Fuel Production from Concentrated Solar Radiation

20th International Conference on Solid State Ionics

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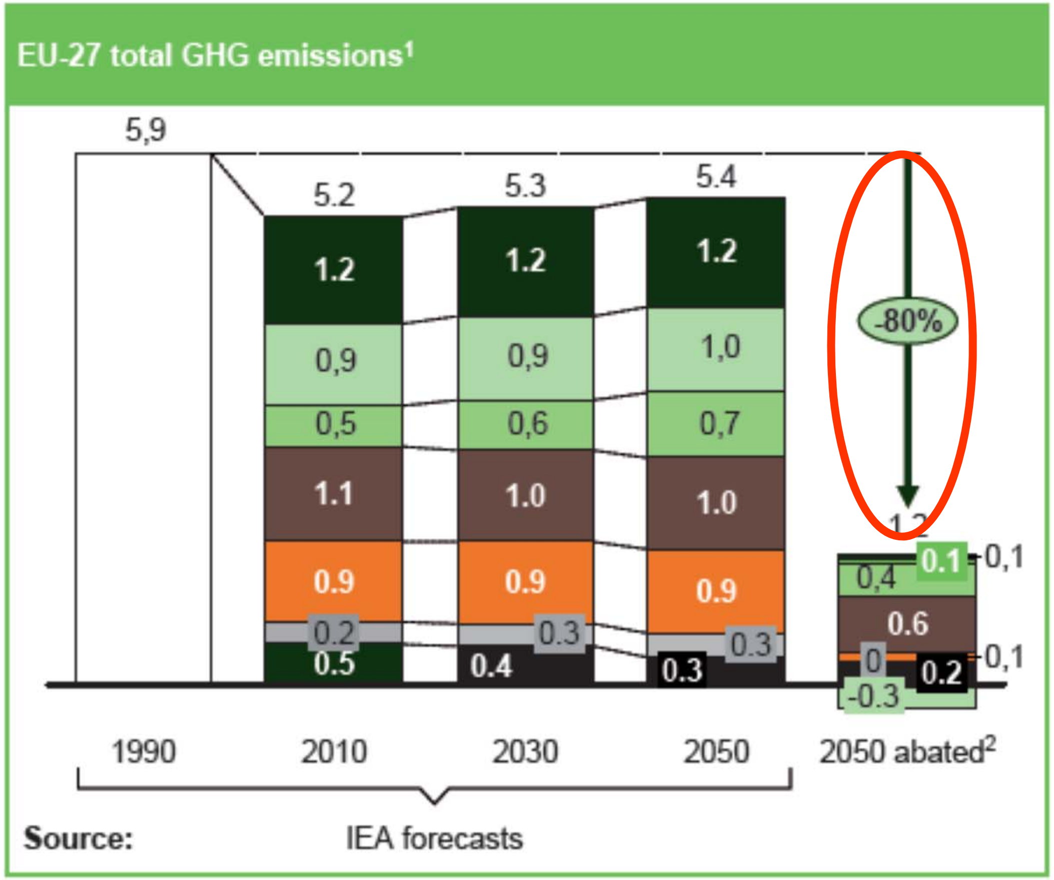
Introduction

- Motivation: Political, Economical, Ecological, Technical
- Concentrating Solar Systems
- Solar fuels technology developments and demonstrations
- R&D needs and networks

Political Drivers: Examples – EU Sustainable Energy Technology Plan (SET-Plan 2007) G7 Goals (2015)

- **Goals of the EU until 2020 (20/20/20)**
  - **20%** higher energy efficiency
  - **20%** less GHG emission
  - **20%** renewable energy
- **Goal of the EU until 2050:**
  - **80%** less CO_2 emissions than in 1990
- **G7 Goals, Elmau, Germany**
  - **100%** Decarbonisation until 2100
  - **100 bln $/year** for climate actions in developing countries, large share by industrial investment

Development of EU GHG emissions [Gt CO_2e]

