Energía Solar Térmica de Concentración

Máster en Energías Renovables y Mercado Energético

Sesión 13:
Producción combustibles solares. Visita IMDEA Energía

Año de realización: 2024-2025

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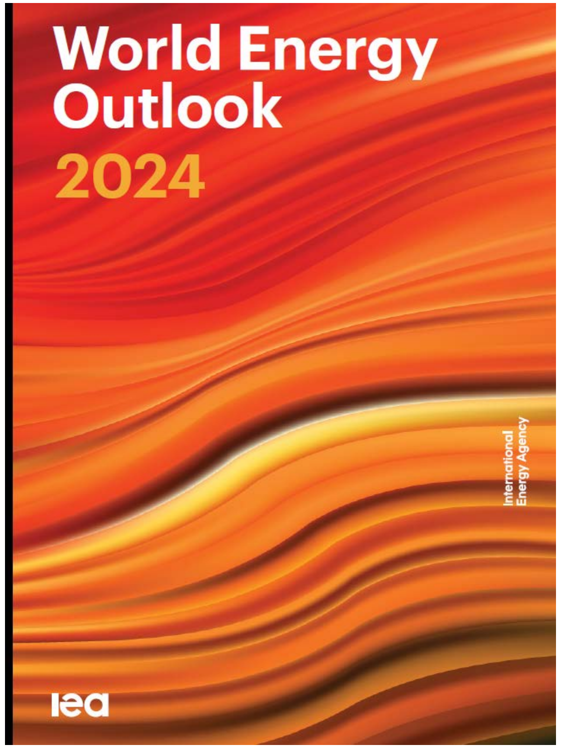
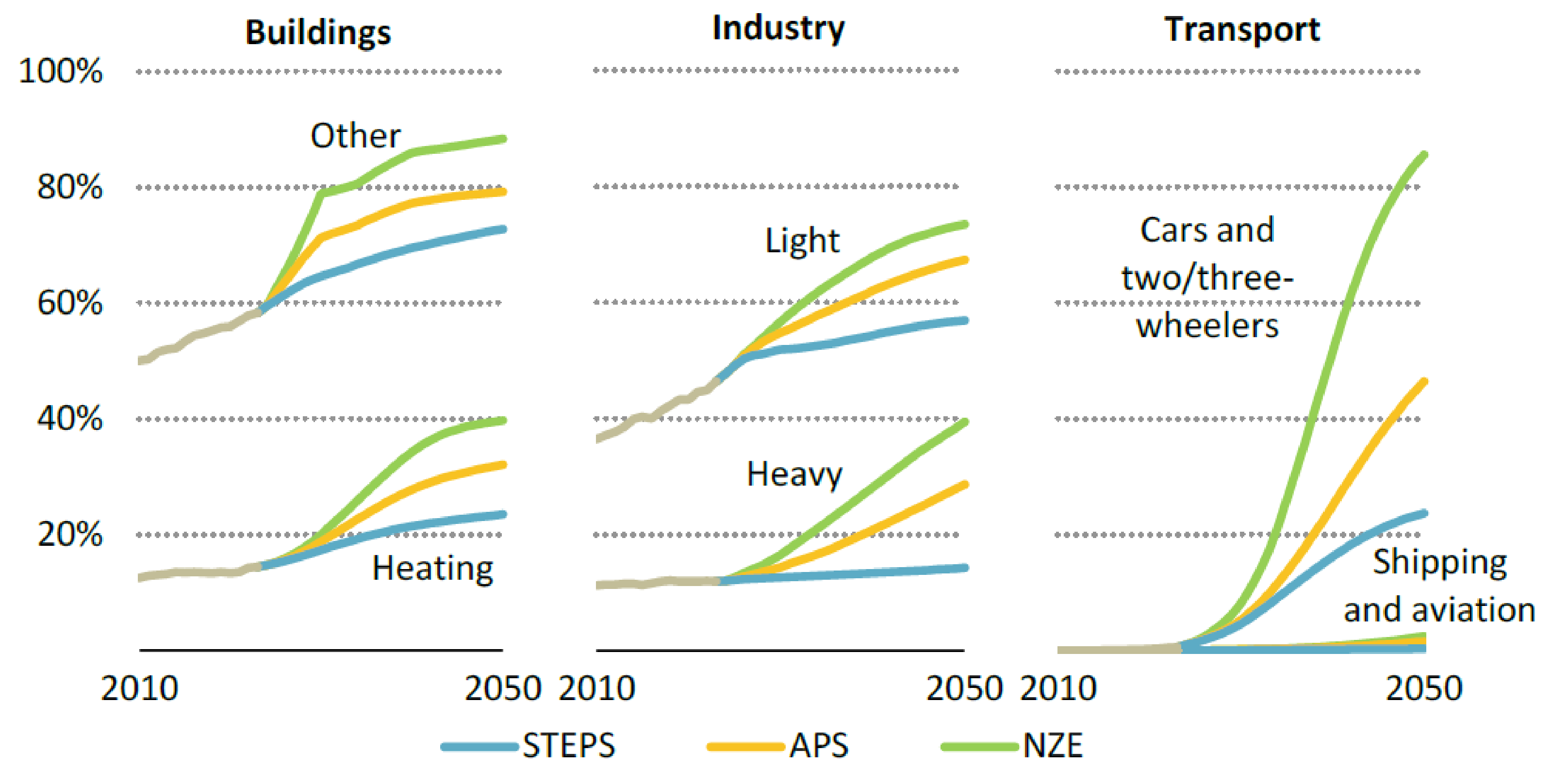
www.eoi.es

The challenge of sectors hard to electrify in the NZE scenario



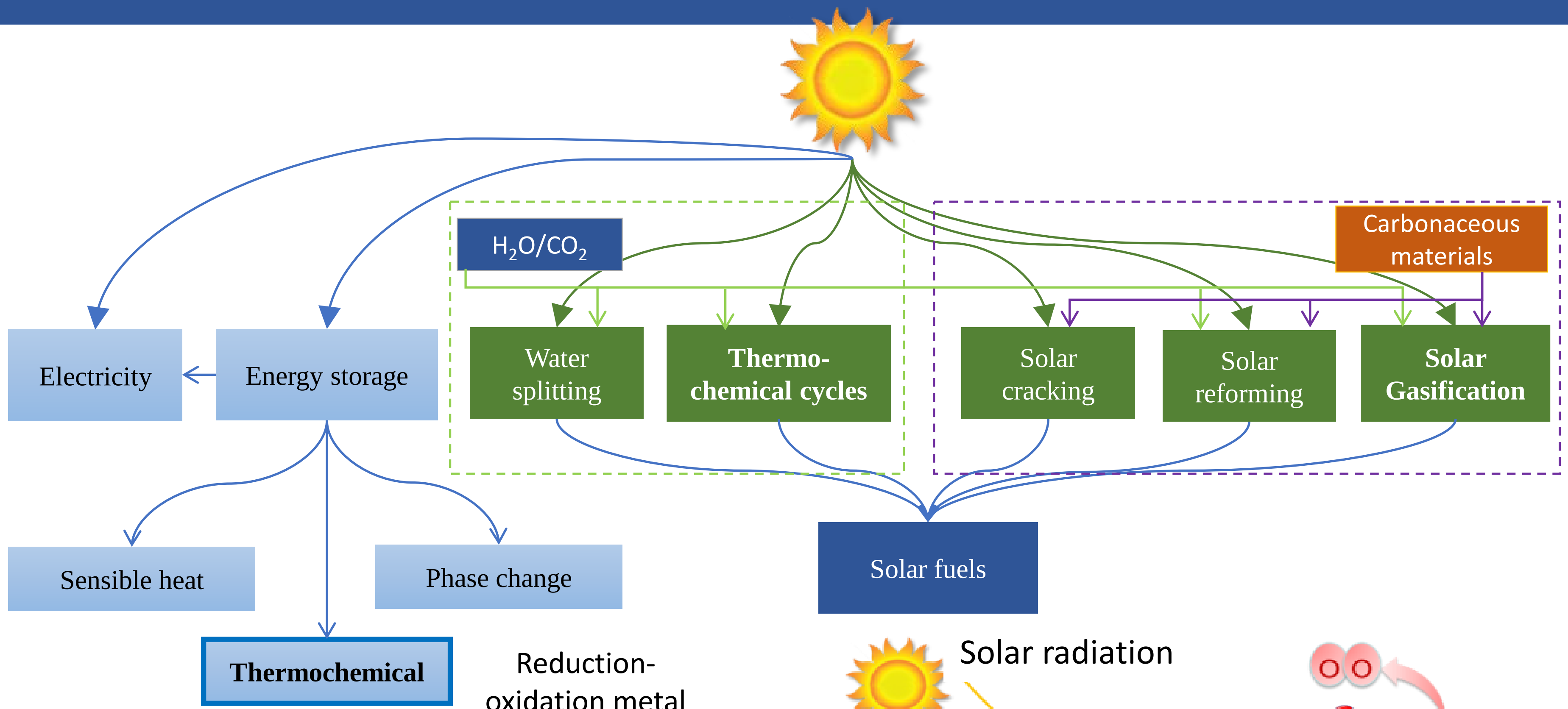
Share of electricity in total final consumption by end-use sector and scenario, 2010-2050



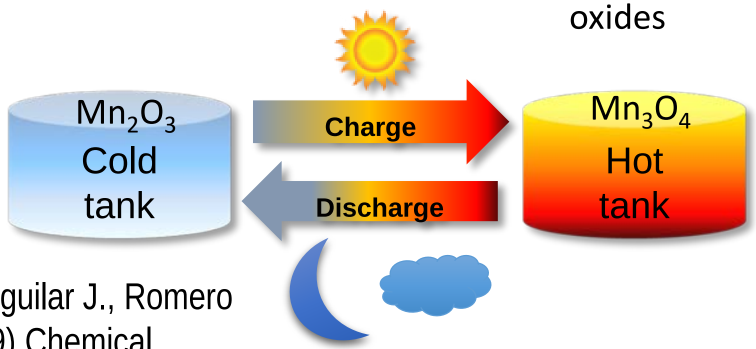
http://www.iea.org/weo

Stated Policies Scenario (STEPS).
Announced Pledges Scenario (APS)
Net Zero Emissions by 2050 (NZE)

