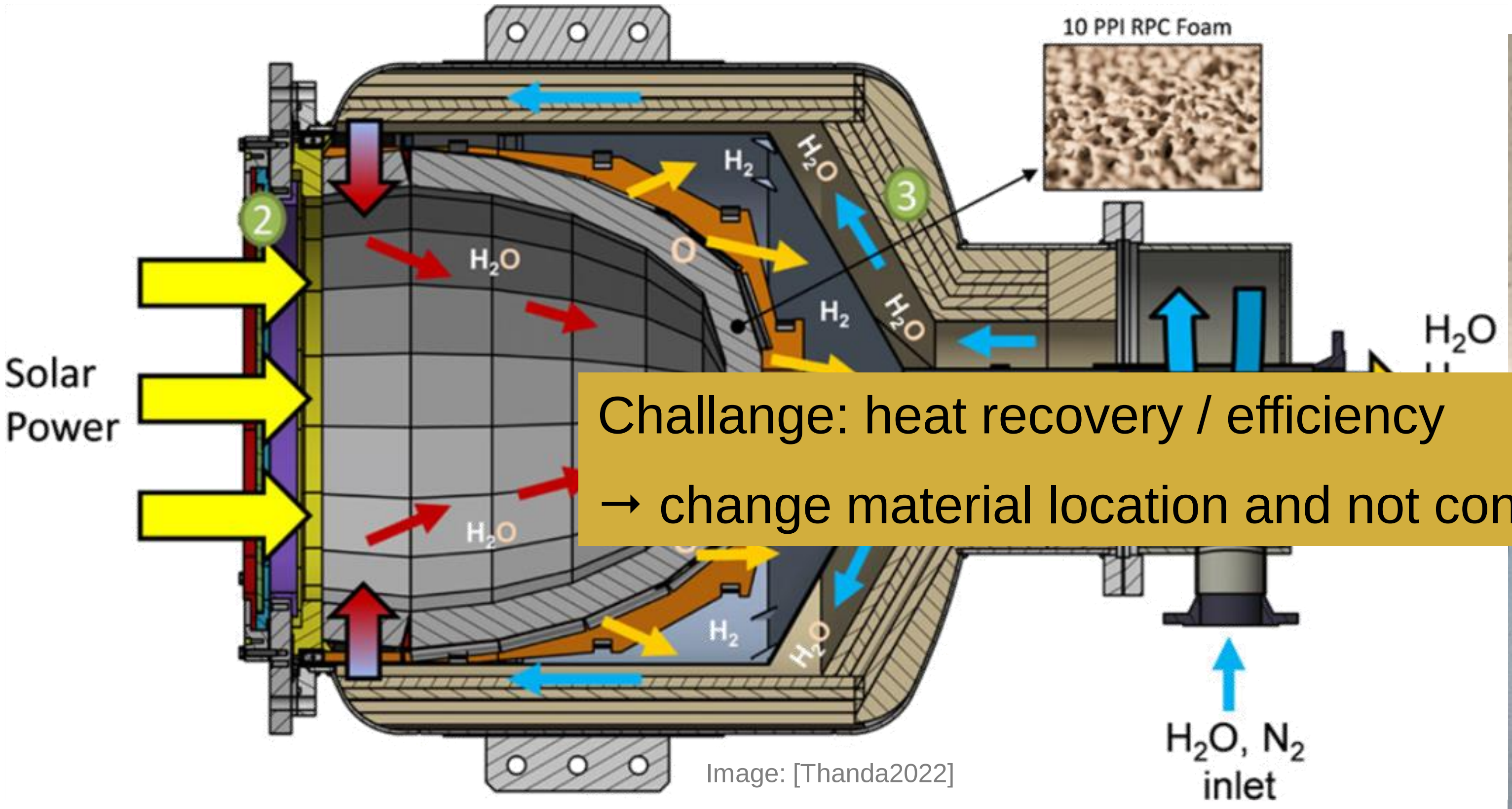
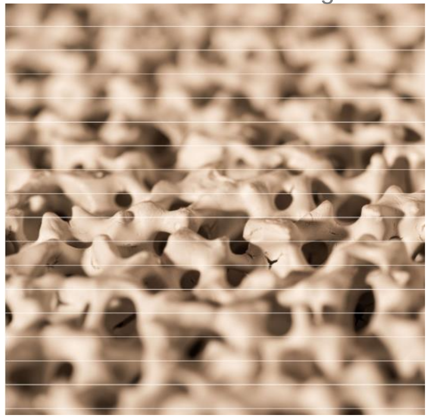
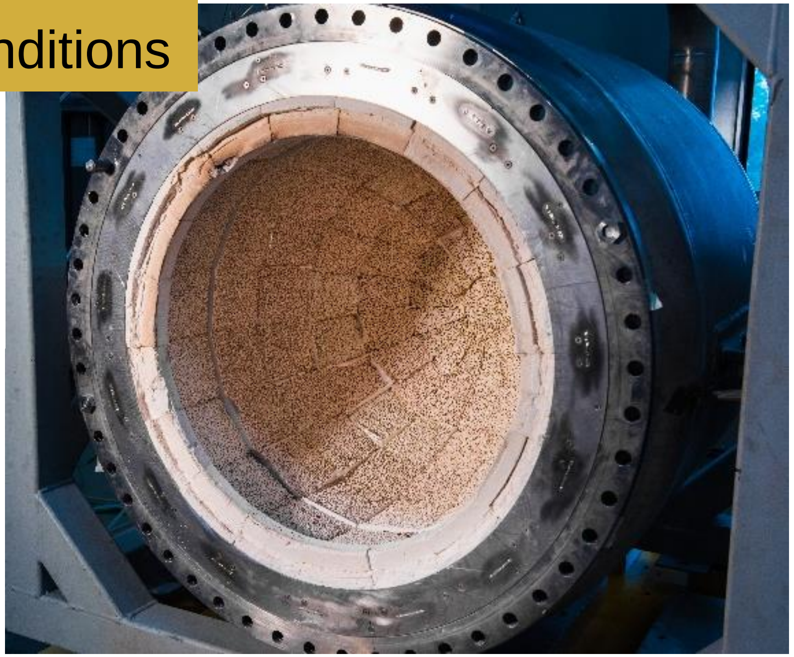