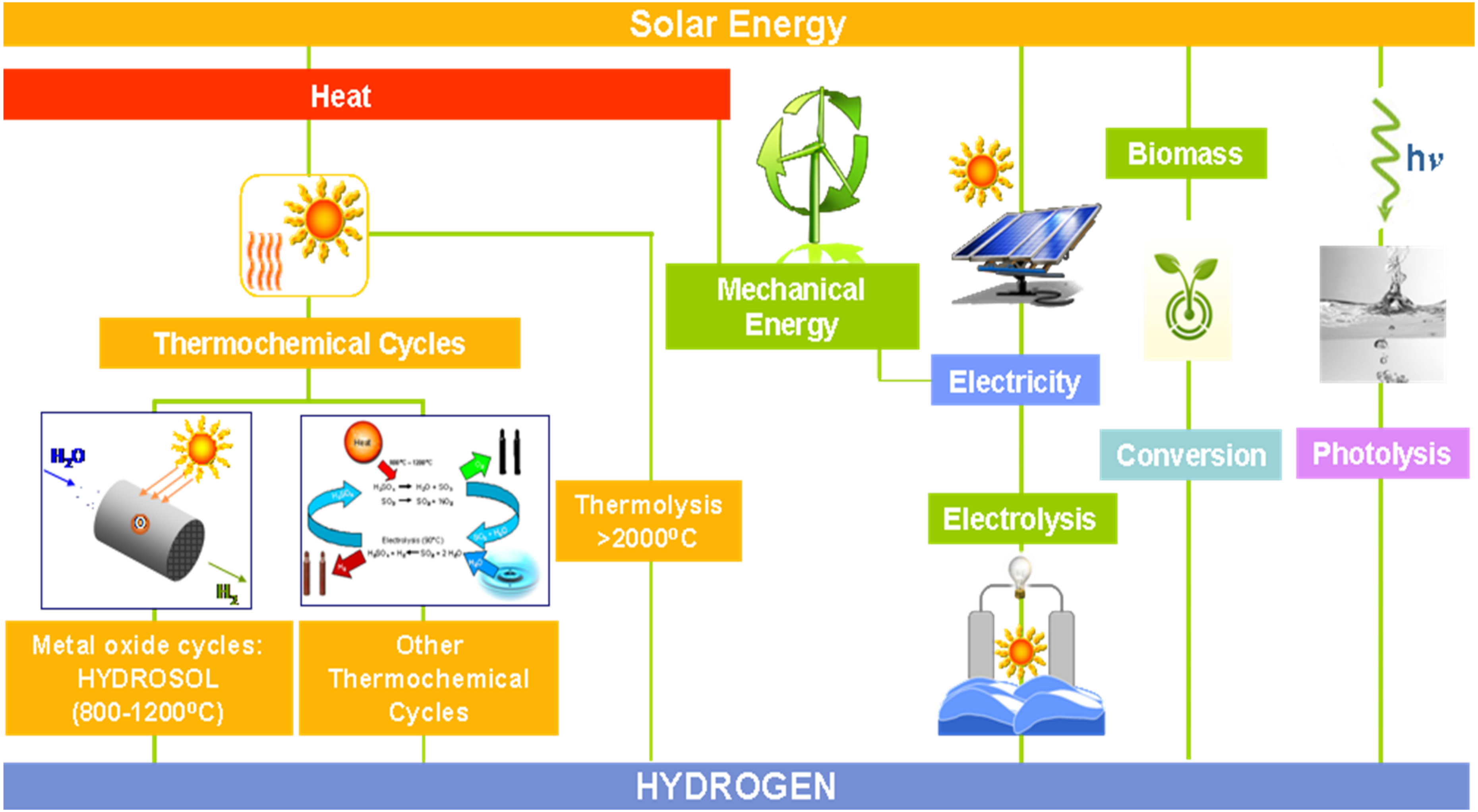


Sector	Total abatement
Power	95-100%
Road transport	95%
Air & sea transport	50%
Industry[3]	40%
Buildings	95%
Waste	100%
Agriculture	20%
Forestry	-0.25 Gt CO_2e

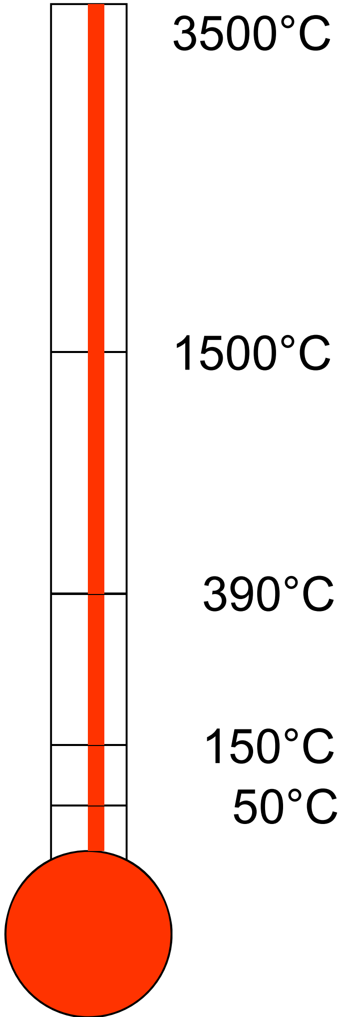
1 Large efficiency improvements are already included in the baseline based on the International Energy Agency, World Energy Outlook 2009, especially for industry
2 Abatement estimates within sector based on Global GHG Cost Curve
3 CCS applied to 50% of large industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

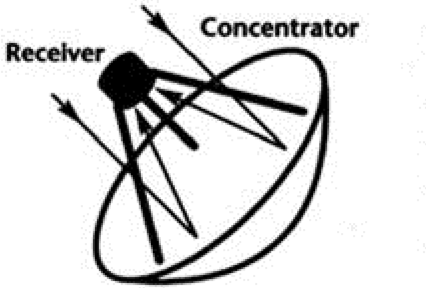
SOURCE: www.roadmap2050.eu

Solar Hydrogen

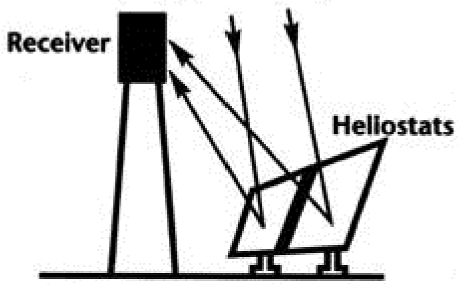


Temperature Levels of CSP Technologies

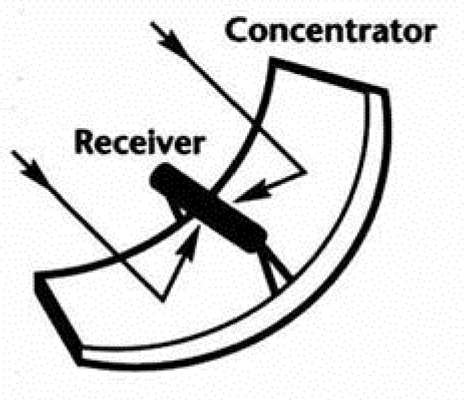




Paraboloid:
„Dish“



Solar Tower
(Central Receiver System)



