Solar Thermal Hydrogen Production

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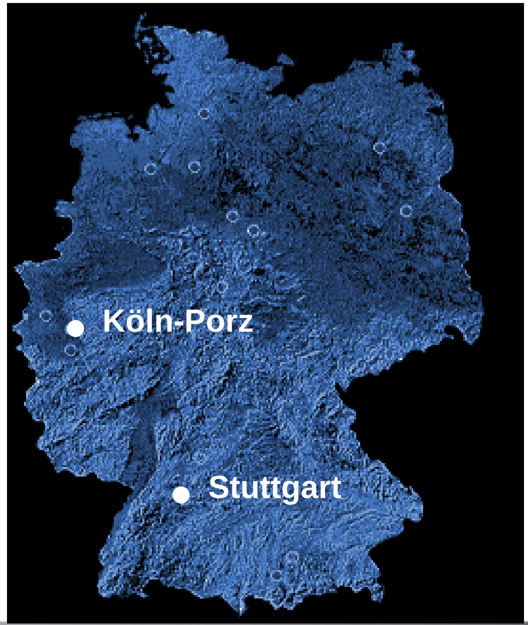
DLR Institute of Technical Thermodynamics – Solar Research

Solar Research of DLR appr. 65 scientists, engineers, and technicians working at three sites energetic utilization of concentrated solar radiation:

Köln-Porz (site and solar furnace)

Stuttgart

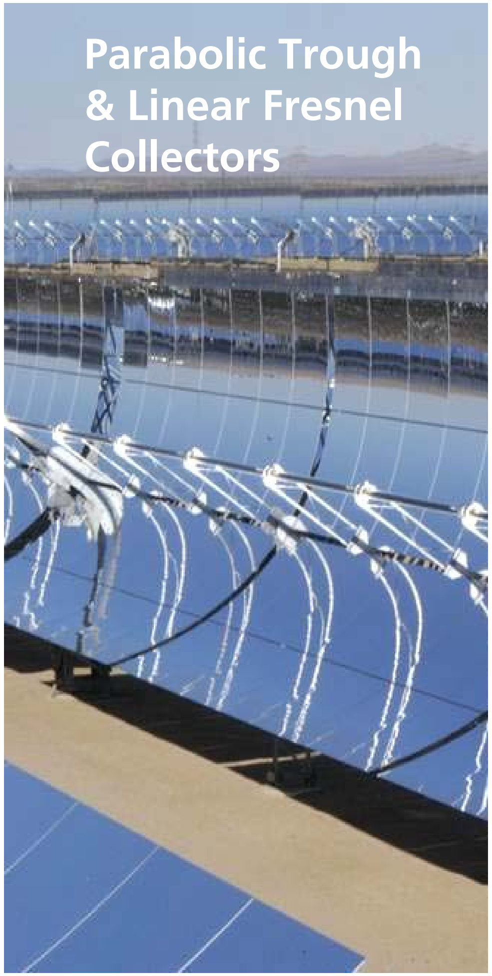
Plataforma Solar de Almería, PSA, Spanien (permanent delegation)