Image: [Thanda2022]

Images: DLR





Challange: heat recovery / efficiency

→ change material location and not conditions

- Alternating operation: reduction ↔ oxidation
- Reduction via vacuum or sweep gas
- Technology scaled-up from 3 kW to 750 kW

Thermochemical fuel production II
Moving redox particle concepts

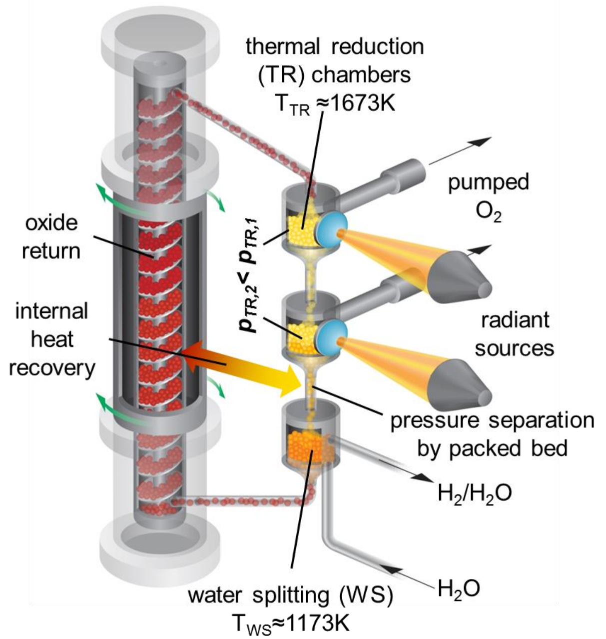
- Particles move through different components

→ spatial separation for different temperatures

→ pressure separation by packed bed

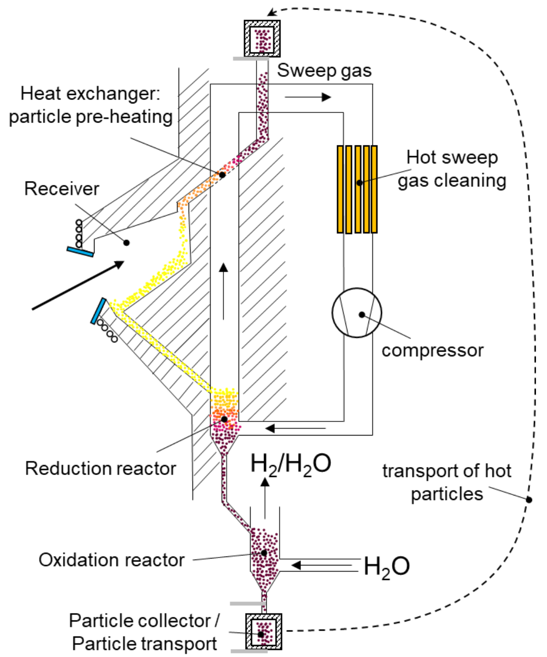
- Advantages:
  - Continuous operation
  - Redox material easily replacable
  - Better heat transfer & recovery possible

Vacuum concept



[Ermanoski2016] $p_{WS} >> p_{TR,1} > p_{TR,2}$

Sweep gas concept



[Weber2023]

Projected Reactor Efficiencies (solar → H_2)

moving particles [Weber2023]

5% | 10% | 15% | 20% | 25%

fixed monoliths [Zoller2019]
(demonstrated, SUN-to-LIQUID)

moving monoliths [Brendelberger2022]

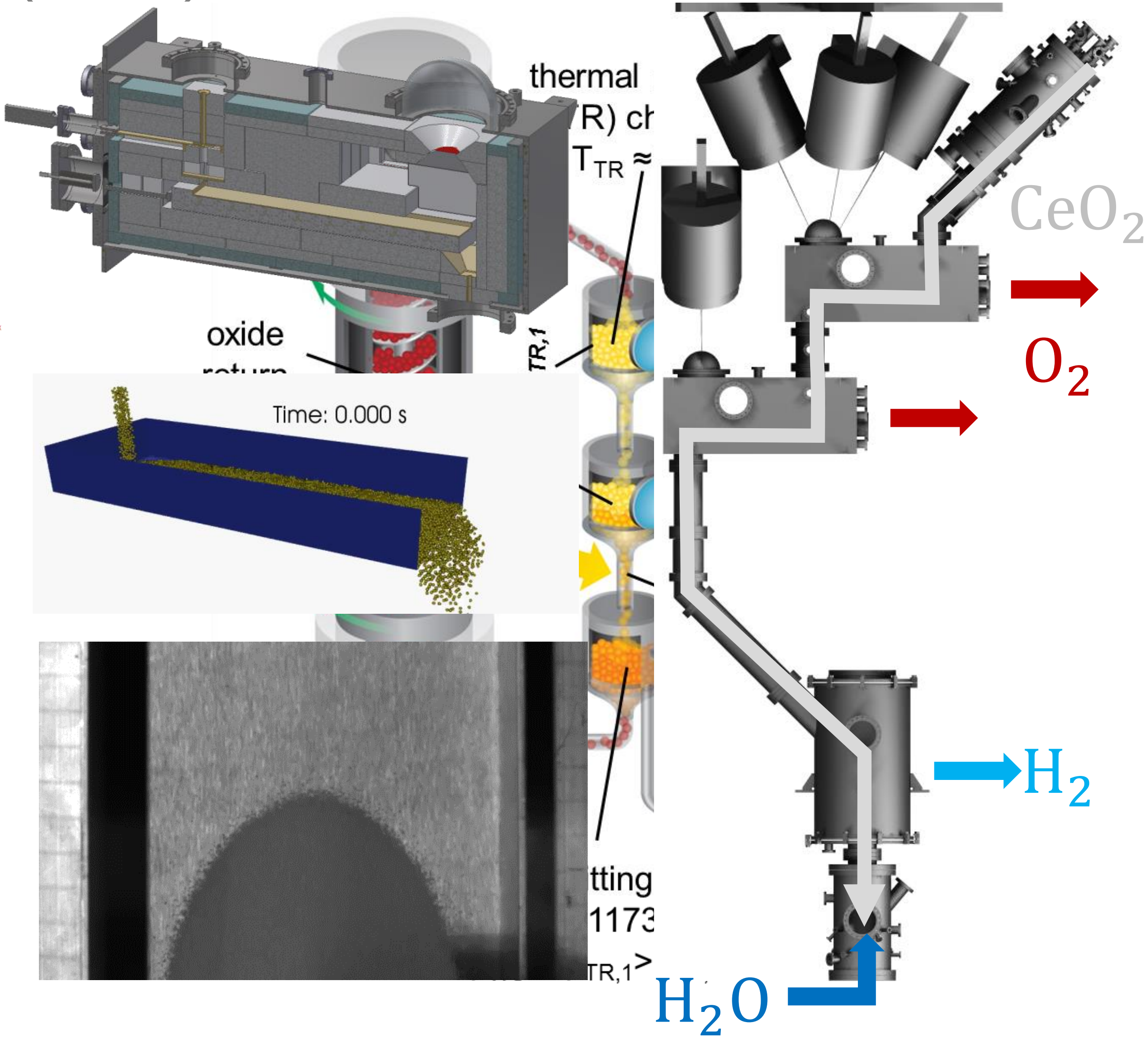
Image:adapted from [Grobbel2023]