Parabolic Trough /
Linear Fresnel

Solar Towers

http://www.ivanpahsolar.com/

-PS10, Ivanpah, Torresol
-PSA CRS, CESA-1,
-Solar-Two, Daggett,

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Technical Optimization in all Dimensions necessary

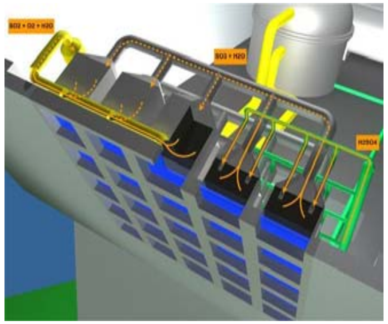
$10^4 – 10^2$ m
Solar Plant

Site

Solar field

Simulation

Environmental impact



$10^2 – 10^1$m
Receiver

Design

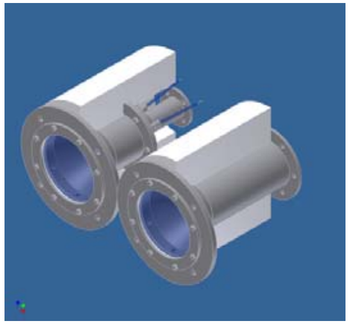
Simulation

Construction

Testing

Next-Generation-

Development



$10^1 – 10^{-2}$m
Receiver-
components

Materials

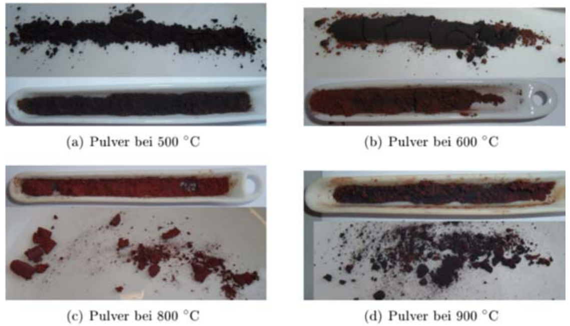
Design

Heat and

Mass transport

Simulation

Testing and Develpment



$10^{-2} – 10^{-8}$ m
Reactive Systems

Simulation

Synthesis

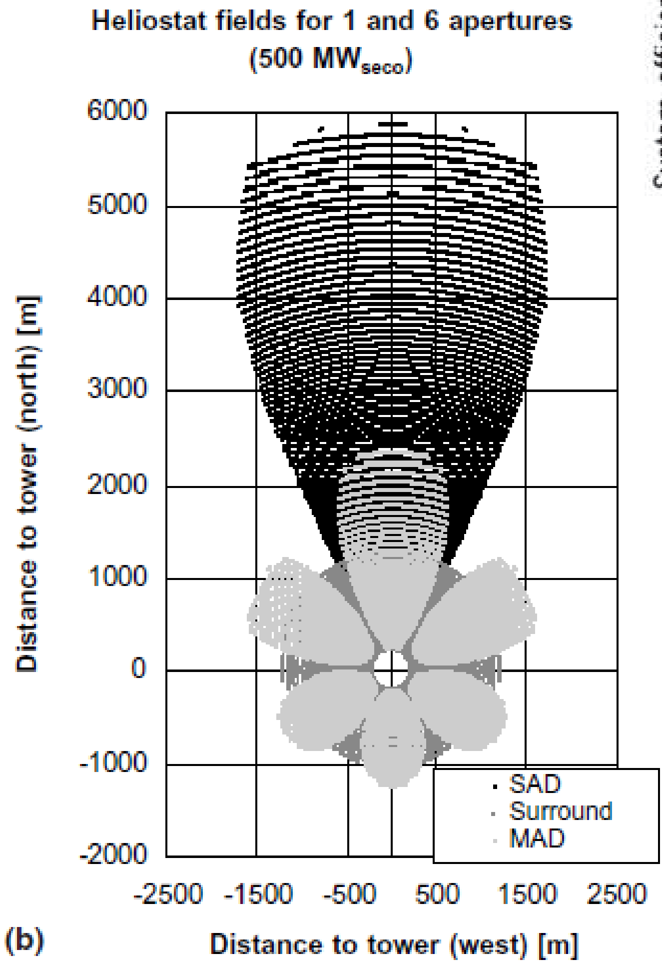
Chemical Charactristics

Physical Characteristics

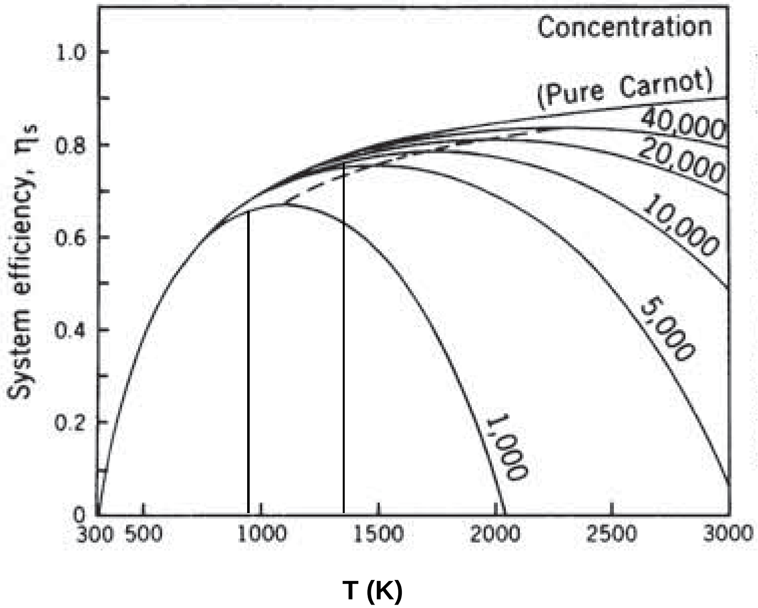
Solar Field Development

The field has to be designed for its application:

