HYDROSOL-3D

Scale Up of Thermochemical HYDROgen Production in a SOLar Monolithic Reactor: a 3rd Generation Design Study

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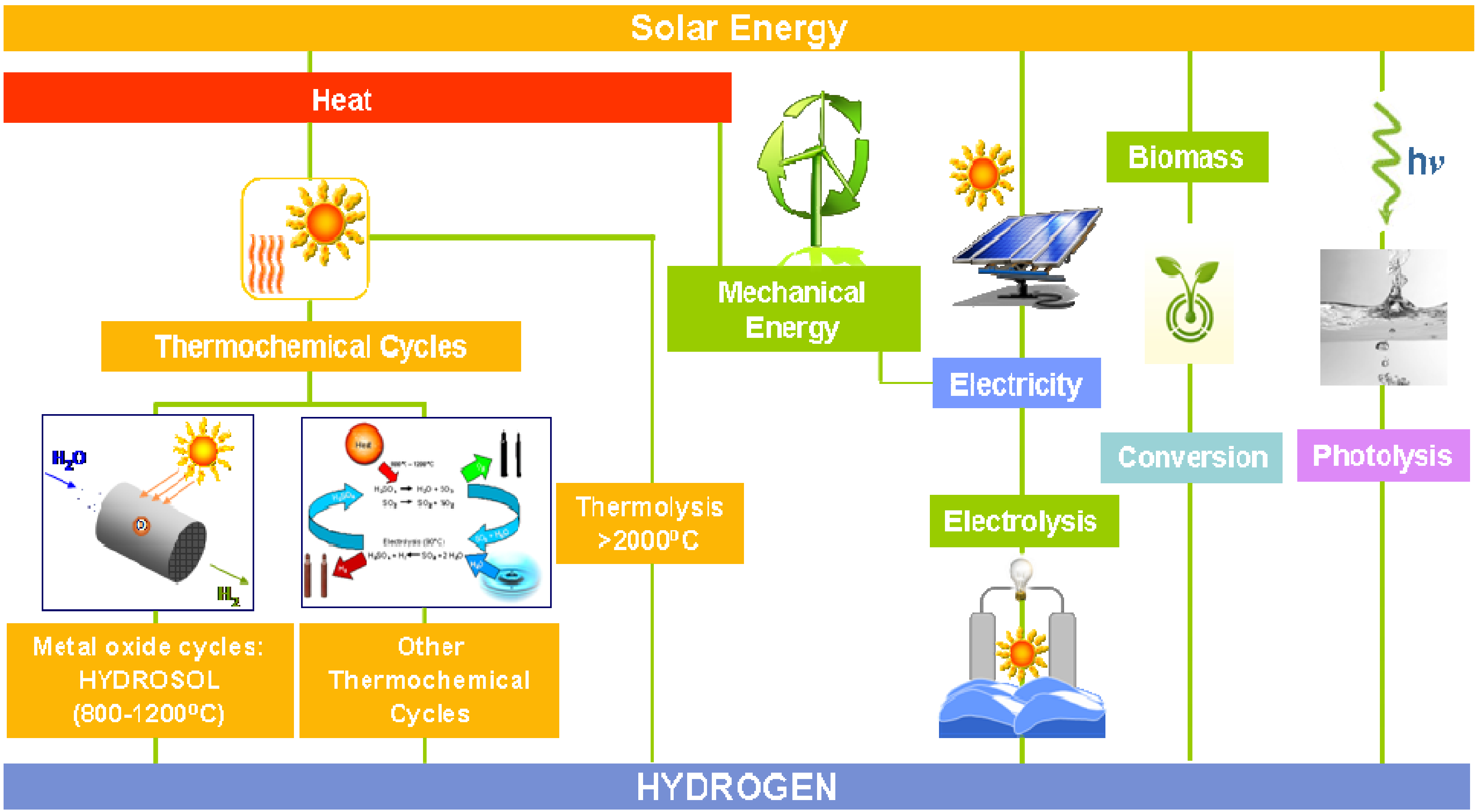
Stakeholders General Assembly of the Fuel Cells and Hydrogen Joint Undertaking

Brussels, November 10th, 2010

Renewable Hydrogen Pathways



Water-splitting via redox-pair based Thermochemical Cycles

- **Water splitting step:** the "reduced" state of the material (usually the lower-valence oxide of a metal that exhibits multiple valences e.g. Fe) is "oxidized" by taking Oxygen from water and producing Hydrogen, according to the scheme :

$$MO_{reduced} + H_2O \rightarrow MO_{oxidized} + H_2$$

Slightly exothermic, significant H_2 production at temperatures above 650 °C

- **Regeneration step:** the oxidized state of the redox material is reduced, "giving away" some of its lattice oxygen, according to the scheme :

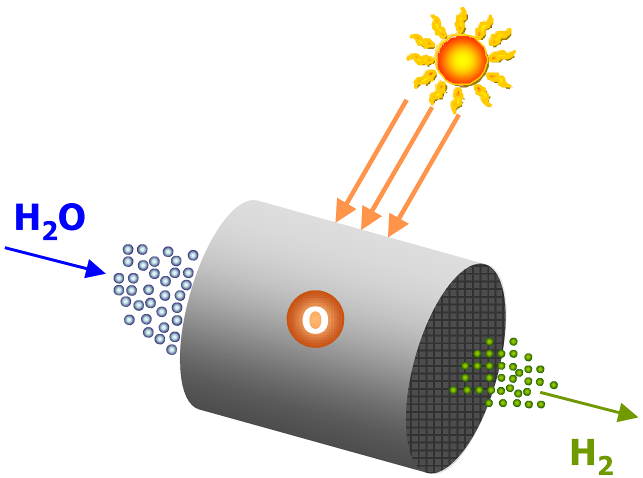
$$MO_{oxidized} \rightarrow MO_{reduced} + O_2$$

