Base materials and fuels production founded on solar heat as the energy input

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Outline

- History on Solar Heat Generation and Use
- Solar Calcination and Solar Cement
- Solar Recycling
- Solar Thermal Fuel Production

Relevance of cement

Most used commodities worldwide

1st Water
2nd Concrete (1)

Water

+

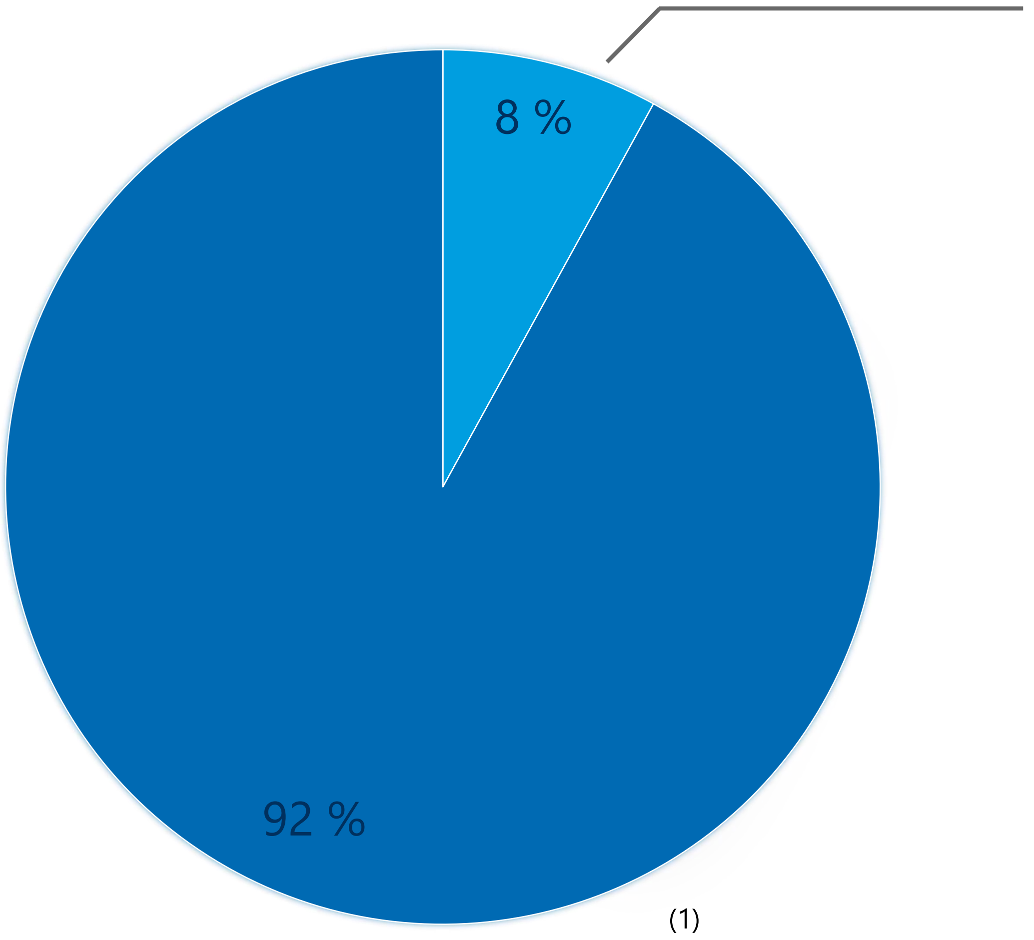
Filler

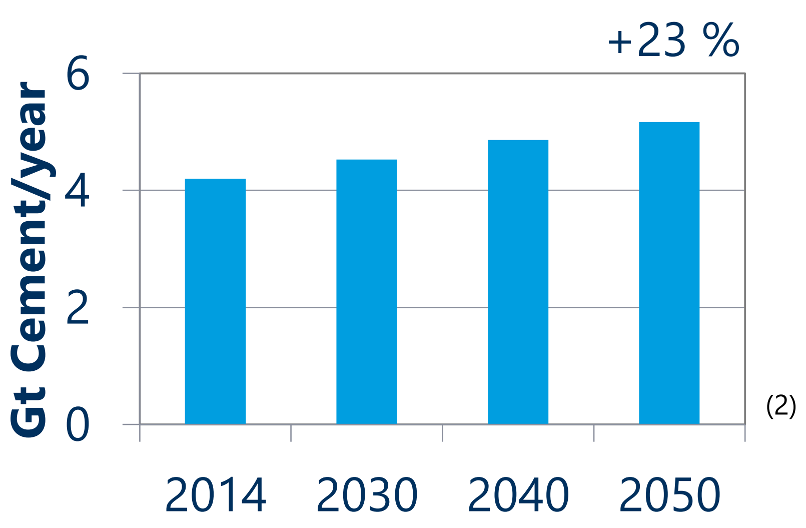
+

Cement (2)

(1) Cement Technology Roadmap, WBSCD, 2009
(2) Concrete constituents, mastour.com

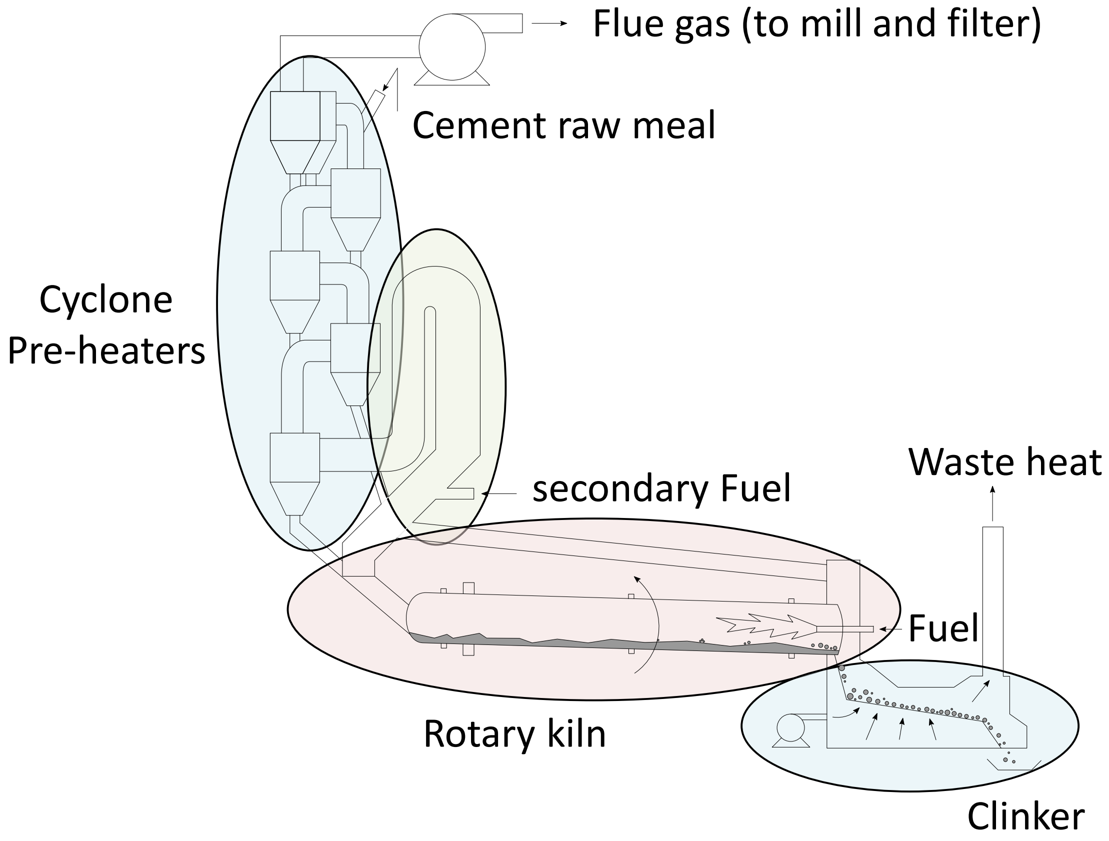
Emissions of cement production





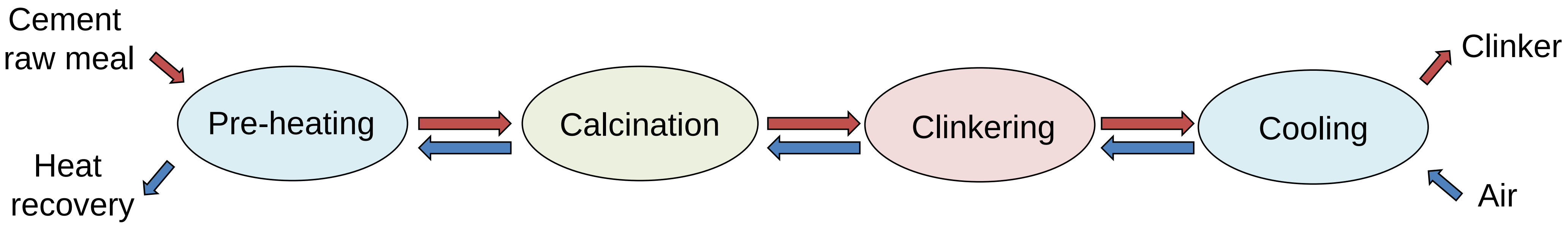
(1) A blueprint for a climate friendly cement industry, WWF, 2008
(2) Technology Roadmap: Low-Carbon Transition in the Cement Industry, IEA, 2018