- Location
- Concentration ratio to achieve the Process temperature
- At high concentration (1000 suns) secondary optics have to be taken into account



M. Schmitz et al., Solar Energy 80 (2006) 111–120.



E.A. Fletcher, R.L. Moen, Science, 197 (1977) 1050-1056.

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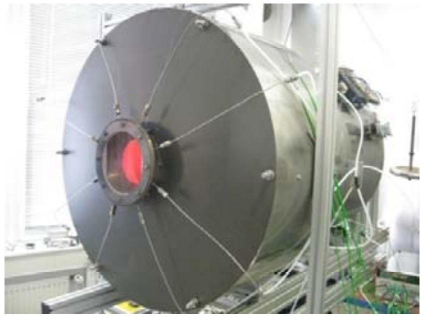
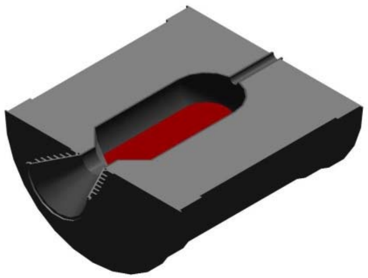
Receiver – Concepts for Solar Chemistry

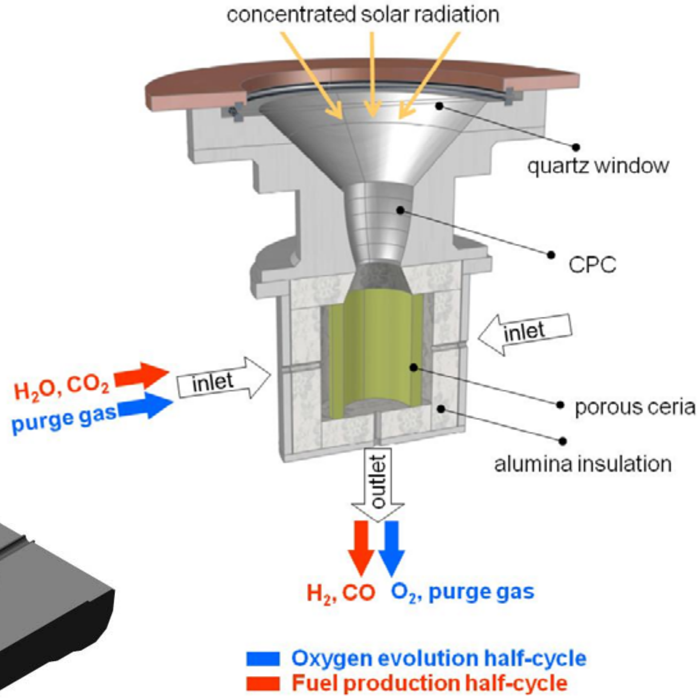
- Challenges:
    - Temperature
    - Corrosion
    - Abrasion
    - Process operation

- Goals:
    - Efficiency
    - Durability
    - Cost

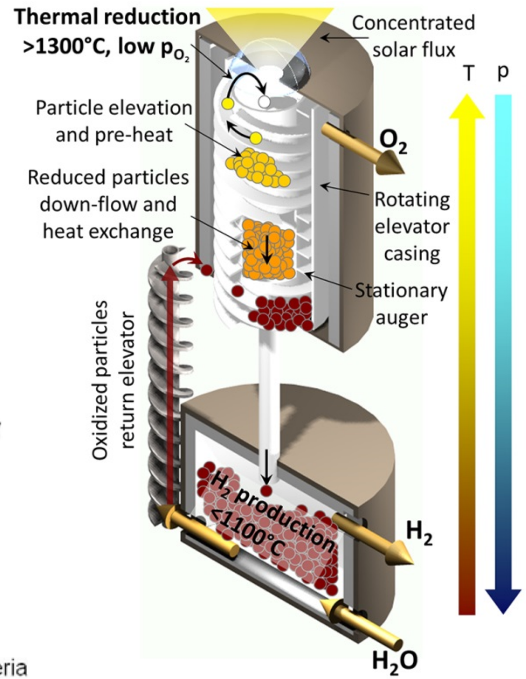


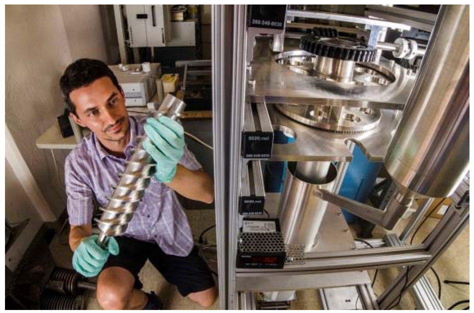


German Project
Solar heated rotary kiln, DLR



European Project
Solar heated Cavity-Gas Receiver
with porous Ceramic structur
A. Steinfeld et al., ETH Zürich

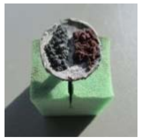




DoE Project with DLR participation
Solar heated Particle-Receiver
I. Ermanoski et al., Sandia Natl. Lab.

