



## HIGH TEMPERATURE SOLAR HEAT



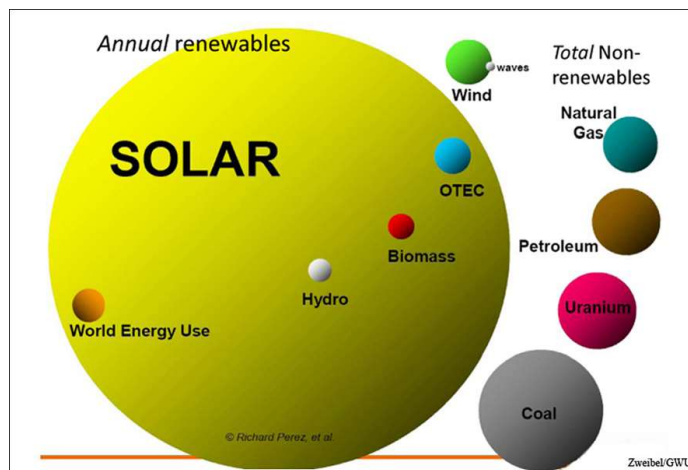
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## INTRODUCTION

- Mitigation of climate change requires the use of more renewable energies.
- Solar energy is a serious candidate.



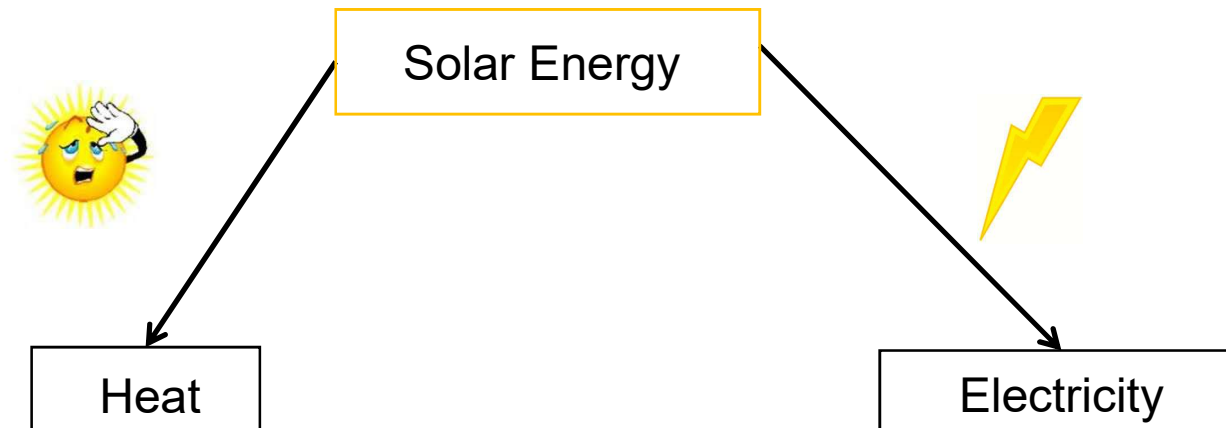
World energy consumption (2019)  
 $=6 \cdot 10^{20}$  J

Annual solar potential  
 $=3.4 \cdot 10^{24}$  J

→ Solar potential is about 7500 times what we need !