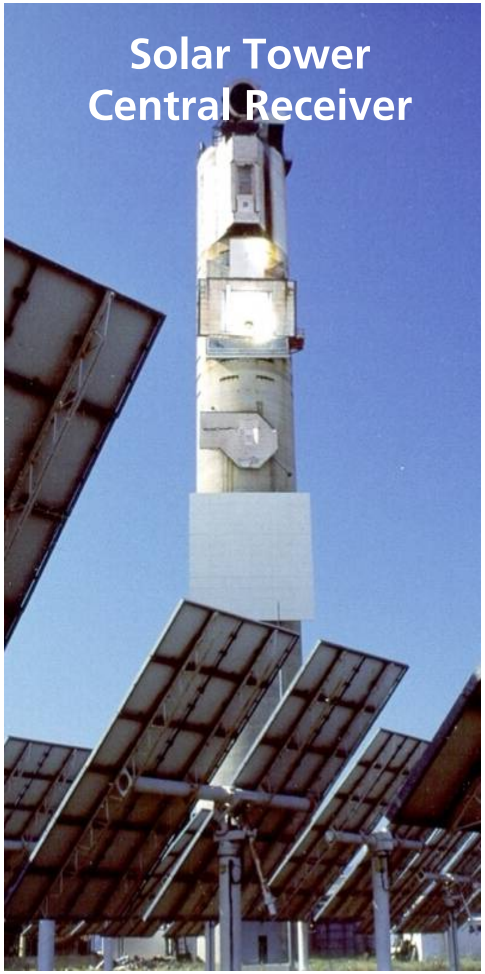


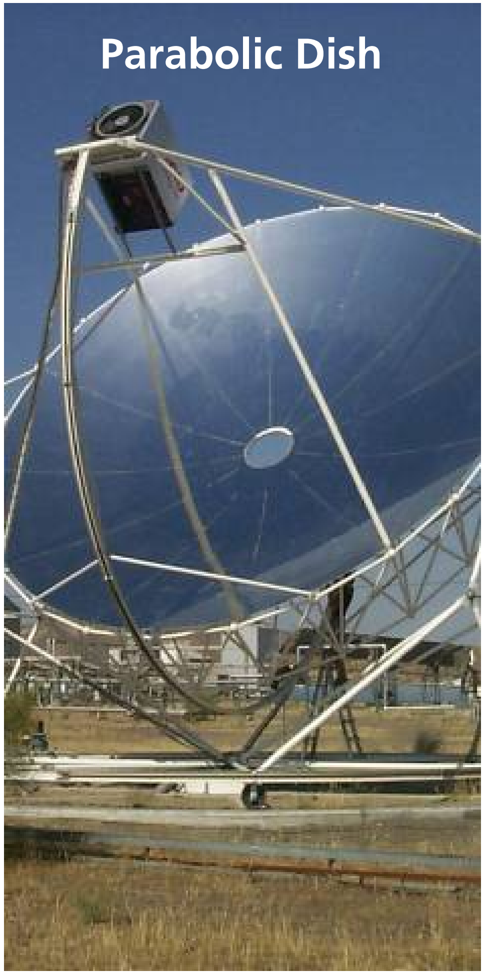
Condition for industrial solar hydrogen production