Thermal treatment



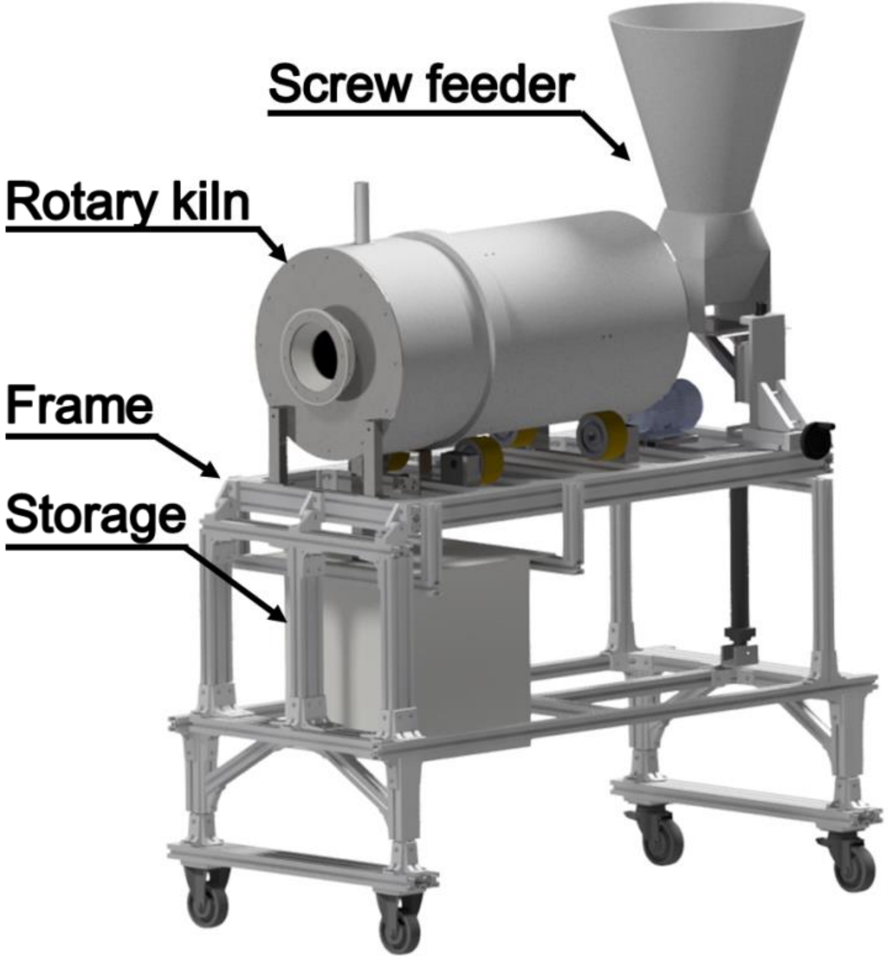
Calcination
~900 °C
$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

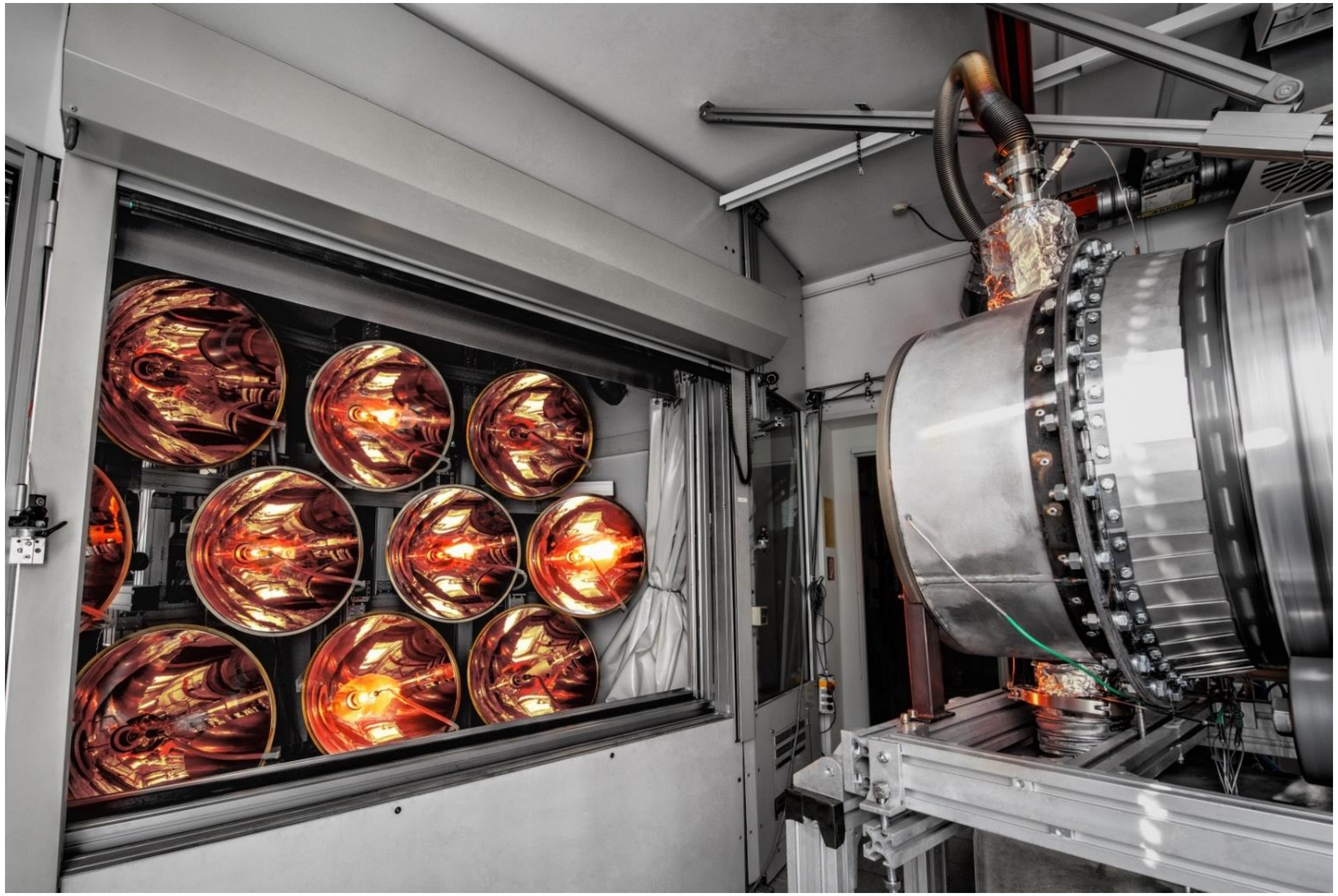
Clinkering
~1500 °C
Formation of new phases



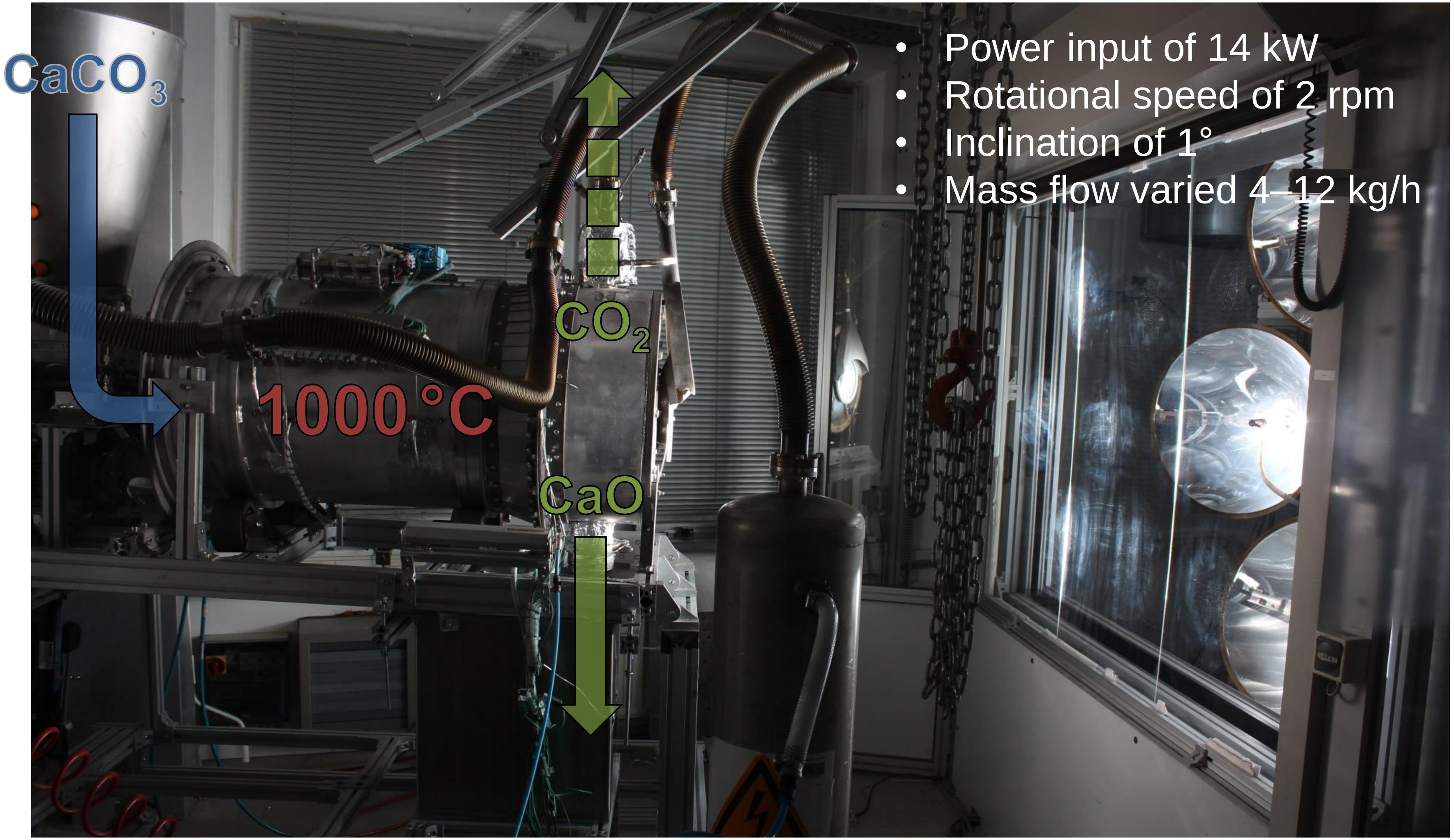
Sprung, S., Cement, in Ullmann's Encyclopedia of Industrial Chemistry, 2008