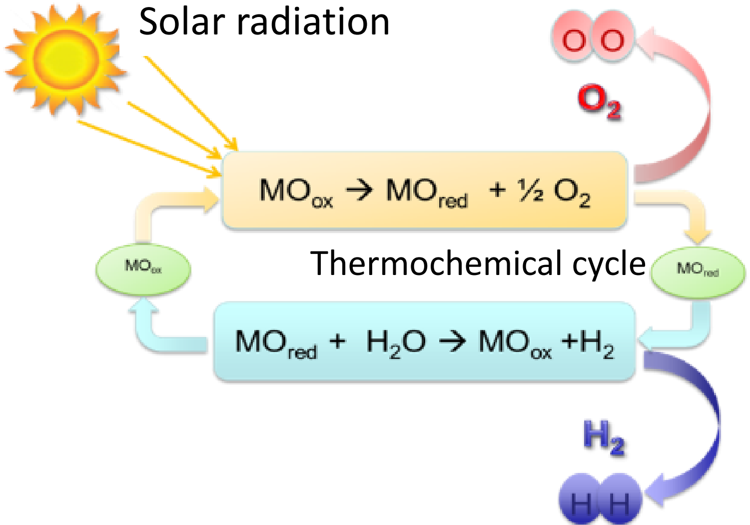
STL: Sun to Liquid Concentrated Solar Radiation



Reduction-oxidation metal oxides

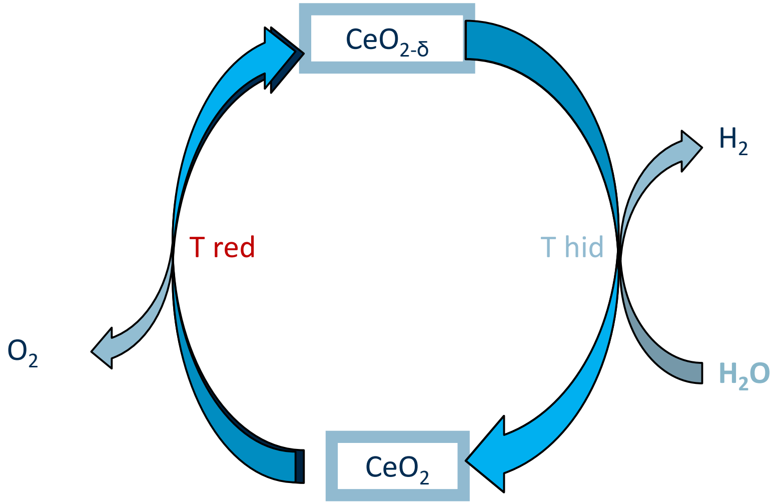


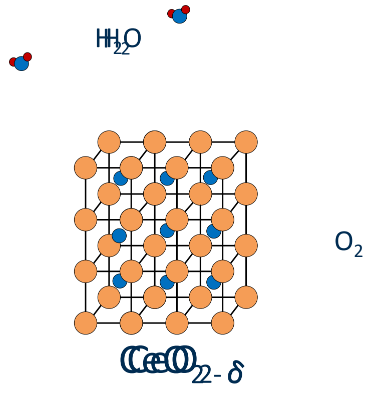
Carrillo A.J., González-Aguilar J., Romero M., Coronado J.M. (2019) Chemical Reviews, 119 (7), pp. 4777 – 4816



J.R. Scheffe, A. Steinfeld, Mater. Today 17 (7) (2014) 341–348 .

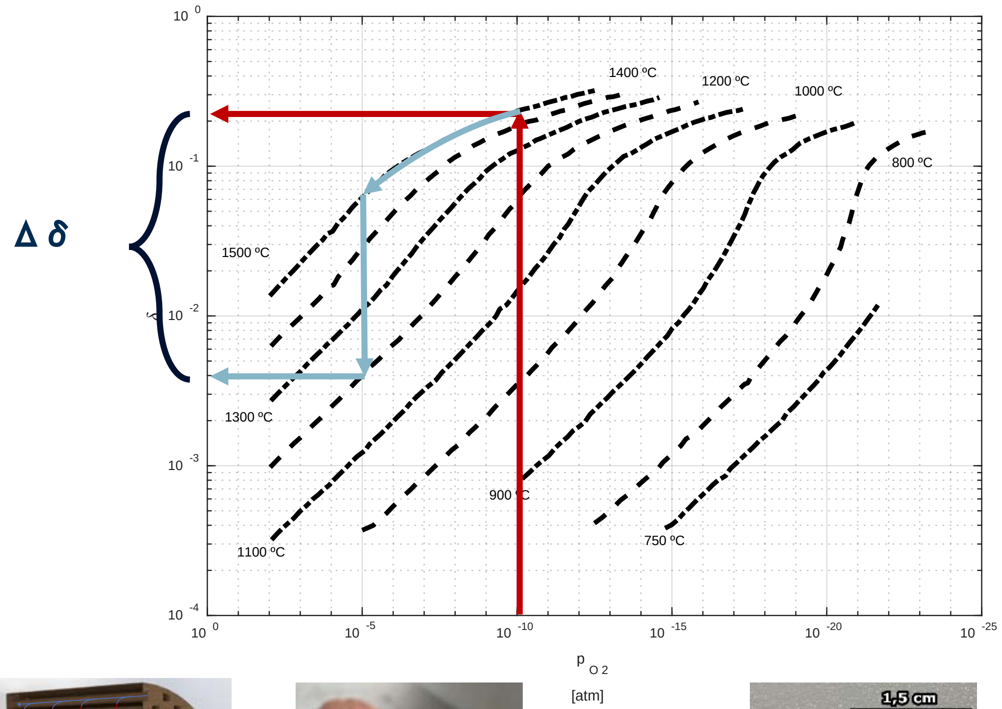
Production of hydrogen with non-stoichiometric metal oxides