Moving redox particle concepts I
Cascading Pressure Reactor/Receiver (CPR2)

- Two-step reduction in vacuum (DLR)
- Water splitting at ambient pressure (Sandia National Labs)
- Pressure separation by moving particle bed

- Particles: 277 µm CeO_2
- Slip-stick plate design to move particles[6]

image: [Grobbel2017]



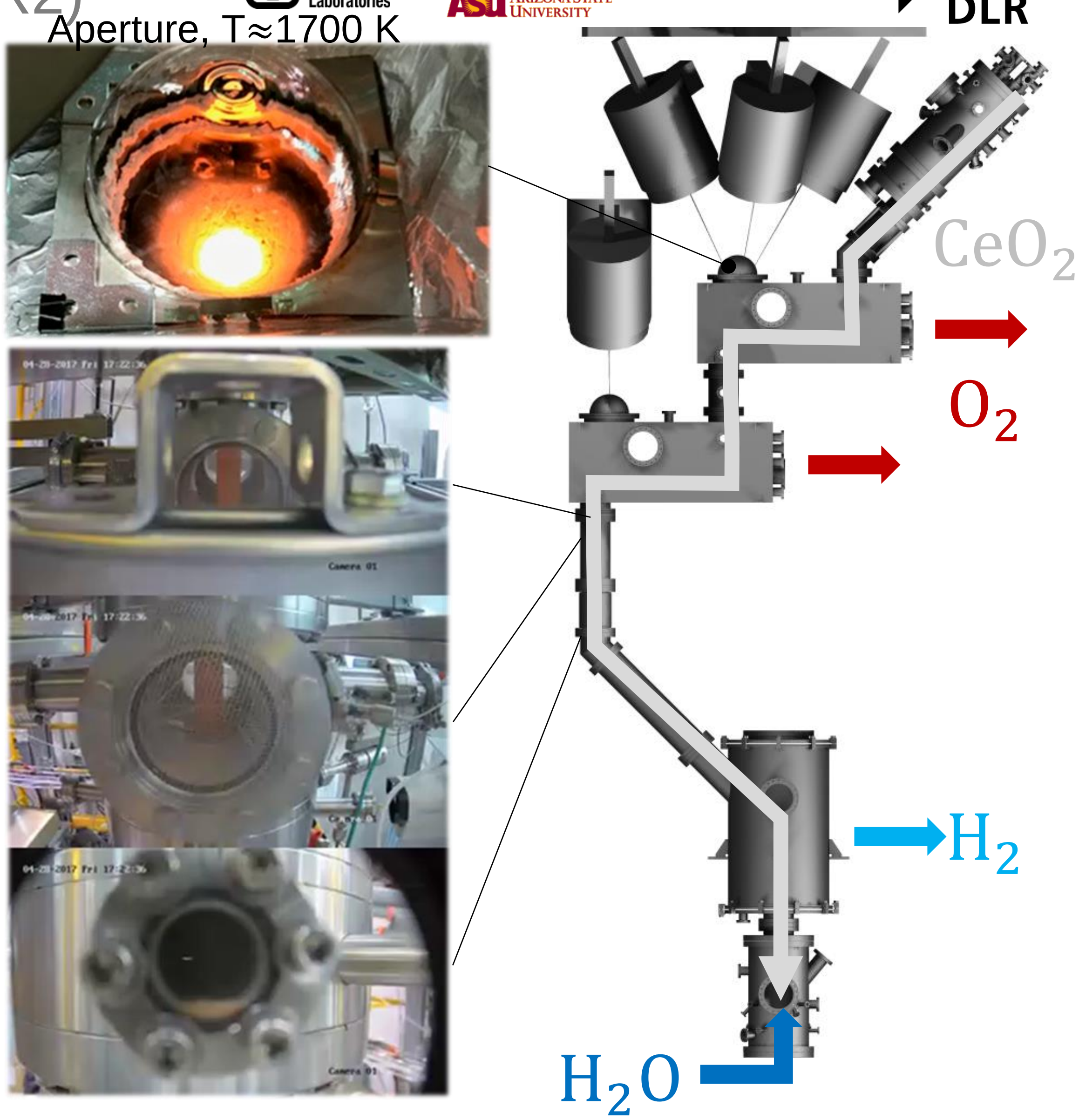
[6] Grobbel et al., US Provisional Patent Application Number 62353885