Solar rotary kiln for calcination

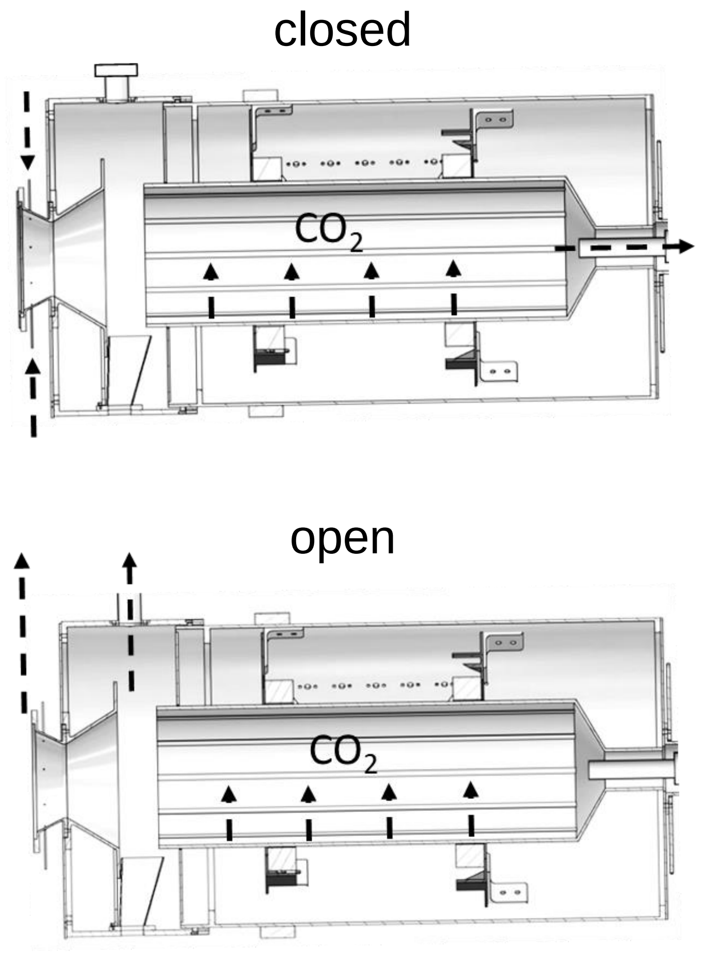


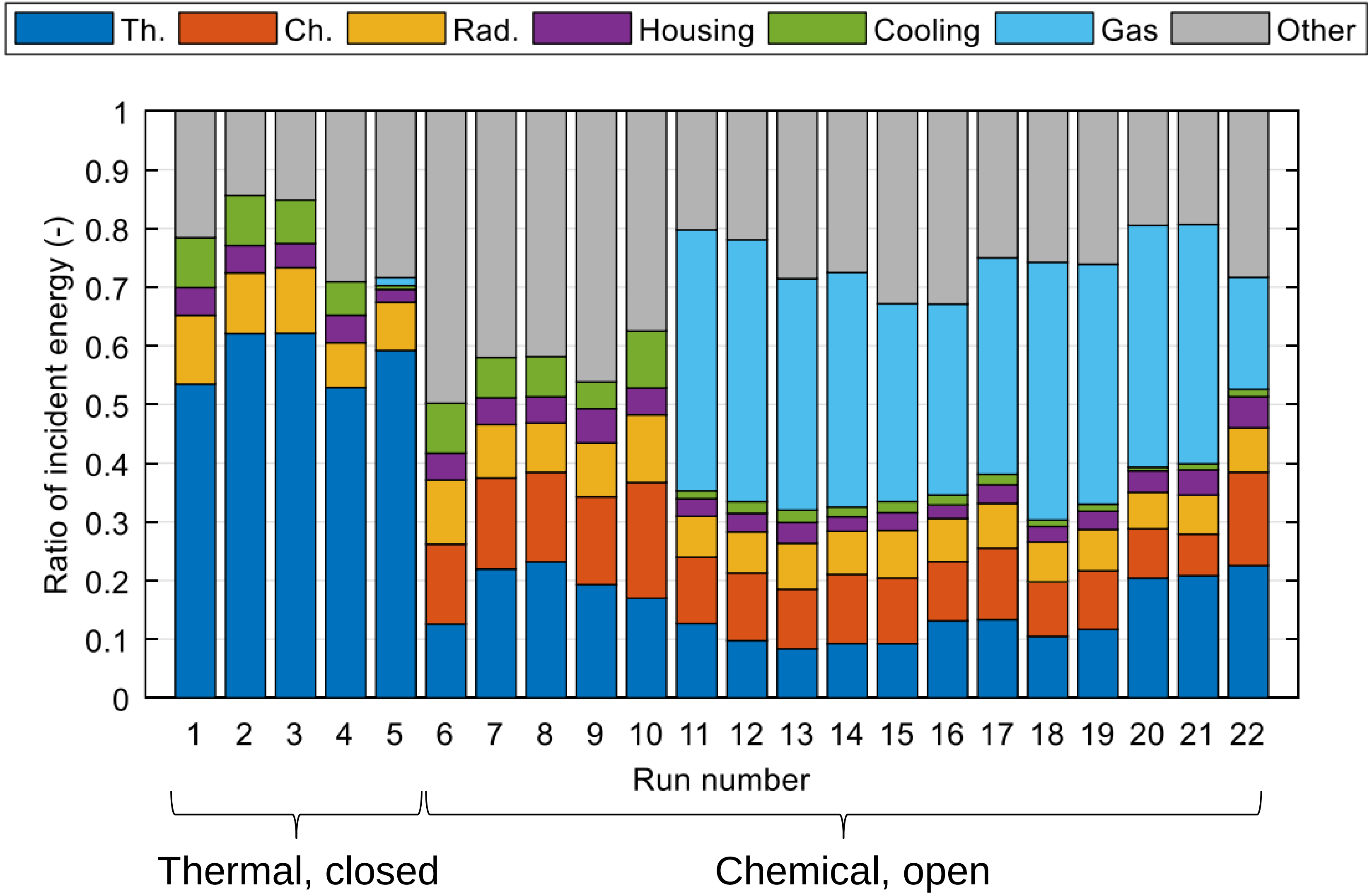


Experiments in the solar simulator

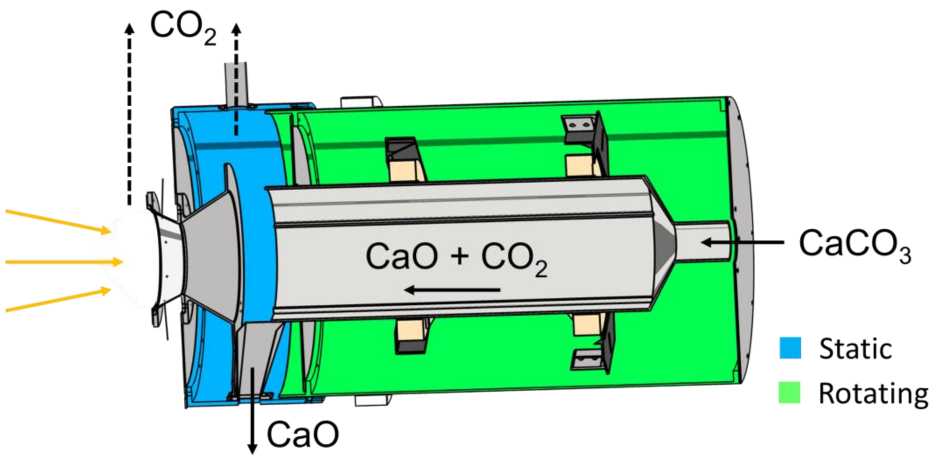


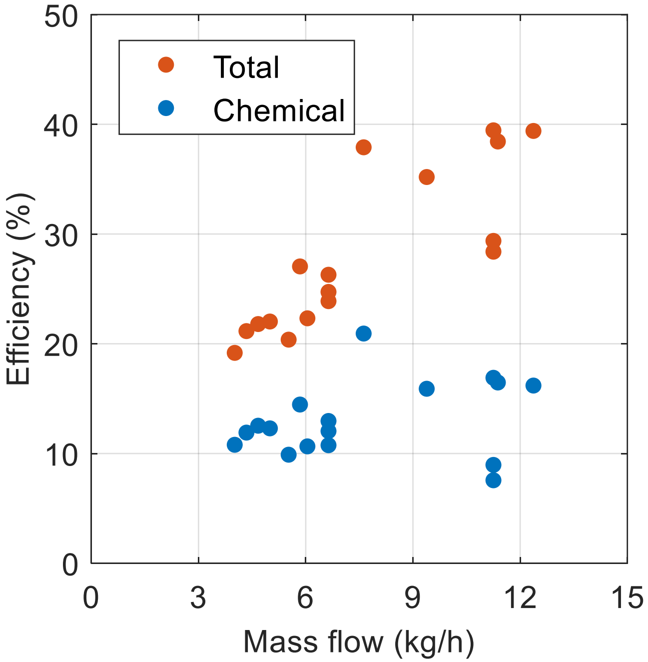
Results of the solar campaigns





Reactor Performance



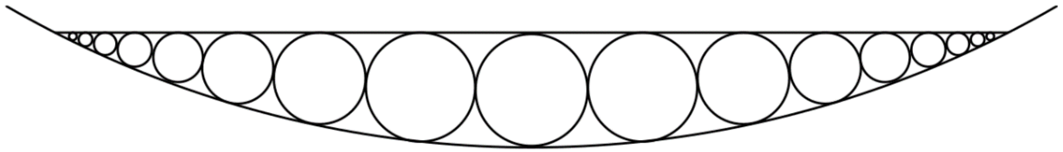


- Successful tests with cement raw meal
- Calcination degrees up to 99 %

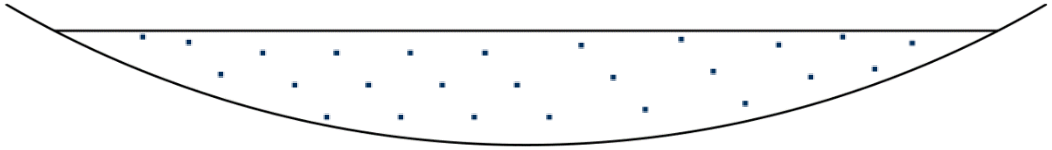
- Total efficiency up to 40 %
- Increase of efficiency with load
- Chemical efficiency lagging behind