Availability of appropriate solar receivers and processes

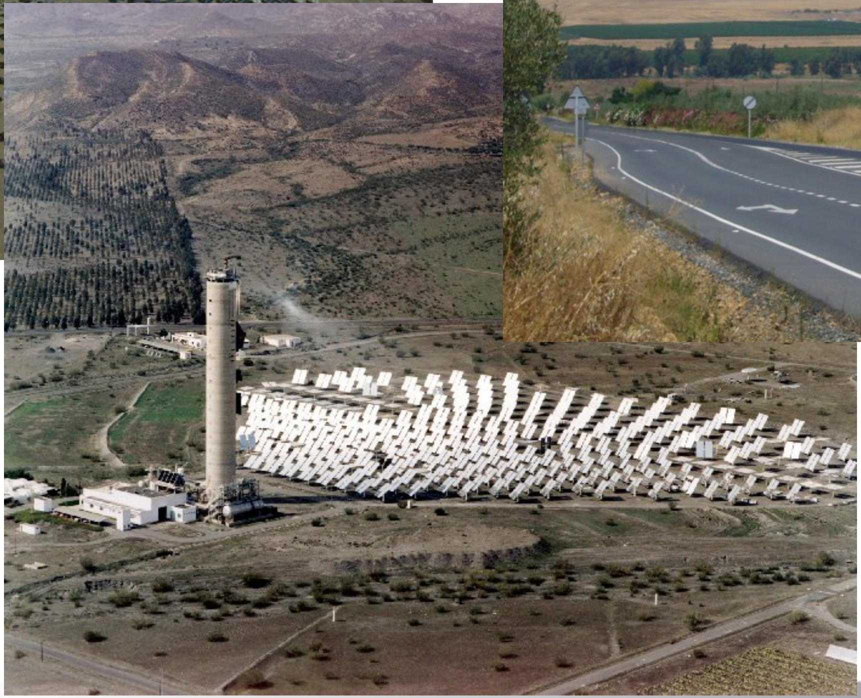
CSP - Concentrating Solar Power







Solar Towers, Central Receiver Systems

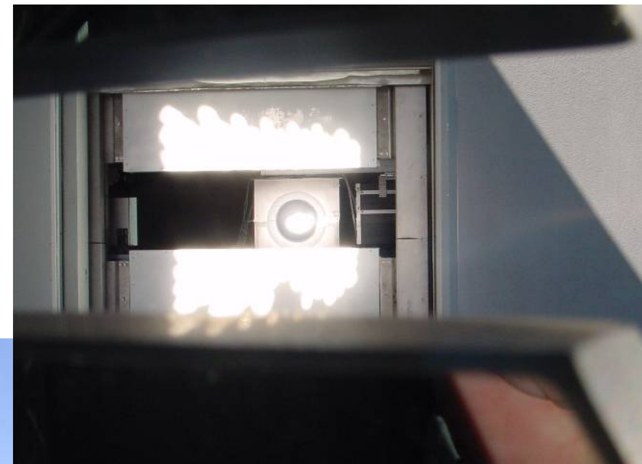


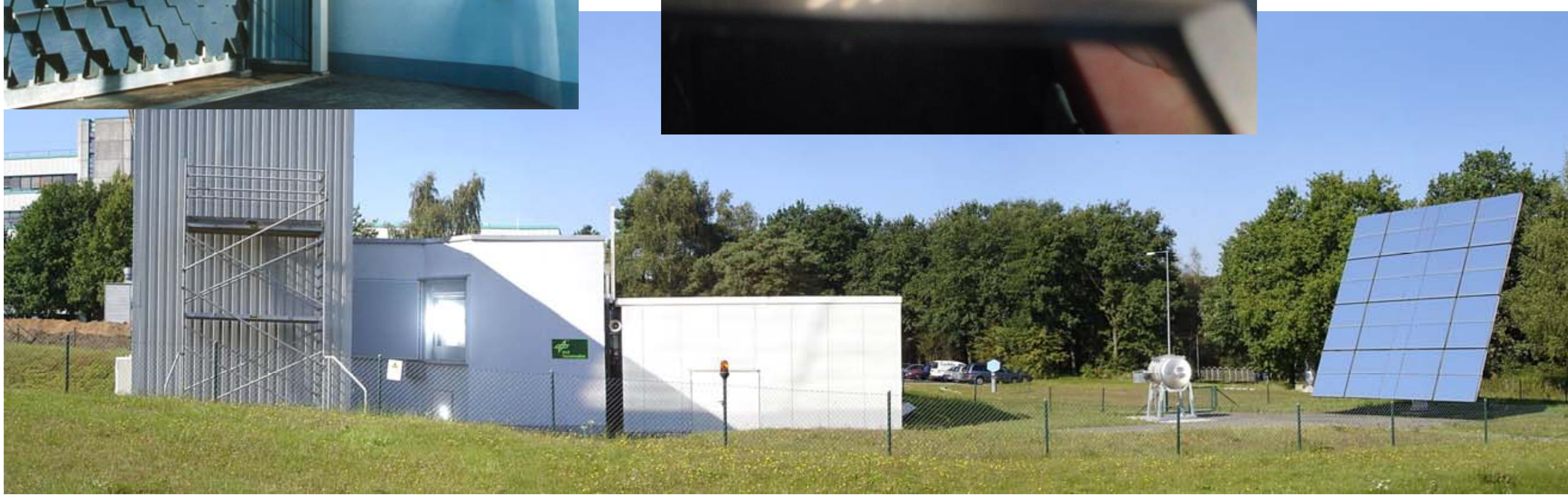
- Solar-Two
- CESA-1
- PS10

Solar Furnace

Solar Radiant Power at Target up to ca. 25 kW

