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European Energy Research Alliance

STAGE-STE related capabilities and infrastructures at **ETH Zürich**

Department of Mechanical and Process Engineering
Professorship of Renewable Energy Carriers, **www.pre.ethz.ch**

Overview

1. Overview ETH Zürich (ETHZ) & Professorship of Renewable Energy Carriers (PREC)
2. Capabilities and major infrastructures
3. Research topics
   3.1 related to WP7
   3.2 related to WP9
   3.3 related to WP12

Overview ETHZ & PREC

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ETH
Swiss Federal Institute of Technology Zurich

Founded in 1854
380 professorships
16,000 students
22 Nobel Prize awardees

PREC
Professorship of Renewable Energy Carriers

Staff (2014):

- 1 professor
- 1 deputy head
- 3 senior scientists
- 5 post docs
- 25 PhD students
- 55 MS students
- 3 engineers, CFD support
- PSI's Solar Technology Lab

Capabilities and major infrastructures

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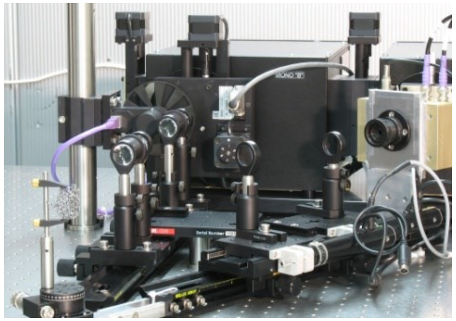
Research Mission

Advancement of the thermal and chemical engineering sciences applied to the field of renewable energy technologies

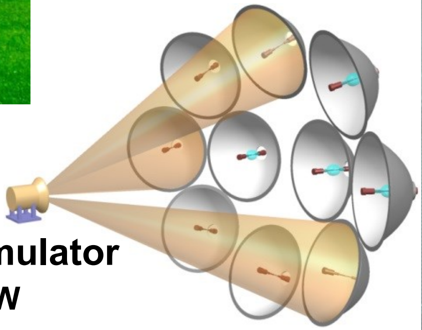
Experimental facilities

Radiation Heat Transfer Lab



Chemistry & Physics Labs

Solar Furnace
Radiative Power: 40 kW
Radiative Flux: 5,000 suns



High-Flux Solar Simulator
Radiative Power: 50 kW
Radiative Flux: 11,000 suns

Research topics related to WP7

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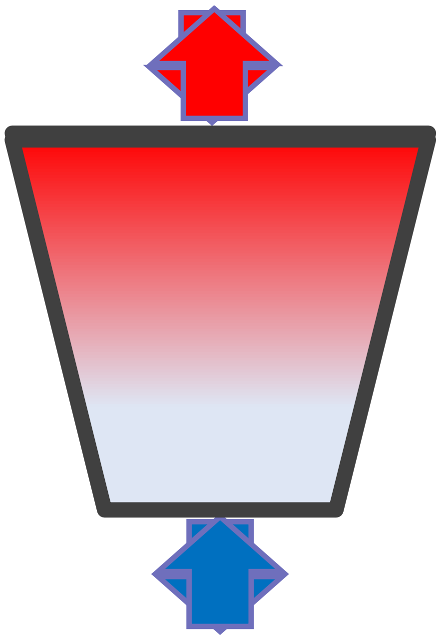
Packed bed of rocks

AIRLIGHT ENERGY **SUPSI**

Discharging



- Abundant and economical storing material
- Applicability in a wide range of temperatures
- Direct heat transfer between storage material and HTF
- No degradation or chemical instability
- No safety concerns
- Mechanical stability due to concrete walls and conical shape

- Haenchen M., Brückner S., Steinfeld A., "High-Temperature Thermal Storage using a Packed Bed of Rocks - Heat Transfer Analysis and Experimental Validation", *Applied Thermal Engineering*, Vol. 31, pp. 1798-1806, 2011.

- Zanganeh G., Pedretti A., Zavattoni S., Barbato M., Steinfeld A., "Packed-Bed Thermal Storage for Concentrated Solar Power – Pilot-Scale Demonstration and Industrial-Scale Design", *Solar Energy,* Vol. 86, pp. 3084–3098, 2012.

Research topics related to WP7

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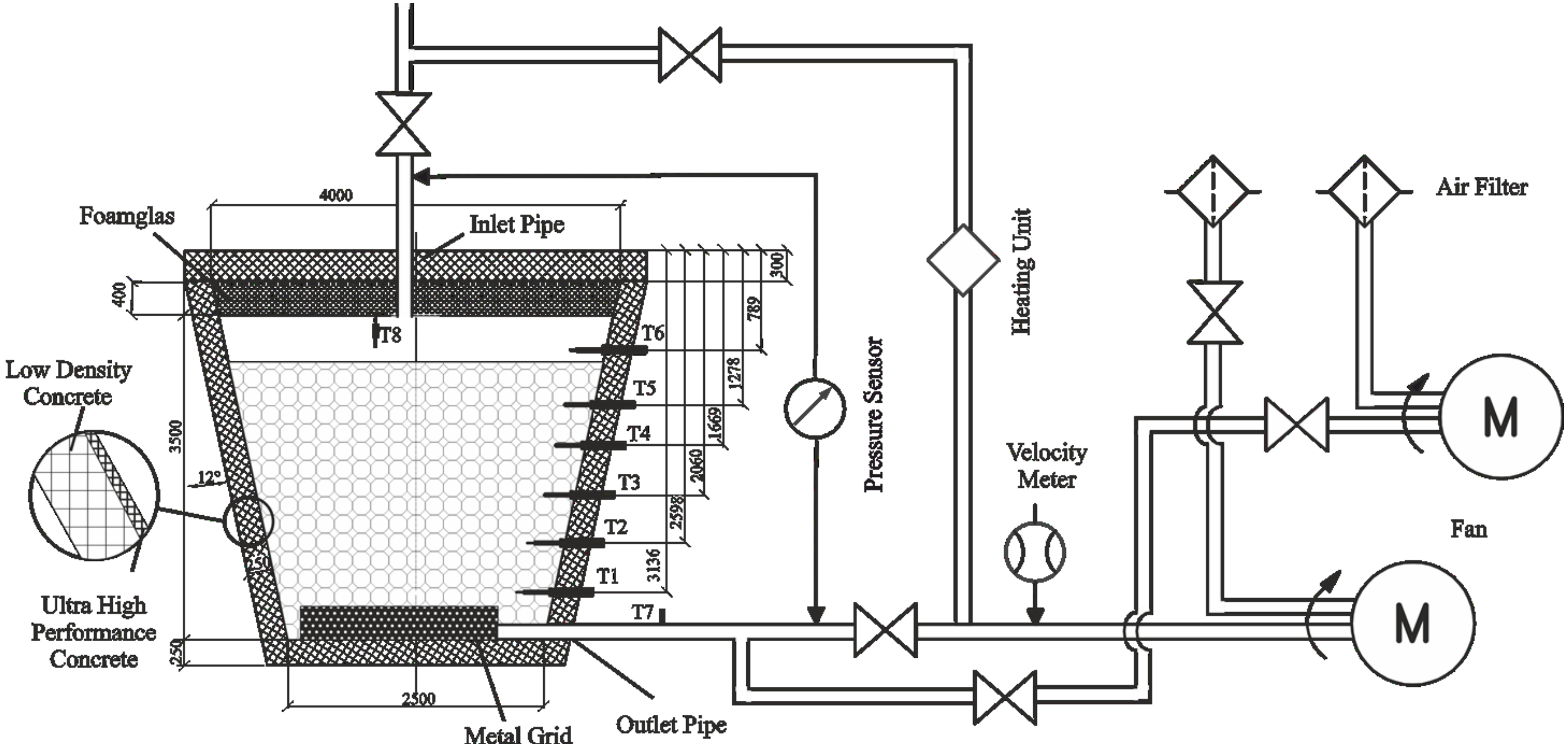
Packed bed of rocks



- Applied Thermal Engineering 31, pp. 1798-1806, 2011.
- Solar Energy 86, pp. 3084–3098, 2012.