Moving redox particle concepts I

Cascading Pressure Reactor/Receiver (CPR2)

- Two-step reduction in vacuum (DLR)
- Water splitting at ambient pressure (Sandia National Labs)
- Pressure separation by moving particle bed

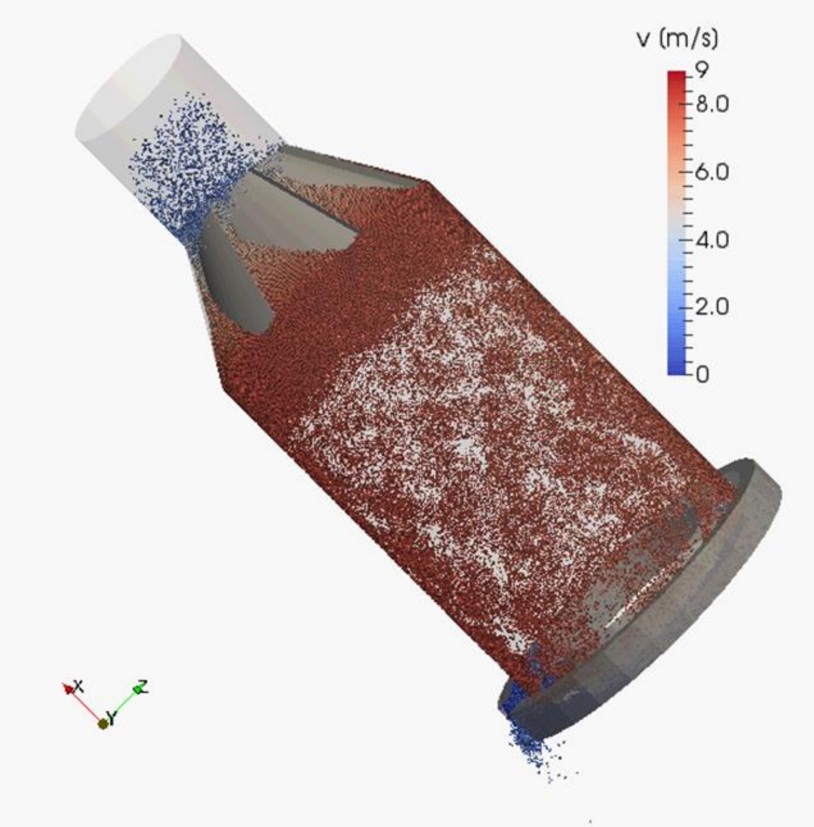
- Particles: 277 µm CeO_2
- Slip-stick plate design to move particles[1]
- Tests in DLR Synlight® at 5-10 kW scale
- Particles heated to more than 1300 °C
- Pressure separation demonstrated @ T > 1000°C
- H2 produced in @ SNL

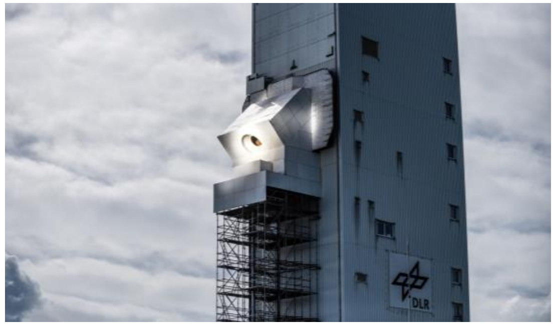


[1] Grobbel et al., US Provisional Patent Application Number 62353885

Particle Technologies – CentRec®
Centrifugal Receiver

- Direct absorption of sunlight by particles
- Patented design used in several projects
- Mass flow controlled by rotation speed (> 40 rpm)
- Particle temperature controlled by mass flow → temperatures > 900 °C reached (965°C)




2013 — First prototyp (15 kW)

2018 — Testing 500 kW scale-up at solar tower Jülich

20 — Use of 300 kW variant in Synlight in PEGASUS

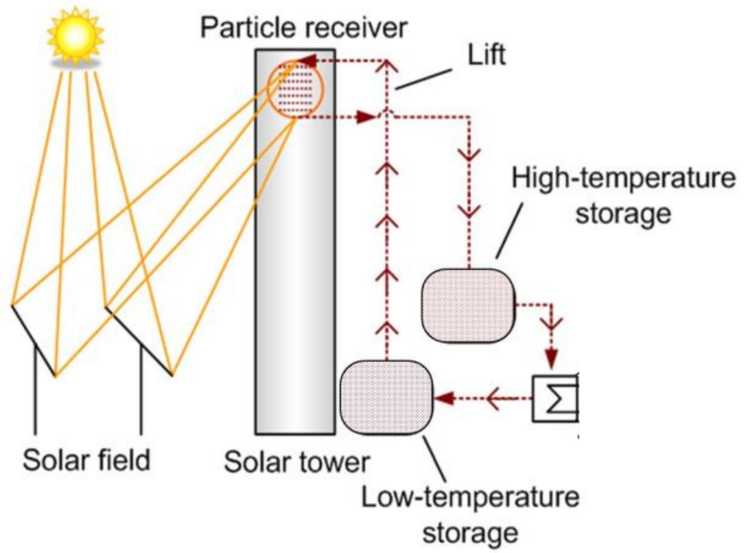
Test of 1 MW reactor in long-term heat storage research facility HEHTRES

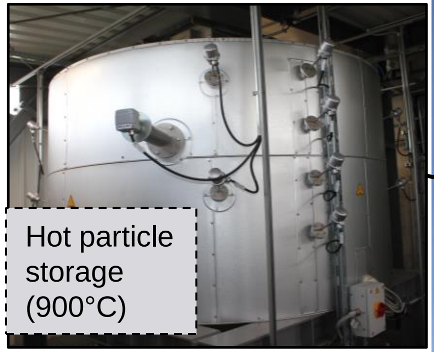
CentRec technology is patented by DLR, currently non-exclusively licensed to Heliogen Inc., USA