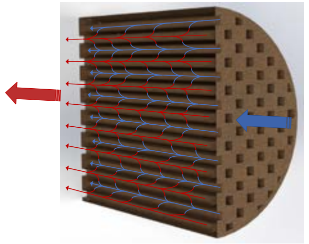




$$CeO_2 \rightleftarrows CeO_{2-\delta} + {}^{\delta}/_{2}\, O_2$$

$$\delta = \frac{mol\ vacancies}{mol\ CeO_2}$$

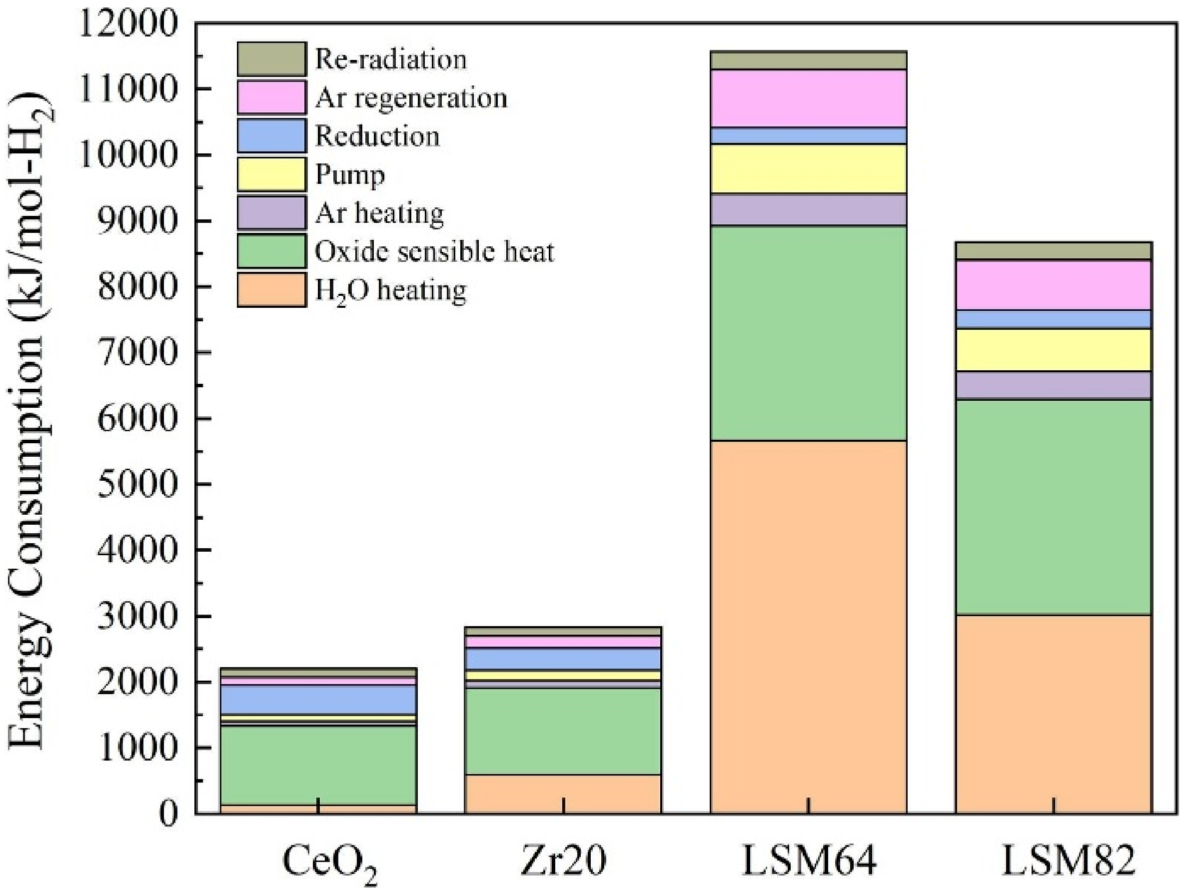


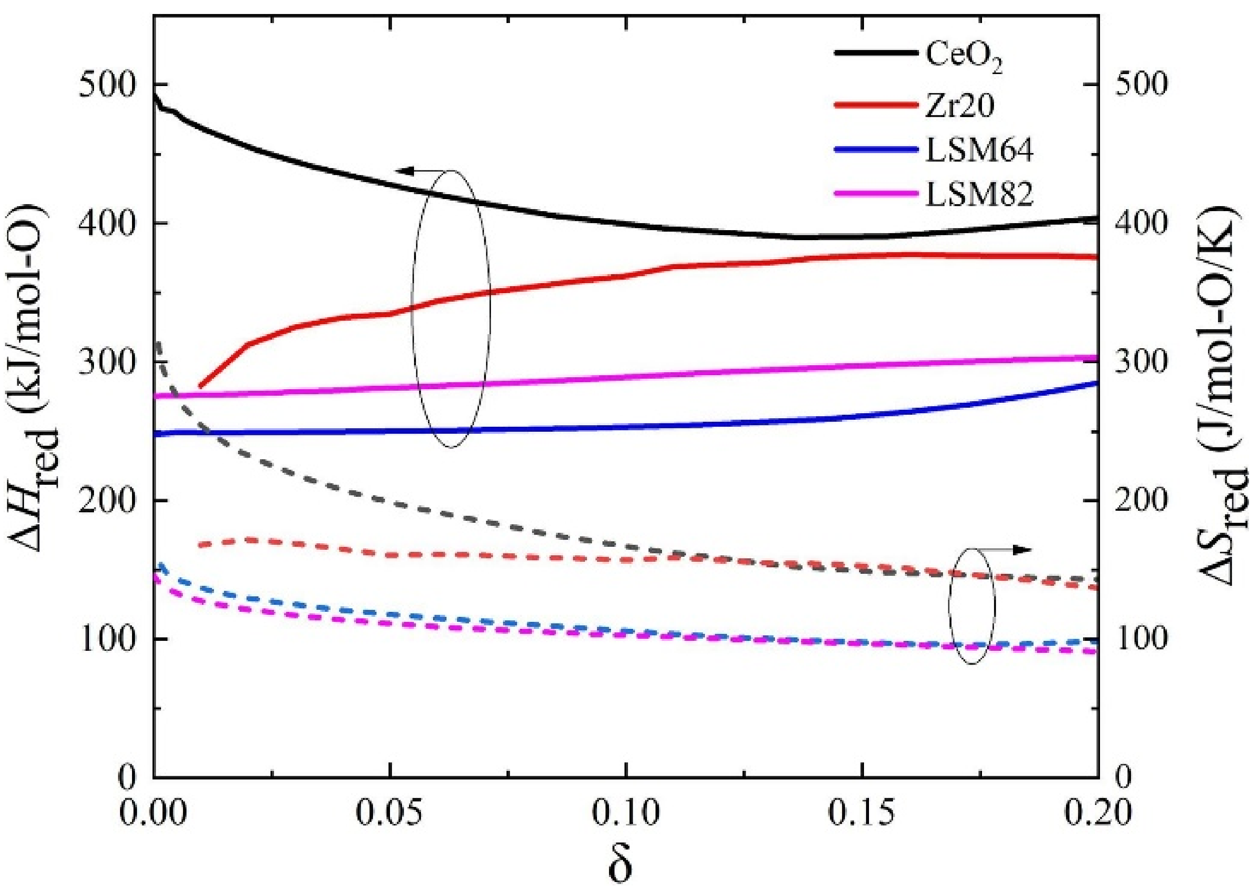


$$CeO_{2-\delta} + \delta H_2O \rightleftarrows CeO_2 + \delta\ H_2$$

Panlener, R. J., Blumenthal, R. N. & Garnier, J. E. A thermodynamic study of nonstoichiometric cerium dioxide. J. Phys. Chem. Solids 36, 1213–1222 (1975)

Efficiency under material optimum conditions

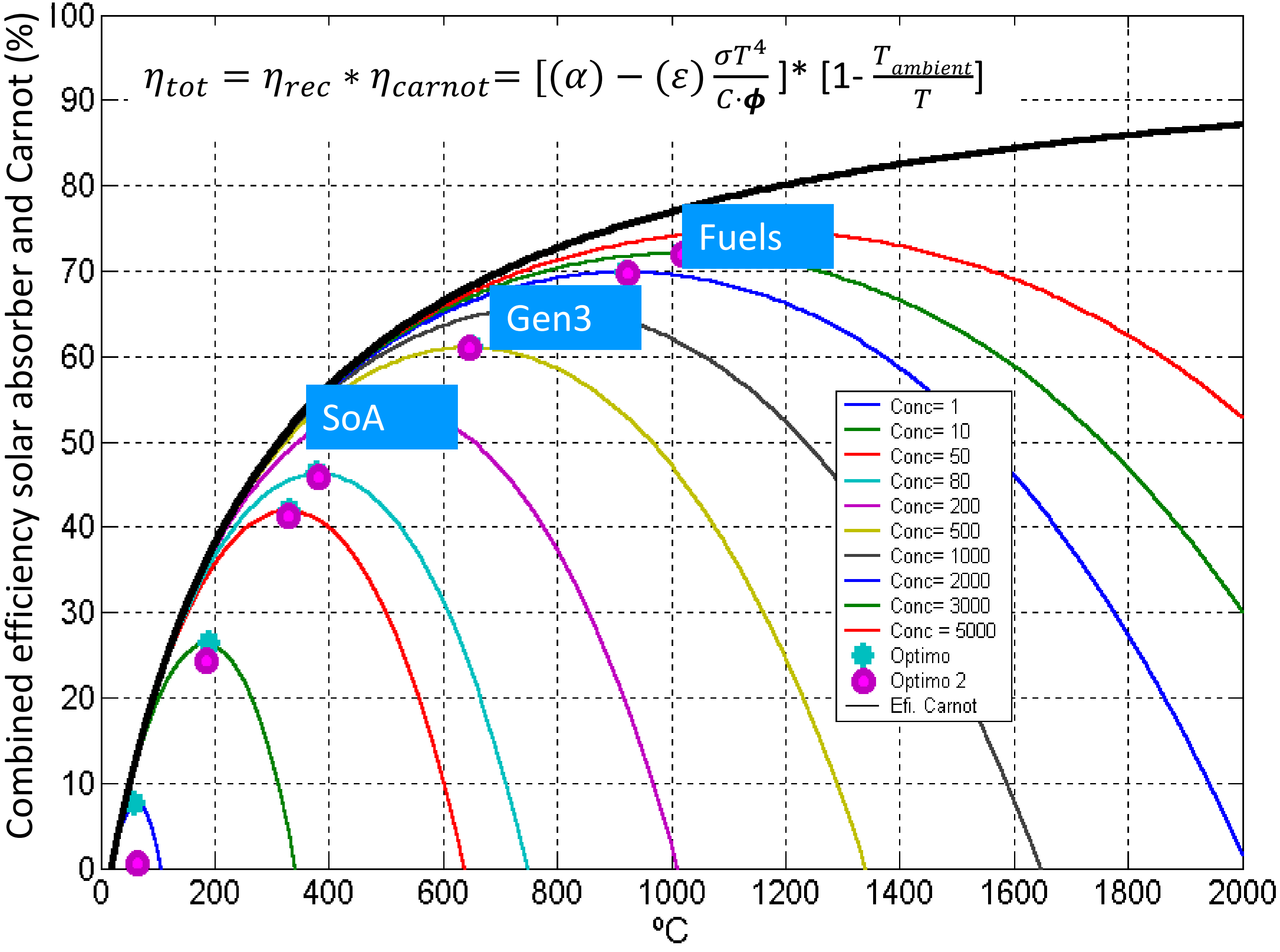


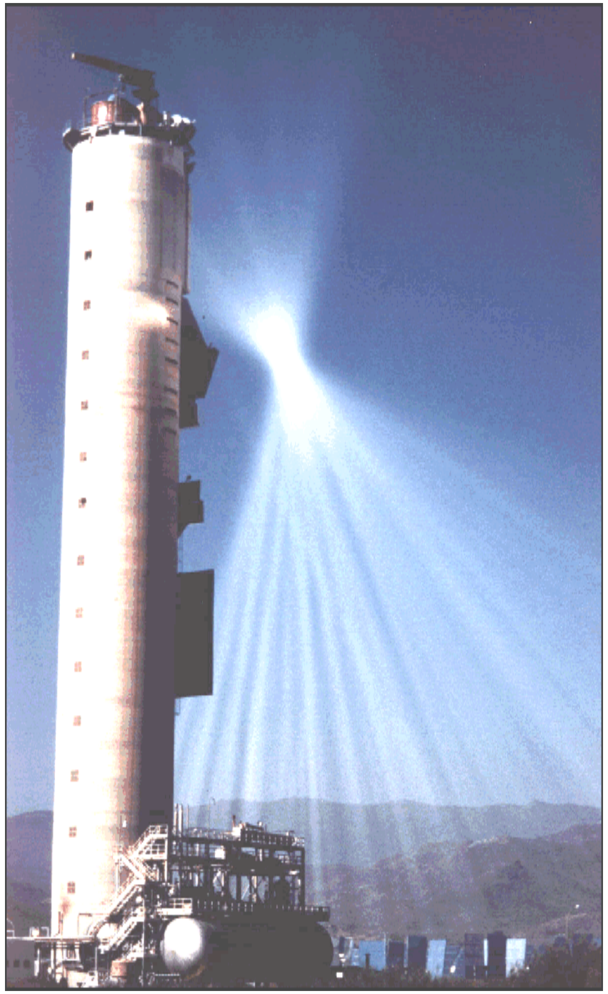


Lou J, Tian Z, Wu Y, Li X, Qian X, Haile S.M.,Hao Y, Solar Energy 241 (2022) 504–514