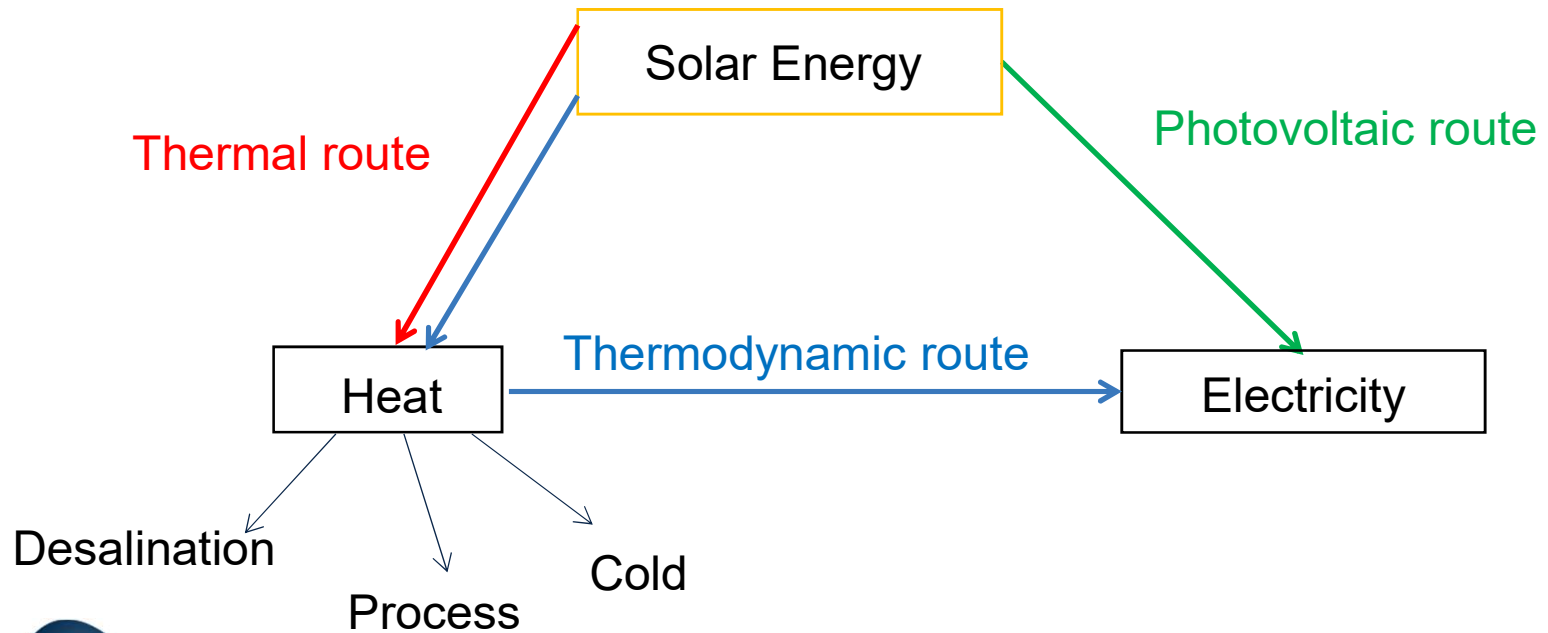
## INTRODUCTION

- Current technologies allow solar energy to be converted into 2 forms: heat or electricity



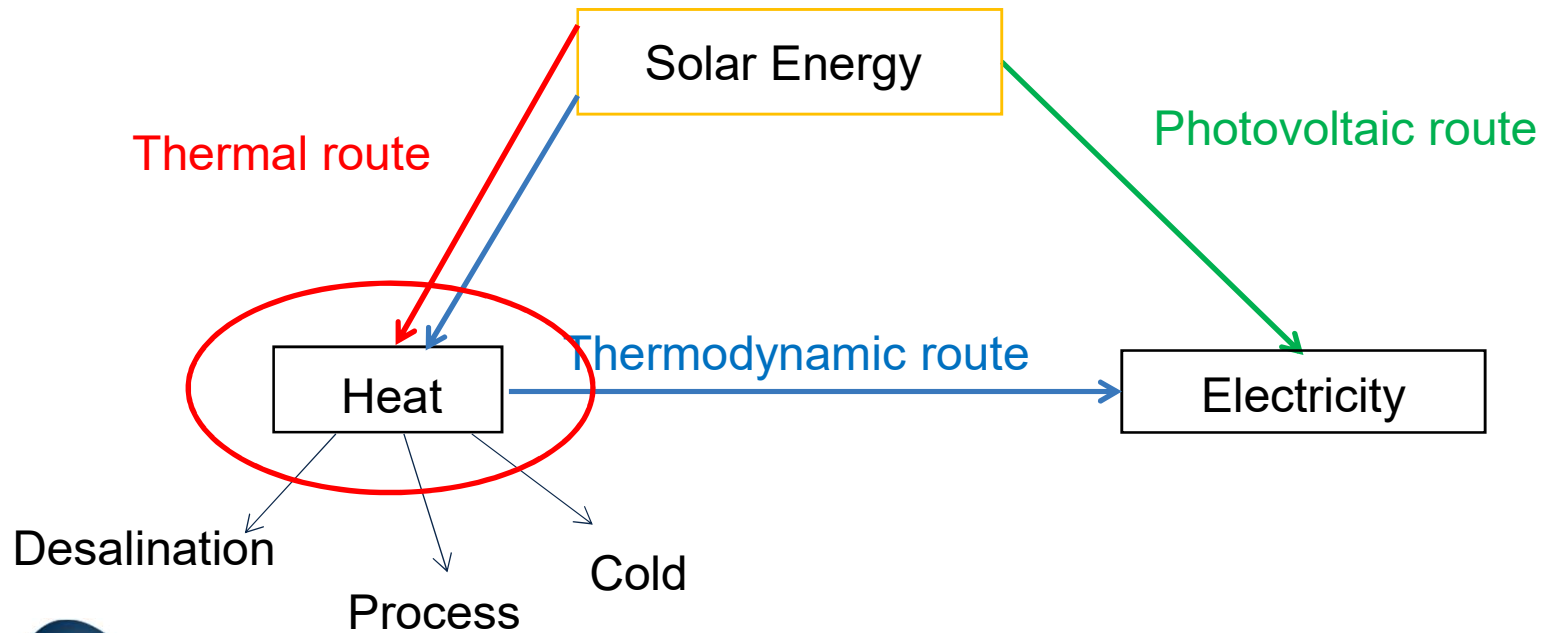
## INTRODUCTION

- Current technologies allow solar energy to be converted into 2 forms: heat or electricity



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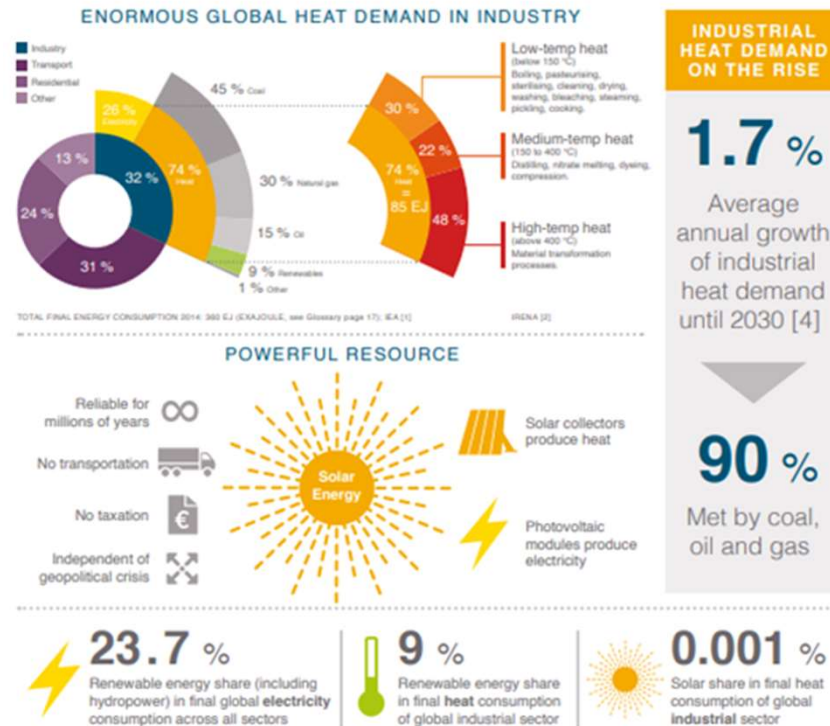