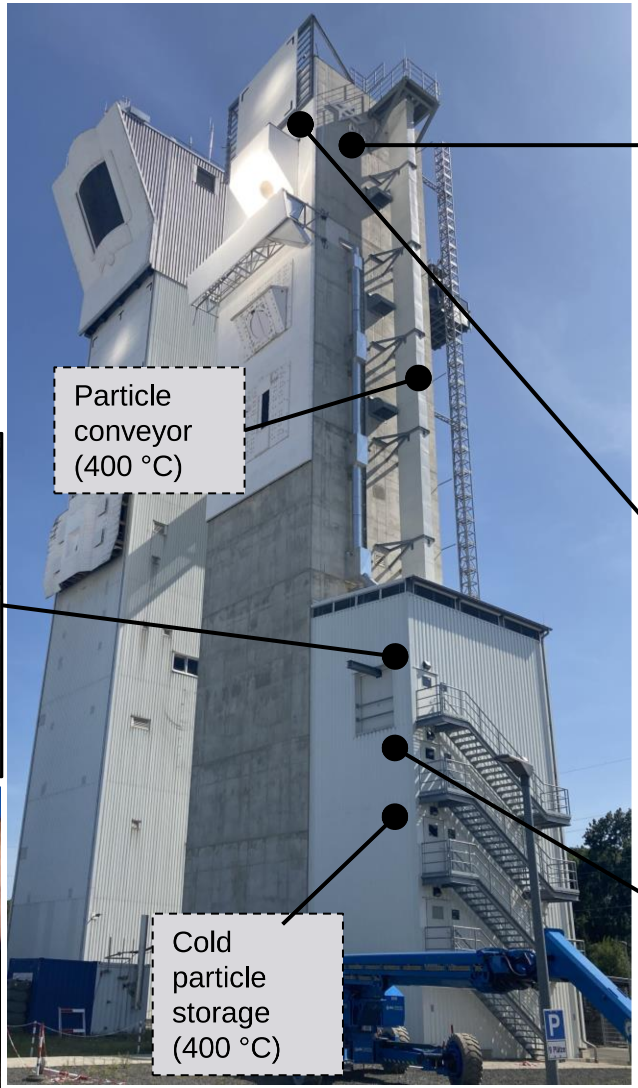
HEHTRES

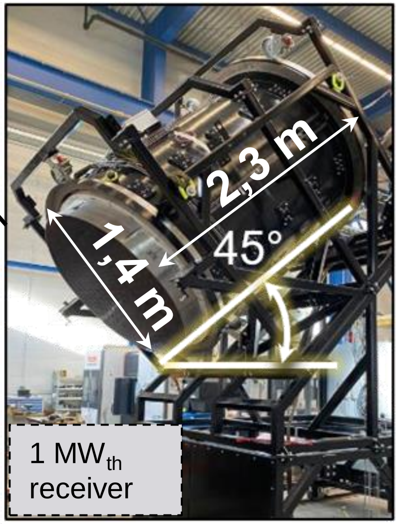
High Efficiency High Temperature Receiver System

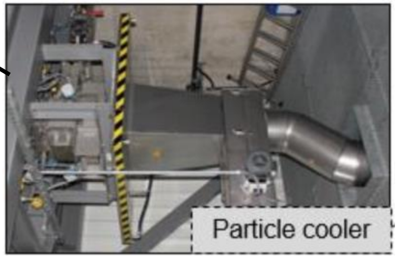
- Full cycle heat storage facility
- Bauxite particles (1 mm) heated and stored at 900 °C
- Heat transferred via heat exchanger
- Cold particles stored and transported at 400 °C