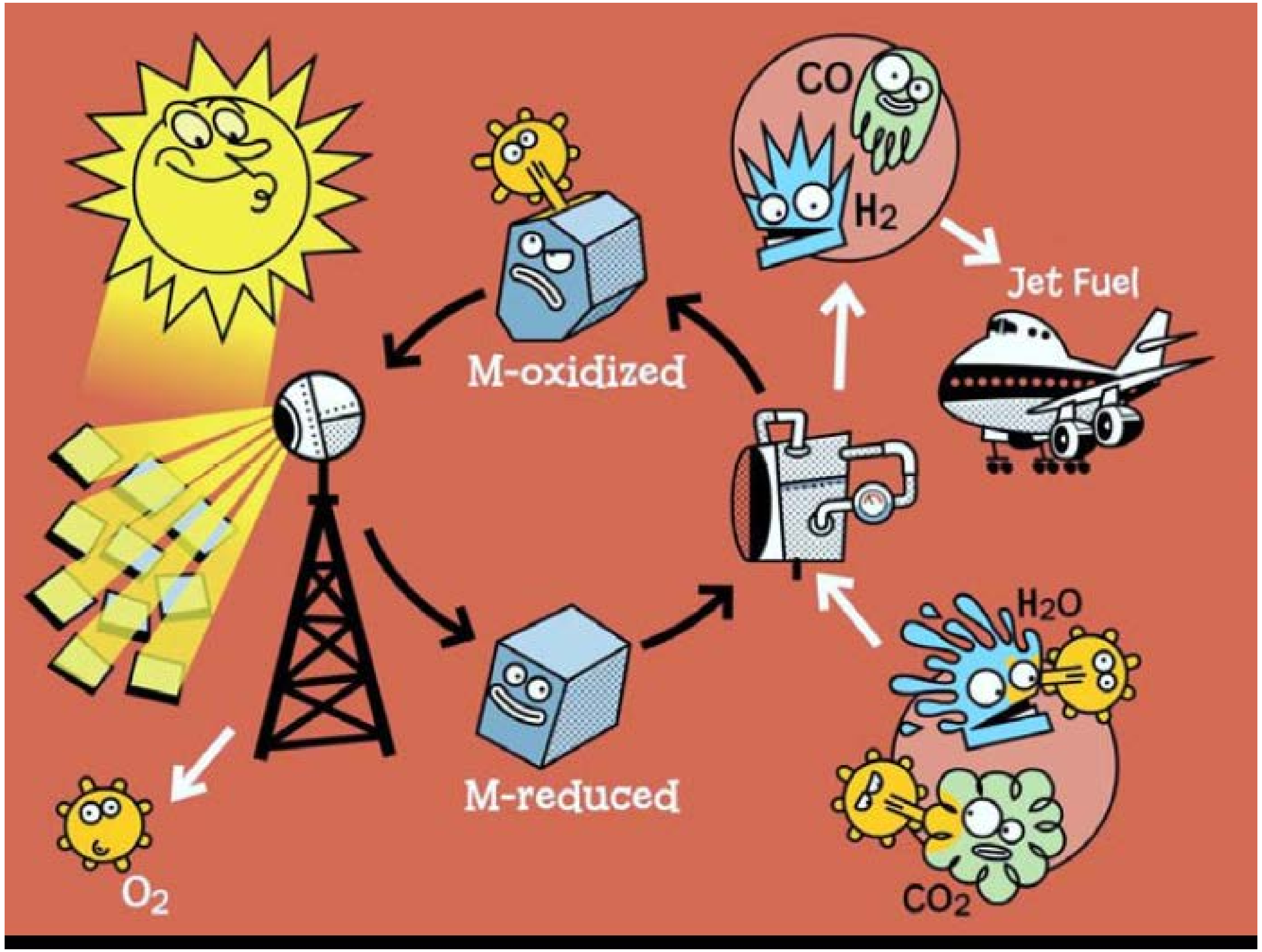
Challenge 1: Solar fuels, beyond SoA of solar towers

T_{amb}=20ºC, ϕ = 770 W/m^2 and $\alpha=\varepsilon=0.95$





The good coupling of solar tower technology and termochemical redox reactors



Romero and Steinfeld, Energy Environ. Sci., 2012, 5, 9234

SolarPACES Lifetime Achievement Award, Rome, October 11th, 2024

SUN to LIQUID (2016-2019)

Fuels from concentrated sunlight

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Germany

A project gathering **7 partners** from **5 European countries:**

ABENGOA

Bauhaus Luftfahrt Neue Wege.

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

ETH zürich

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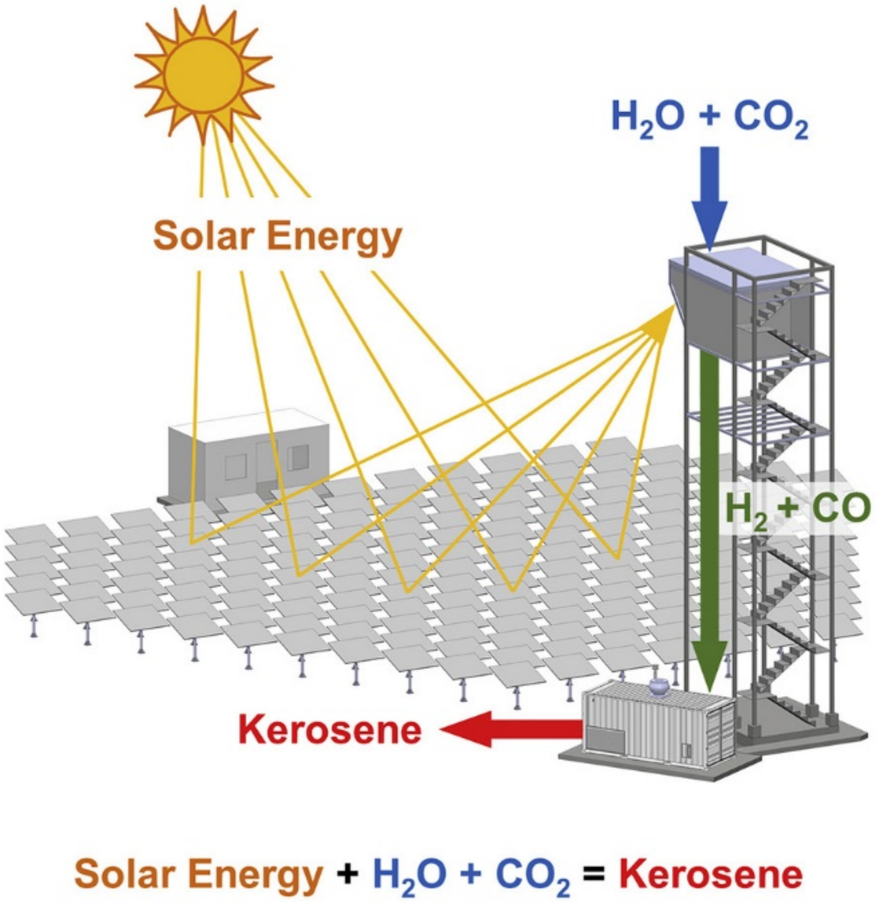
ARTTIC INTERNATIONAL MANAGEMENT SERVICES

SUN-to-LIQUID
http://www.sun-to-liquid.eu

This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.0330

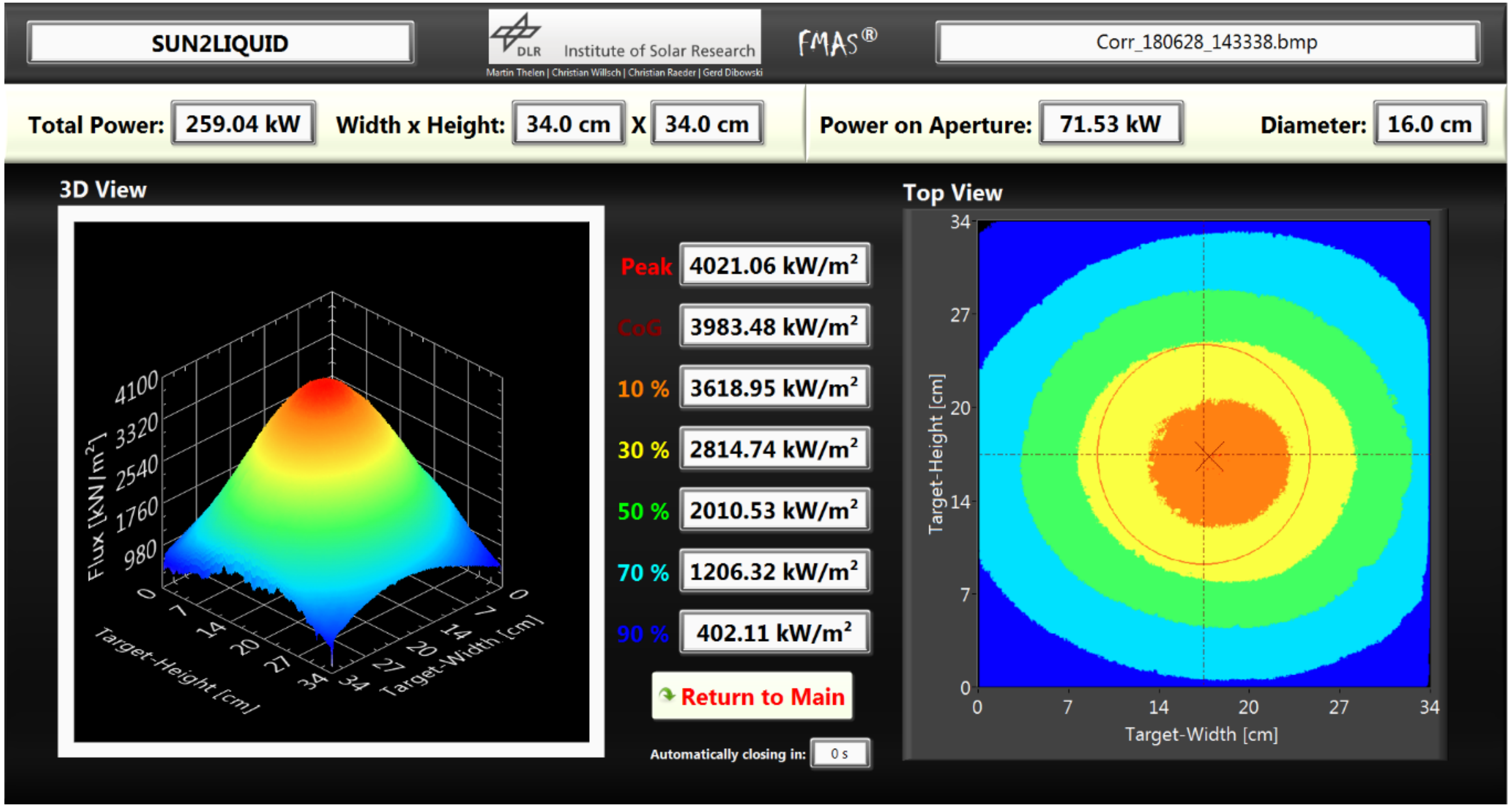
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 654408