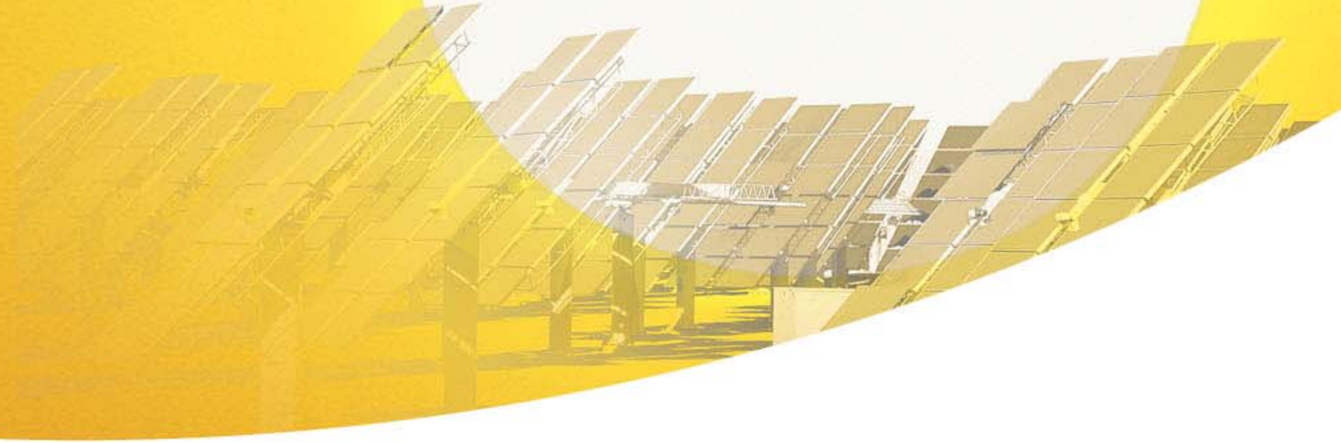
Irradiance > 5 MW/m²





High Power Lamp Arrangement

- Electrical Power Demand: 60 kW
- Maximum Radiant Power at Target (Objective): 25 kW
- Irradiance (Proof): > 4 MW/m^2



Solar Hydrogen Generation

Solar Fuels

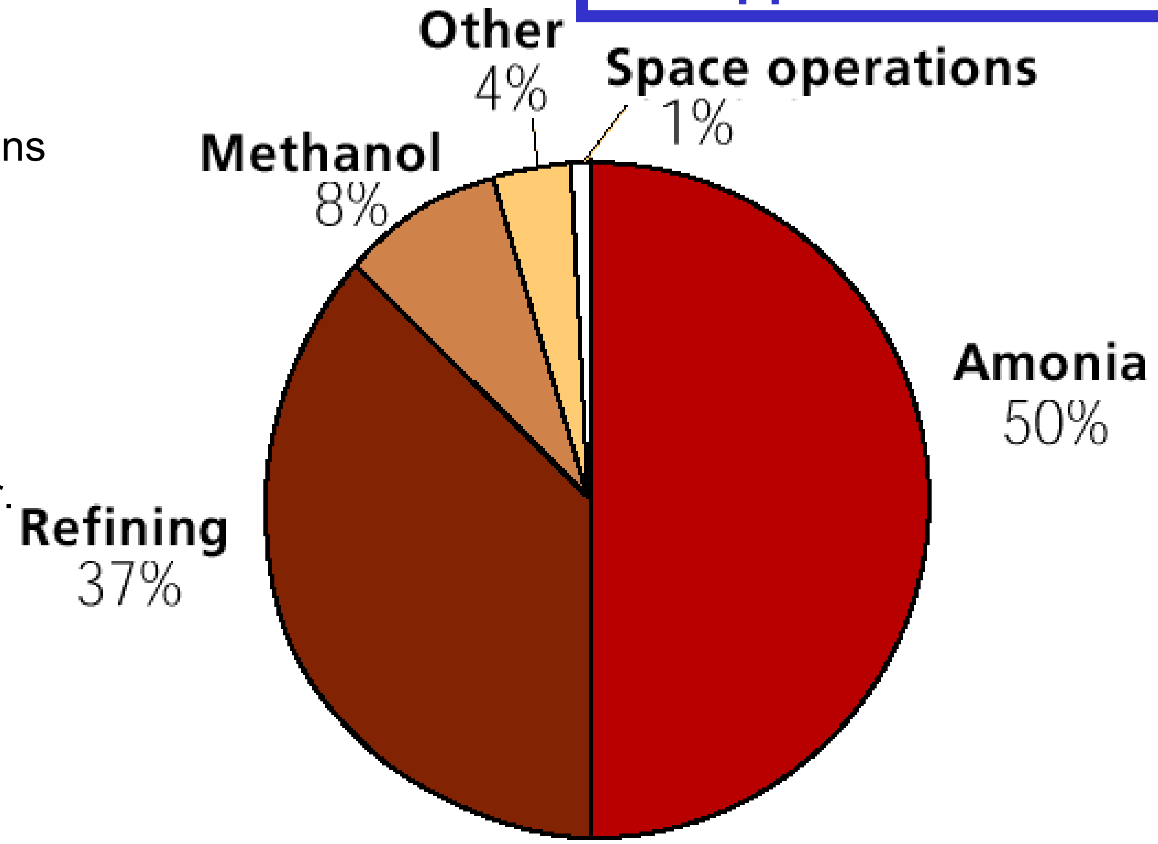
Solar fuels: chemically stored solar energy, potentially available for mobile applications