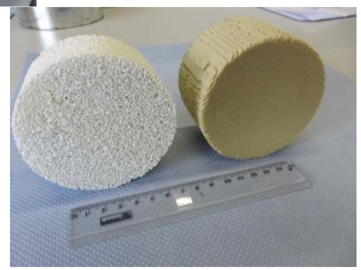
Scale evolution

TGA



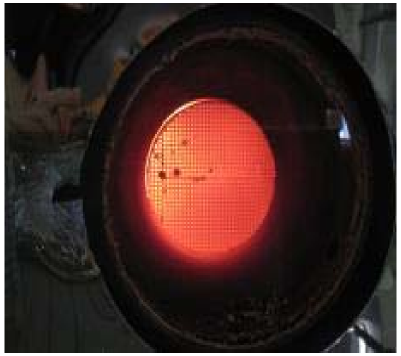
Lab-scale
furnace test rig

Solar receivers

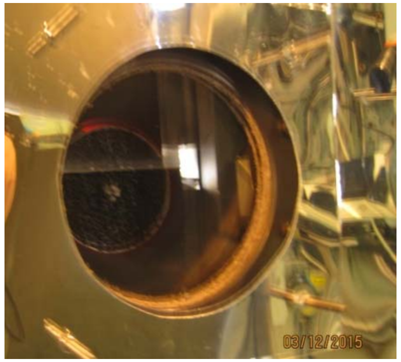


Comparative testing of three SiC receivers (190 slm)

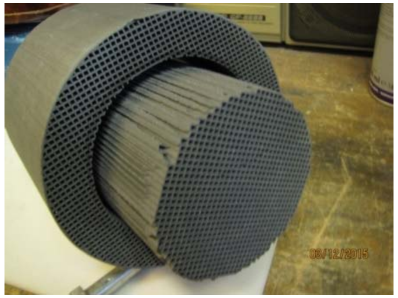
SiSiC honeycomb
90 cpsi; Schunk
Weight ≈1404 g
Length = 15 cm



3 SiSiC foams
10 ppi; ERBICOL
Weight ≈ 246 g
Length = 12 cm

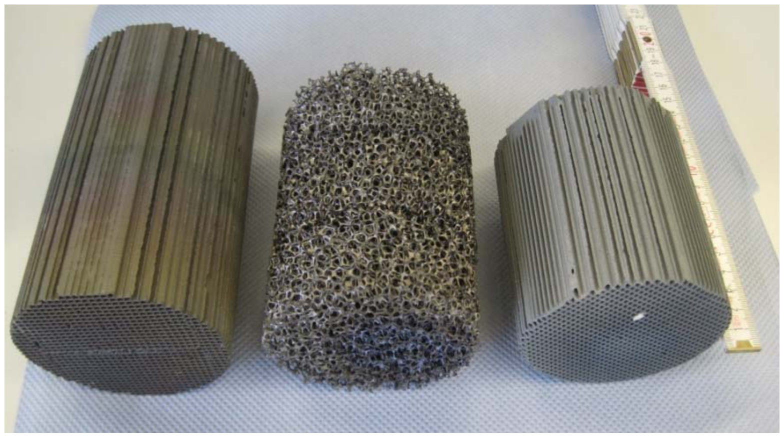


ReSiC honeycomb
90 cpsi; Stobbe TC
Weight ≈ 584 g
Length = 10 cm



Rationale for using ReSiC

- Possibility to exceed 1370ºC on the front irradiated surface (m.p. > 2000ºC).
- Temperature measurement with an IR camera ("matched" to TC1 indication for T < 1370ºC).



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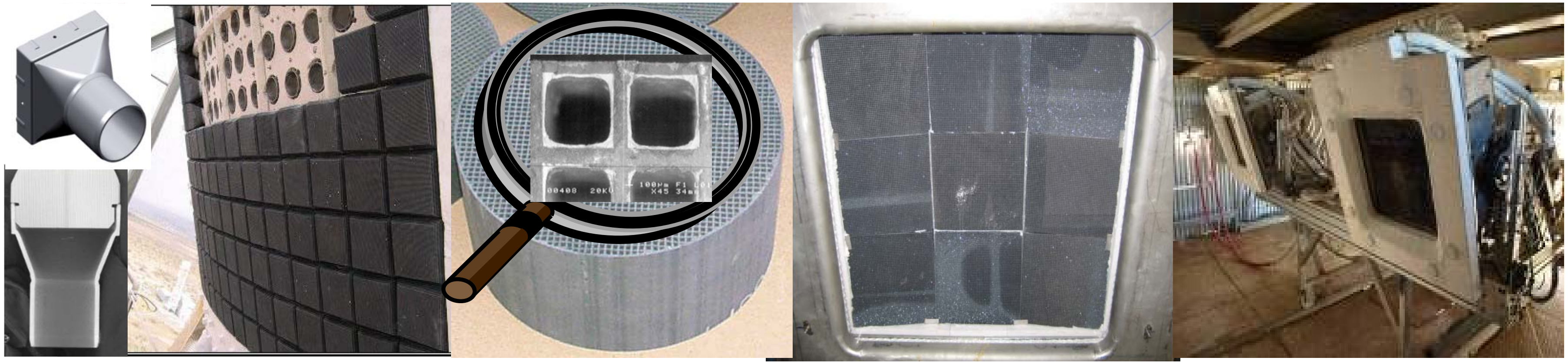
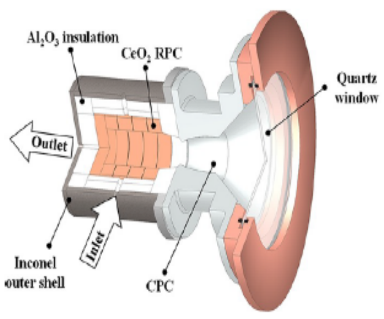
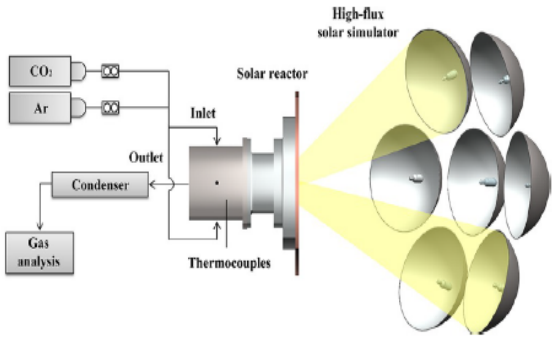
Solar Receiver Components and reactive Systems