Solar field ACES / VHCST

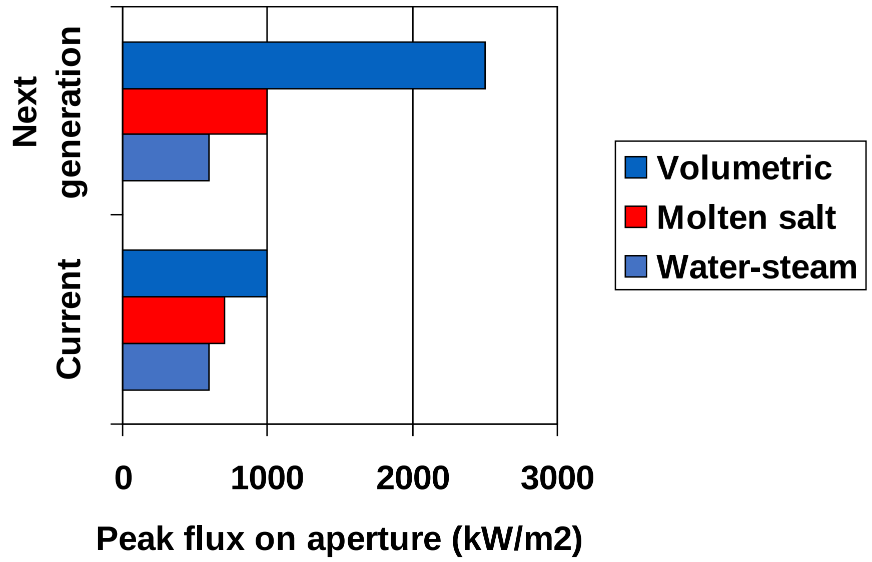


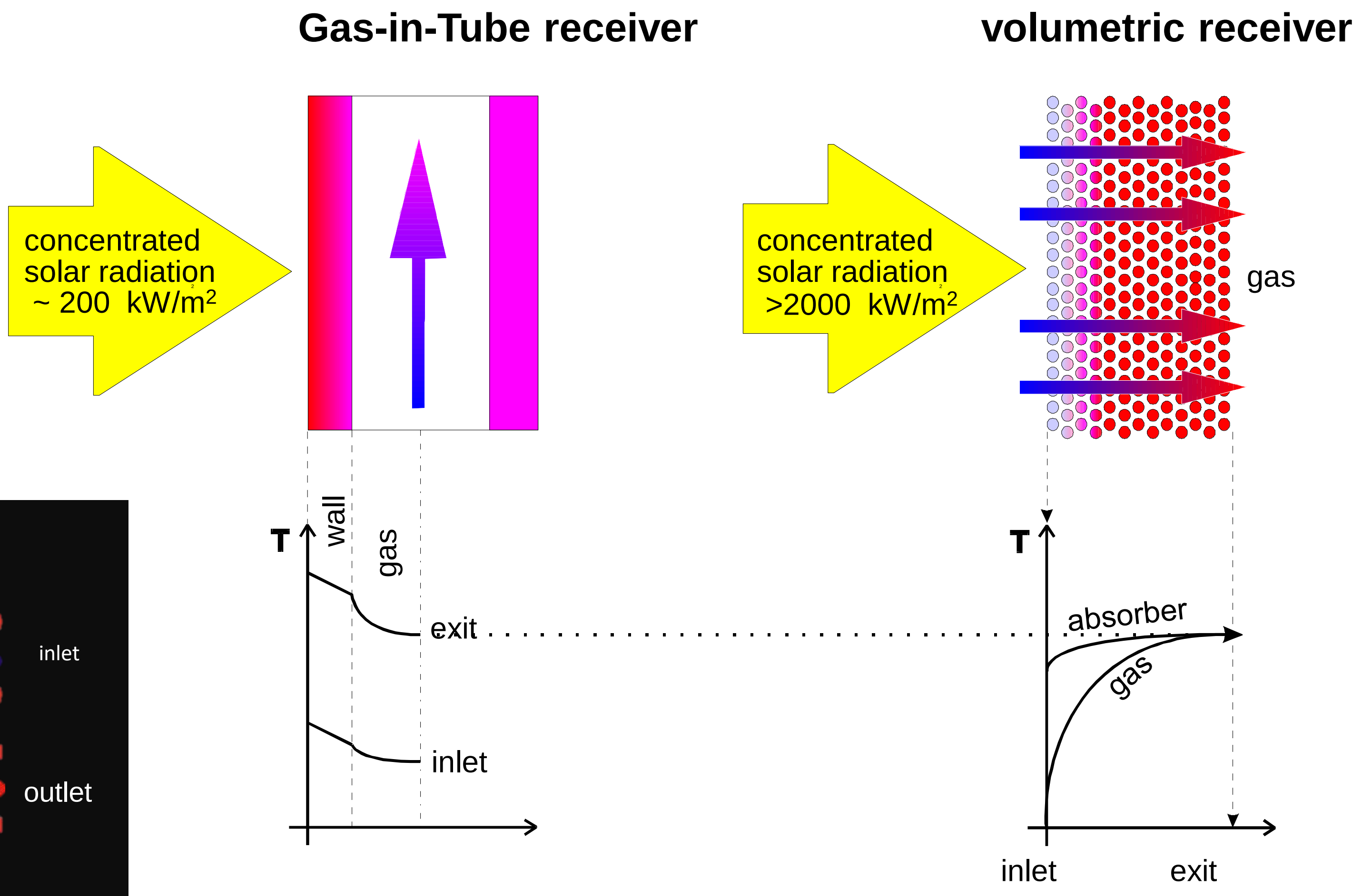
Testing and characterization of high-flux solar concentration system

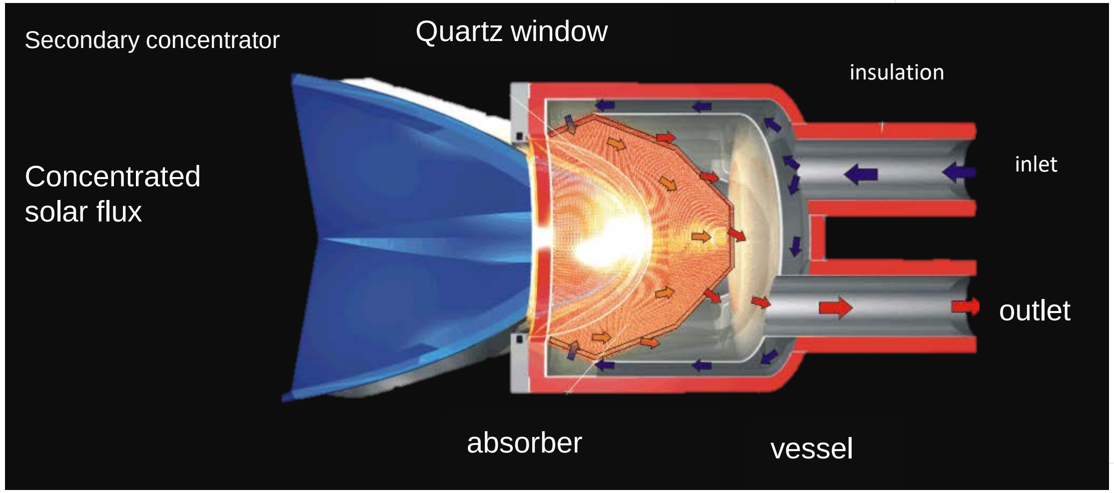
- Highest measured power ever achieved: 71.5 kW onto 16-cm aperture (new calorimeter on site), solar noon on 28th June 2018, for a DNI of 800 W/m^2



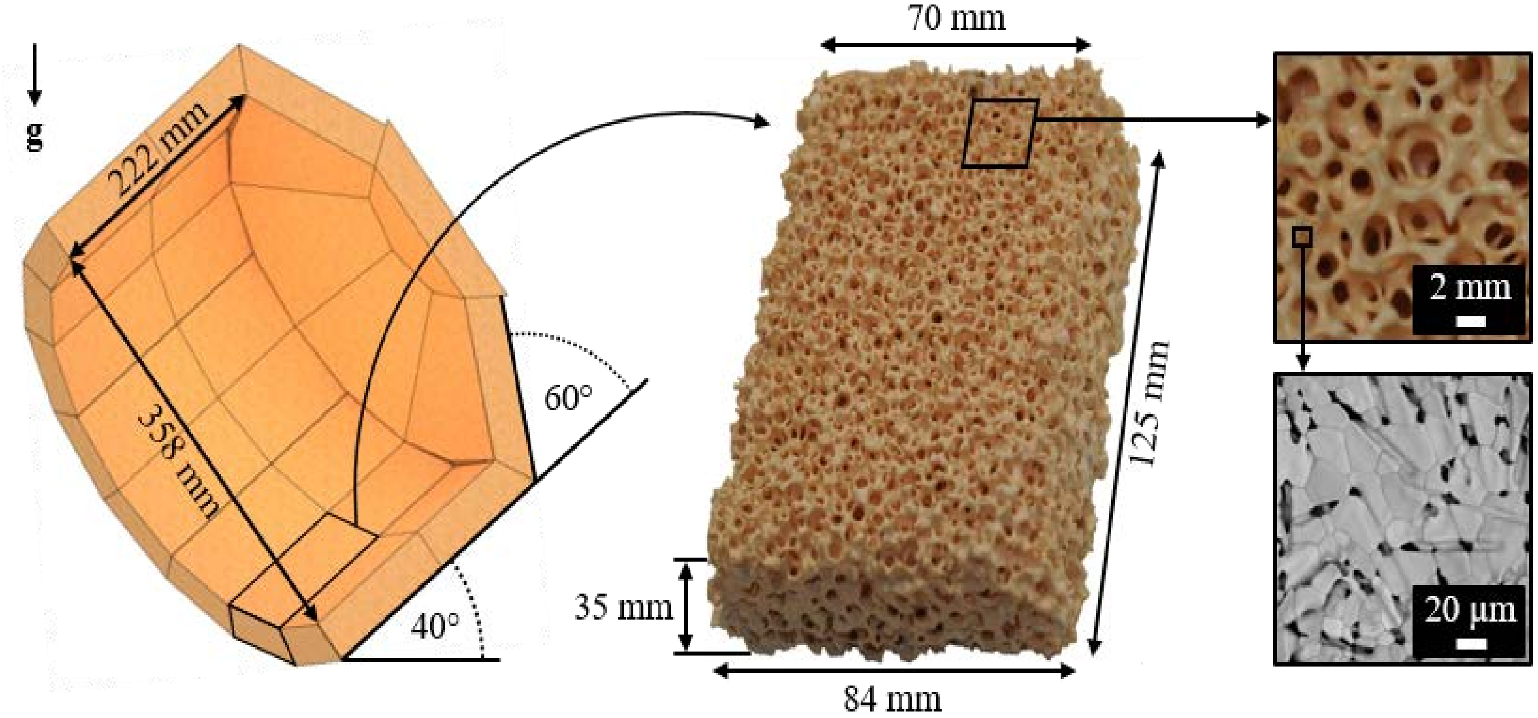
Fundamentals of a volumetric solar receiver







Internal distribution of Ceria RPC bricks



Details on the self-supporting, interlocking ceria structure assembled out of 41 separate RPC bricks, including the center-back keystone. The RPC features dual-scale porosity: millimeter-scale pores made by struts which contain micrometer-scale pores.