- Natural: → Biomass
- Synthetically: → Hydrogen, Syngas, other synthetic fuels

Hydrogen Today

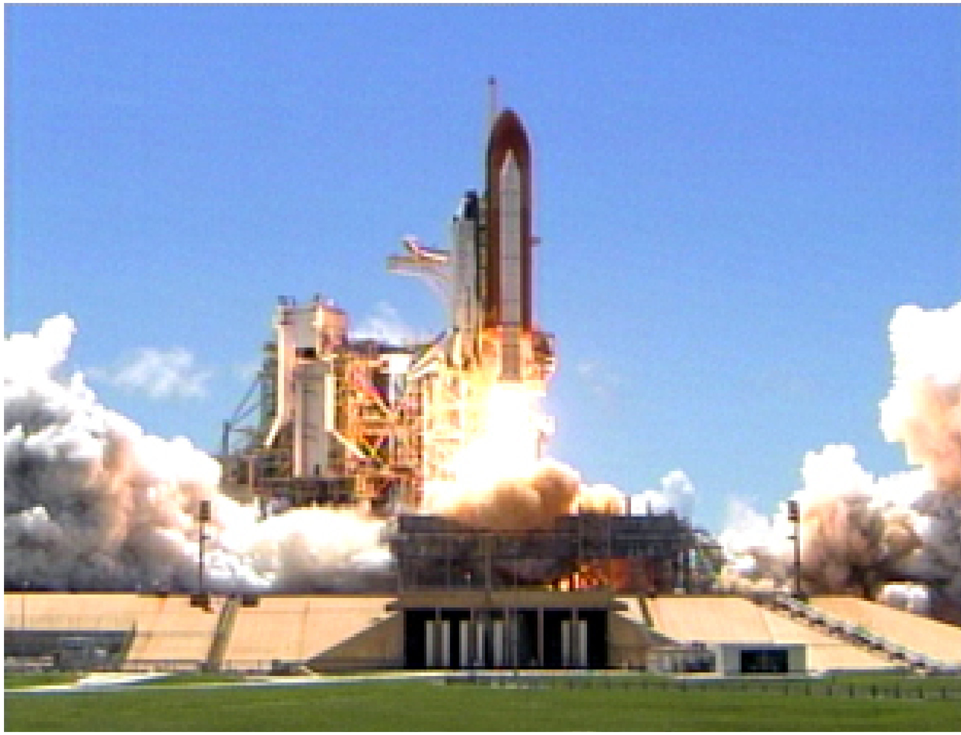
- Hydrogen today mainly chemical intermediate, only marginal energetic applications
- Production
600 – 700 Mrd. Nm^3/a
= 53 – 62 Mt/a
- Virtual Value
100 Mrd. €/a
- Production growth rate appr. 10 %/a
- Only appr. 4 % are traded!
- Production of ammonia responsible for appr. 250 Mt CO_2/a