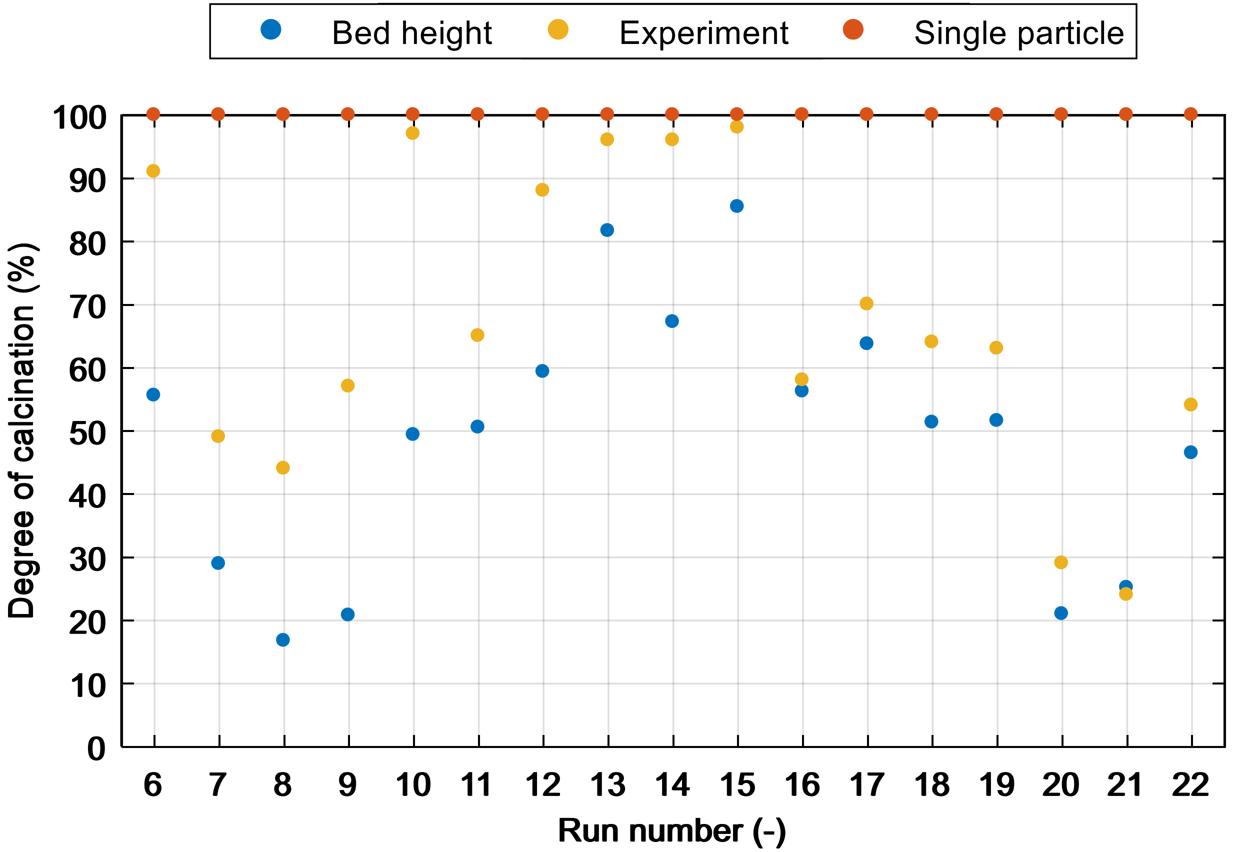
Degree of calcination

Particles with bed height (non-mixed)

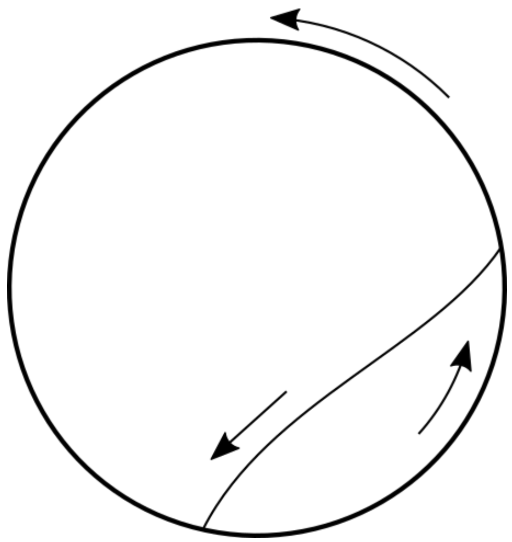


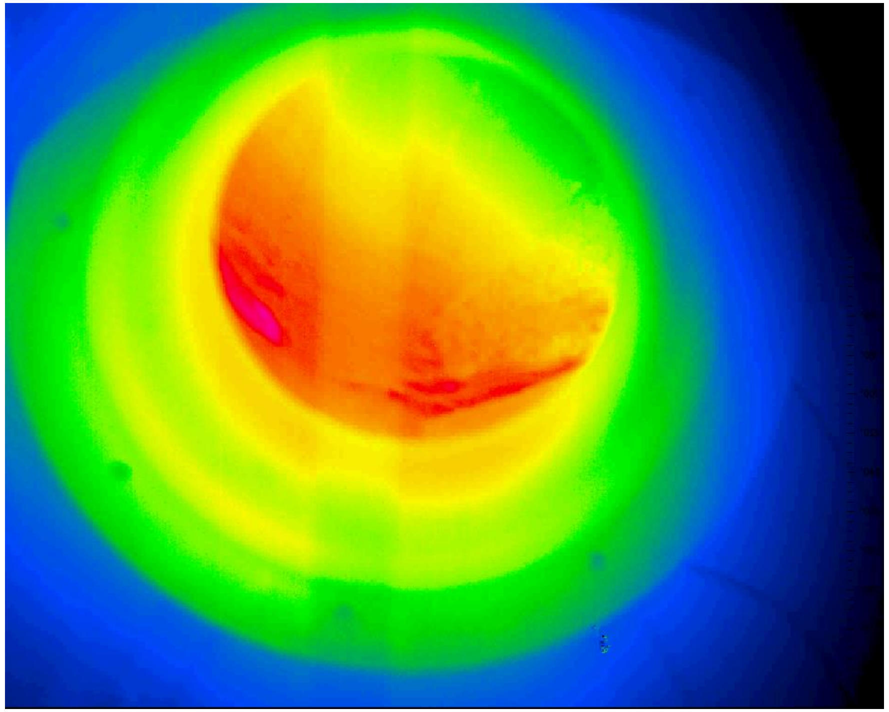
Single particles (perfectly mixed)