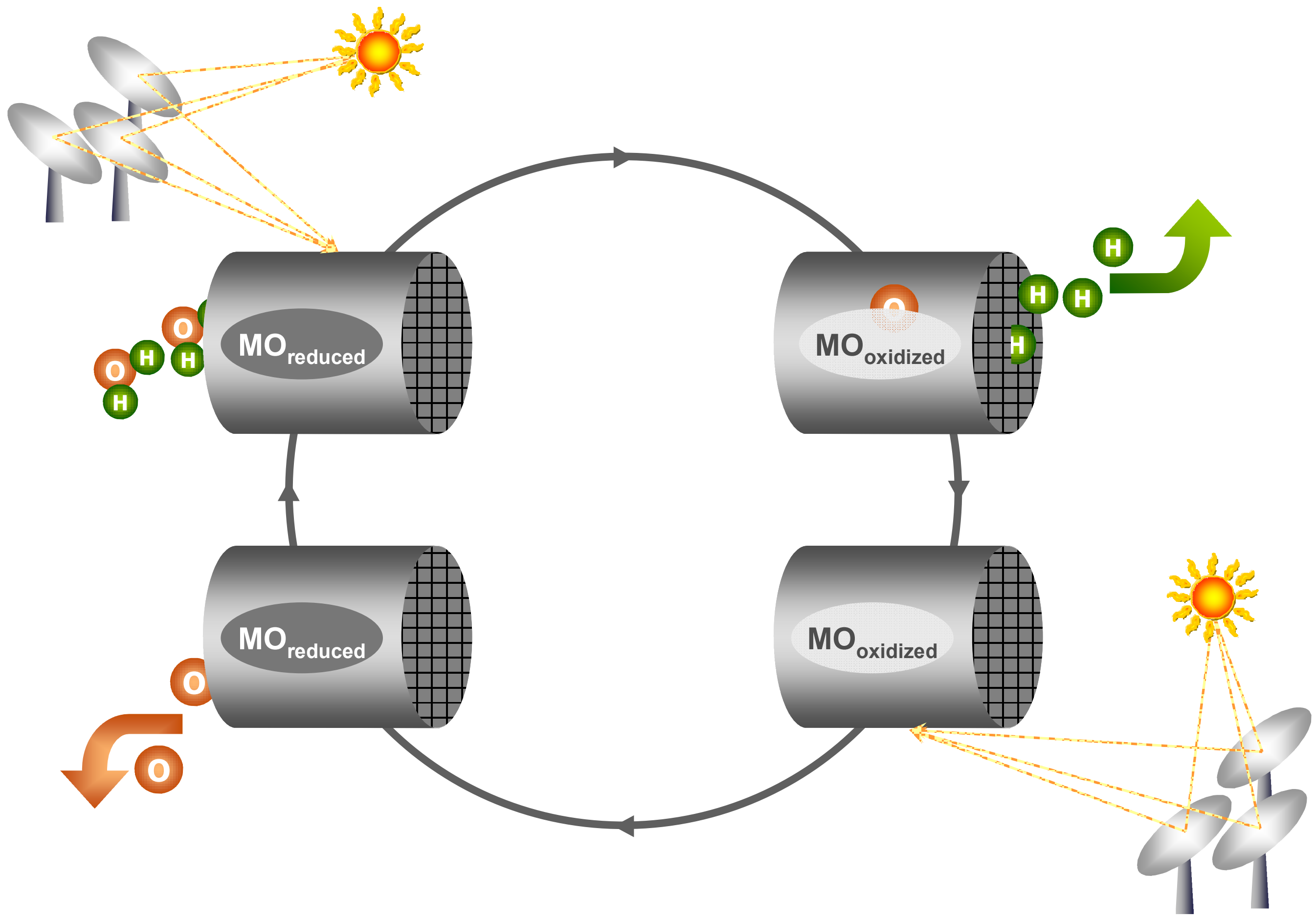
Highly endothermic, needs higher temperatures > 1200 °C ; solar-aided

- **MO redox material :** Typical "redox pairs": FeO-Fe_3O_4/Fe_2O_3, MnO/Mn_3O_4, Zn/ZnO and their combinations

The HYDROSOL reactor concept

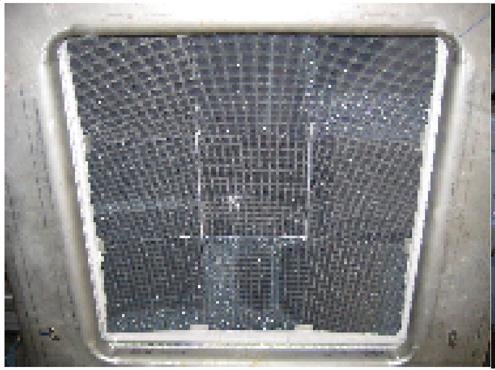
Monolithic honeycomb capable to absorb concentrated solar irradiation coated with redox water splitting materials