AIRLIGHT ENERGY

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Research topics related to WP7

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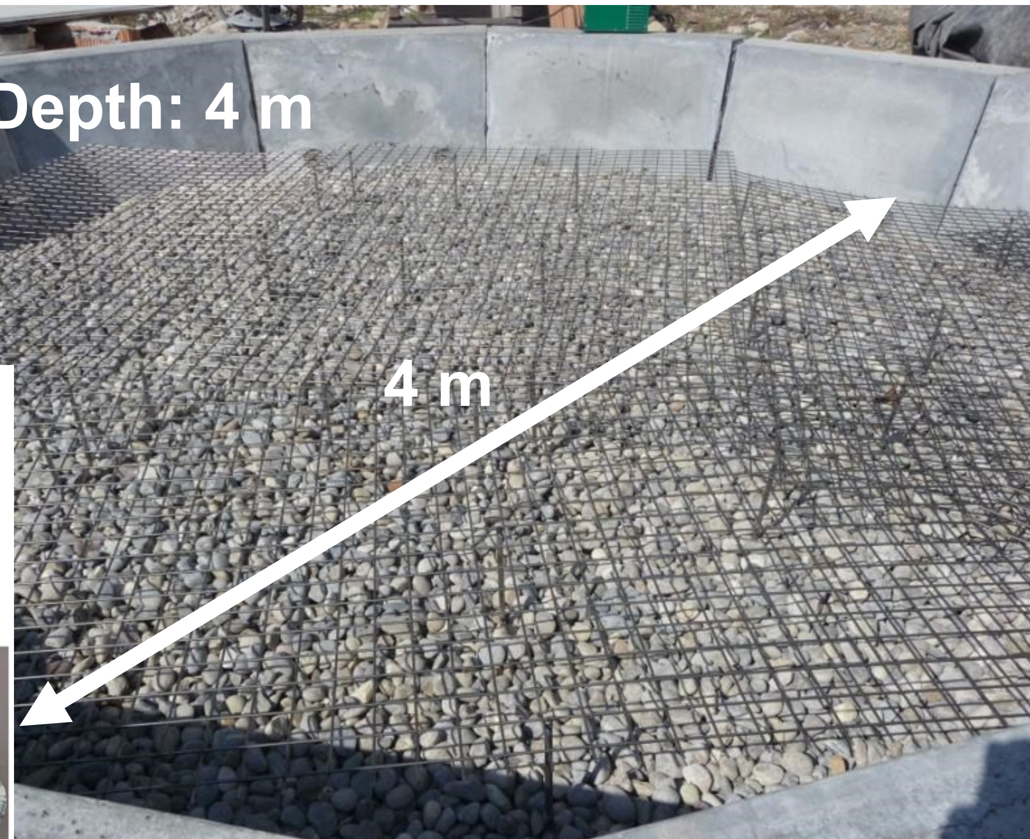
Thermal storage prototype in Biasca, Switzerland



- Applied Thermal Engineering 31, pp. 1798-1806, 2011.
- Solar Energy 86, pp. 3084–3098, 2012.

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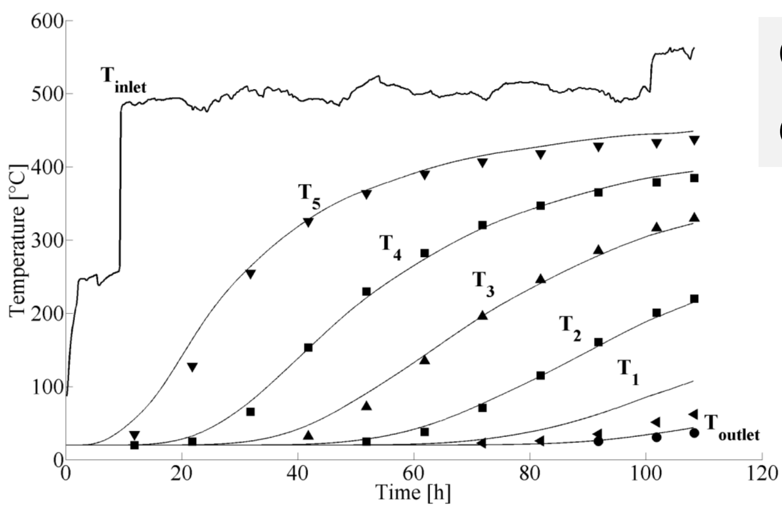
Research topics related to WP7

Modelling: Transient Heat Transfer

$$\underbrace{\varepsilon A \rho_f \frac{\partial u_f}{\partial t}\delta z}_{\text{internal energy change}} + \underbrace{\dot{m} \frac{\partial h_f}{\partial z}\delta z}_{\text{convection of energy by flow}} = \underbrace{A h_v \delta z (T_s - T_f)}_{\text{convection fluid-solid phases}} + \underbrace{U_{wall} C \delta z (T_w - T_f)}_{\text{conduction at lateral walls}}$$

$$\underbrace{(1-\varepsilon) A \rho_s \frac{\partial u_s}{\partial t}\delta z}_{\text{internal energy change}} = \underbrace{A h_v \delta z (T_f - T_s)}_{\text{convection fluid-solid phases}} + \underbrace{\frac{\partial}{\partial z}\left(k_{eff} A \frac{\partial T_s}{\partial z}\right)\delta z}_{\text{axial dispersion by conduction-radiation}}$$



Cycle efficiency = 96.6%

Outflow air temperature = 640 - 590 °C

- Applied Thermal Engineering 31, pp. 1798-1806, 2011.
- Solar Energy 86, pp. 3084–3098, 2012.

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Research topics related to WP7

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Phase-change materials & Gas-solid reactions for thermal storage

PCMs
- Al/Si eutectic metal alloys
- atop the packed bed of rocks

Gas-solid reactions
- Manganese oxide reaction cycle
- Calcium hydroxide reaction cycle

	Manganese oxide	**Calcium hydroxide**
Application	Central tower CSP	Trough receiver CSP
Stoichiometry	$6\ Mn_2O_3 \leftrightarrow 4\ Mn_3O_4 + O_2$	$Ca(OH)_2 \leftrightarrow CaO + H_2O$
Reaction temperature	700 - 1000 °C	350 – 550 °C

Partners: DLR (D), Siemens (IL), Eramet & Comilog (BE), IMDEA (ES), U. Siegen (D), Bühler AG (CH), PSI (CH)