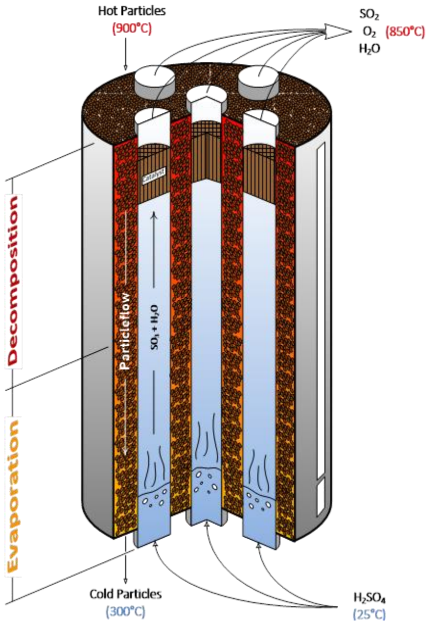


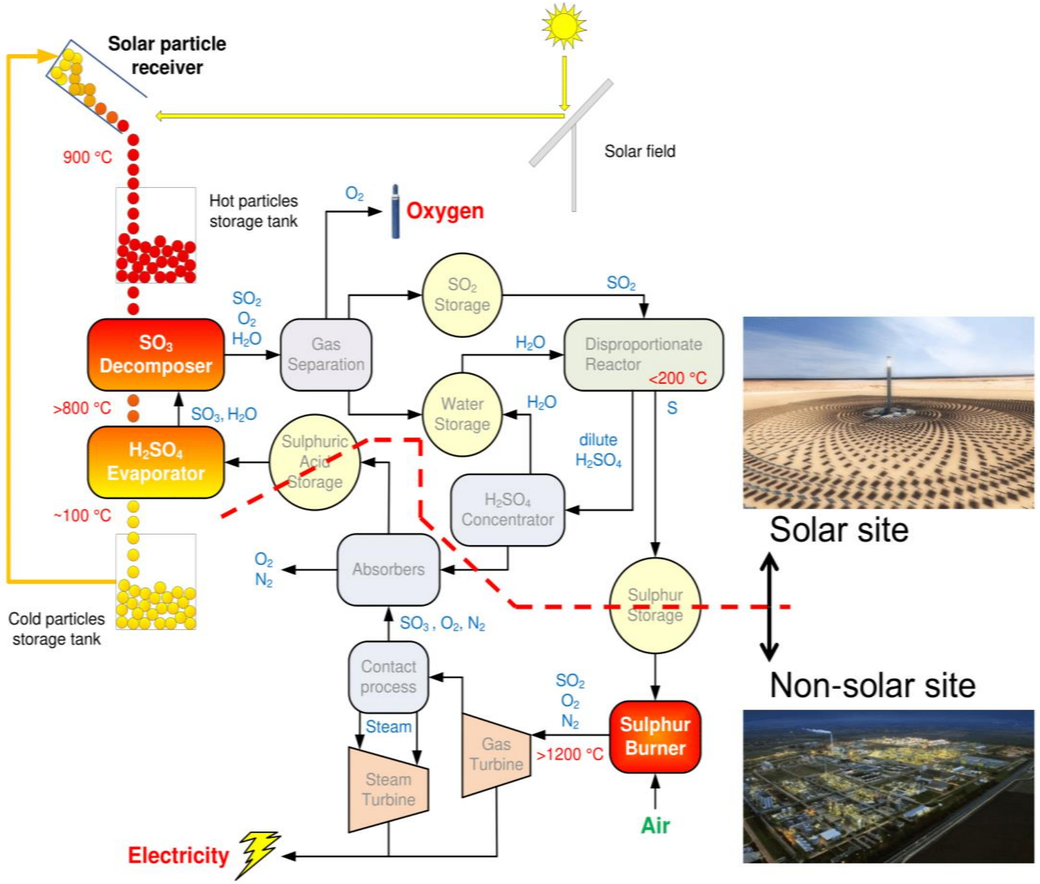
Images: DLR, CC BY-NC-ND 3.0 and according to [Roeb2024]

PEGASUS

Renewable Power Generation by Solar Particle Receiver Driven Sulphur Storage Cycle

- Using solid Sulphur as indirect thermochemical storage of solar energy
- Solar heated bauxite particles heated by CentRec technology and used as indirect heat source
- Development of hot particle powered SO_3 decomposer (T > 800 °C) and sulphuric acid evaporator (T > 400 °C)
- Operation test with 300 kW CentRec receiver in Synlight





Source: [Thanda2022]

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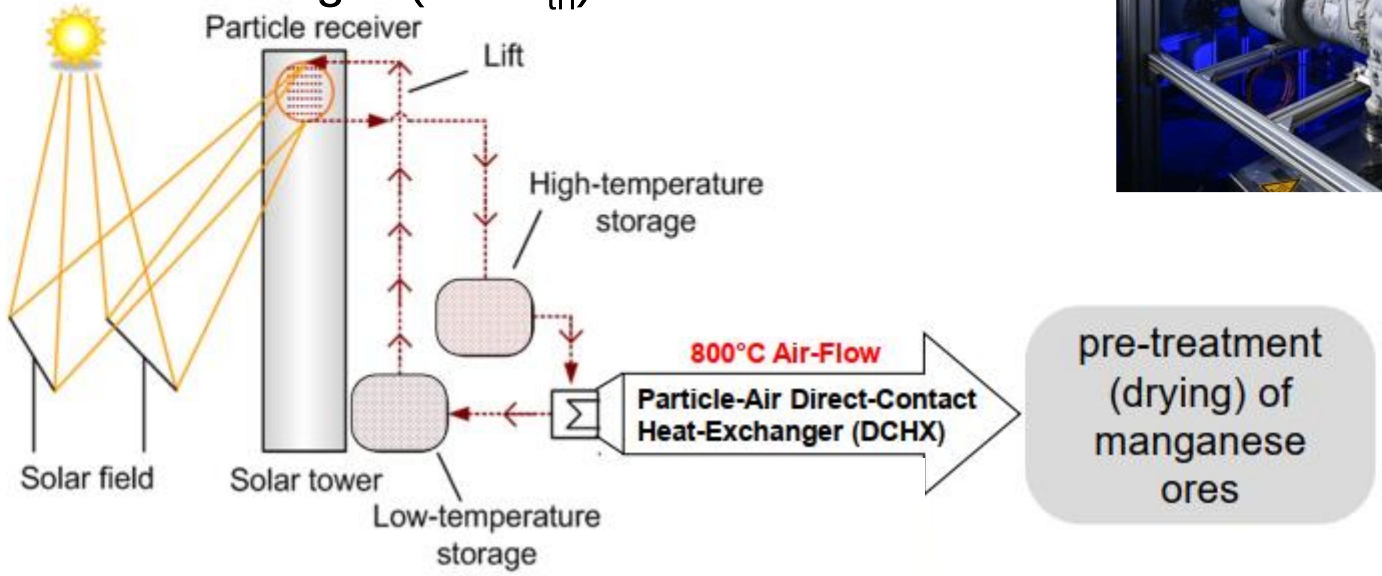
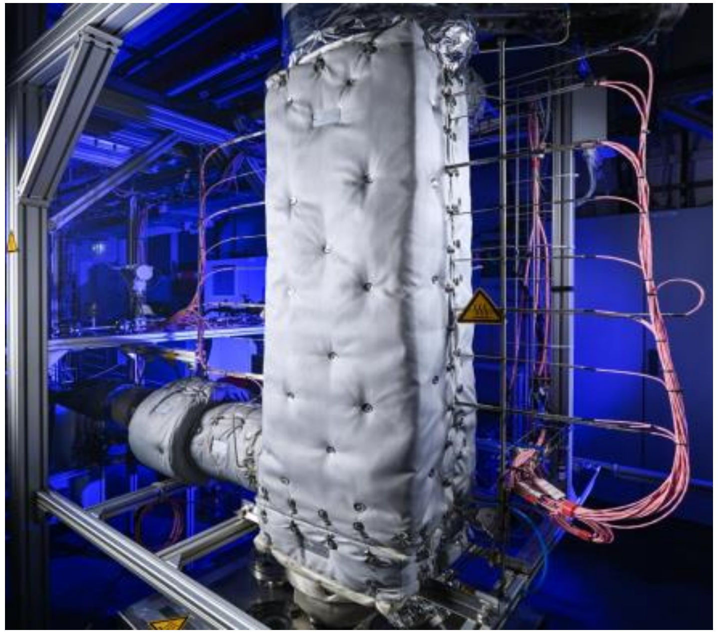
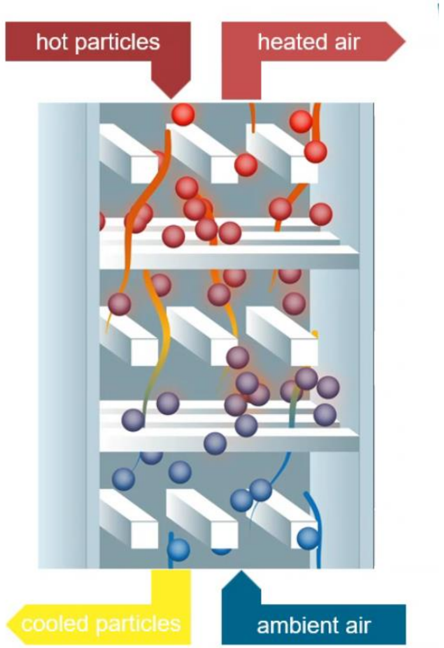
PREMA
Pre-heating of Manganese ferroalloys