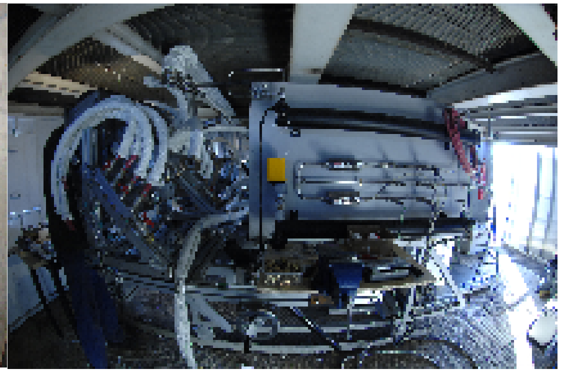




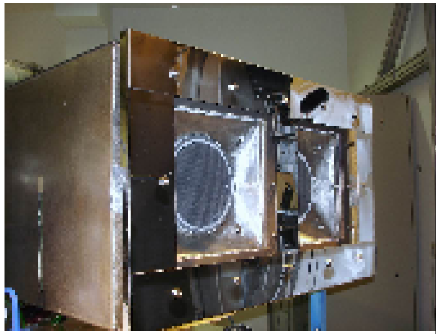
HYDROSOL TECHNOLOGY EVOLUTION

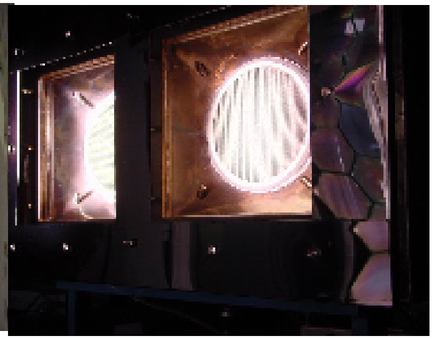
2008: 100 kW

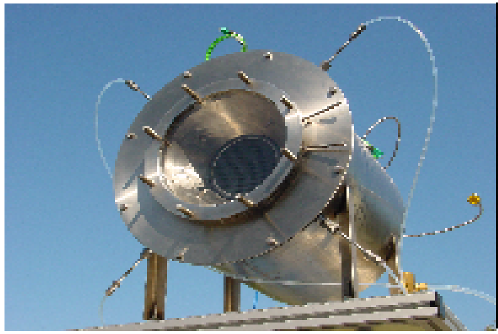


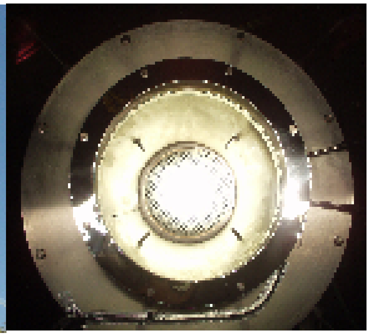


2004: 3 kW







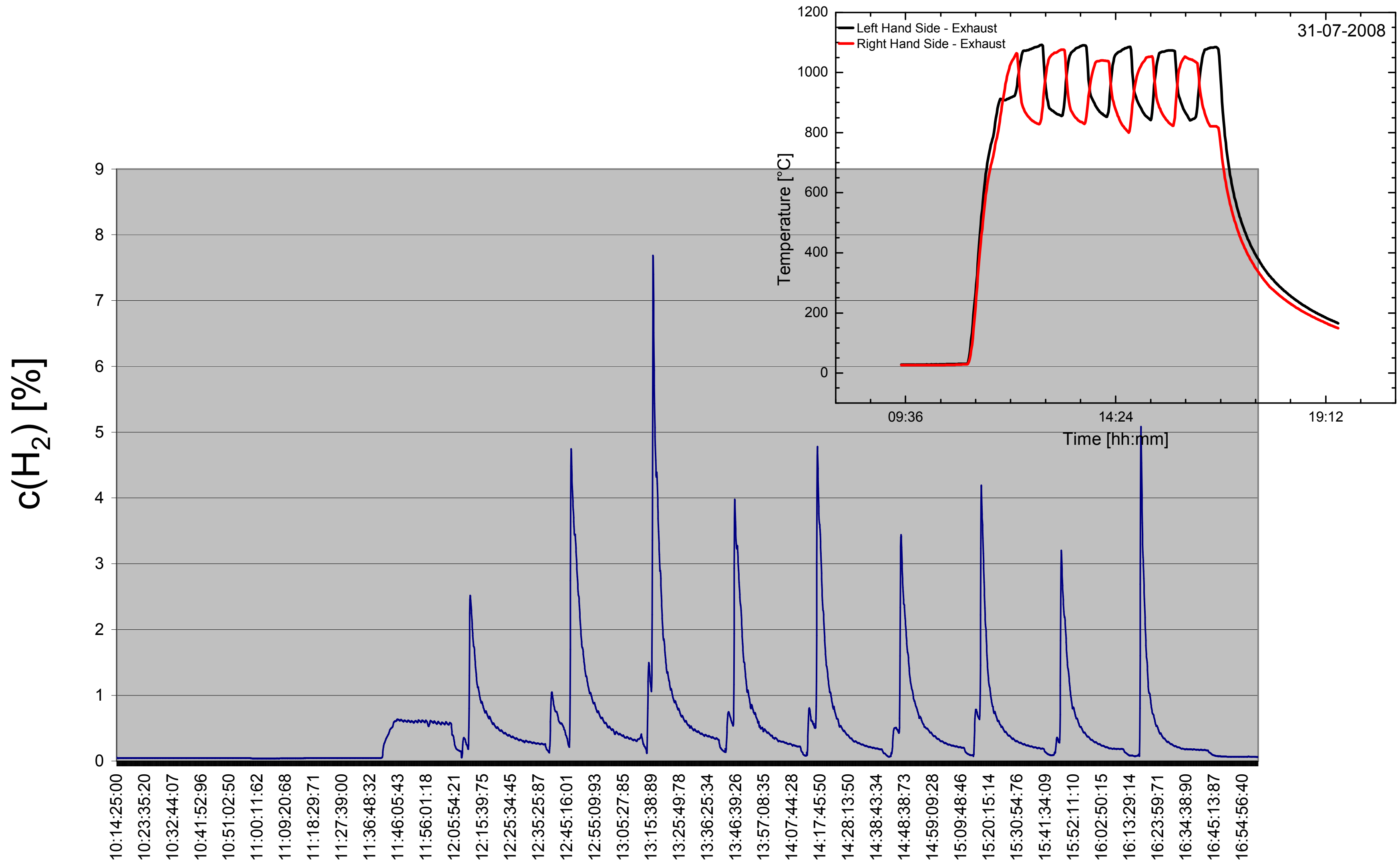


HYDROSOL-II: THE REALITY

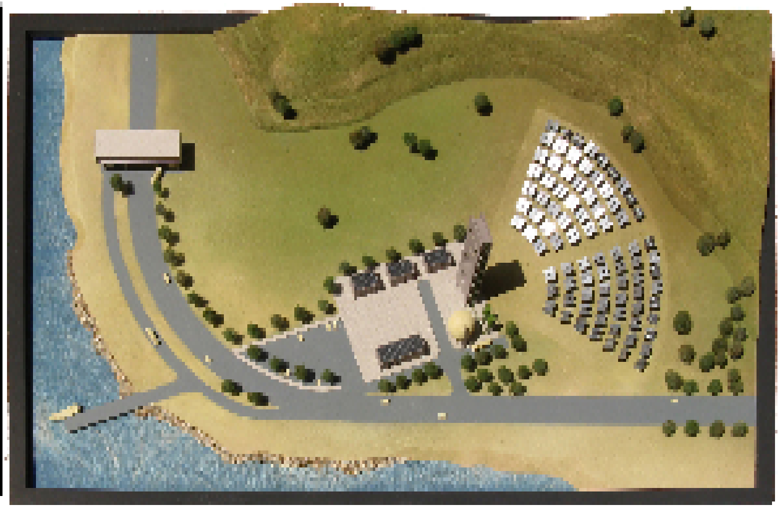
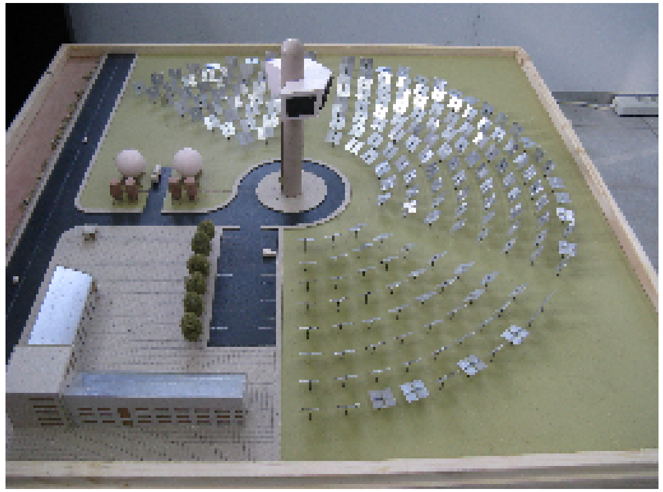
HYDROSOL-II 100 kW Pilot plant Inauguration: March 31st, 2008

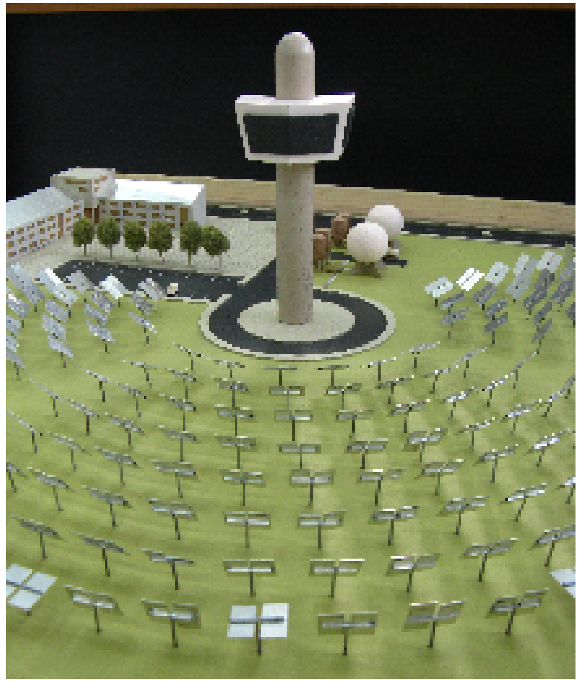
HYDROSOL-II: CYCLIC SOLAR H_2 PRODUCTION

Hydrogen production in experimental series in July 2009



HYDROSOL-3D: A VISION OF THE FUTURE

THE HYDROSOL-3D PARTNERSHIP

- **APTL/CERTH/CPERI - Aerosol & Particle Technology Laboratory (Coordinator) (RES) - advanced material synthesis, solar reactor design**
- **DLR - Deutsches Zentrum für Luft- und Raumfahrt (RES) – solar reactor engineering, solar field/plant design and operation**
- **CIEMAT - Centro de Investigaciones Energéticas, MedioAmbientales Y Tecnológicas (RES) – owner/ operator of PSA solar platform**
- **TOTAL S.A. (IND) - end-user; techno-economic process evaluation**
- **HYGEAR (SME) - product gas treatment units**

DURATION: 01/01/10-31/12/12; Total cost: 1.787.750 € ; FCH-JU funding: 984.375 €

HYDROSOL-3D GOALS

- The principal objective of HYDROSOL-3D is the in-detail preparation of a plant for solar thermo-chemical hydrogen production from water via the HYDROSOL technology, in a 1 MW scale on a solar tower.

- In this respect HYDROSOL-3D is concerned with the complete pre-design and design of the whole plant including the solar hydrogen reactor and all necessary upstream and downstream units needed to feed in the reactants and separate the products and the calculation of the necessary plant erection and hydrogen supply costs.

