



ÉCOLE POLYTECHNIQUE  
FÉDÉRALE DE LAUSANNE

# Laboratory of Renewable Energy Science and Engineering

-

## Large-scale solar fuel processing plant

Prof. Sophia Haussener

Institute of Mechanical Engineering, EPFL, Switzerland

- Project d'ingénierie simultanée
- **Large-scale solar fuel processing plant**
- *The objective of the project is the design of a sustainable (concentrating) solar facility for thermochemical or photo-electrochemical processing of solar fuels (hydrogen and/or synthesis gas) and the prediction of the solar fuel's cost.*

## Analysis of large-scale concentrated solar power (CSP) hydrogen processing plant

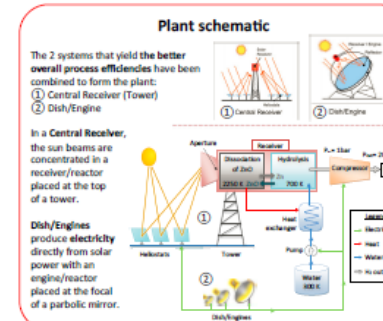
Authors: Laura Magni, Sabine Yousfi, Romain Zuber

Supervised by Prof. Haussener

Institute of Mechanical Engineering – Spring Semester 2014

### Introduction & objectives

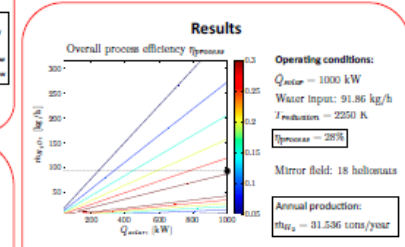
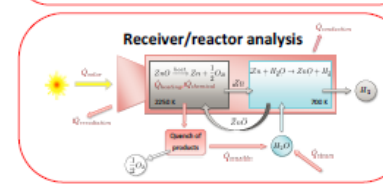
- The storage of solar energy (e.g. as a fuel), within sight of later utilisation, might be a suitable way to help to compensate energy needs where and when sufficient energy cannot be produced.
- This project aims to analyse a thermochemical hydrogen processing plant, in order to determine optimal operating conditions for a large-scale installation.
- CSP processes consist in producing hydrogen-based by splitting water using a metallic substrate (heterogeneous reaction, T=700 K), which is obtained through high temperature reduction (T=2250 K) of a corresponding metal oxide, ZnO in our case. We restrict the analysis to hydrogen (H<sub>2</sub>) production, mostly because it is a clean fuel.
- While the original goal of the project was to optimise a plant, the complexity of such systems in terms of equipment needed as well as thermodynamical and chemical aspects make the way to the optimisation of a plant very long. Therefore, the attention has been focused on a first analysis of a plant.
- Numerous plant types already exist, designed for different scales and efficiencies. It might then be interesting to design a hybrid system that would yield better performances.



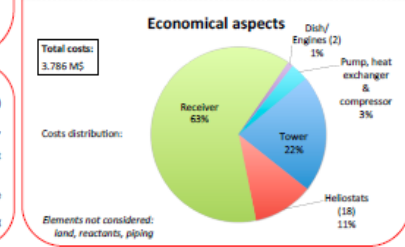
### Methodology

Concerning the following explanations, refer to section "Receiver/reactor analysis".

- Power balance<sup>[1]</sup> for the system:  
 $Q_{\text{tower}} = Q_{\text{heating}} + Q_{\text{chemical}} + Q_{\text{reduction}} + Q_{\text{condensation}} \rightarrow \text{losses}$
- Overall process efficiency (output is enthalpy of hydrogen after compression, input is enthalpy of water at standard conditions):  
 $\eta_{\text{process}} = \frac{\dot{m}_{\text{H}_2} (\Delta h_{\text{H}_2}^0 + \Delta h_{\text{compression}})}{Q_{\text{tower}} + Q_{\text{heating}}}$
- Optical efficiency:  $\eta_{\text{optical}} = \eta_{\text{concentrator}} \cdot \eta_{\text{reflector}} \cdot \eta_{\text{modeling}} \cdot \eta_{\text{loss}}$



- ### Conclusions
- The results actually describe a « medium-scale » (+30 tons of H<sub>2</sub> per year) rather than a « large-scale » plant.
  - The production obtained through this medium-scale process seems promising, as 1kg of H<sub>2</sub> is nowadays energetically equivalent to 4l of oil.
  - Several assumptions have been made during this analysis, making this project a basis for further research:
    - Chemistry should be investigated, notably different reactants,
    - Many aspects regarding heat exchanges (power balance) have been simplified, resulting in a « lumped parameters » model,
    - The optical efficiency's prediction can be improved by considering the height of the tower.