- Use of CSP heat for Mn-alloy production
- Pre-heated ore needs less fossile fuel and reduces CO_2
- Use particles as heat transfer medium
- Development of particle/air trickle down heat exchanger (5 kW_{th})





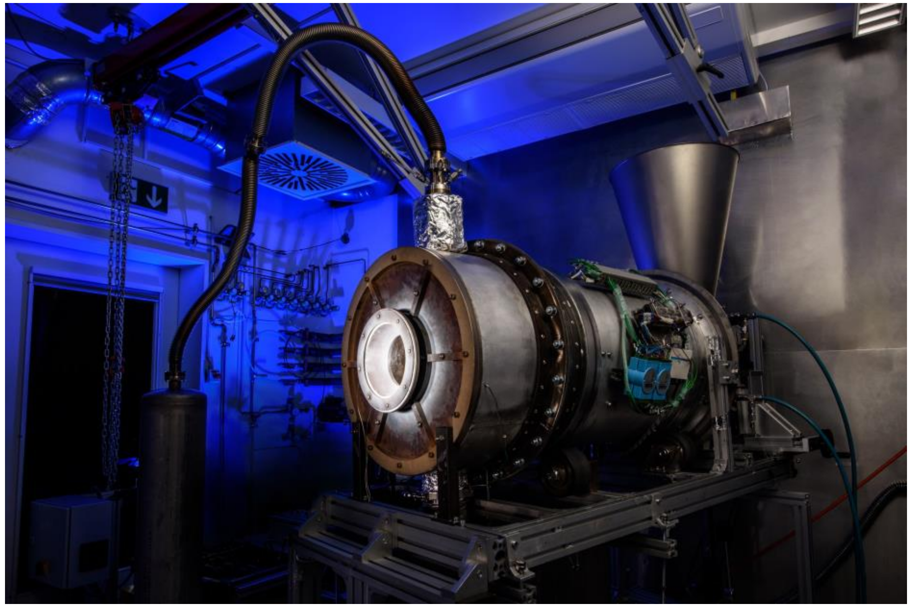


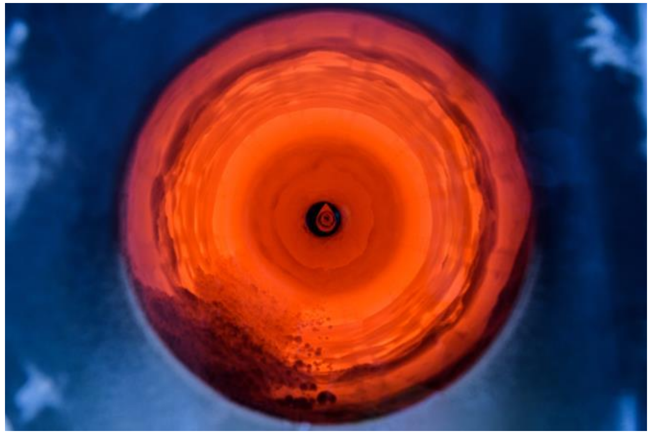
Source: [Reichart2024]

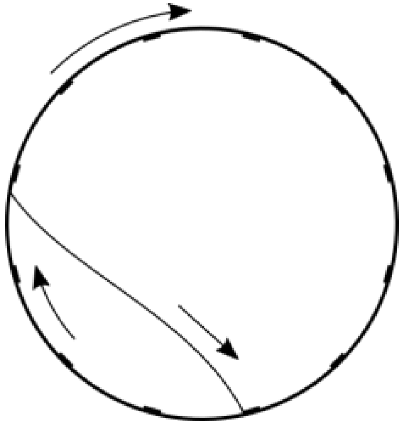
Achieved:
- particle enter @ 930°C
- air out @ 800 °C
- Mn-ore pre-heated to 600 °C

Particle Technologies – Rotary kiln
Slow rotation

- Calcination of cement raw materials / limestone with direct solar heat (SolPart, CemSol)
- Pyrolysis of biomass (PySolo)