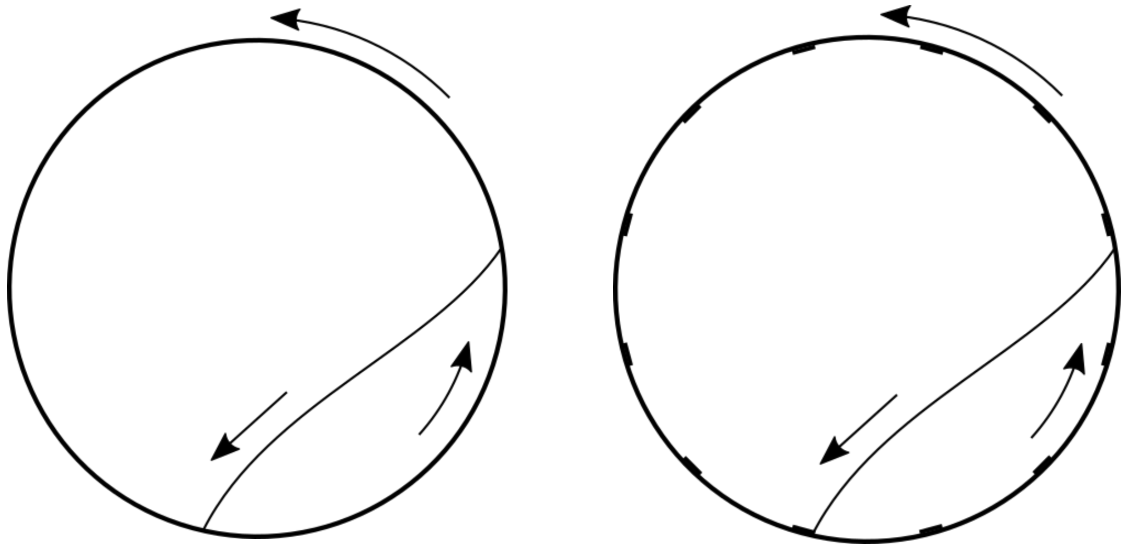


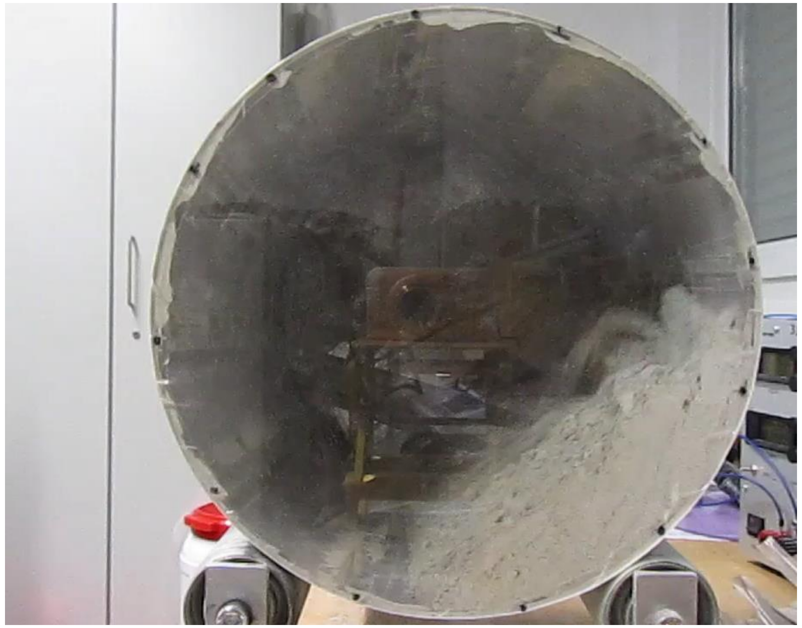
Bed motion inside the kiln



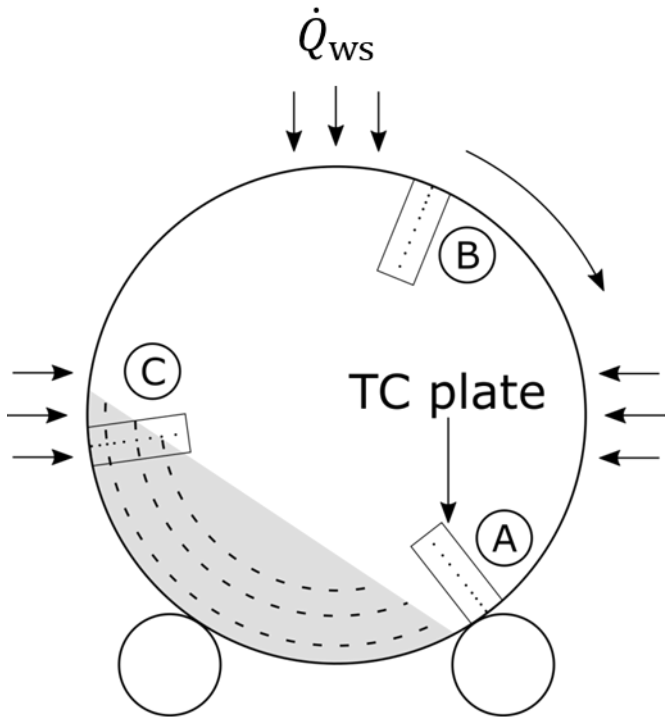


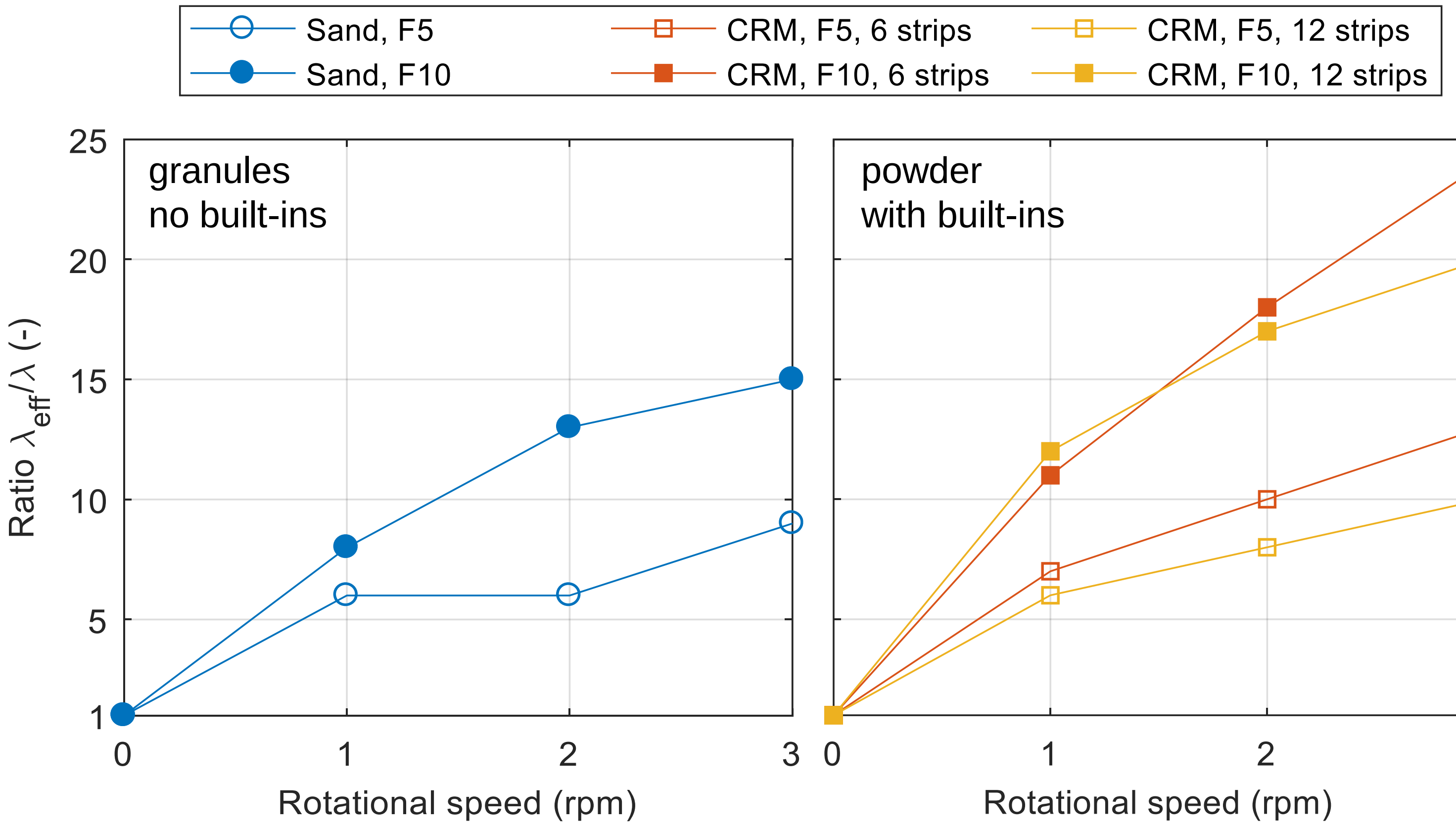
Bed motion inside the kiln



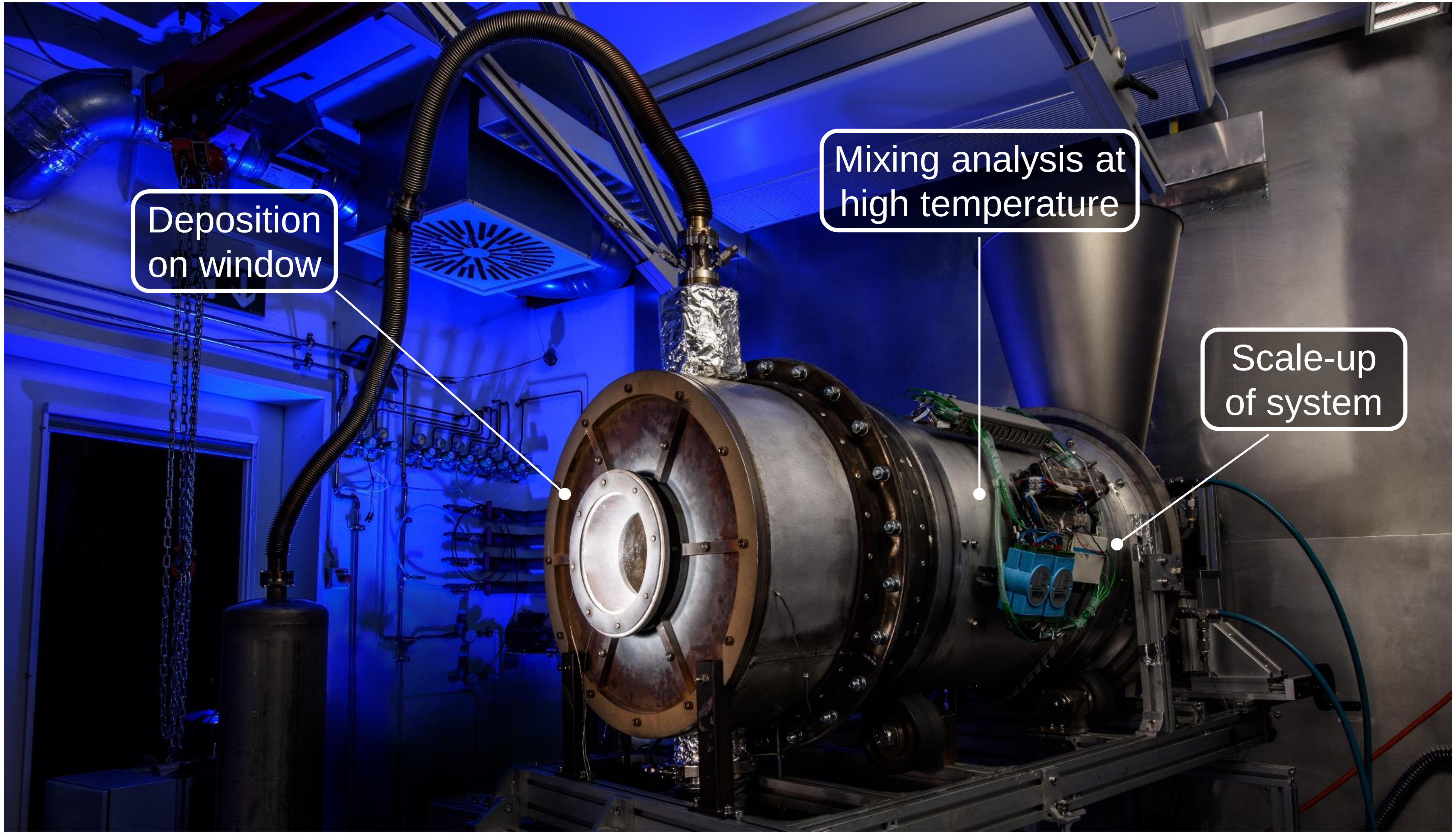


Impact on the bed thermal conductivity





Present and planned studies



And going beyond?

500 °C

Kaolinite

600 °C — Colemanite (Boron)