## INTRODUCTION

- Heat demand in industry represents 75% of the energy need
- How to provide renewable heat?

## INDUSTRIAL SOLAR HEAT PAYS OFF

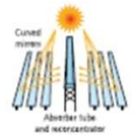

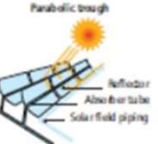
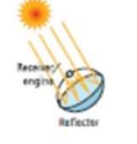
There is more final energy consumption of heat in the industrial sector than there is electricity consumed worldwide. Electricity, however, is talked about more.

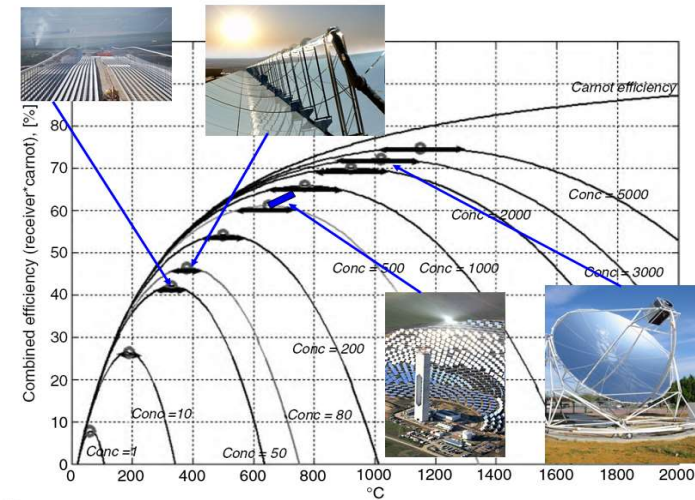


Source:  
Solar Payback project-2017

# INTRODUCTION

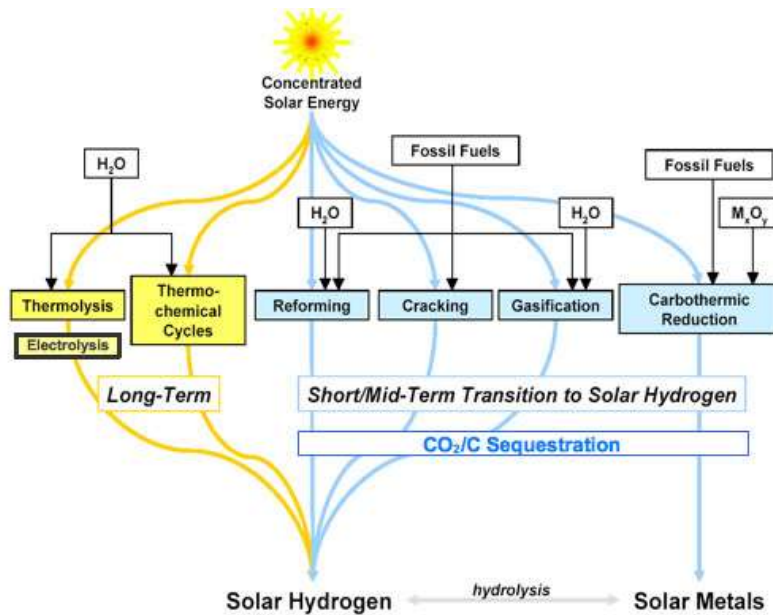
- Concentrated solar power enables to concentrate Direct Normal Irradiance to convert solar energy into high temperature heat

Receiver type \ Focus type	Line focus	Point focus
<b>Fixed</b>	<p>Collectors track the sun along a single axis and focus irradiance on a linear receiver. This makes tracking the sun simpler.</p> <p><b>Linear Fresnel Reflectors</b></p> 	<p>Collectors track the sun along two axes and focus irradiance at a single point receiver. This allows for higher temperatures.</p> <p><b>Towers (CRS)</b></p> 
<b>Mobile</b>	<p>Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.</p> <p><b>Parabolic Troughs</b></p> 	<p>Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.</p> <p><b>Parabolic Dishes</b></p> 