HYDROSOL-3D GOALS

- This design starts with the fine-tuning the materials composition and the reactor configurations advanced through the Projects HYDROSOL and HYDROSOL-II in order to ensure long-term, reliable solar-aided Hydrogen production at industrially attractive yields.

- Extensive modeling and simulation activities in conjunction with thermodymamic calculations will be employed to improve the performance of both the materials and the solar reactor. Designs and concepts that will enhance incorporation of redox material in the reactor and reduction of radiation losses will be considered and implemented. In parallel, the control concepts, algorithms and procedures necessary for the operation of such a plant will be developed and integrated in a pertinent process simulation software.

HYDROSOL-3D GOALS

- **The pre-design components and the control strategies will be thoroughly validated by experiments spanning the whole reactors' range: from small lab-scale to pilot ones coupled with solar tower facilities, in order to fully verify their transferability to large-scale operation.**

- **Two alternative plant scenario options will be analyzed: adapting the hydrogen production plant to an existing solar field/tower facility or developing "from scratch" a new, completely optimised hydrogen production/solar plant. The most promising option will be selected and analysed in detail, delivering the complete plant layout, defining and sizing in detail all necessary components, finalizing the control system and simulating the operation of the whole plant.**

HYDROSOL-3D GOALS

- **A techno-economic and market analysis will determine the feasibility of process scale-up to the MW scale, by calculating the cost necessary to erect a 1 MW demonstration plant and the respective hydrogen production and supply costs.**

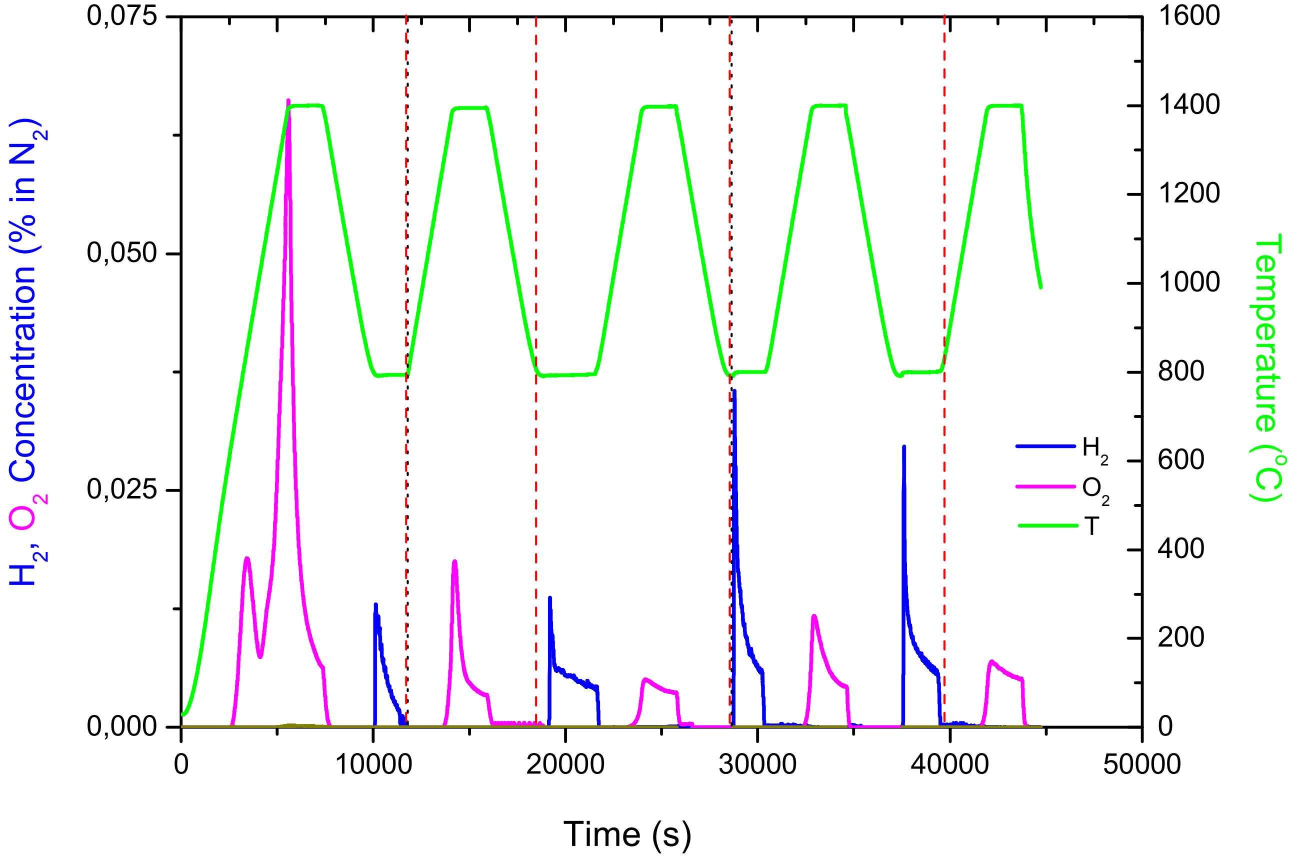
- **Finally, elaborated realistic scenarios for market penetration and on potential synergies with other technologies will complement the Project, with the aim to demonstrate that the combination of concentrated solar thermal tower facilities coupled with high temperature processes is a viable way to produce large amounts of Hydrogen via water decomposition at a reasonable cost without any greenhouse emissions, paving the way for a future sustainable, purely renewable hydrogen economy.**

HYDROSOL-3D GANTT DIAGRAM

Project HYDROSOL-3D Gantt (Manpower/Bar) chart	Partners Person-Months					Duration 1st year				2nd year				3rd year			
Workpackage Descriptions	APTL	DLR	CIEMAT	TOTAL	HYGEAR	3	6	9	12	15	18	21	24	27	30	33	36
WP1 Project management, dissemination and international cooperation	**6**	**3**	**2**	**0,5**	**0,5**												
Task 1.1 . Project management, co-ordination and dissemination activities	4	2	1	0,5	0,5												
Task 1.2. Linking with other European and National projects	2	1	1	0	0												
WP2 Refinement of core components and materials	**12**	**7**	**0**	**0**	**3**												
Task 2.1. Fine-tuning of metal oxide and its implementation into an absorber structure	4	0	0	0	0												
Task 2.2. Fine-tuning of surface characteristics and transport properties	6	2	0	0	0												
Task 2.3. Optimisation of reactor design	2	5	0	0	3												
WP3 Pre-design of the control system and operational conditions of an 1 MW demo-plant	**0**	**8**	**21**	**8**	**5**												
Task 3.1. Control concept based on HYDROSOL-2 experience	0	3	3	3	0												
Task 3.2. Development of a control /system program	0	0	15	0	5												
Task 3.3. Case and pre-design studies	0	5	3	5	0												
WP4 Experimental validation of pre-design components and process strategies	**17**	**7**	**13**	**0**	**7**												
Task 4.1: Development and construction of a laboratory hydrogen drying unit	0	0	0	0	4												
Task 4.2. Test operation of lab units and prototypes	13	4	0	0	3												
Task 4.3. Evaluation of rate equations and characterization of reactor performance	4	0	4	0	0												
Task 4.4. Pilot plant operation, verification of process strategies and optimization of operational ranges and process parameters.	0	3	9	0	0												
WP5 Design of an 1 MW demo-plant	**12**	**9**	**5**	**7**	**5**												
Task 5.1 Detailed design study	4	5	0	4	3												
Task 5.2. Modelling/simulation of core components and of the process as a whole	8	1	3	3	0												
Task 5.3. Selection and definition of control system and necessary hardware and components	0	3	2	0	2												
WP6 Techno-economic and market analysis	**2**	**9**	**4**	**27,5**	**2**												
Task 6.1. Analysis of hydrogen production and supply cost	2	3	0	9	0												
Task 6.2.Calculation of demonstration plant cost	0	3	0	8	0												
Task 6.3. Analysis of market introduction scenarios	0	2	2	5,5	0												
Task 6.4. Potential synergies with other technologies	0	1	2	5	2												
TOTAL PERSON-MONTHS	**49**	**43**	**45**	**43**	**22,5**												
MILESTONES									2				3 4 5			6	
	1	2	3	4	5	3	6	9	12	15	18	21	24	27	30	33	36
	Partners Person-Months					1st year				2nd year				3rd year			

WP2. Refinement of core components and materials

Task 2.1: Fine-tuning of metal oxide and its implementation into an absorber structure



Thermal reduction capability and cyclic operation.