TCS Power
thermochemical energy storage

Research topics related to WP9

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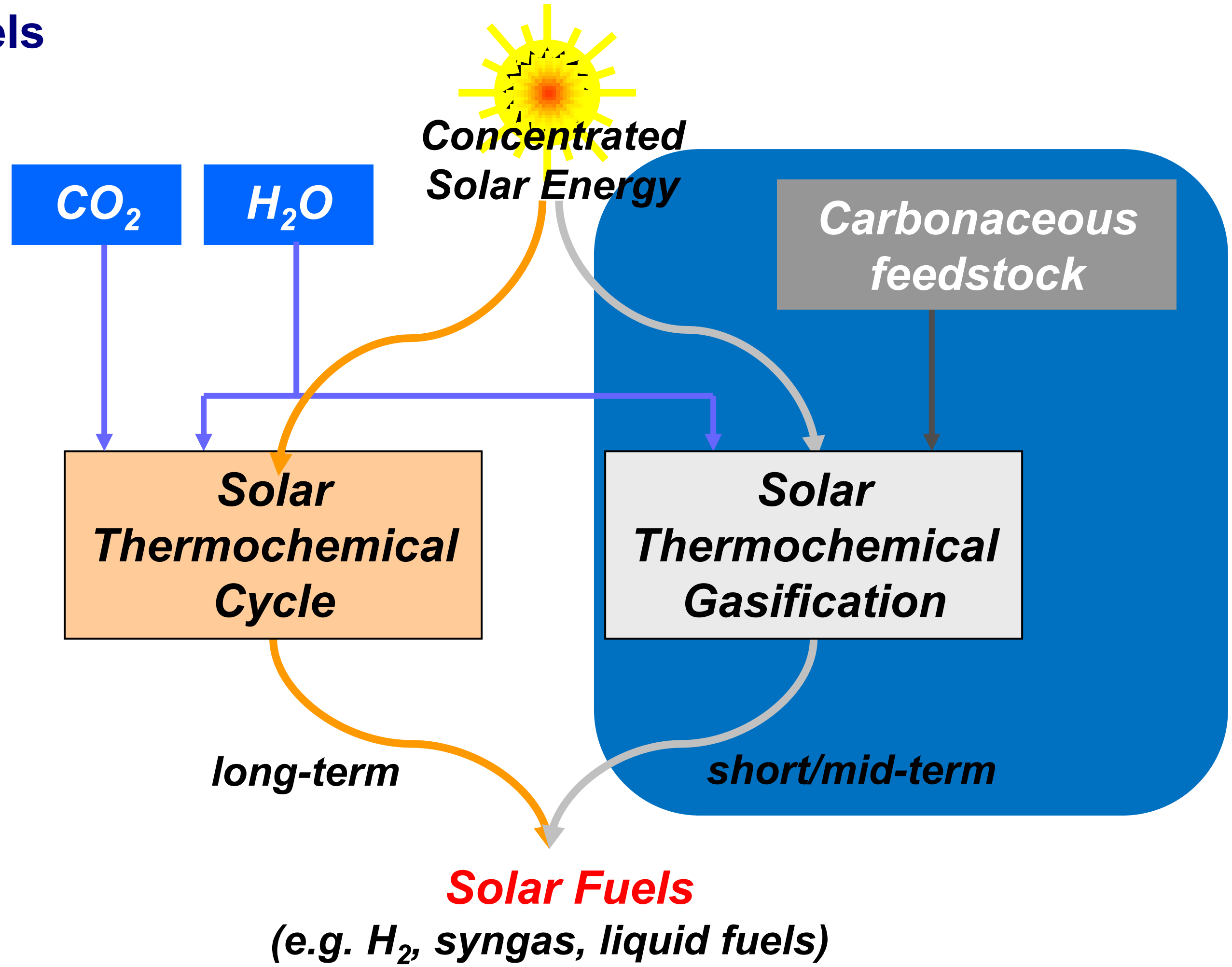
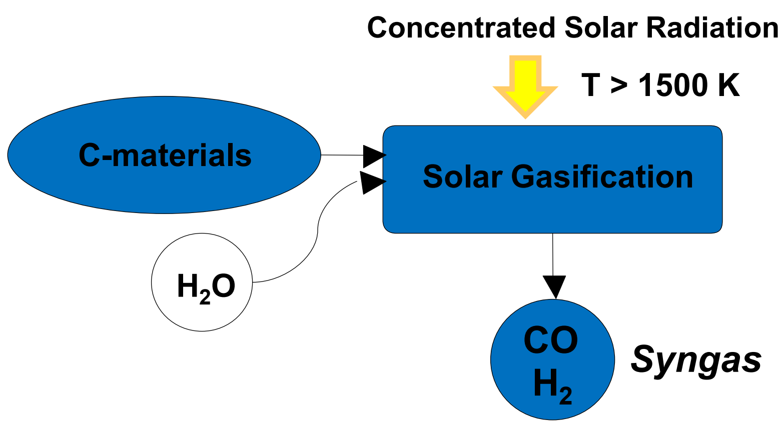
Solar fuels



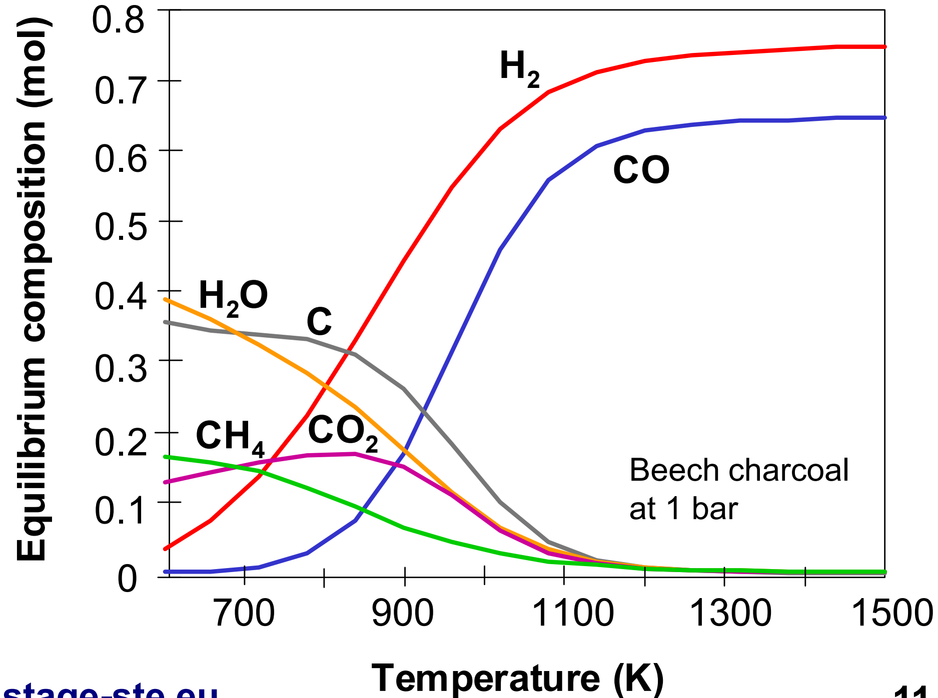
Research topics related to WP9

Solar fuels from carbonaceous feedstock

- **Solar-driven vis-à-vis autothermal**
- Higher energetic value of the syngas produced
- Higher syngas output per unit of feedstock
- Higher quality of the syngas produced
- Elimination of air-separation unit



$$\frac{LHV_{syngas}}{LHV_{C\text{-}feedstock}} = 1.33$$



- *Fuel* 89, 1133–1140, 2010.
- *Energy & Env. Science* 4, 73-82, 2011.
- *AIChE Journal* 57, 3522-3533, 2011