## SOLAR FUELS

- Solar heat can be used to produce solar fuels



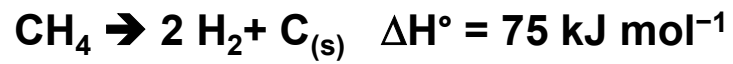
Solar upgrade factor

$$U = \frac{\text{HHV}_{\text{products}}}{\text{HHV}_{\text{reactants}}} > 1$$

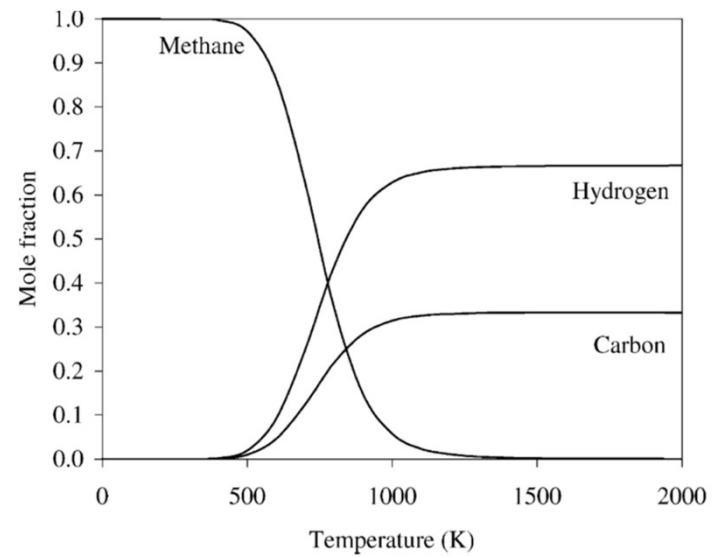
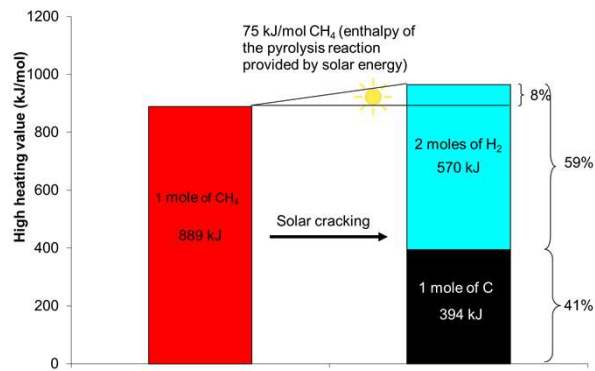