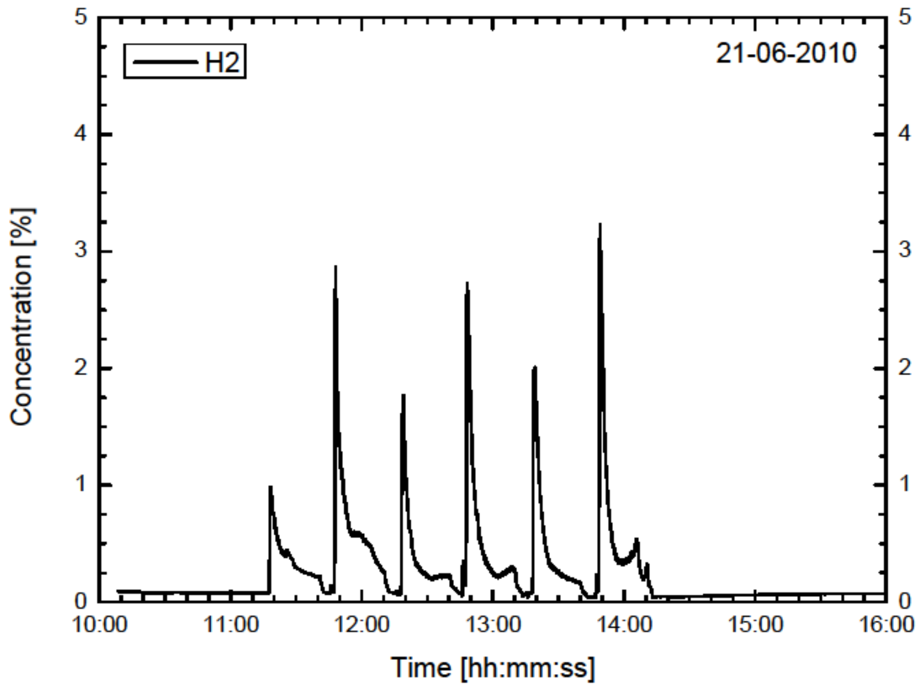
WP2. Refinement of core components and materials

Task 2.3: Optimisation of reactor design

Aims of Process Model:

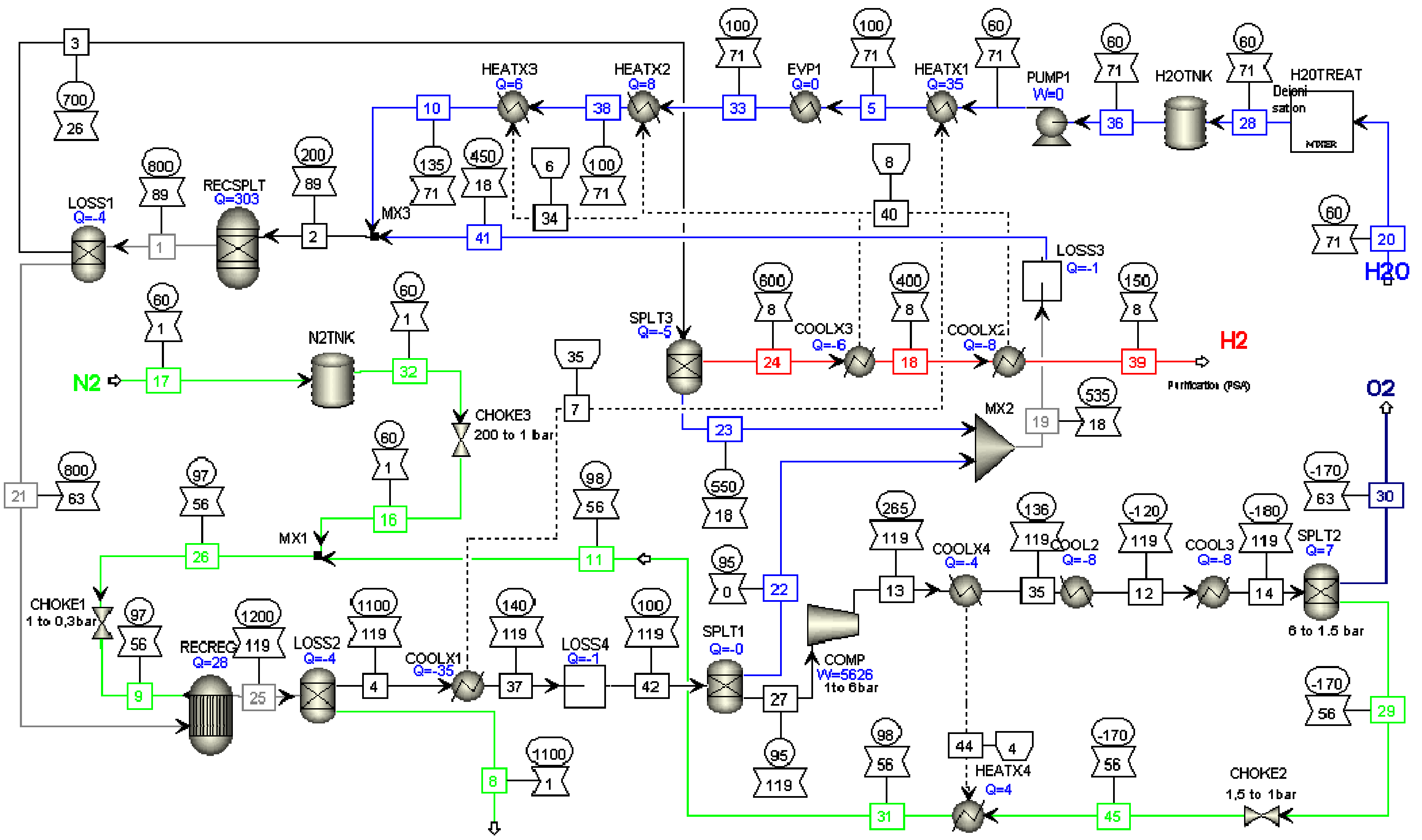
Analysis of…

- **Cycle times**
- **Start up and shut down phase**
- **Dynamic disturbances**
- **Heat recovery schemes**