Research topics related to WP9

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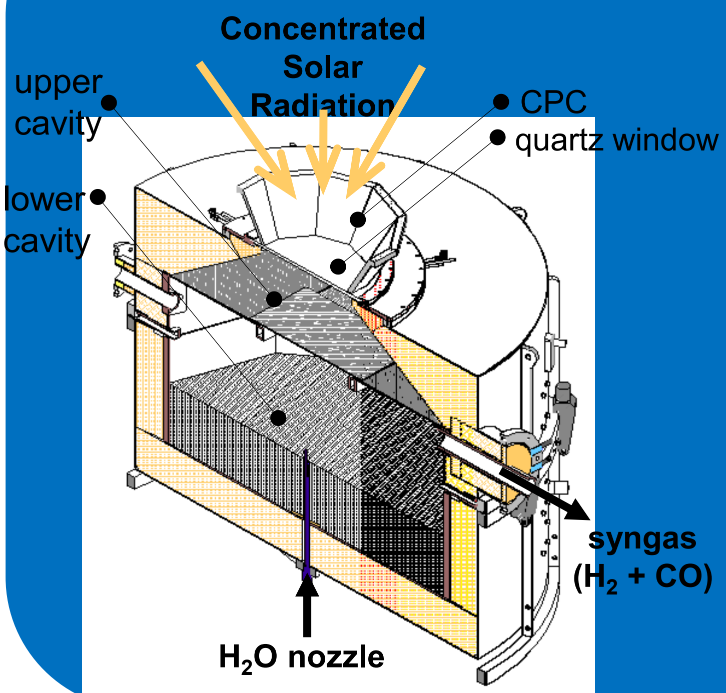
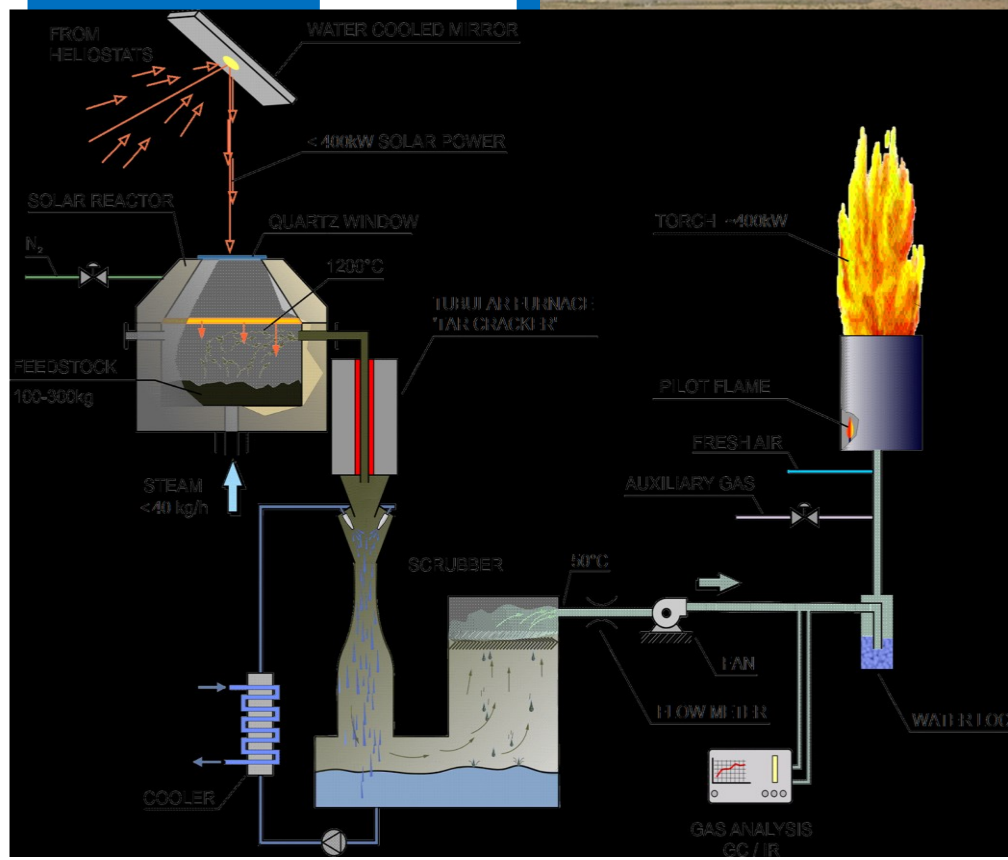
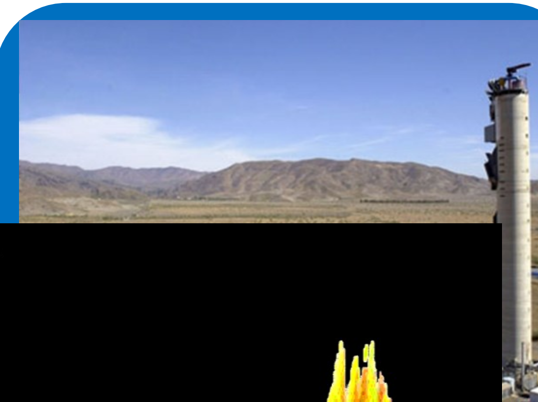
Solar Thermochemical Gasification, 250 kW

Solar Reactor Technology



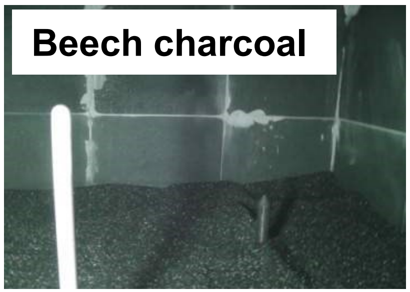




- *Fuel* 89, 1133–1140, 2010.
- *Energy & Env. Science* 4, 73-82, 2011.
- *AIChE Journal* 57, 3522-3533, 2011

Research topics related to WP9

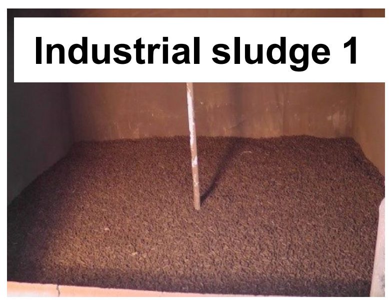
Solar Thermochemical Gasification Feedstock