## SOLAR FUELS

- Solar methane cracking

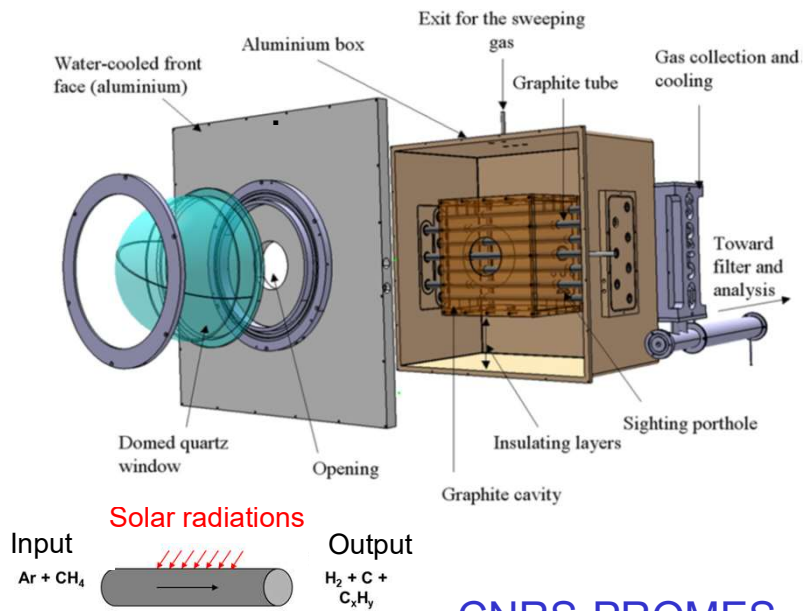


U=1.08

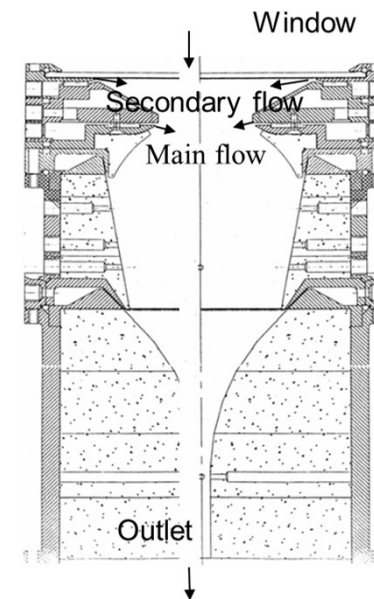


## SOLAR FUELS

- SOLHYCARB project: indirect vs. direct heating concept



CNRS-PROMES



WIS-ISRAEL



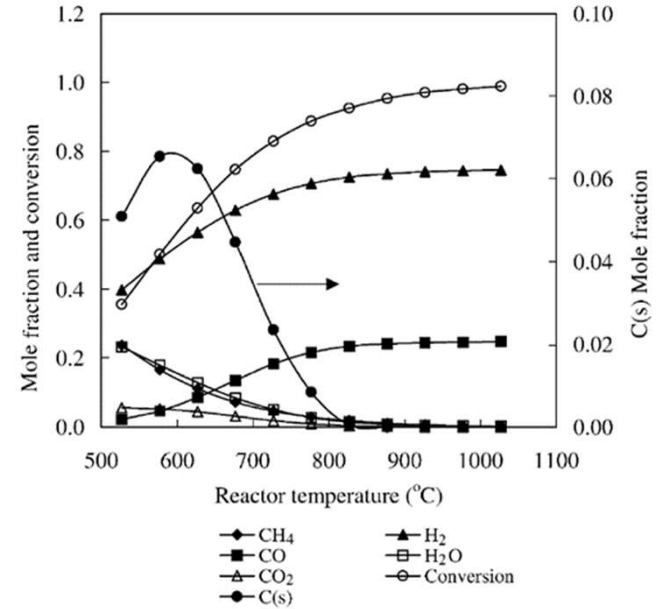
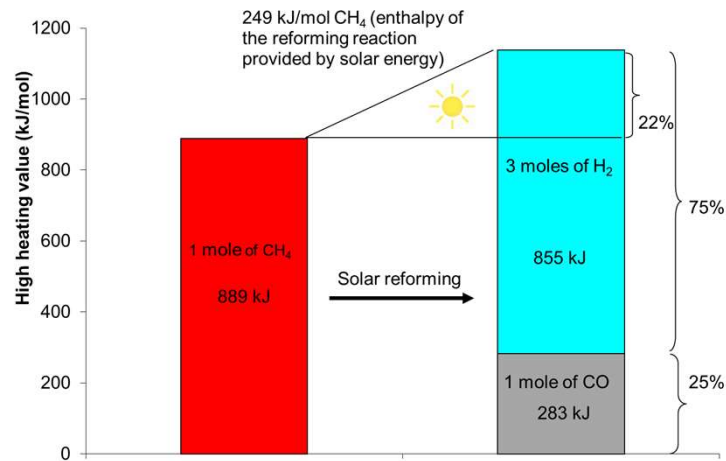
S. Rodat, S. Abanades, J.L. Sans, G. Flamant, International Journal of Hydrogen Energy, 35(15), 2010, 7748-7758  
 A. Kogan, M. Israeli, E. Alcobí, Production of hydrogen and carbon by solar thermal methane splitting International Journal of Hydrogen Energy, 32(18), 2007, 4800-4810.

## SOLAR FUELS

- Solar reforming



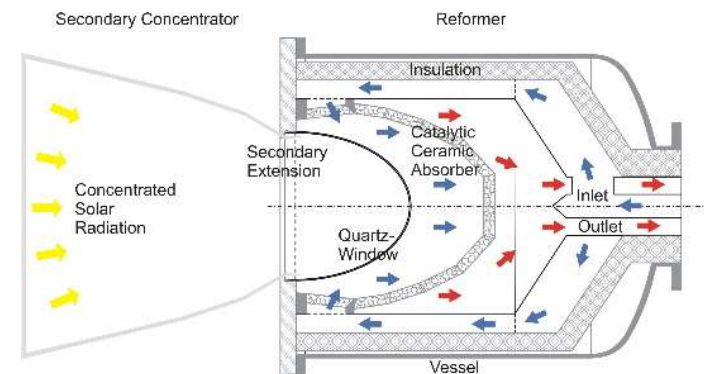
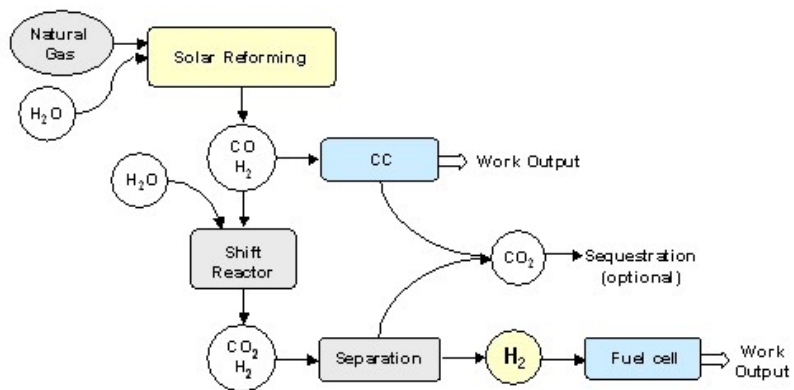
U=1.28





## SOLAR FUELS

- Solar reforming: SOLREF

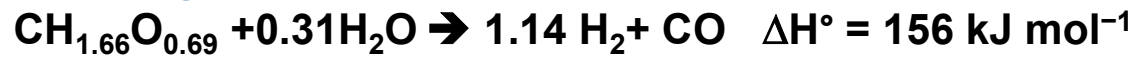


S. Möller, D. Kaucic, C. Sattler, Hydrogen production by solar reforming of natural gas: a comparison study of two possible process configurations, Journal of Solar Energy Engineering, 128(1), 2006, 16-23.

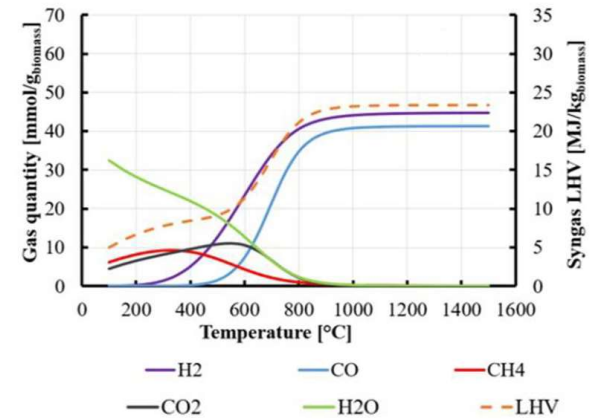
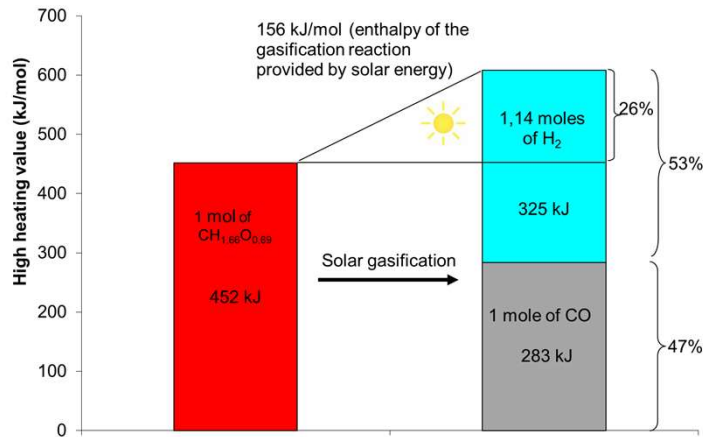