700 °C — Phosphate ore

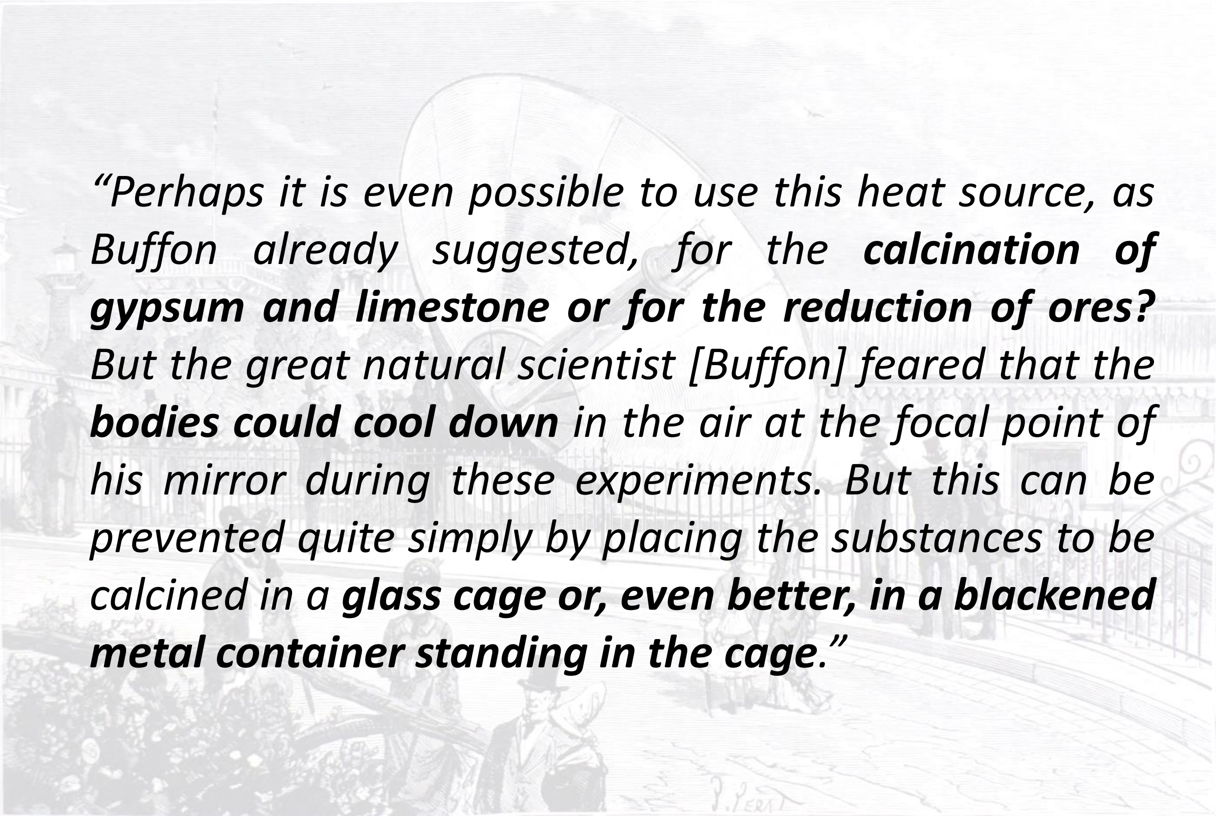
Magnesium carbonate

800 °C

900 °C

Limestone

1000 °C

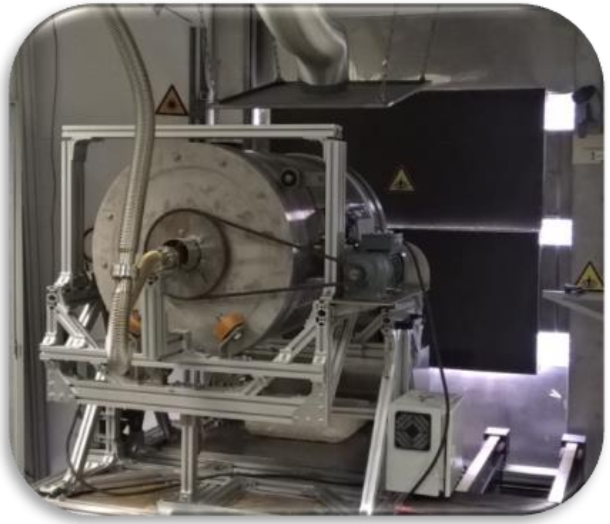


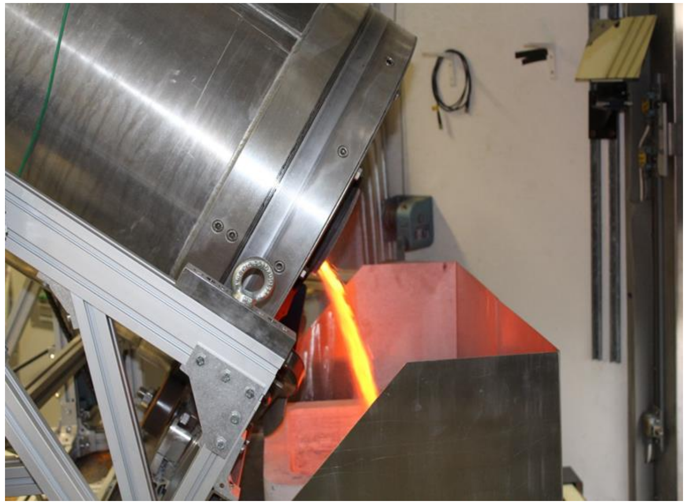
"Perhaps it is even possible to use this heat source, as Buffon already suggested, for the ***calcination of gypsum and limestone or for the reduction of ores?*** *But the great natural scientist [Buffon] feared that the* ***bodies could cool down*** *in the air at the focal point of his mirror during these experiments. But this can be prevented quite simply by placing the substances to be calcined in a* ***glass cage or, even better, in a blackened metal container standing in the cage****."*

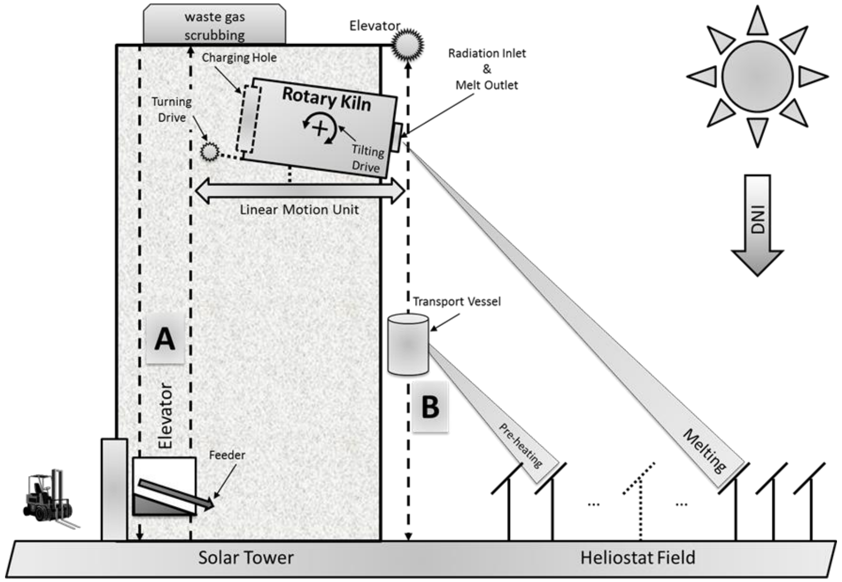
A. Mouchot, „Die Sonnenwärme und ihre industriellen Anwendungen", translated from French original 1879, 1987

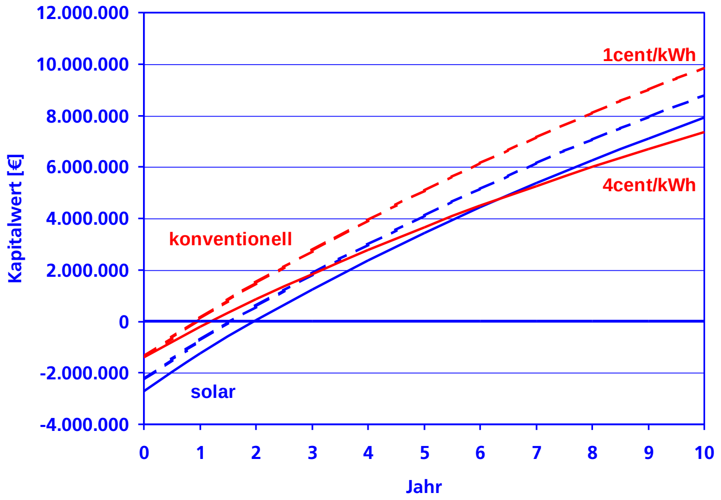
Aluminium Recycling

- Development and testing of 20 kg pilot-scale rotary kiln in Solar Furnace in Köln
- Scale-up study: Integration of pilot-scale rotary kiln at a solar tower plant

