Scaling-up solar thermochemical cycles: HYDROSOL experience

Dr. Christian Sattler
German Aerospace Center – DLR
Institute of Solar Research
Solar Chemical Engineering
Christian.sattler@dlr.de
The HYDROSOL Idea

2001, Almería, Spain – Discussion between APTL and DLR
Open Volumetric Solar Receiver Design: High Temperature Air Receiver (HiTRec)

- PSA Demonstration:
  Power: 3 MW$_{th}$

- Irradiation > 750 kW/m$^2$
- Long term test at PSA

The HYDROSOL Concept
Coated Ceramic Honeycomb Structures

1) Fixation of the redox materials on the surface of the absorber
2) Use of ceramic honeycomb structures

⇒ no circulation of (hot) solid reactants
⇒ product separation straightforward
⇒ recovery of high temperature heat not too difficult
The HYDROSOL Concept
2 Step Thermochemical Cycle for H₂O Splitting

1. Water Splitting
H₂O + MO_{red} \rightarrow MO_{ox} + H₂

2. Regeneration
MO_{ox} \rightarrow MO_{red} + \frac{1}{2} O₂

Net Reaction: H₂O \rightarrow H₂ + \frac{1}{2} O₂
The HYDROSOL Test Facility - DLR Solar Furnace, Cologne, Germany

Operation started in 1994
Off-axis Concept
Heliostat 60 m²
Concentrator 39 m²
160 Facettes, 3 Focal lengths
Concentration: $5500 = 5\text{ MW/m}^2$
Power max. 25 kW
Focus 13 cm (90%)

$T_{\text{max}}$ 2700 °C
The HYDROSOL Batch-Reactor:

after completion in operation
1. Step September 2004:
The first solar Hydrogen by the HYDROSOL process

\[(\text{ZnMn})\text{Fe}_2\text{O}_4\] on ReSiC
2. Step April 2005:
Improvement of conversion and stability of the coating / support assemblies
The HYDROSOL Reactor for continuous hydrogen production – “Conti-Reactor”

- Reactor with two modules
- Two different alternating processes:
  - Production: 800°C, water steam, nitrogen, exothermic
  - Regeneration: 1200°C, nitrogen, endothermic
- Transient steps like
  - Switching between half cycle
  - Start-up / Shutdown
- Temperature gradient on the coated structure
- Fluctuating irradiation (daily / annually)
The „Conti-Reactor“
during test-operation
3. Step June 2005: Quasi-continuous hydrogen production in the solar furnace
4. Step: Long-term tests

Hydrogen generation for 53 cycles performed with one sample

HYDROSOL was awarded

- Eco Tech Award Expo 2005, Tokyo
- IPHE Technical Achievement Award 2006
- Descartes Research Prize 2006
HYDROSOL 2 – Operation on a Solar Tower EU FP6

- Modular construction, two times 100 kW\textsubscript{th}
- One module consists of 9 coated honeycomb structures
- 2 Reaction chambers

In operation hydrogen and oxygen are produced in parallel the processes are reversible

→ quasi-continuous production
Heliostatt Field Control

- 24 heliostats
- 21 heliostats
- 7 additional heliostats for heating

Receiver plane

- 0 kW/m²
- ca 110 kW/m²
- ca 110+250 kW/m²
Experiments – Process Control Software:

Flux Measurement at test operation

\[ \text{Flux}_{\text{Max}} = 115 \text{kW/m}^2 \]
Experiments – Process Control Software:

Temperature measurement at test operation

\[ T_{\text{Max, both Modules}} = 800^\circ \text{C} \]
First experiments on hydrogen production on the CRS Solar Tower, PSA, Spain
HYDROSOL 3D – FCH JU project
Design and Economic analysis of a demonstration plant

- Demonstration plant thermal energy input: 1 MW
- Cost calculation of the new designed reactor was carried out.
- Cost calculation of the overall process units was performed.
- More than half of process investment results from the solar system.
HYDROSOL Plant
Demonstration on the CRS tower PSA, Spain

- European FCH-JU project
- Partner: APTL (GR), DLR (DE), HELPE (GR), CIEMAT (ES), HYGEAR (NL)
- 750 kW<sub>th</sub> demonstration of thermochemical water splitting
- Location: Plataforma Solar de Almería, Spain, 2016
- Use of all heliostats
- Reactor located on the CRS tower
- Storage tanks and PSA on the ground
HYDROSOL, HYDROSOL 2, HYDROSOL-3D, HYDROSOL Plant

- 2002 Start HYDROSOL, EU FP5
- 2004 First solar hydrogen, DLR
- 2005 Quasi-continuous solar hydrogen, DLR
- 2008 HYDROSOL 2, EU FP6, 100 kW demonstration CRS Tower PSA, Spain
- 2013 HYDROSOL-3D, FCH JU, Design of a MW demonstration plant ready
- 2014 HYDROSOL PLANT, FCH JU
- 2016 Operation of the 750 kW Demonstration plant, CRS Tower, PSA, Spain
- 2020 Pre-commercial plant

APTL (GR), DLR (DE), CIEMAT (SP), StobbeTech (DK), Johnson Matthey (UK), HyGear (NL), HELPE (GR), Total (FR)
Thank you very much for your attention!