Energetic Applications 1 %



Belona Report 6, 2002

Hydrogen Today



Space Shuttle Discovery

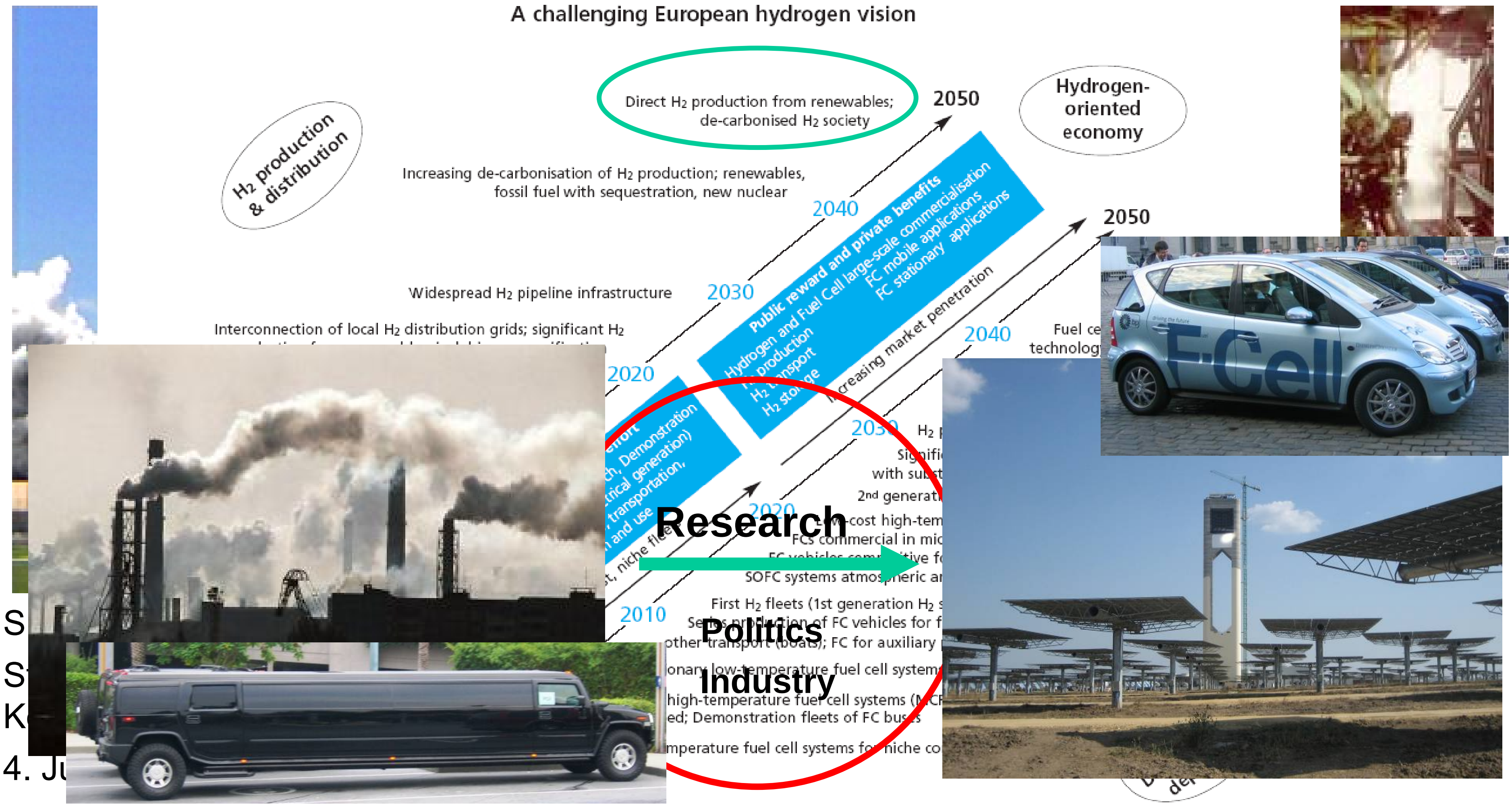
Start from Pad 39B
Kennedy Space Center, FL