### Main reference

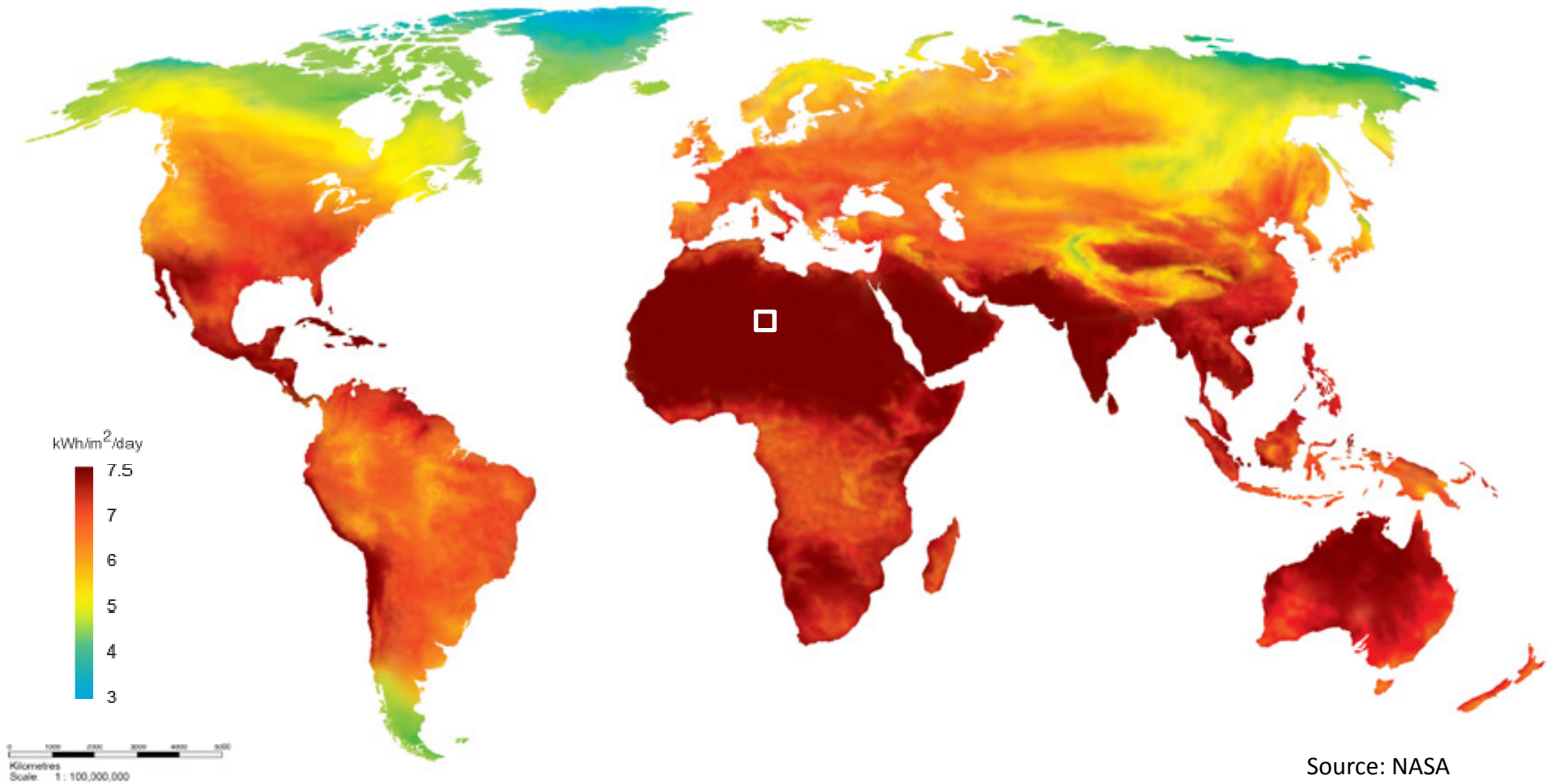
[1] A. Zgraggen, Solar production of carbonaceous materials – Reactor design, modelling and experimentation, 2008.

### Acknowledgements

This material is based upon some developments presented in the thesis cited, and has been elaborated thanks to the contribution of Prof. Sophie Haussener.