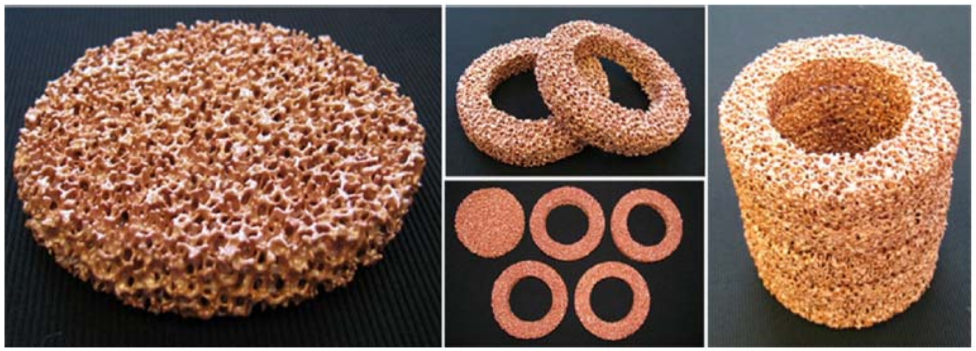


C. Agrafiotis, M. Roeb, A.G. Konstandopoulos, L. Nalbandian, V.T. Zaspalis, C. Sattler, P. Stobbe, A.M. Steele, Solar water splitting for hydrogen production with monolithic reactor, Solar Energy, 79(4), 409-421, (2005).

Reactive coated structures and structures made from reactive materials







P. Furler, J. Scheffe, M.Gorbar, L. Moes, U. Vogt, A. Steinfeld, Solar Thermochemical CO_2 Splitting Utilizing a Reticulated Porous Ceria Redox System, Energy & Fuels, 26(11), 7051-59, (2012).

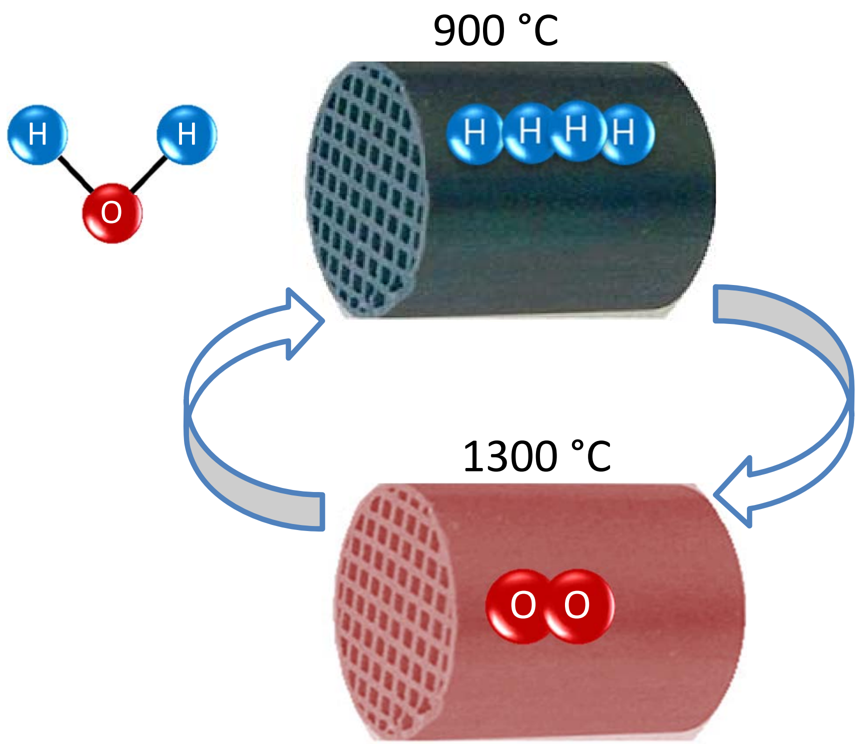
Example how a technology is developed
The HYDROSOL concept