Beech charcoal

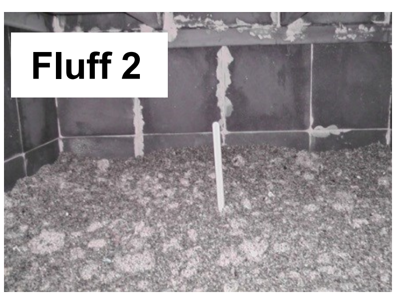

Low Rank Coal

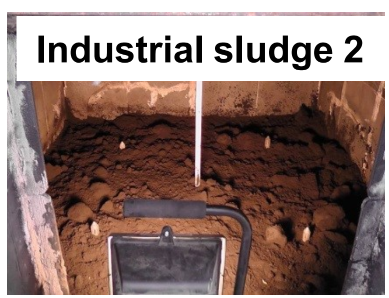

Tire chips


Fluff 1


Industrial sludge 1


Dried sewage sludge

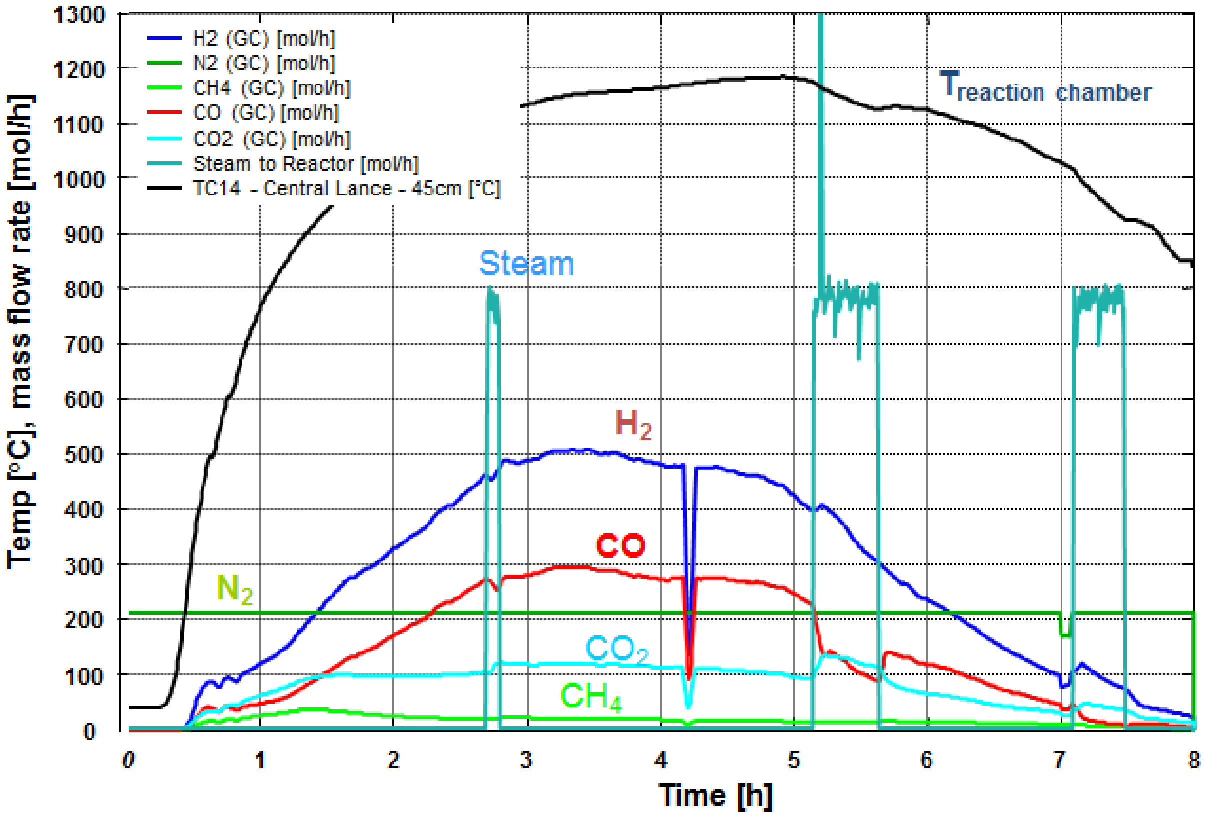

Fluff 2


Industrial sludge 2


Bagasse

Research topics related to WP9

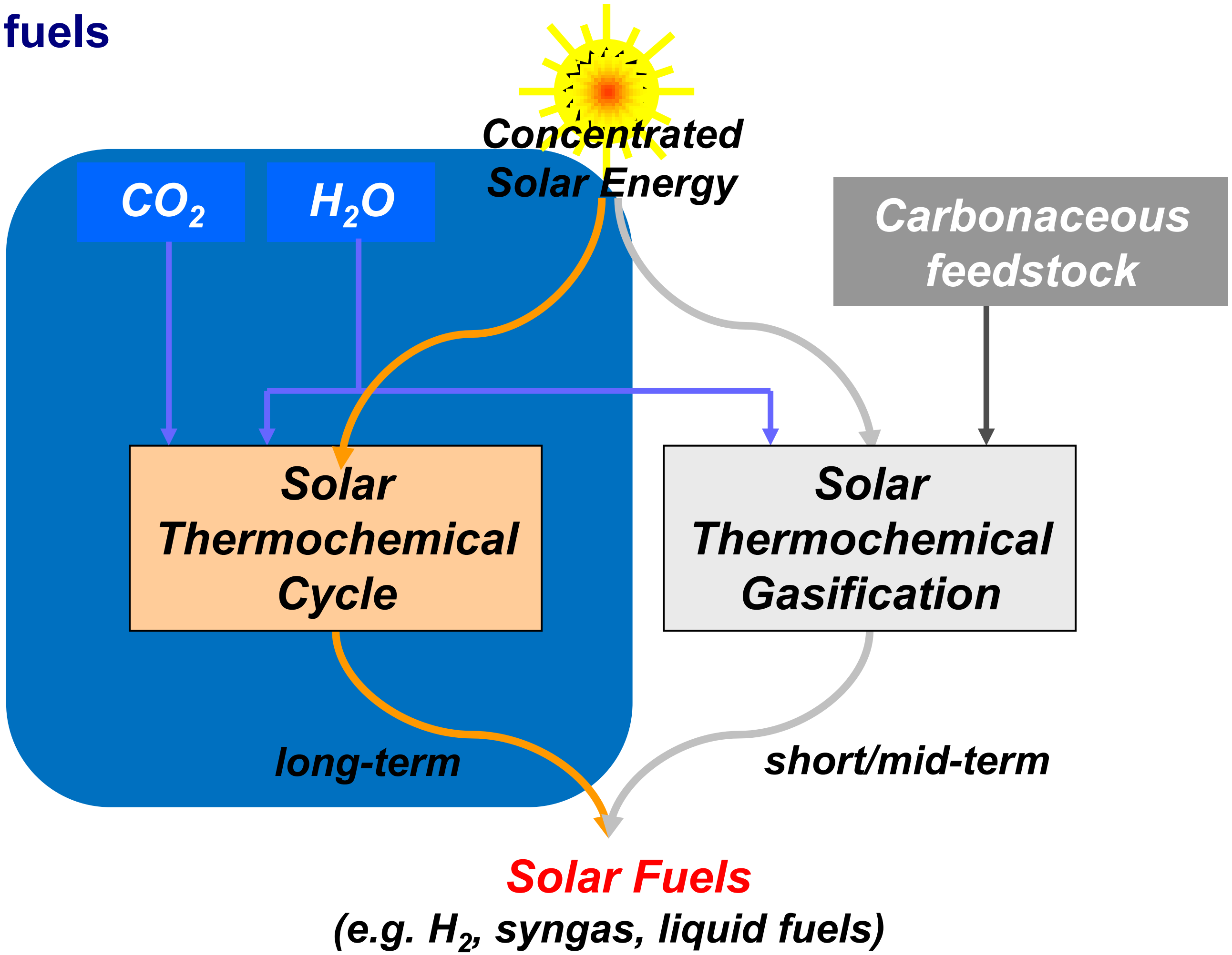
Experimental run with wet bagasse



Wieckert C., Obrist A., von Zedtwitz P., Maag G., Steinfeld A., "Syngas production by thermochemical gasification of carbonaceous waste materials in a 150 kWth packed-bed solar reactor", *Energy & Fuels*, Vol. *27*, pp. 4770-4776, 2013.