Operation of the Solar Reactor

1st step: **Reduction**

$$CeO_2 \rightarrow CeO_{2-\delta} + \frac{\delta}{2} O_2$$

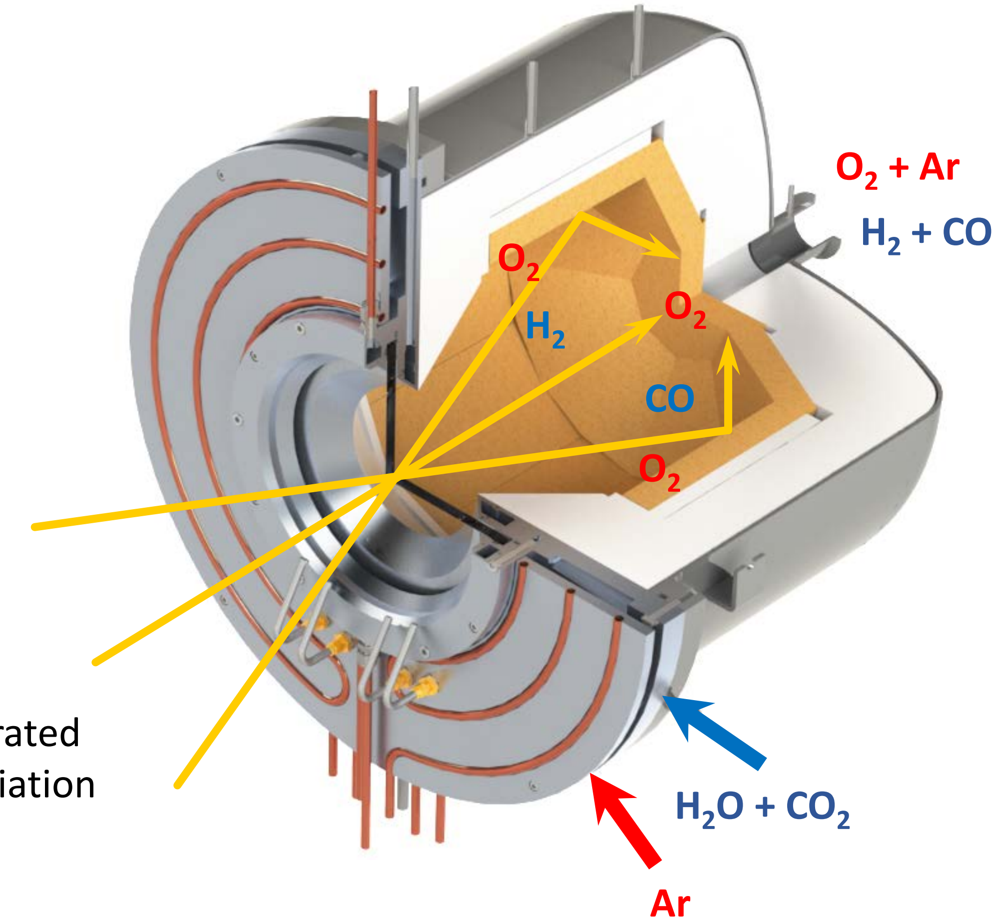
1500 °C, vacuum

2nd step: **Oxidation**

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

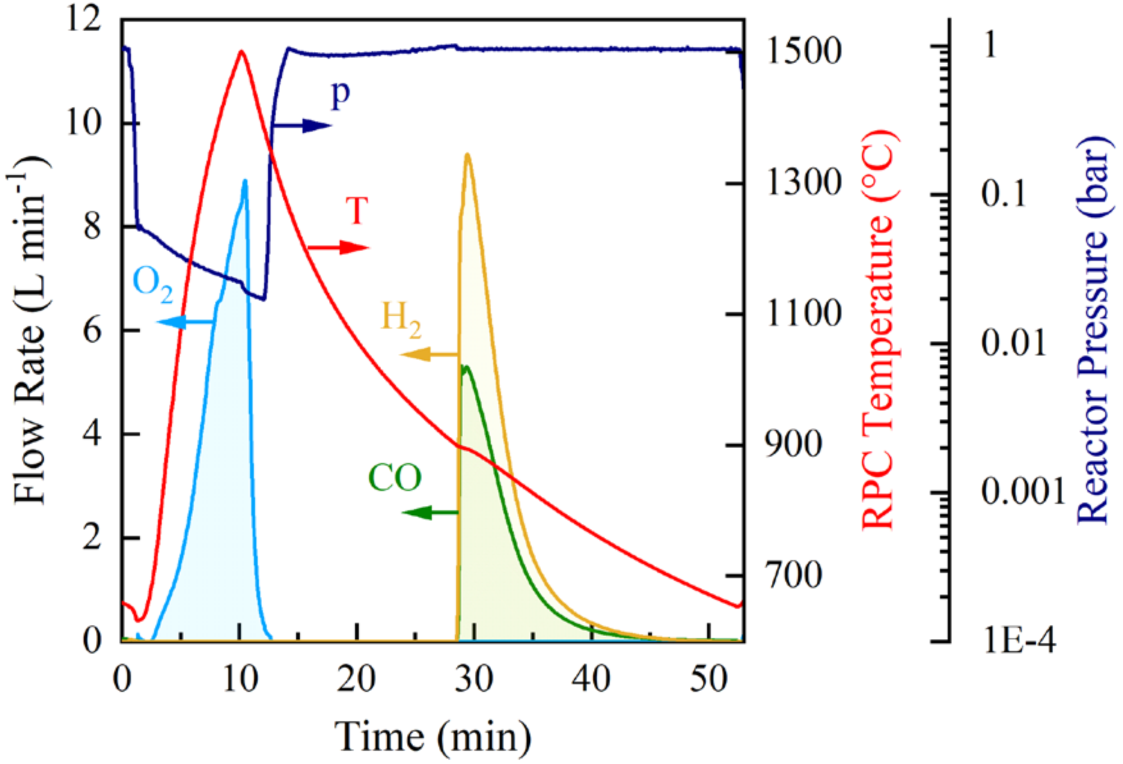
$$CeO_{2-\delta} + \delta CO_2 \rightarrow CeO_2 + \delta CO$$

900 °C, atmospheric pressure



Zoller S., Koepf E., Nizamian D., Stephan M., Patané A., Haueter Ph., Romero M., Gonzalez-Aguilar J., Lieftink D., de Wit E., Brendelberger S., Sizmann A., Steinfeld A. Joule 6, 1606–1616, July 20, 2022

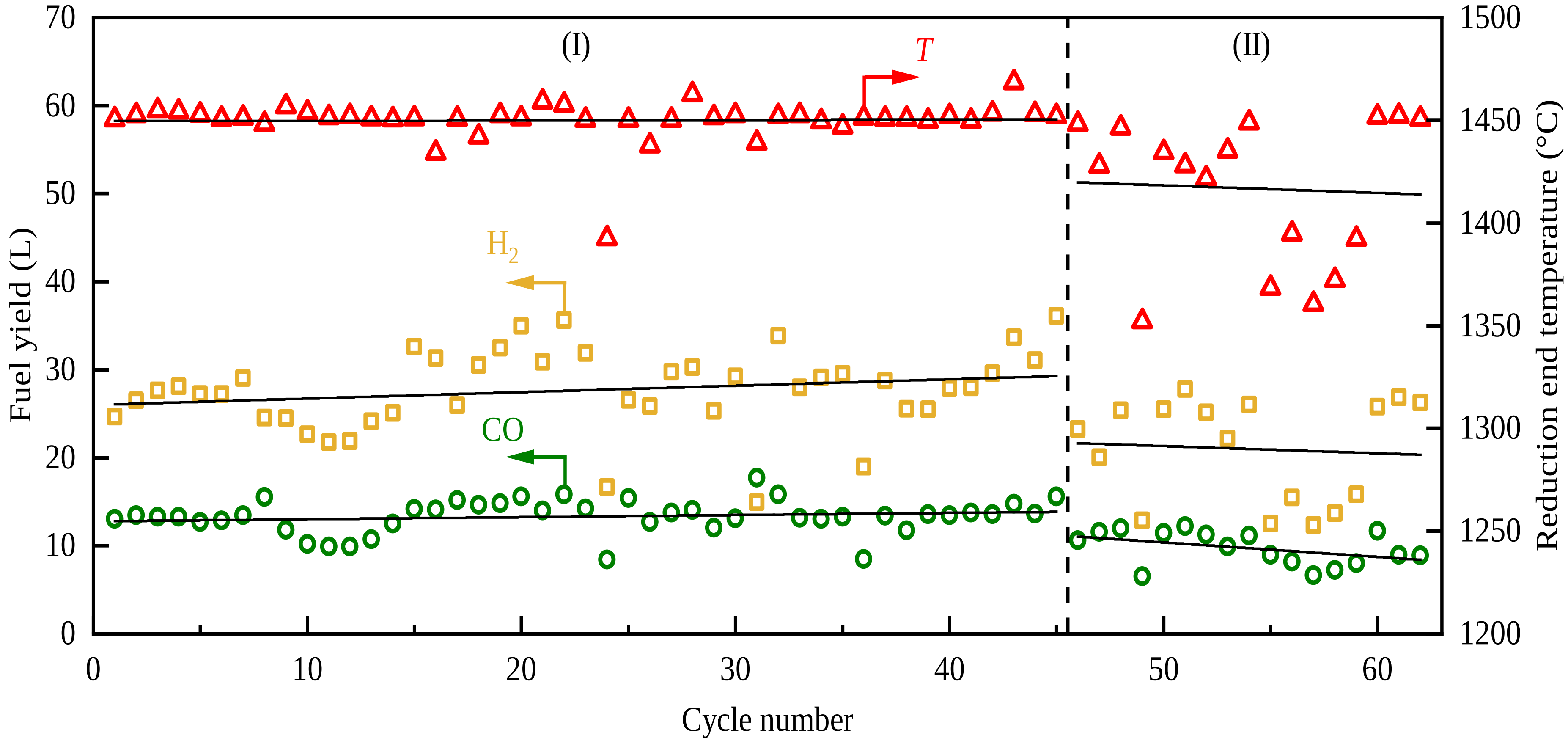
Co-Splitting of H_2O and CO_2 at mean solar flux concentration of 2,500 kW/m^2



$$\eta_{solar-to-syngas} = \frac{Q_{syngas}}{Q_{input}} = \frac{Q_{syngas}}{Q_{solar}+Q_{pump}+Q_{inert}}$$