1. Water Splitting

$H_2O + MO_{red} \rightarrow MO_{ox} + H_2$

2. Regeneration

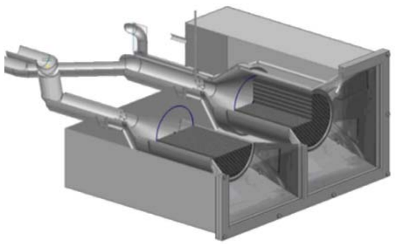
$MO_{ox} \rightarrow MO_{red} + ½ O_2$



Net Reaction: $H_2O \rightarrow H_2 + ½ O_2$

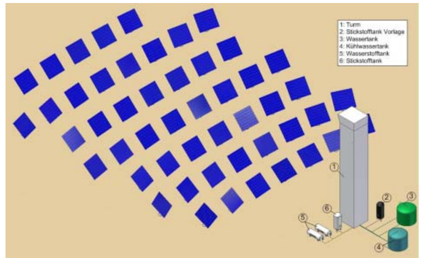
HYDROSOL Development

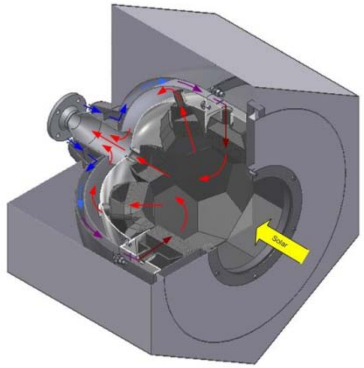
Hydrosol I
2002 – 2005
< 10 kW



Hydrosol II
2006 – 2009
100 kW

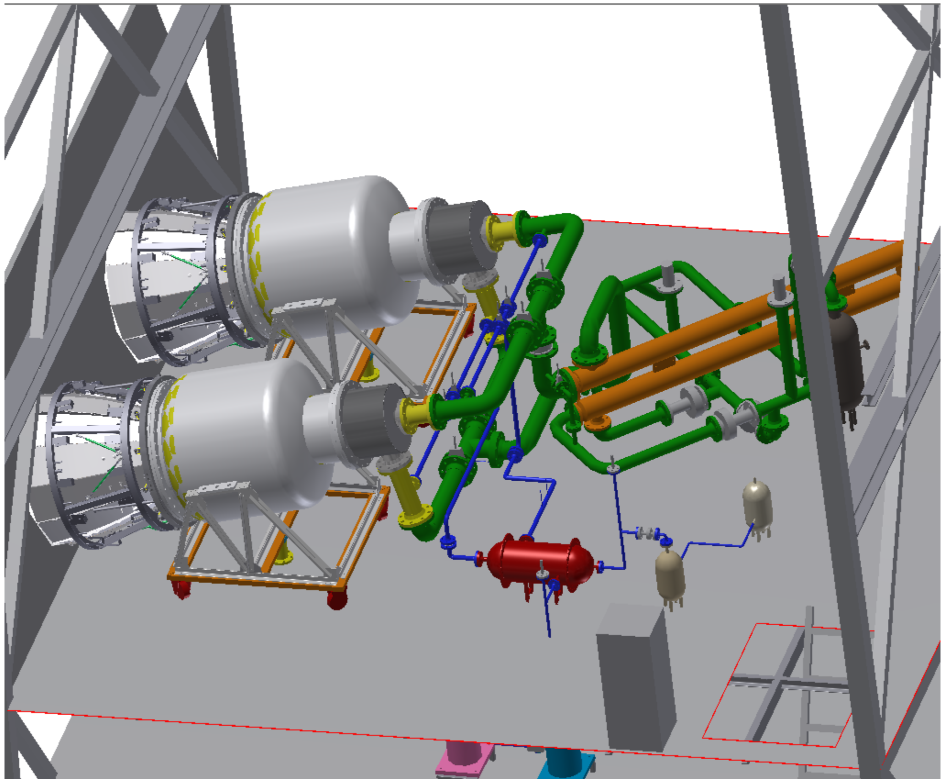
Hydrosol 3D
2010 – 2012
1 MW





Hydrosol Plant - Design for CRS tower PSA, Spain

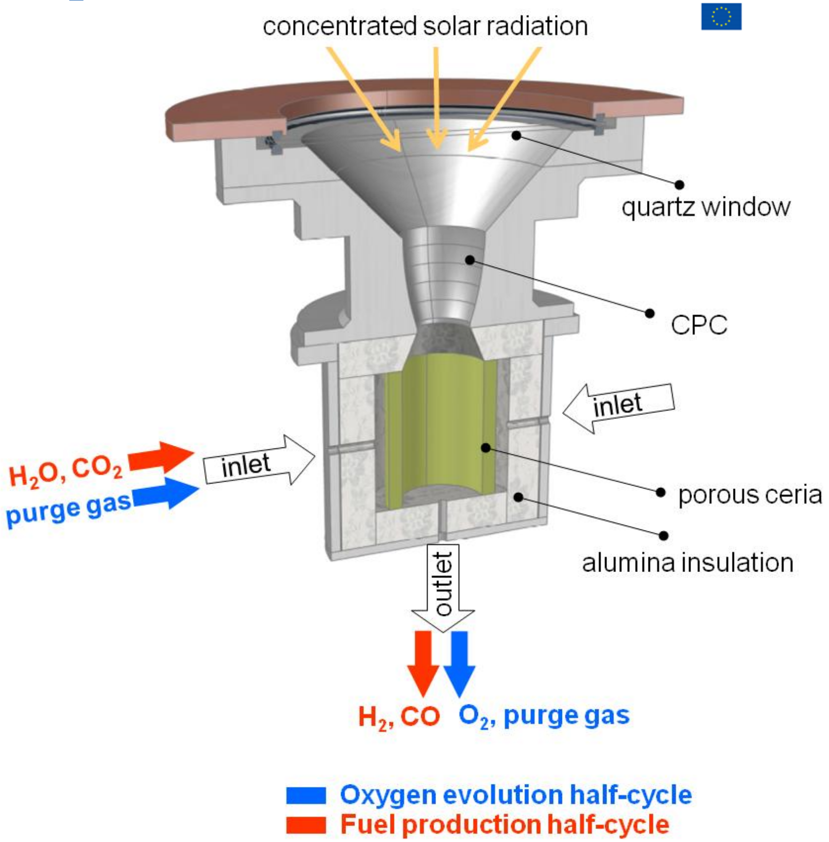
- European FCH-JU project
- Partner: APTL (GR), HELPE (GR), CIEMAT (ES), HYGEAR (NL)
- 750 kW_{th} demonstration of thermochemical water splitting
- Location: Plataforma Solar de Almería, Spain, 2016
- Use of all heliostats
- Reactor set-up on the CRS tower
- Storage tanks and PSA on the ground