Research topics related to WP9

Solar fuels



Research topics related to WP9

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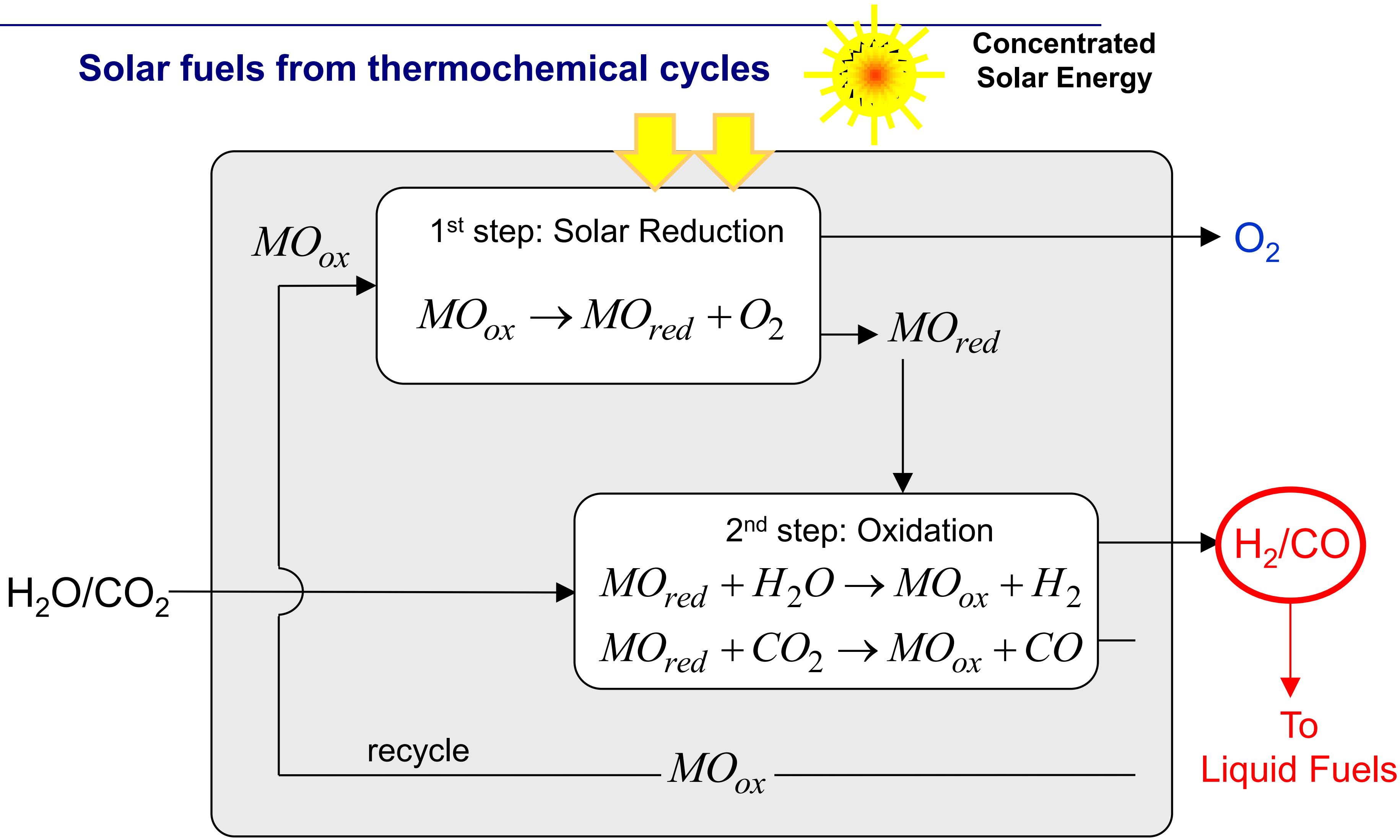
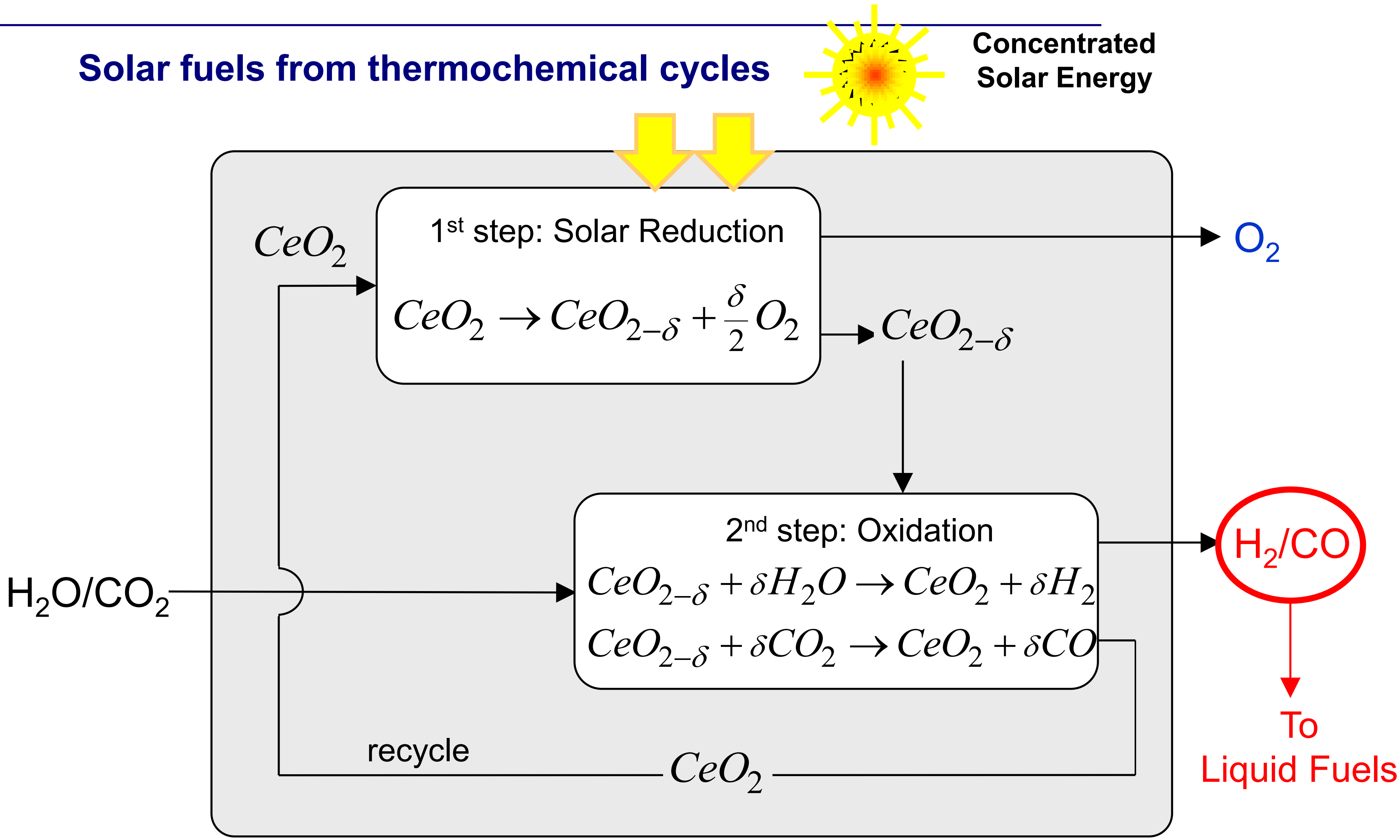
Solar fuels from thermochemical cycles