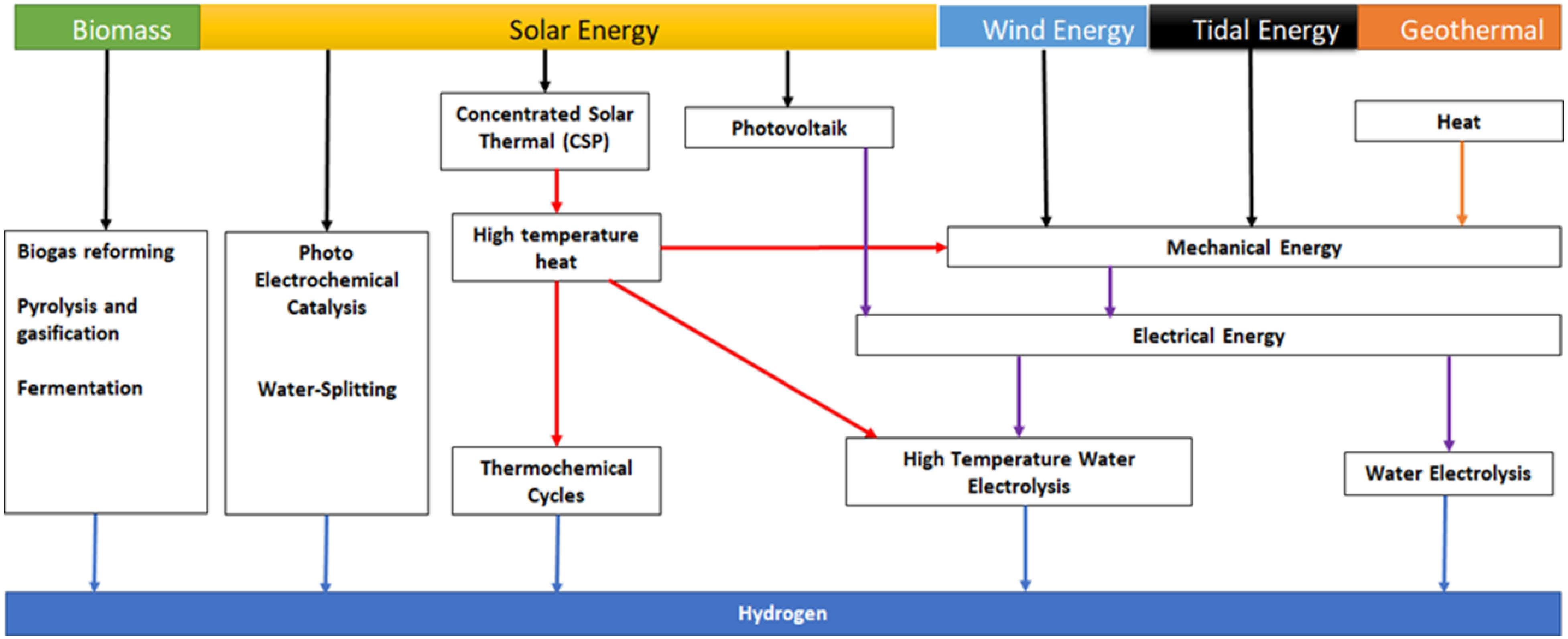




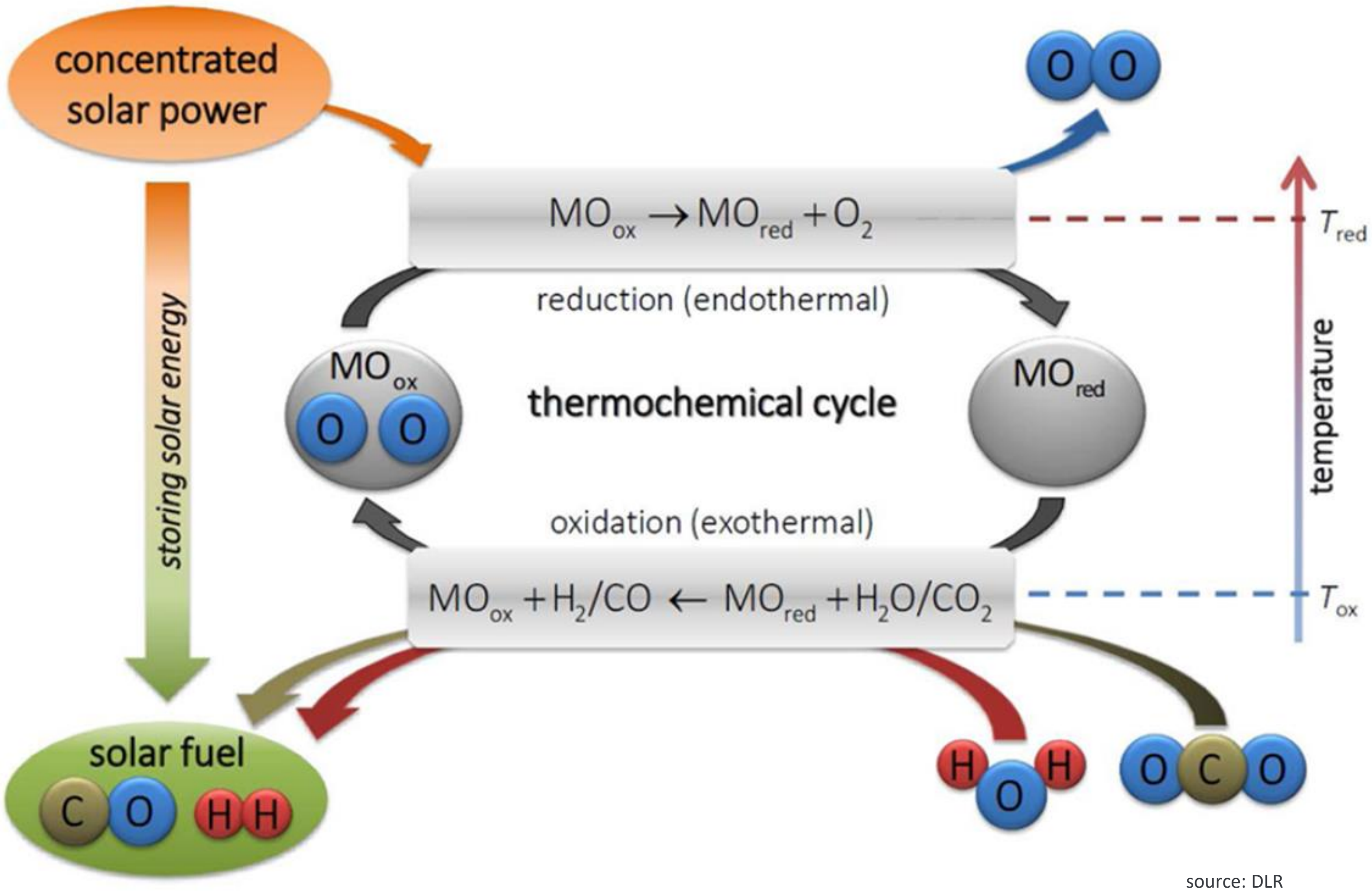




Portfolio of technologies for renewable fuels production



Thermochemical syngas production



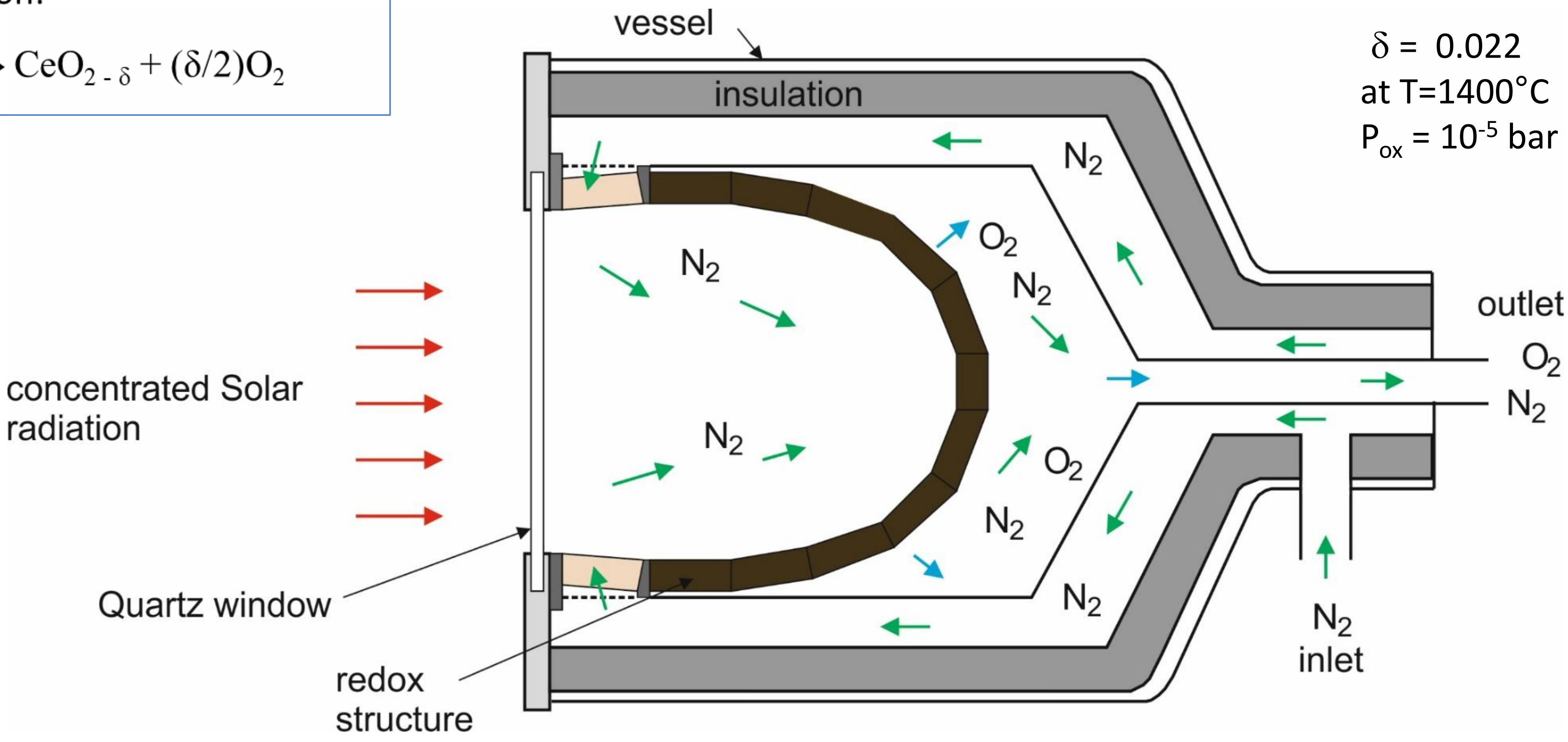
source: DLR

source: sun-to-liquid.eu

Background: Plant based on Plant of Prior Project ASTOR

Reduction:

$$CeO_2 \rightarrow CeO_{2-\delta} + (\delta/2)O_2$$



Non-stoichiometry:

δ = 0.022
at T=1400°C
P_{ox} = 10^{-5} bar

Background: Plant based on Plant of Prior Project ASTOR

Oxidation:

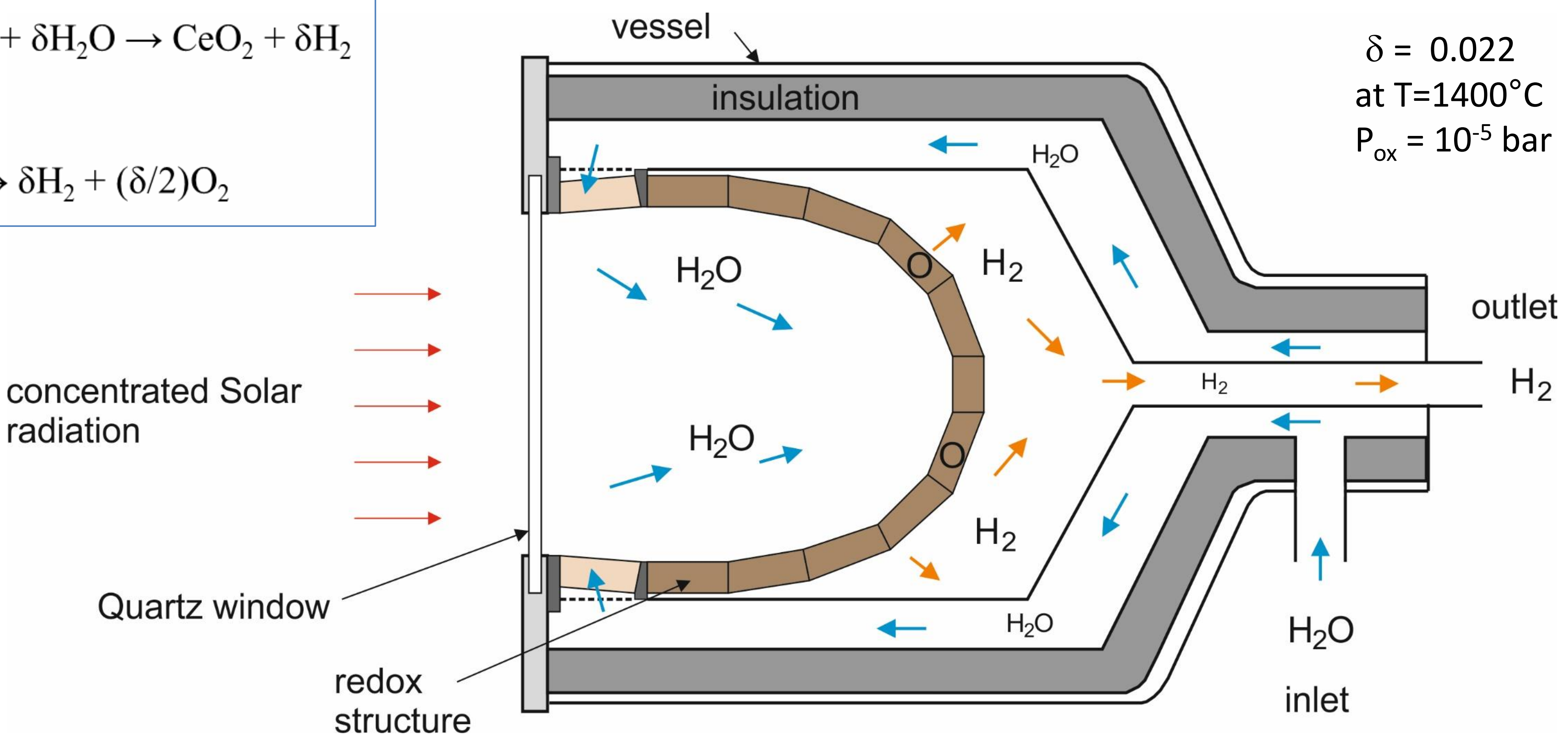
$$CeO_{2-\delta} + \delta H_2O \rightarrow CeO_2 + \delta H_2$$

Total:

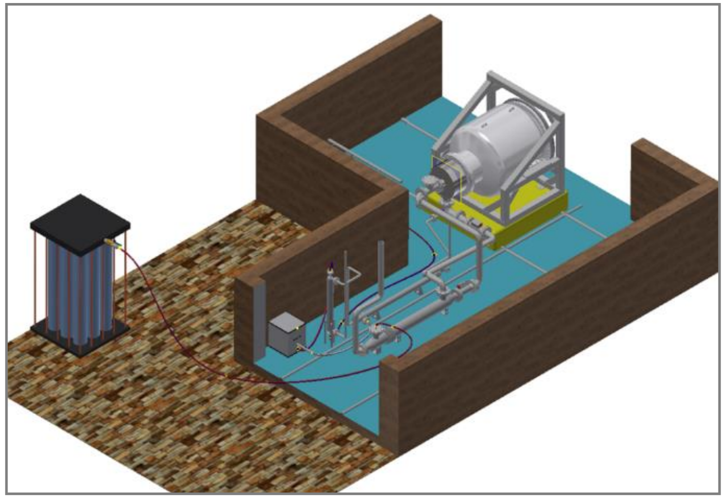
$$\delta H_2O \rightarrow \delta H_2 + (\delta/2)O_2$$