# LRESE

- Solar irradiation:
  - Earth's ultimate recoverable oil resource delivered in 1.5 days
  - Global annual energy need delivered in 1 hour
  - 0.1% of earth surface covered (20% efficient) delivers global annual energy



---

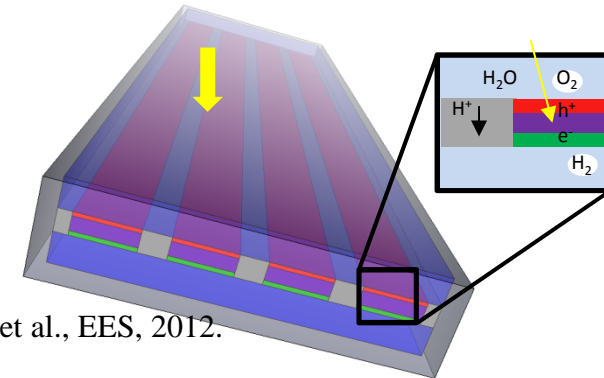
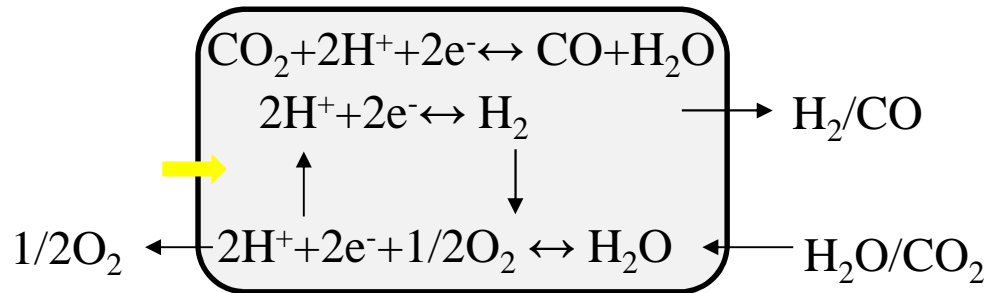
# LRESE

---

- But solar energy is:
  - Dilute
  - Unequally distributed
  - Intermittent
- Storage (e.g. as fuel)!

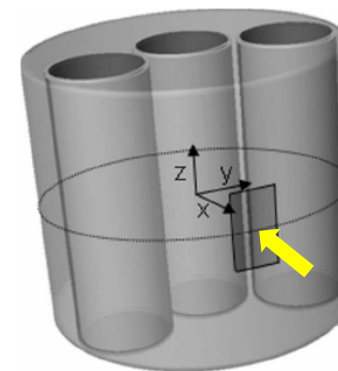
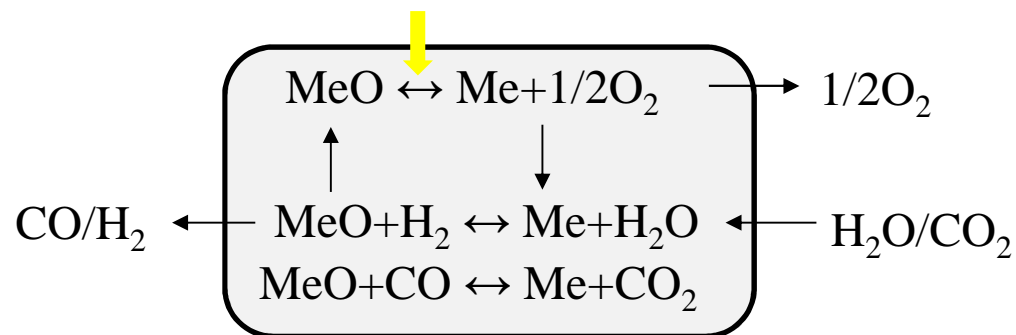
# LRESE

- Photoelectrochemical fuel production



Haussener et al., EES, 2012.

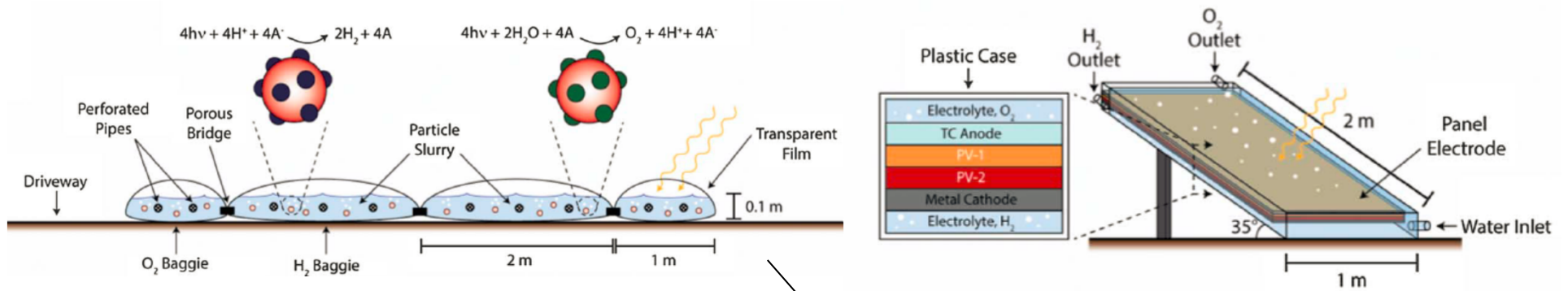
- Solar thermochemical fuel production (temperatures > 1400°C)