## SOLAR FUELS

- Solar gasification



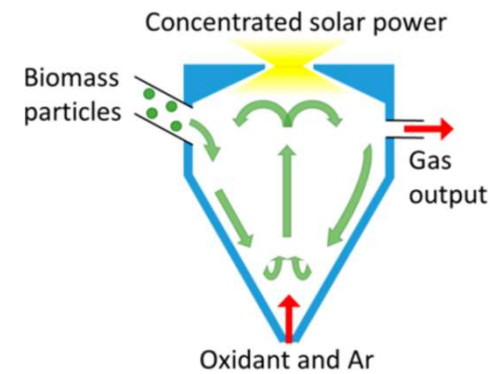
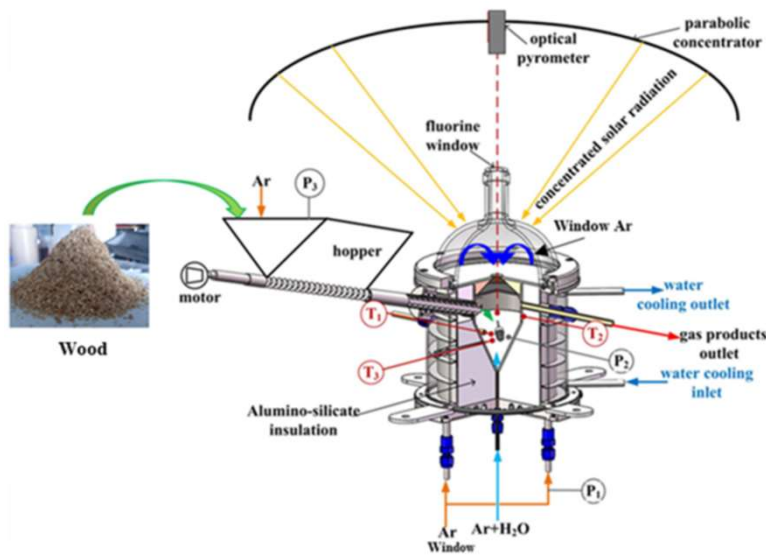
**U=1.35**





## SOLAR FUELS

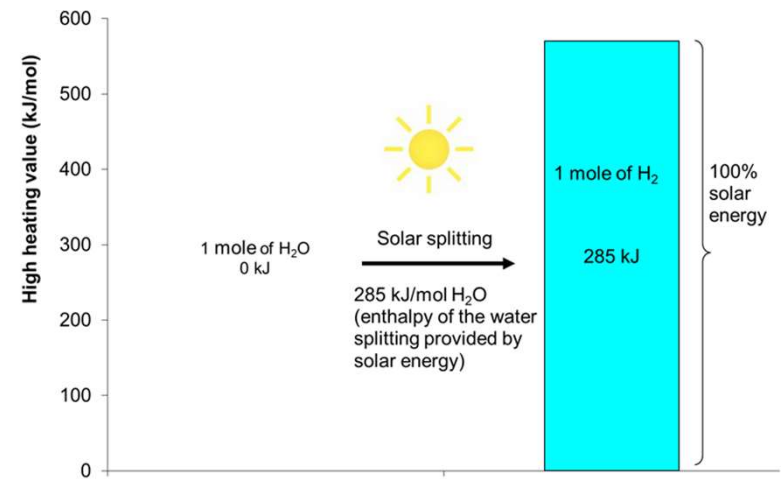
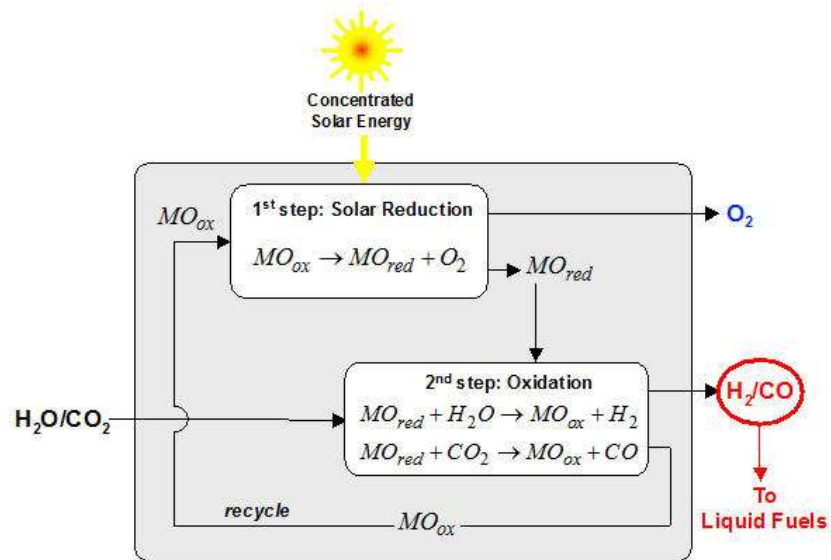
- Spouted bed reactor



Boujjat, H., Rodat, S., Chuayboon, S., & Abanades, S. (2020). Experimental and CFD investigation of inert bed materials effects in a high-temperature conical cavity-type reactor for continuous solar-driven steam gasification of biomass. *Chemical Engineering Science*, 115970.