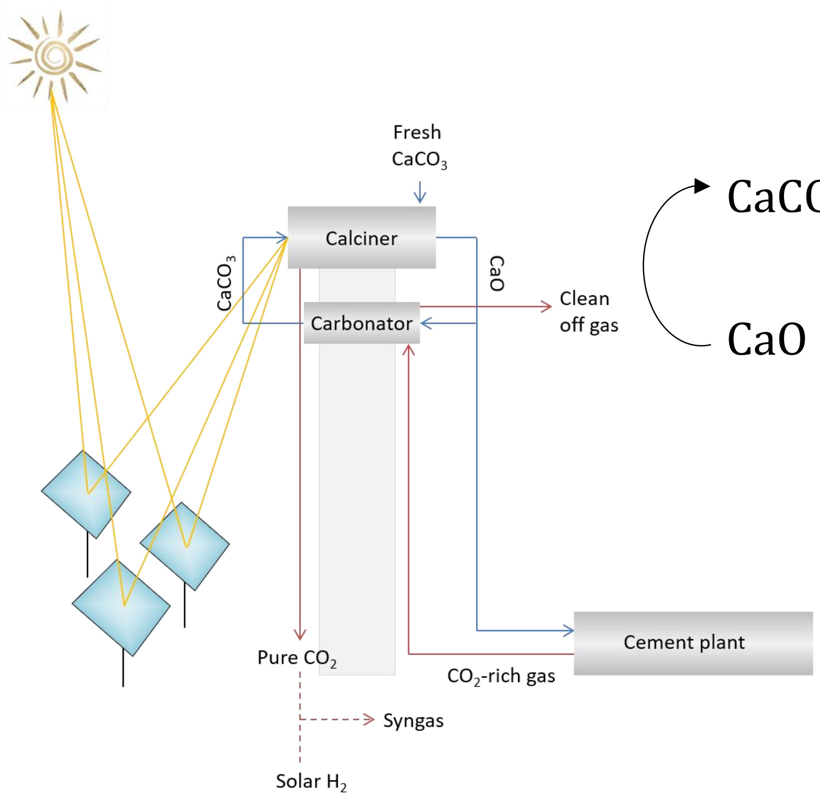






CEMSOL
Solarization of cement process

- Calcination of granular limestone (solid $CaCO_3$) in rotating calciner
- calcium looping cycle

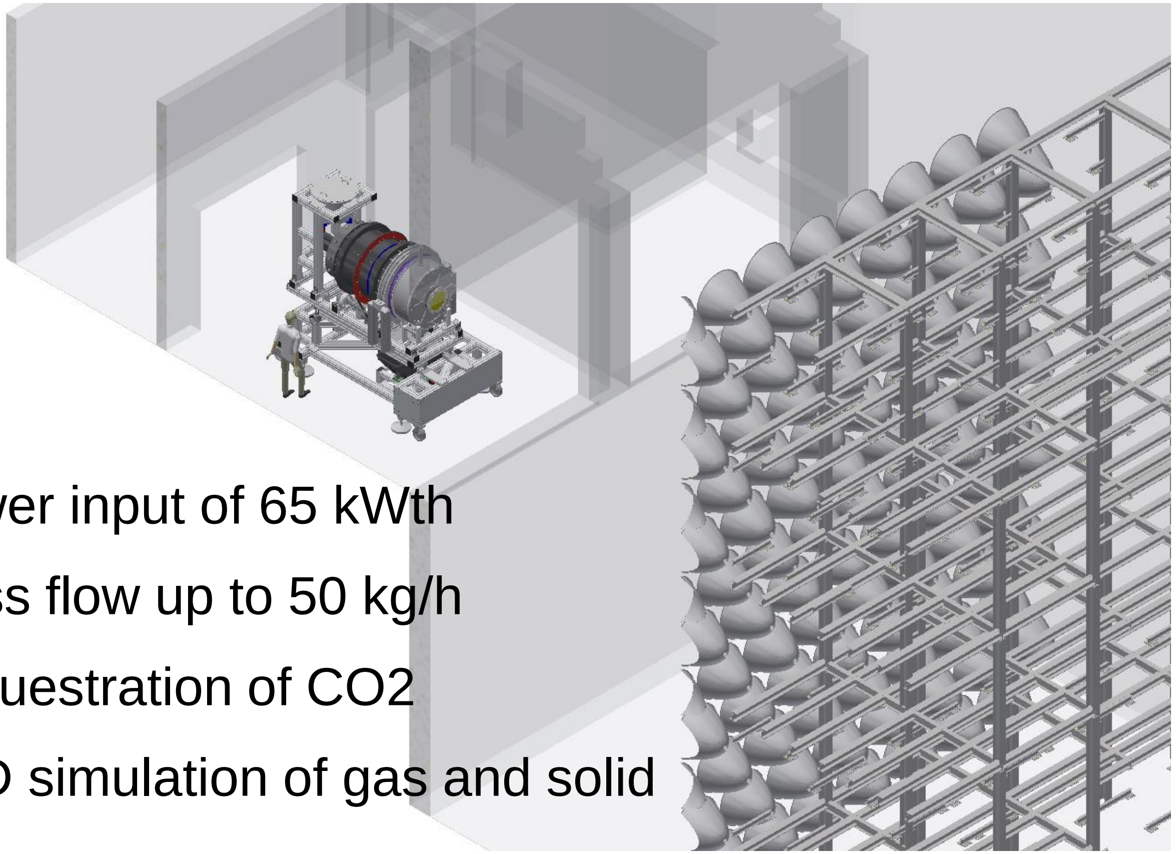


>900 °C

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + CO_2 \rightarrow CaCO_3$$

~650 °C

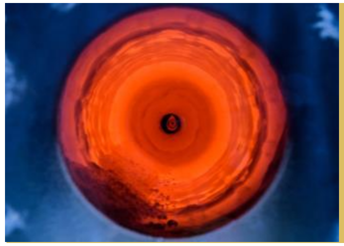


- Power input of 65 kWth
- Mass flow up to 50 kg/h
- Sequestration of CO2
- CFD simulation of gas and solid

Summary

Concentrated solar power can be employed with particles systems to produce green fuels

Technologies for high-temperature particles are far developed (scaled-up, varified on-sun)



Integration of CSP heated particles enable other technologies to become more sustainable

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