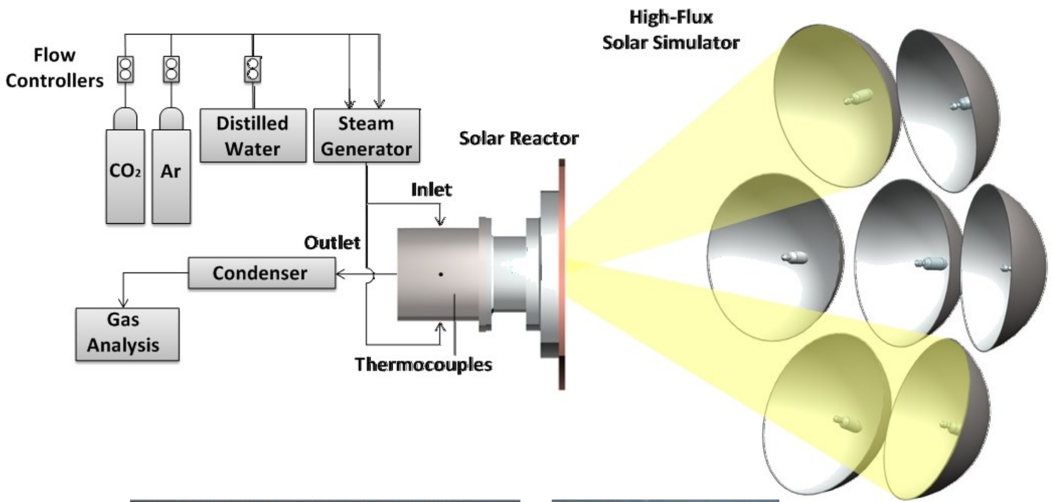
Research topics related to WP9

Solar fuels from thermochemical cycles

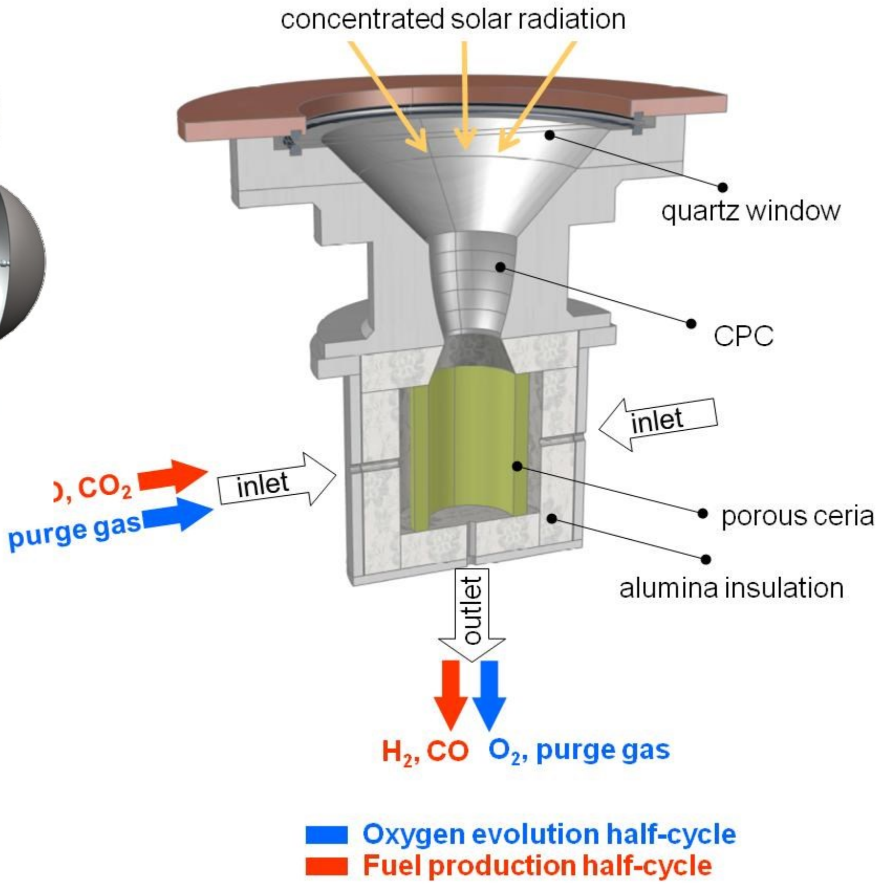


Research topics related to WP9

Solar fuels from thermochemical cycles



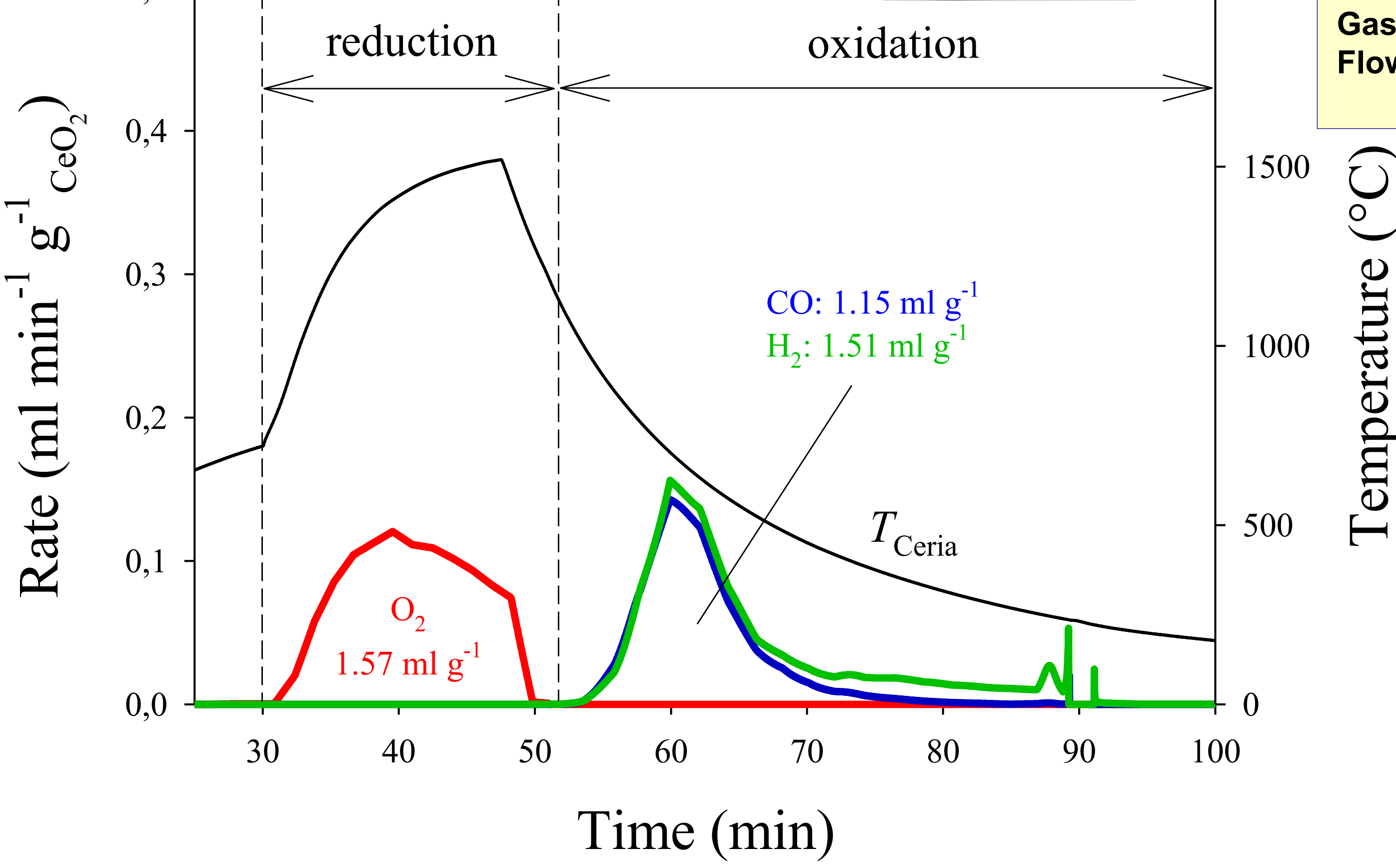
reticulated porous ceria



- Science 330, 1797-1801, 2010.
- *Energy & Env. Science* 5, 6098-6103, 2012.
- Energy & Fuels 26, 7051–7059, 2012.

Research topics related to WP9

Simultaneous CO_2/H_2O splitting



	Reduction	Oxidation
Solar Power	3.4 kW	0 kW
Gas Flows	Ar: 2 l min^{-1}	CO_2: 0.4 l min^{-1} H_2O: 2.2 l min^{-1}

- O_2 : Fuel = 0.5 ± 0.05
- No hydrocarbons
- No C depositions
- Total selectivity

- *Energy & Env. Science* 5, 6098-6103, 2012.

Research topics related to WP12

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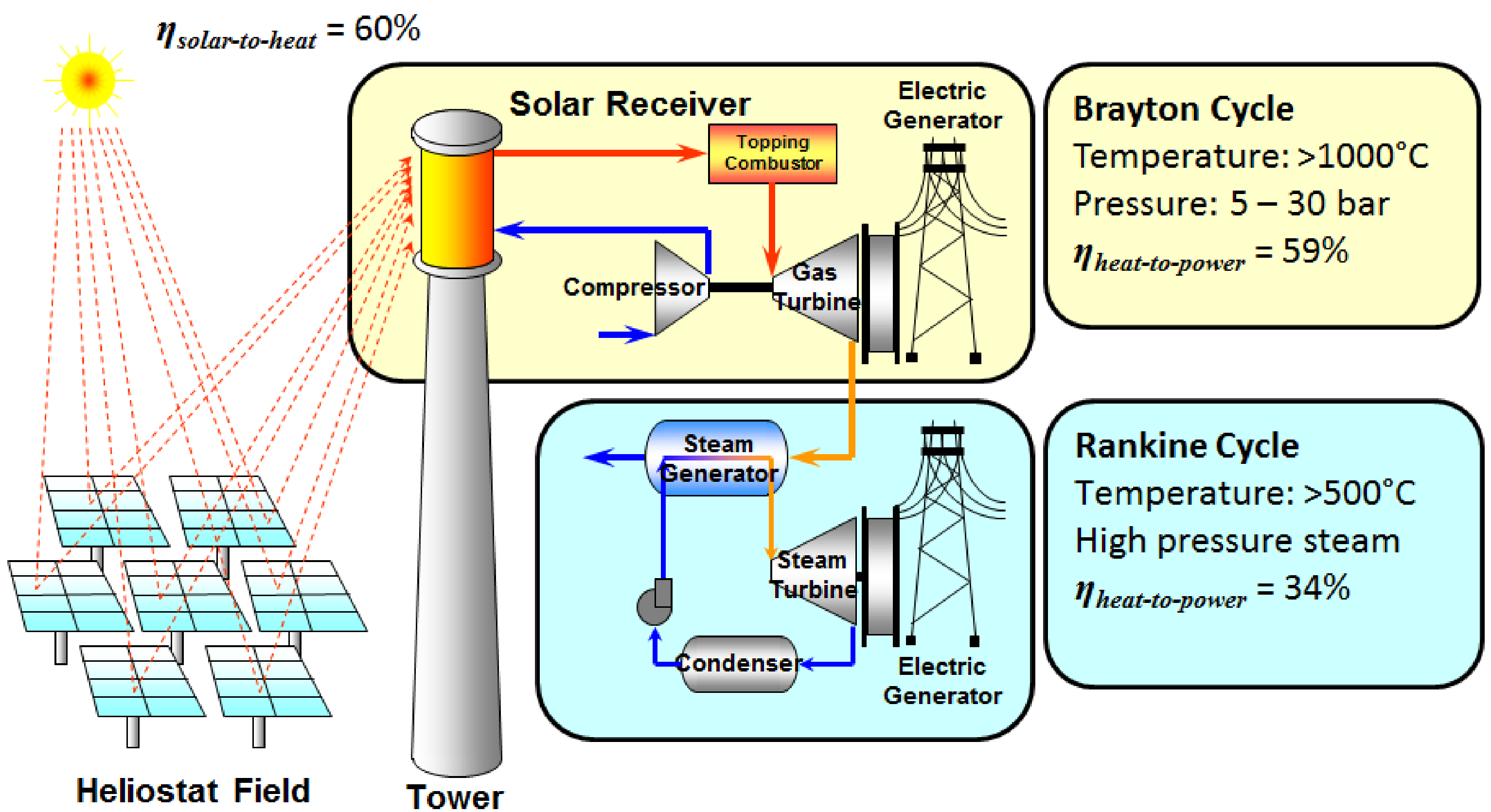
Development of a novel indirect-irradiation solar receiver based on annular reticulate porous ceramics with air as working fluid