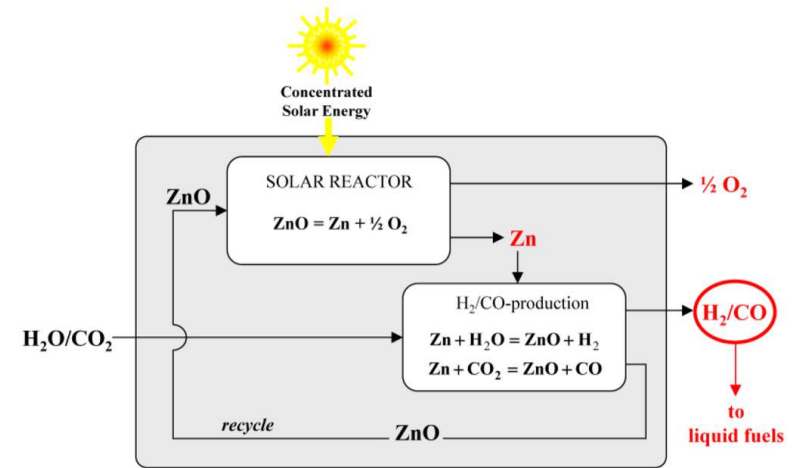
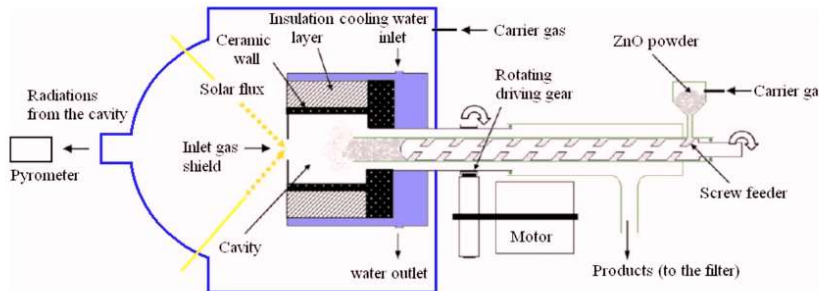
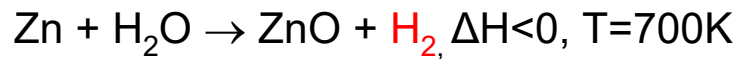
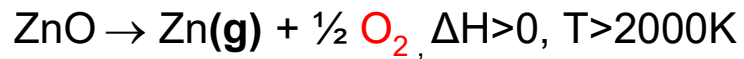
# SOLAR FUELS

- Thermochemical cycles



## SOLAR FUELS

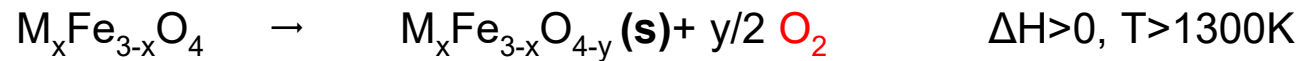
- Thermochemical cycles (ZnO/Zn)



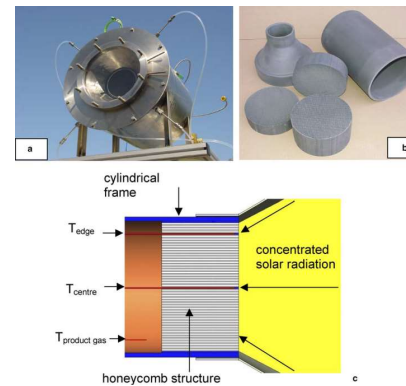
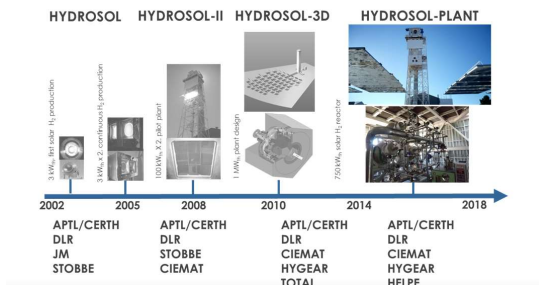


## SOLAR FUELS

- Thermochemical cycles (ferrites)



Previous HYDROSOL-projects

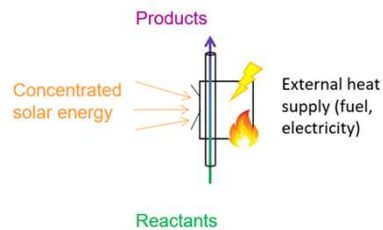


González-Pardo, A., Denk, T., & Vidal, A. (2020, December). Lessons learnt during the construction and start-up of 3 cylindrical cavity-receivers facility integrated in a 750 kW solar tower plant for hydrogen production. In AIP Conference Proceedings (Vol. 2303, No. 1, p. 170008). AIP Publishing LLC.