WP2. Refinement of core components and materials

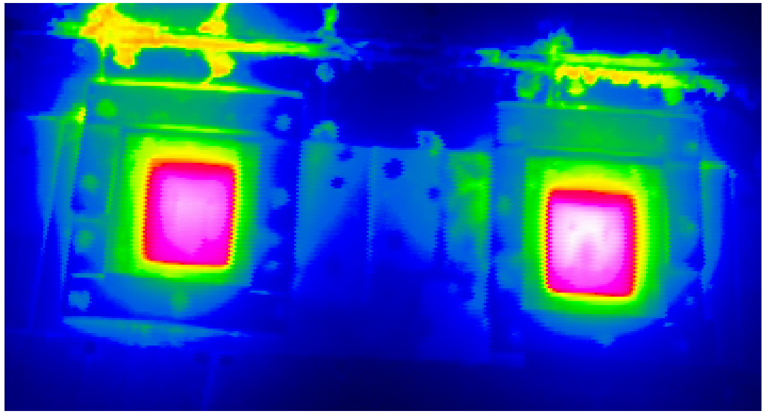
Steady state model in Aspen



WP2. Refinement of core components and materials

Motivation: Losses of Reactor / state of the art

- Most important heat loss mechanism: Re-radiation
- Black-body radiation for size of one chamber front at 1200 °C: **54 kW**



WP2. Refinement of core components and materials

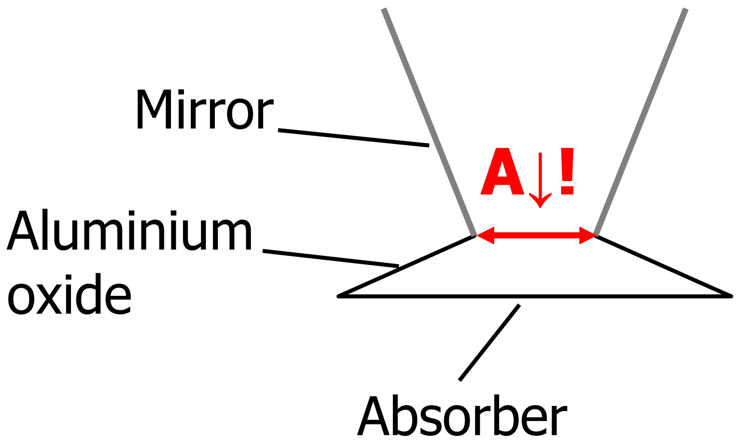
Framework of design study

Restrictions

- Solair concept
- Adequate for industrial application
  - Easy maintenance
  - Low production costs

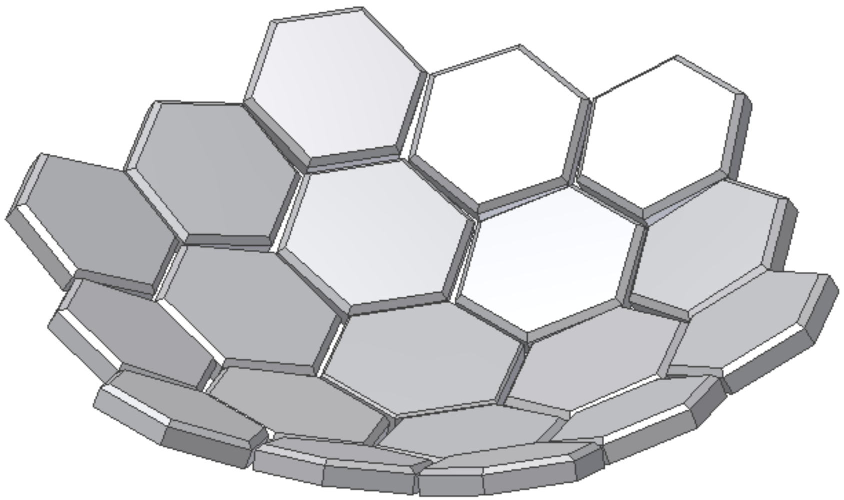
Goal

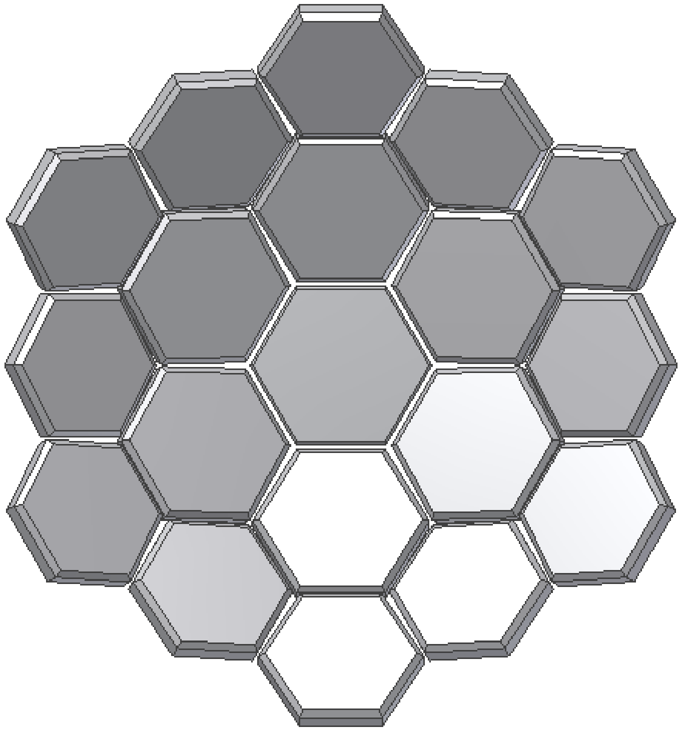
- Small aperture area
- Homogeneous Temp. distribution
  - Flux distribution
  - Pressure loss



WP2. Refinement of core components and materials

Preliminary study – curved absorber design





WP4: Experimental validation of pre-design components and process strategies

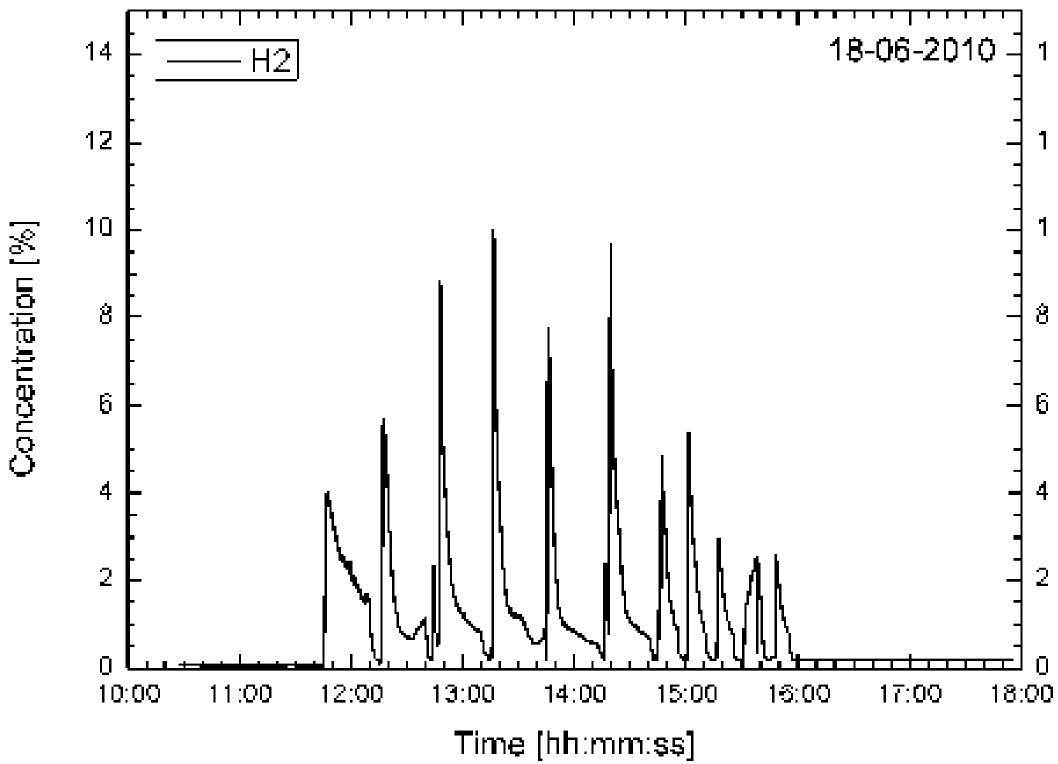
Assembly of new honeycombs, plus fixing of sealings, thermocouples, springs, insulation etc.