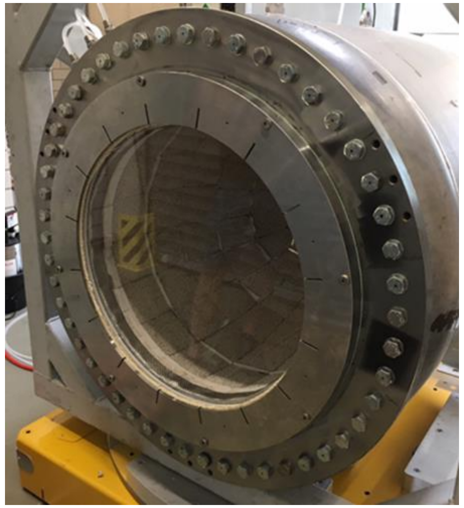
Non-stoichiometry:

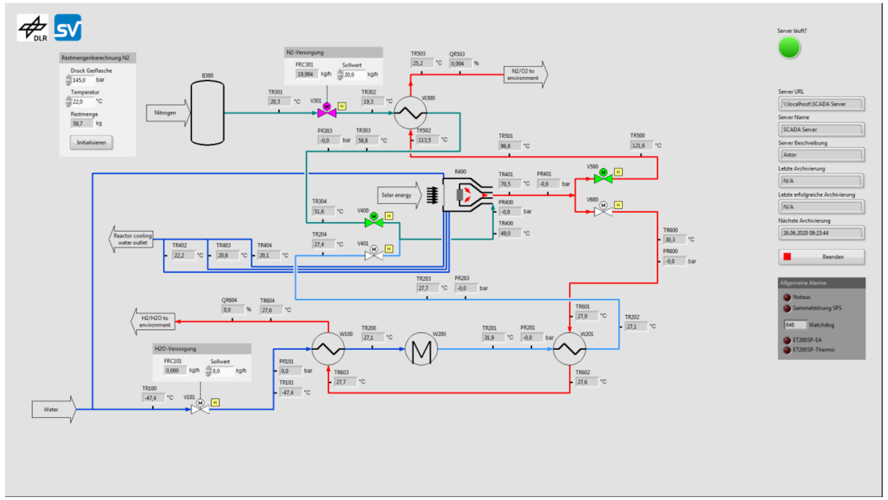
δ = 0.022
at T=1400°C
$P_{ox} = 10^{-5}$ bar

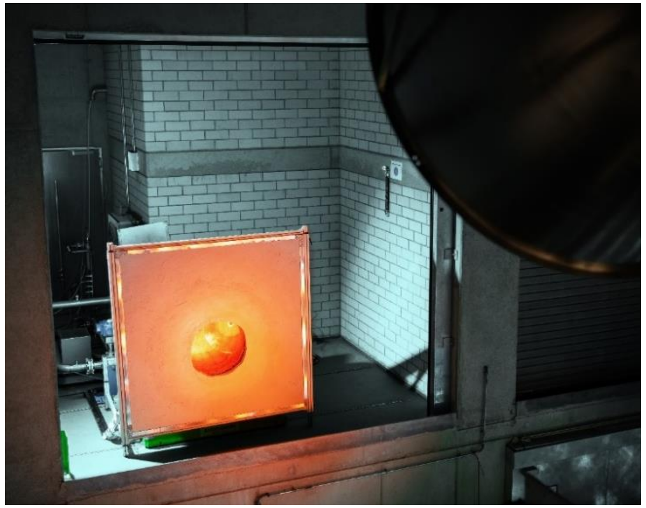


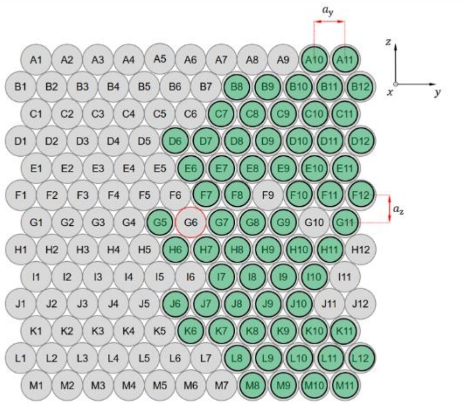
Background: Plant and Process of Project ASTOR

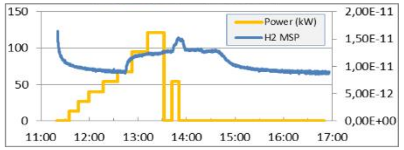


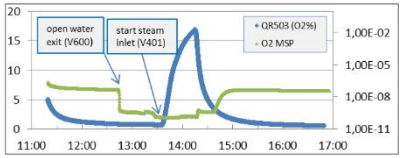


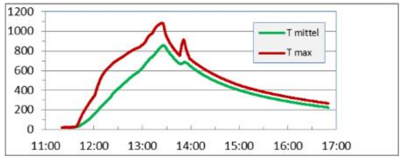








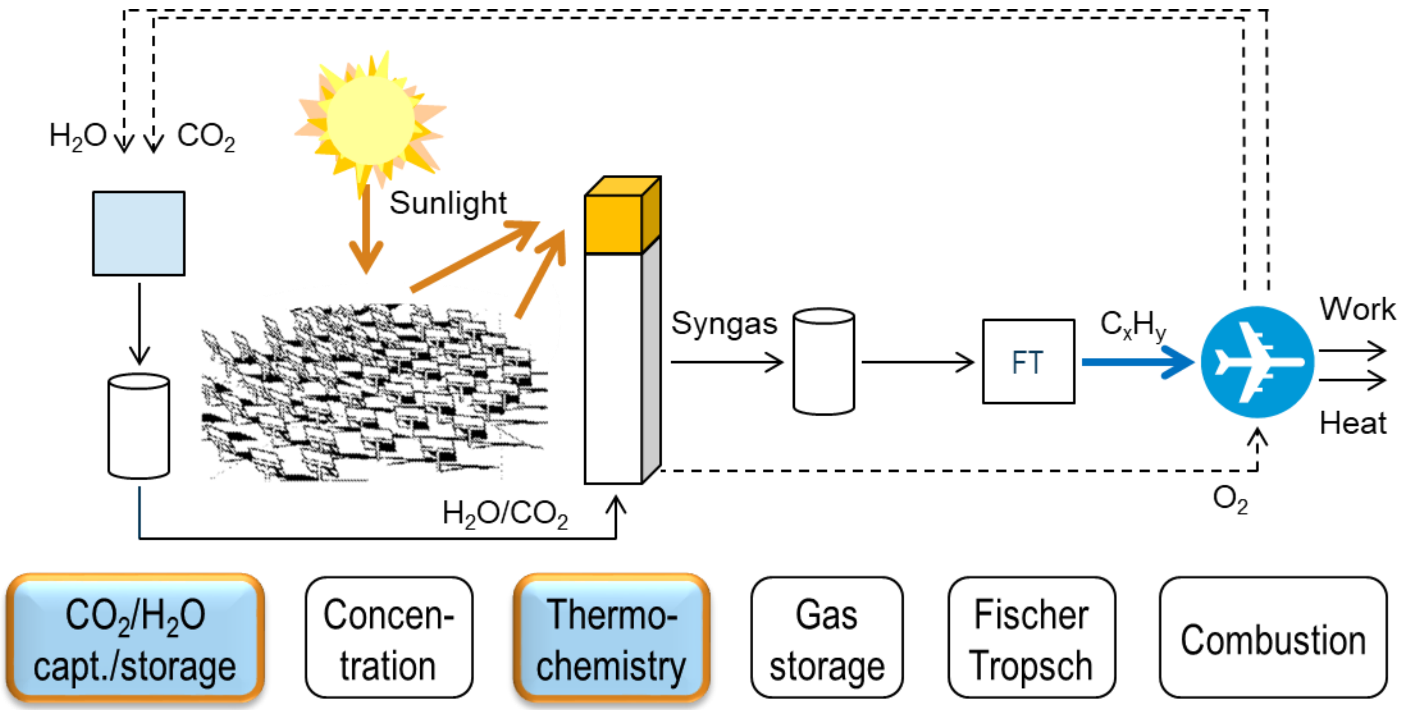




DLR

Sun2Liquid – EU H2020

IMDEA Energy · ETH zürich · HYGEAR · Deutsches Zentrum für Luft- und Raumfahrt (DLR) German Aerospace Center · Bauhaus Luftfahrt · ABENGOA · ARTTIC



- Move from laboratory to field environment
- Demonstration of complete fuel production cycle in a relevant environment
- Increase TRL from 3 to 5
- Scale-up of thermal power input from 4 kW to 50 kW
- Optimization of reactor geometry and material structure to increase efficiency from 2% to 5-10%
- On-site conversion of produced syngas to hydrocarbons

Sun2Liquid Solar Plant in Mostoles (Overview)

Photos: Sun2Liquid/IMDEA Energia

Economic analysis: Regional variability of production cost

Production costs of jet fuel for six countries with favourable solar resource.

	USA	Australia	Spain	Morocco	Chile	South Africa
DNI [kWh/(m^2 y)]	2800	2800	2000	2500	3500	3100
Mirror area [10^6 m^2]	8.15	8.15	11.4	9.12	6.52	7.36
Labour costs [10^6 €]	19.1	19.6	8.71	2.14	3.42	3.46
Investment costs [10^9 €]	1.53	1.53	1.89	1.64	1.35	1.45
O&M costs [10^6 €]	82.9	83.4	79.0	67.9	64.4	65.7
WACC [%]	5.7	6.2	4.9	8.1	7.1	13.1
Production costs [€/L jet fuel]	2.17	2.30	2.21	2.37	2.12	3.10

C. Falter et al. Energies 2020, 13, 802.

Economic analysis: Sensitivity of production cost

Core assumptions for baseline case and for low-cost scenario.

Subsystem	Baseline case	Low-cost scenario
Heliostat costs [€/m²]	100	75
DNI [kWh/(m² y)]	2500	3500
Thermochemical efficiency	15.1%	20%
Cost of CO_2 capture [€/t]	108	45
Production costs [€/L jet fuel]	2.37	1.60

C. Falter et al. Energies 2020, 13, 802.

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HORIZON 2020

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Thank you for your attention!

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