Haussener et al., JSEE, 2009.

# LRESE

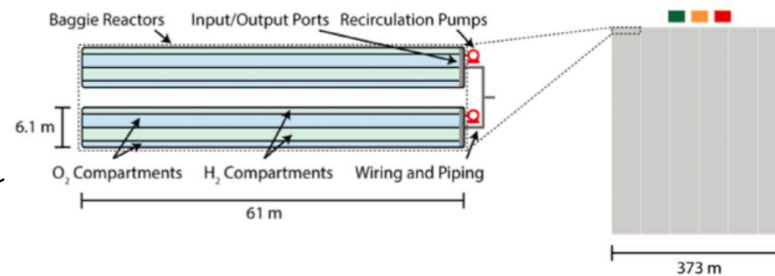
- Possible plant design - photoelectrochemical:



Pinaud et al., EES, 2013.

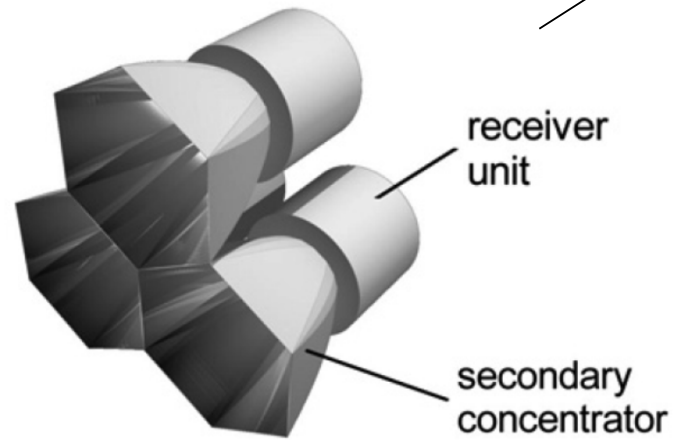
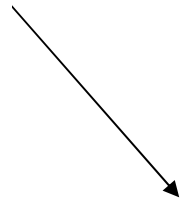
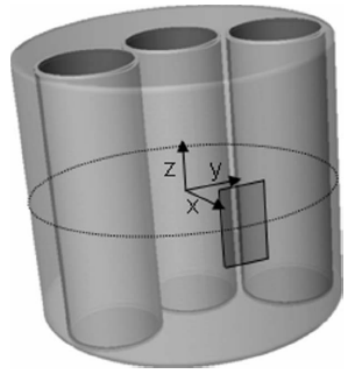


greendiary.com

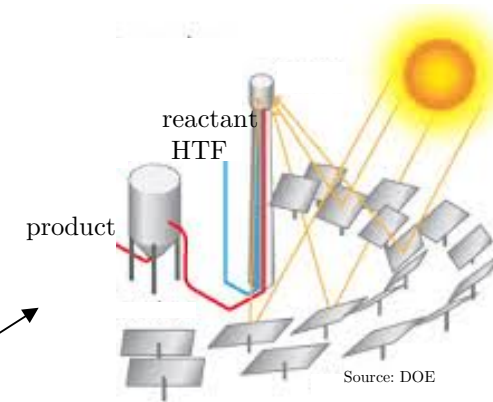


# LRESE

- Possible plant design – solar thermochemical:



Romero et al., JSEE, 2002.



---

# LRESE

---

- Project d'ingénierie simultanée
- **Large-scale solar fuel processing plant**
- *The objective of the project is the design of a sustainable (concentrating) solar facility for thermochemical or photoelectrochemical processing of solar fuels (hydrogen and/or synthesis gas) and the prediction of the solar fuel's cost.*
- Choice of chemistry: thermodynamics, kinetics ...
- Reactor design: modeling (heat and mass transport) ...
- Plant design: external components, concentration, interfaces ...
- Economics: prices of materials, components ...
- Life cycle assessment: energy requirements of materials and components ...
- 2 teams of 2 students