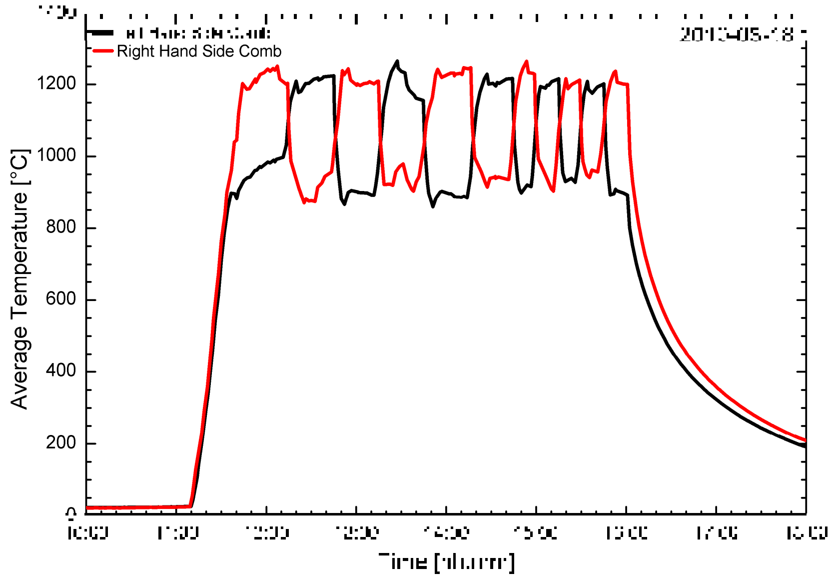
Testing plan

- Set parameter: temperature of honeycomb (900 and 1200°C)
- Control parameter: Number of heliostats
- Cycling of the modules
- Optimisation of cycle duration (decrease)
- Parametric studies: Variation of mass flows