H_2O/CO_2-Splitting Thermochemical Cycles

Solar Production of Jet Fuel

- EU-FP7 Project SOLAR-JET (2011-2015)
- SOLAR-JET aims to ascertain the potential for producing jet fuel from concentrated sunlight, CO_2, and water.
- SOLAR-JET: optimize a two-step ceria based solar thermochemical cycle to produce synthesis gas (syngas) from CO_2 and water, achieving higher solar-to-fuel energy conversion efficiency over current bio and solar fuel processes.
- **First jet fuel produced in Fischer-Tropsch (FT) unit from solar-produced syngas**!

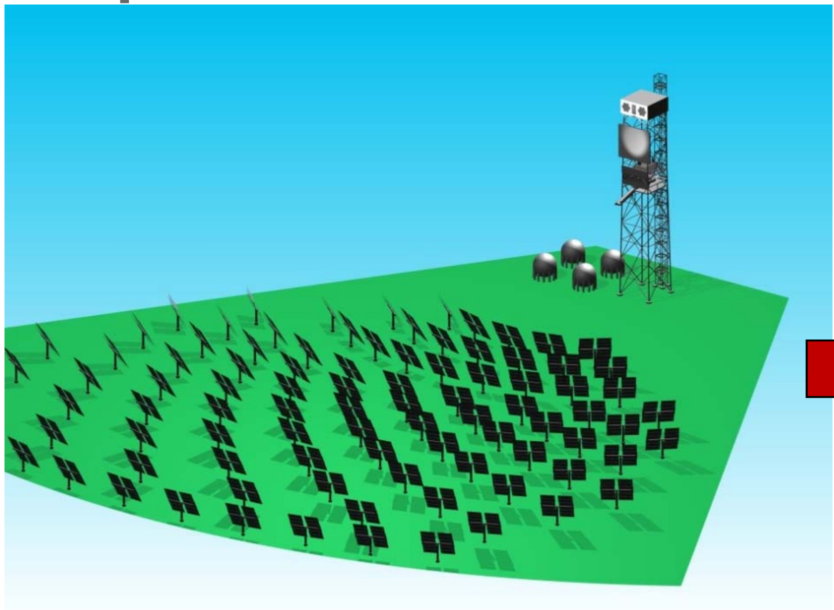


Int. J. Heat & Fluid Flow 29, 315-326, 2008.
Materials 5, 192-209, 2012.

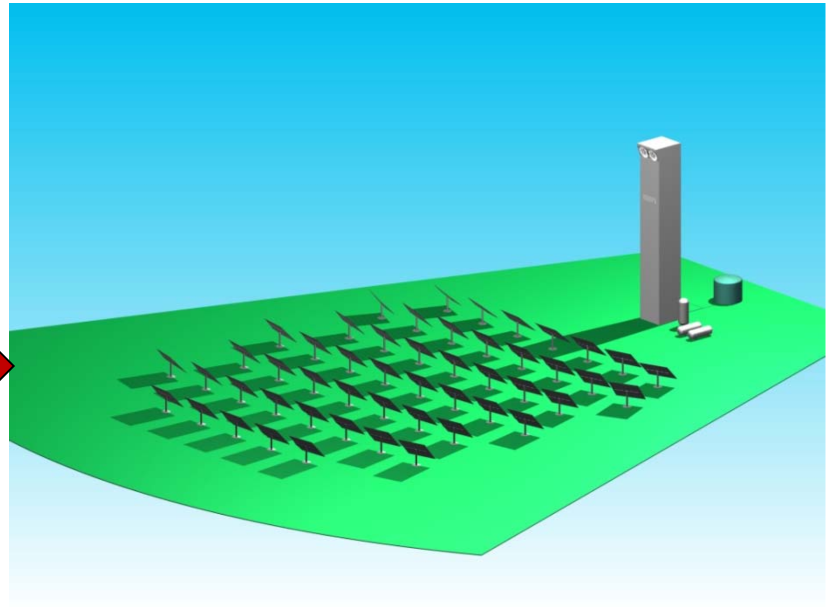
Partners: Bauhaus Luftfahrt (D), ETH (CH), DLR (D), SHELL (NL), ARTTIC (F)
Funding: EC FP7

http://www.solar-jet.aero/

Outlook
Specific Solar Fuel Demonstration Tower needed!



CRS Tower PSA, Spain
2008 and 2016



Solar Fuels Tower, Location?
2020

- High concentration > 1000
- Heliostats fit to receiver size
- Field control adapted to fuel production processes

Thank you very much for your attention!