Variable	Symbol	Value	Unit
Ceria RPC mass	m_{RPC}	18.1	kg
Average solar power input during reduction	P_{solar}	42.0±6.2	kW
Reduction start-end temperature	$T_{reduction,start}$	632-1502	°C
Oxidation start-end temperature	$T_{oxidation,start}$	900-654	°C
Ar flow rate during reduction	$\dot{V}_{Ar}$	5.0	L min^{-1}
H_2O flow rate during oxidation	$\dot{n}_{H2O}$	0.033	mol s^{-1}
CO_2 flow rate during oxidation	$\dot{n}_{CO2}$	0.0074	mol s^{-1}
Reactor pressure during reduction		26-70	mbar
Reactor pressure during oxidation		atmospheric	
Reduction duration		8.8	min
Duration of cooling-down		18.3	min
Oxidation duration		24.0	min
Cycle duration		51.1	min
Total amount of O_2 released		36.2±0.7	L
Avg. nonstoichiometry of ceria after reduction	δ	0.031±0.001	
Total amount of H_2O produced		48.9±3.9	L
Total amount of CO produced		24.4±2.0	L
Molar ratio H_2/CO		2.01±0.35	
Solar-to-syngas energy efficiency	$\eta_{solar-to-syngas}$	4.1±0.8	%

Total amounts of produced H2 and CO per cycle for 62 consecutive redox cycles



Nominal ceria RPC temperature at the end of the reduction step and total amounts of produced H2 and CO per cycle for 62 consecutive redox cycles, yielding 5,191 G 364 L of syngas with a composition 31.8% G 3.2% H2, 15.2% G 2.4% CO, and 53.0% G 3.6% CO2 (H2O condensed).

Zoller S., Koepf E., Nizamian D., Stephan M., Patané A., Haueter Ph., Romero M., Gonzalez-Aguilar J., Lieftink D., de Wit E., Brendelberger S., Sizmann A., Steinfeld A. Joule 6, 1606–1616, July 20, 2022

Specific test validation

SUNtoLIQUID II

FUELS FROM CONCENTRATED SUNLIGHT

(2023-2027)

Efficient solar thermochemical synthesis of liquid hydrocarbon fuels using tailored porous-structured materials and heat recuperation

HORIZON-CL5-2022-D3-03-07 - Development of algal and renewable fuels of non-biological origin

Grant Agreement number	101122206
Project acronym	SUN-to-LIQUID II
Project title	SUNlight-to-LIQUID – Efficient solar thermochemical synthesis of liquid hydrocarbon fuels using tailored porous-structured materials and heat recuperation
Type of action	Research and Innovation (RIA)
Start date of the project	01/11/2023
Duration	48 months
Coordinator	Dr Andreas Sizmann (Bauhaus Luftfahrt)
Contact	contact@sun-to-liquid-2.eu
Link to Cordis	https://cordis.europa.eu/project/id/101122206
Link to Press release	Press release
Link to previous project	https://www.sun-to-liquid.eu/

Bauhaus Luftfahrt The Aviation Think Tank

instituto imdea energía

DLR

HYGEAR THE GLOBAL HYDROGEN SOURCE

UPL

Synhelion

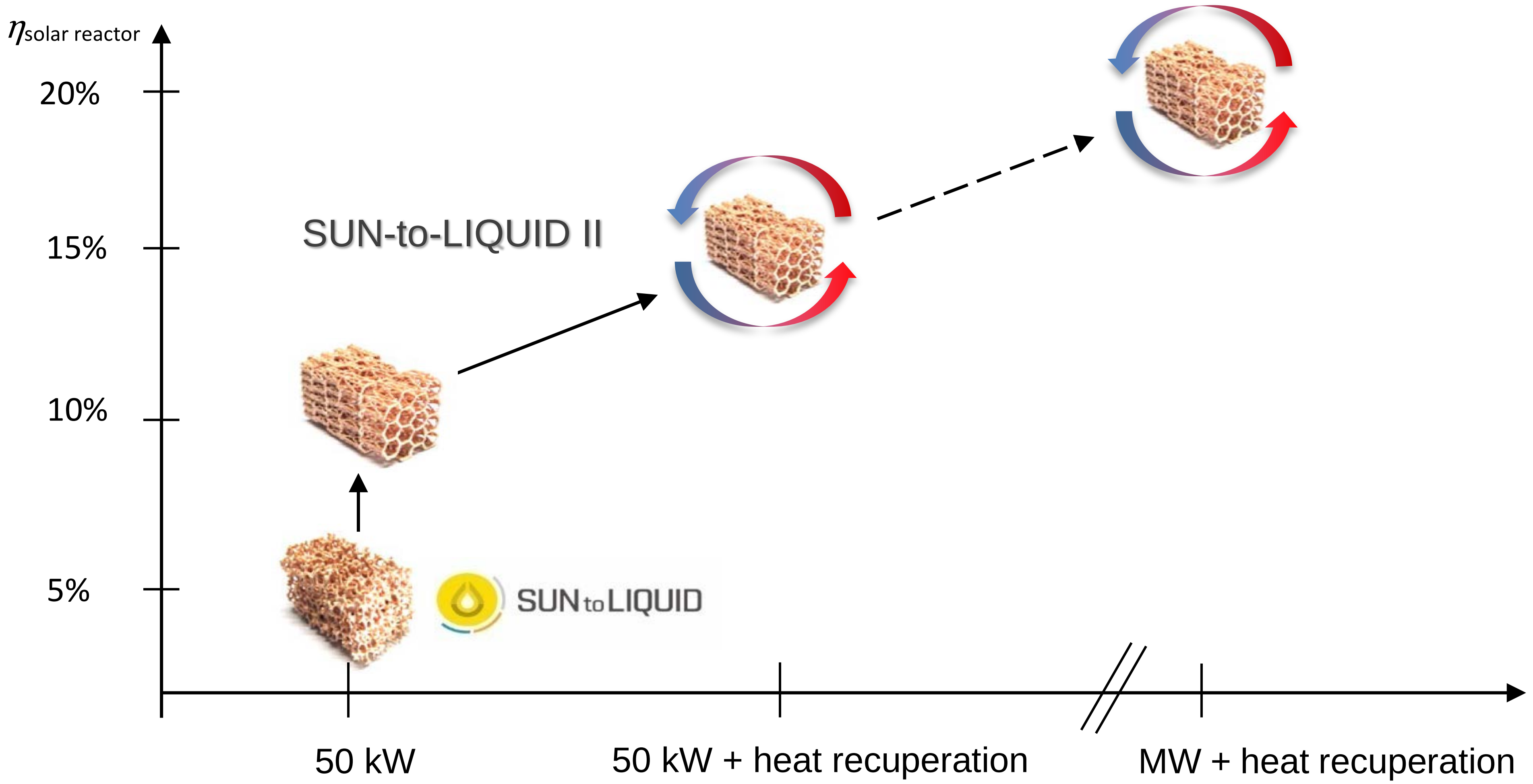
Project funded by

Schweizerische Eidgenossenschaft
Confédération Suisse
Condederazione Svizzera
Confedeaziun svizraSwiss confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and innovation SERI