WP4: Experimental validation of pre-design components and process strategies

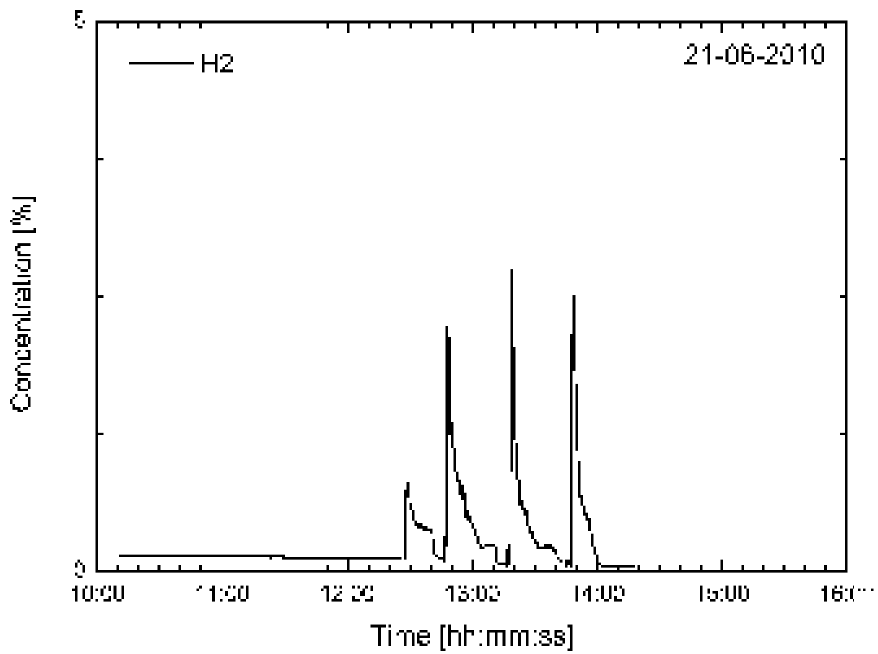
Hydrogen production on June 18th 2010

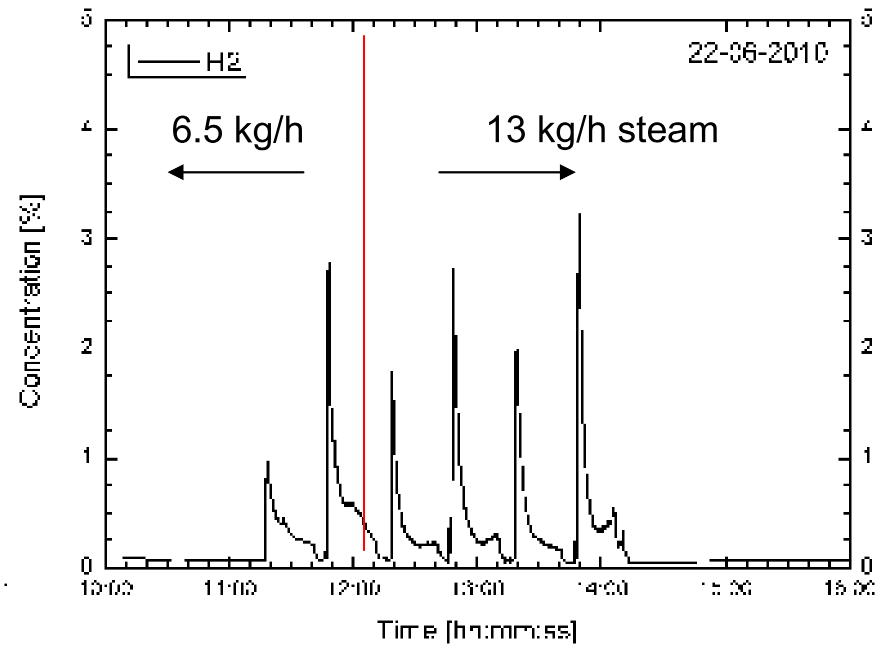




WP4: Experimental validation of pre-design components and process strategies

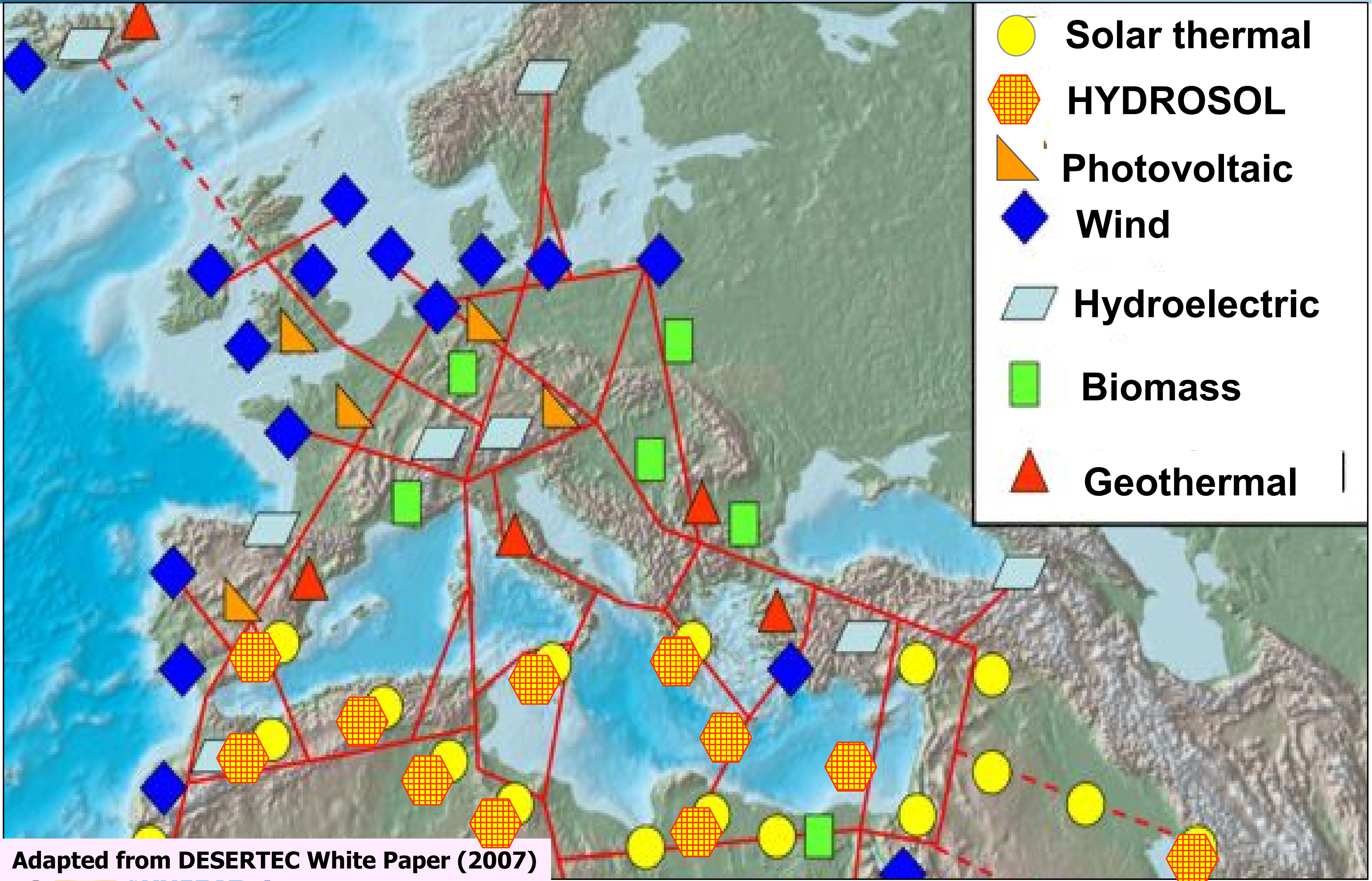
Hydrogen production on June 21st/22nd 2010





HYDROSOL-3D: A VISION OF THE FUTURE:

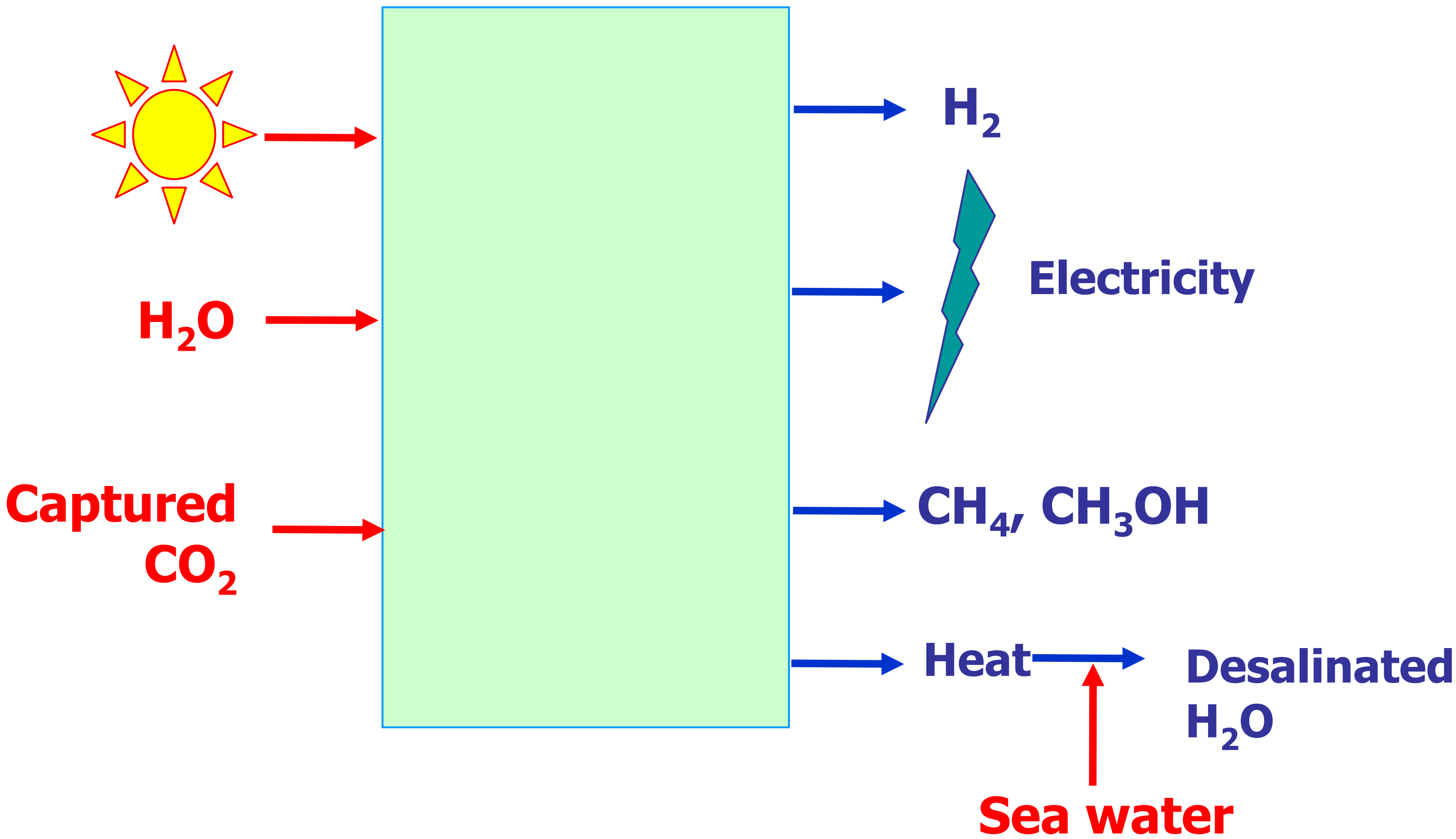
Integration of Solar Fuels with Energy Infrastructures: A Renewable Future for Europe



Adapted from DESERTEC White Paper (2007)

Tomorrow's Solar Thermochemical Plant

Production of Solar Fuels (renewable H_2 and CH_4 / CH_3OH), Recycling of CO_2, Production of Electricity and Desalinated H_2O



Acknowledgments

- European Commission for supporting our Solar Hydrogen research with projects: HYDROSOL-I, HYDROSOL-II, HYDROSOL-3D, and HYCYCLES

- FCH-JU for supporting our Solar Hydrogen research with HYDROSOL-3D

- HYDROSOL I & II consortium members from APTL/CPERI, DLR, Stobbe Technical Ceramics, Johnson Matthey, CIEMAT/PSA

Thank you for your attention!

http://www.hydrosol3d.org/