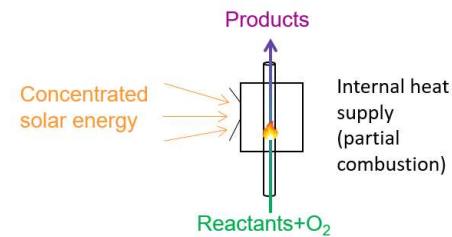


## CHALLENGES

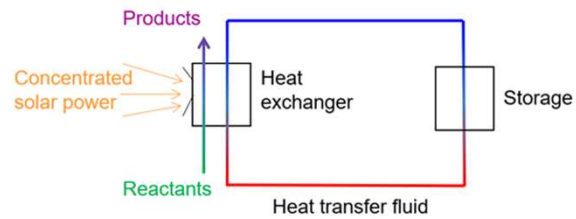
- Continuous (H24) solar processes



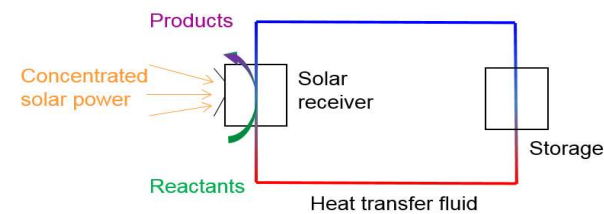
External heating of a hybrid solar process



Internal heating of a hybrid solar process



Indirect heat supply



Direct heat supply



Rodat, S., Abanades, S., Boujjat, H., & Chuayboon, S. (2020). On the path toward day and night continuous solar high temperature thermochemical processes: A review. *Renewable and Sustainable Energy Reviews*, 132, 110061.







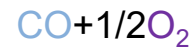
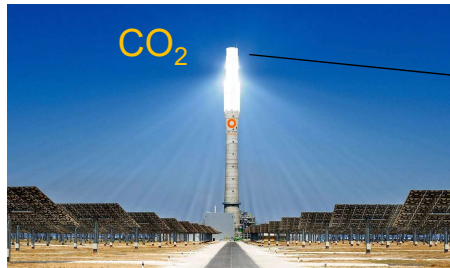
## CONCLUSION

- Concentrated solar energy, a serious alternative to fossil heat (same value if solar processes are continuous).
- Continuous solar processes allow better product quality and improve the reliability and profitability of the processes and therefore their credibility for large-scale deployment.
- Can be used for a multitude of processes.
- Solar energy: a good for all.
- With solar energy you can do everything ...



## PERSPECTIVES

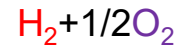
Solar energy enables to convert atmospheric CO<sub>2</sub>



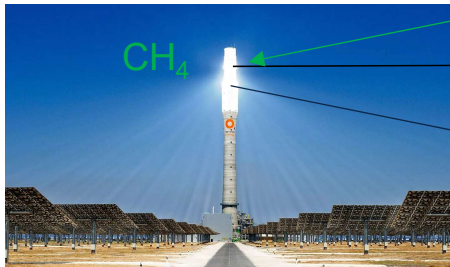
Fischer Tropsch (exo)



Hydrogen production



And it is possible to refill coal mines!



C



## PERSPECTIVES 2050

Everything is back to normal...



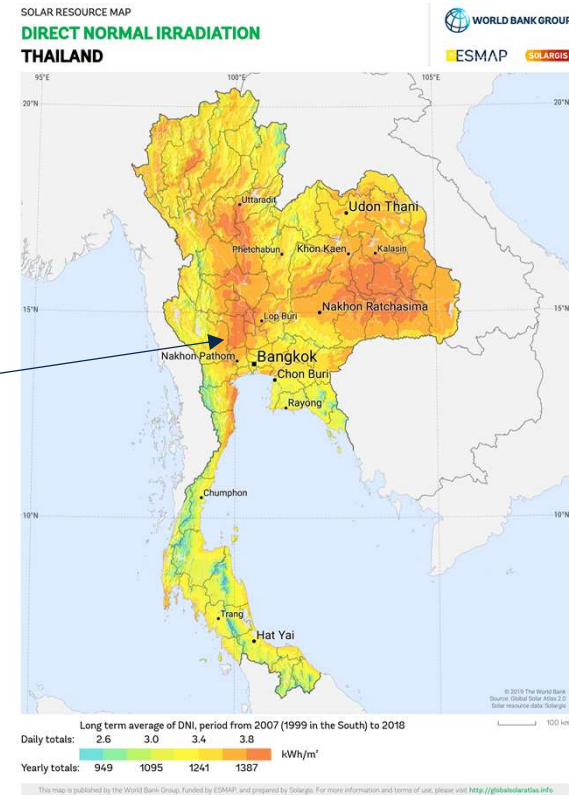


## PERSPECTIVES

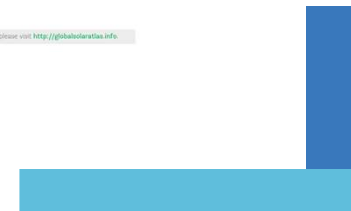
- CSP in Thailand !



5 MWe  
Direct steam generation  
Parabolic trough (30 bars, 330°C)



Willwerth, L., Feldhoff, J. F., Krüger, D., Keller, L., Eickhoff, M., Krüger, J., ... & Khenissi, A. (2018). Experience of operating a solar parabolic trough direct steam generation power plant with superheating. *Solar Energy*, 171, 310-319.







**Thank you for your attention !**  
**Enjoy the conference and good work !**  
**Questions ?**

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