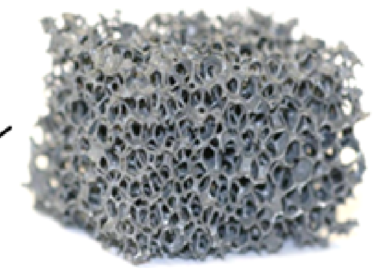


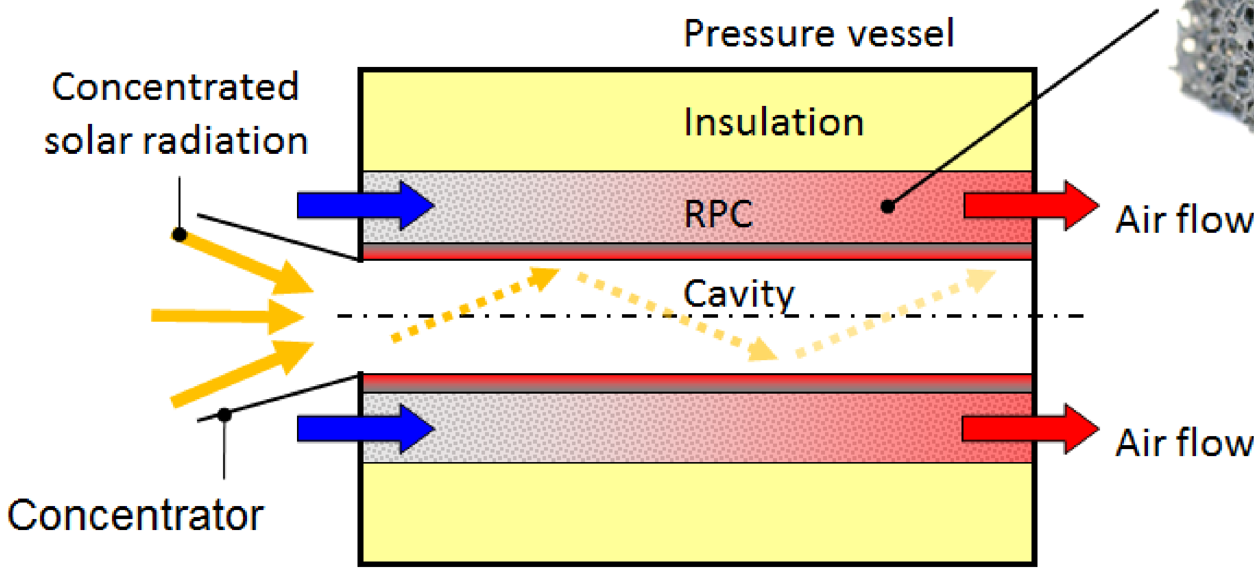
Research topics related to WP12

Development of a novel indirect-irradiation solar receiver based on annular reticulate porous ceramics with air as working fluid

The ETH – Alstom Receiver concept

Indirectly irradiated pressurized ceramic cavity (SiC)





Objectives

T_{air} **>>** 585 °C

T_{target} = 700-900 °C

Thermal receiver efficiency ~ 80 %

Efficiency, $\eta_{th} \times \eta_{carnot}$ ≥ 56 %

ASME JTSEA 1, p. 041002-1, 2009
ASME JSEE 134, p. 021003, 2012

Research topics related to WP12

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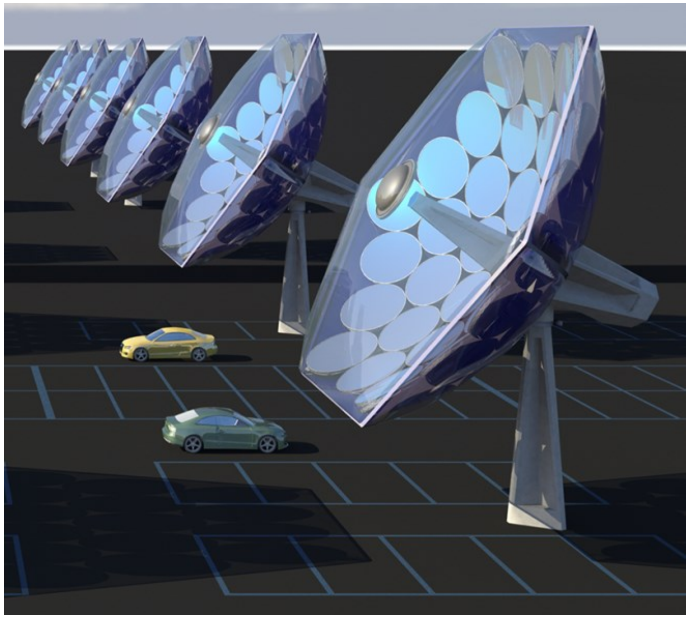
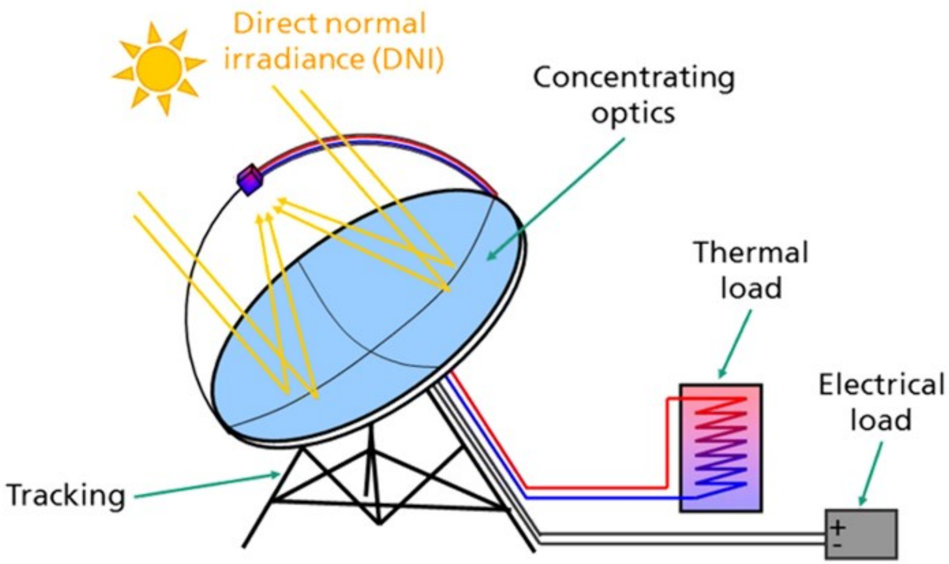
Ray-tracing analysis for the design of non-imaging secondary concentrators for solar parabolic dishes and solar towers

- Goal: approximate parabolic shape with a array of membranes
- Design of secondary non-imaging concentrators: CPC, trumpets, dielectrics.





Partners: Airlight Energy