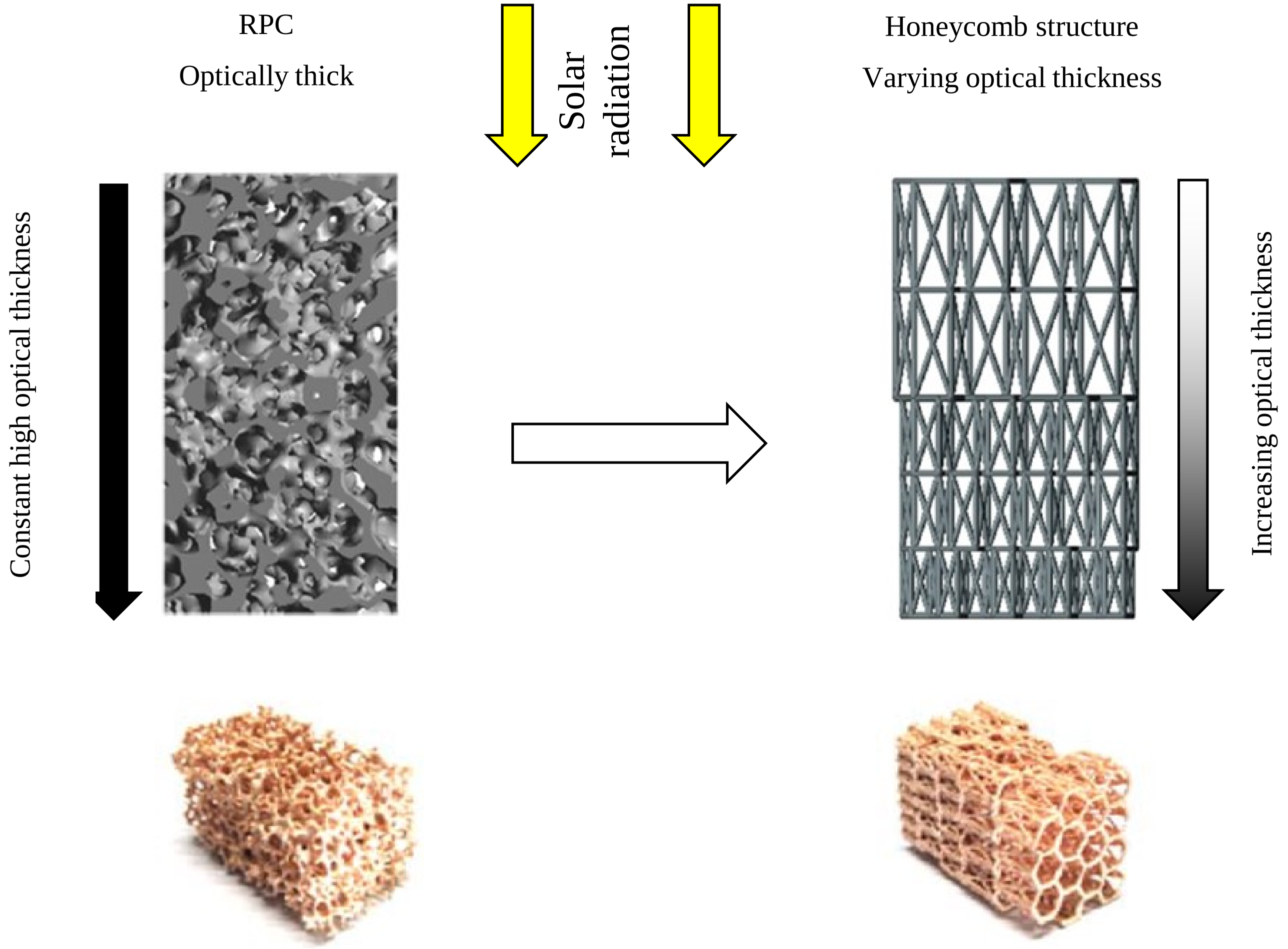
Funded by the European Union

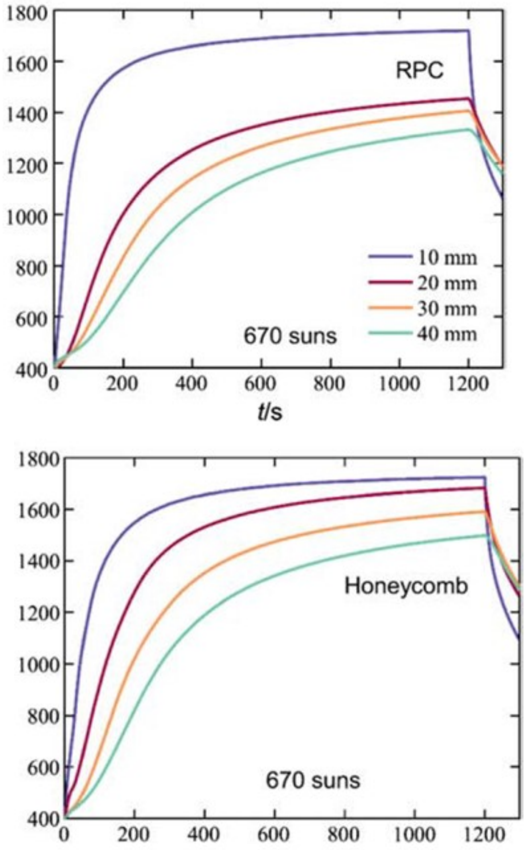
Ambition



$\eta_{solar\ reactor}$
20%
15%
10%
5%
SUN-to-LIQUID II
SUN to LIQUID
50 kW
50 kW + heat recuperation
MW + heat recuperation

Outlook: Ceria ordered structures



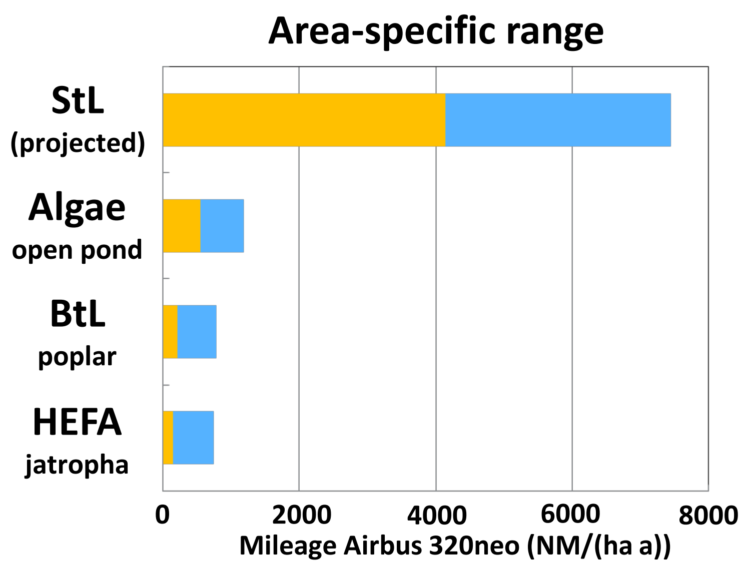


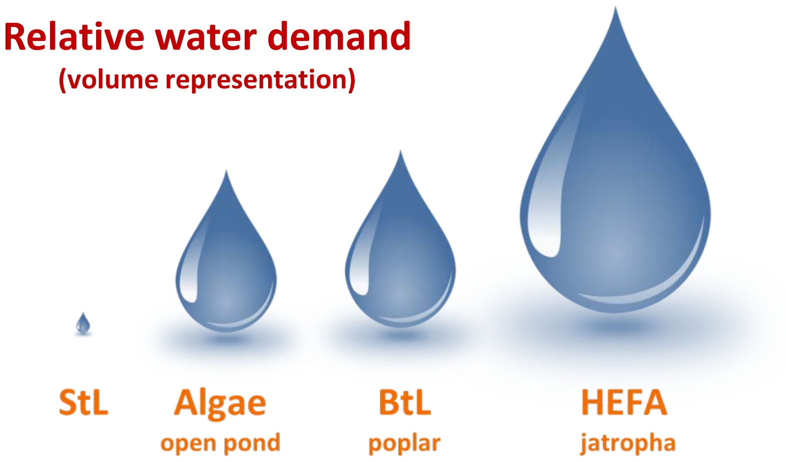
- *M. Hoes, S. Ackermann, D. Theiler, P. Furler, A. Steinfeld, 2019, 1900484.*
- *S. Sas Brunser, F.L. Bargardi, R. Libanori, N. Kaufmann, H. Braun, A. Steinfeld, A.R. Studart. Adv. Mater. Interfaces 2023, 2300452*

Perspectives: Resource Efficiency

- Use of biofuels is controversial
  - Biofuels are available (TRL 9) and approved for civil aviation (e.g. FT-SPK, HEFA, AtJ)
  - Controversial environmental performance
  - Relatively low area specific yield
  - High water demand
  - Limited GHG reduction potential (LUC)

- Solar fuel production from H_2O and CO_2
  - Large GHG reduction potential
  - Resource efficiency: High yield, no arable land required, very low water consumption
  - Complementary production to biofuels

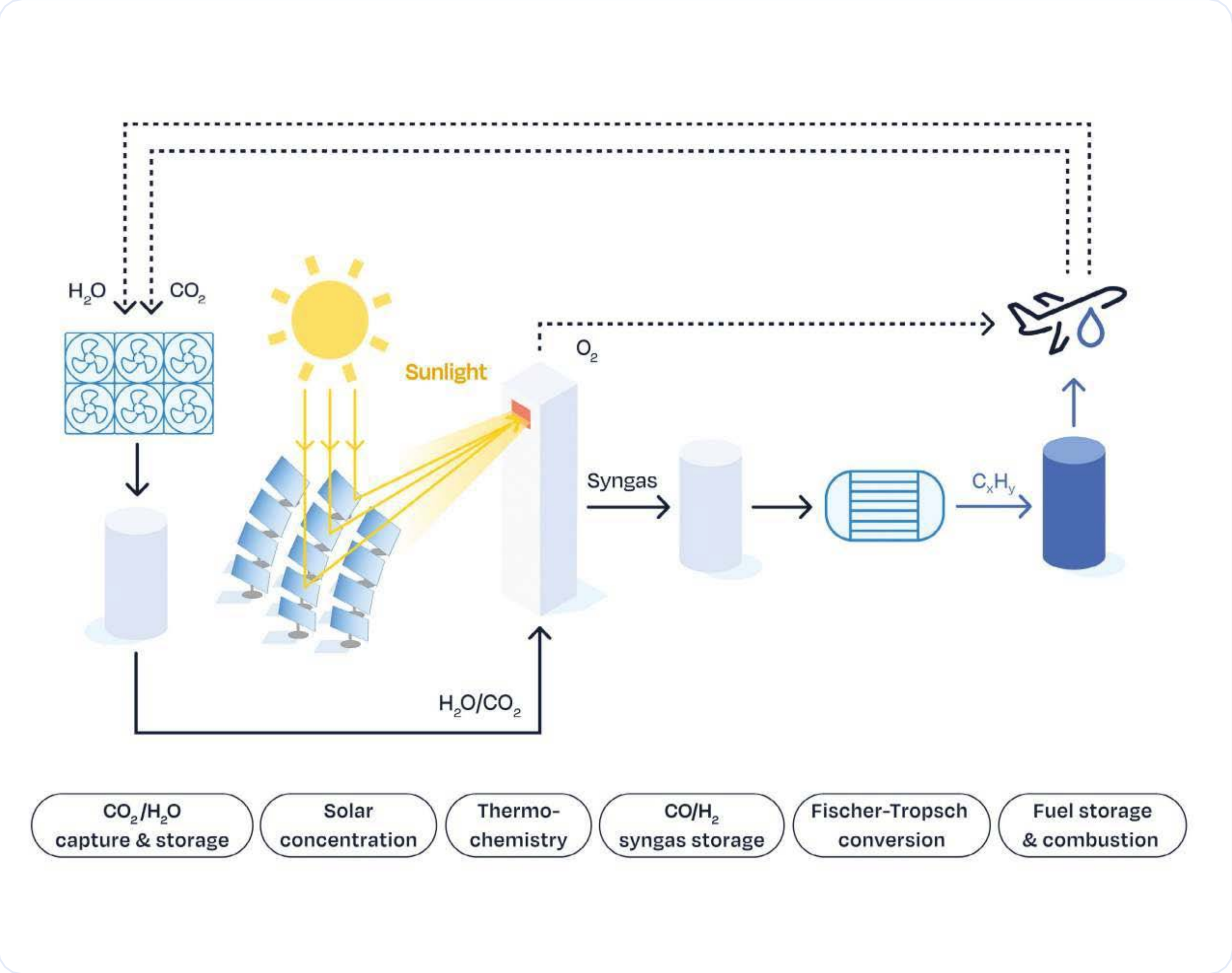




Data: C. Falter, *Climate Impact and Economic Feasibility of Solar Thermochemical Jet Fuel Production*, Environ. Sci. Technol., 2016, 50 (1)

Thank you for your attention!

SUN to LIQUID
Fuels from concentrated sunlight



SUN to LIQUID II
FUELS FROM CONCENTRATED SUNLIGHT

Results presented originating from educational cooperation between Dr. Manuel Romero and Dr. José González-Aguilar, IMDEA Energía and Prof. Steinfeld's PREC-ETHZ and from partnerships at H2020 EU project Sun-to-Liquid (EU GA 654408), HE Sun to Liquid II (EU GA 101122206) and Swiss SERI.