4. July 2006

Vulcain-1 Vulcain-2

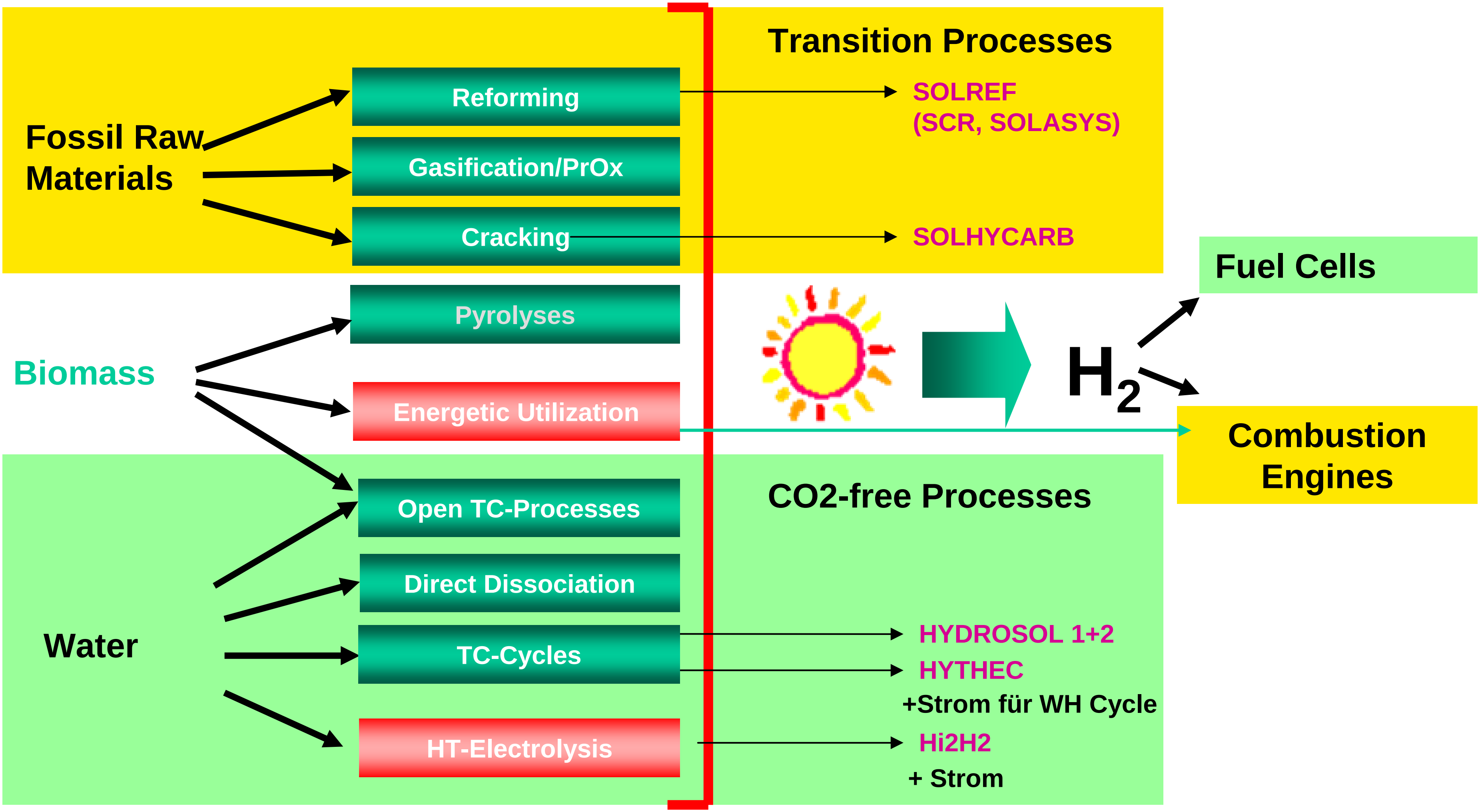
Tests of Rocket Motors
DLR Lampoldshausen

Hydrogen Tomorrow



Cf. European Commission, Hydrogen Energy and Fuel Cells – A vision of our future, Final Report of the High Level Group, EUR 20719 EN, Brussels 2003

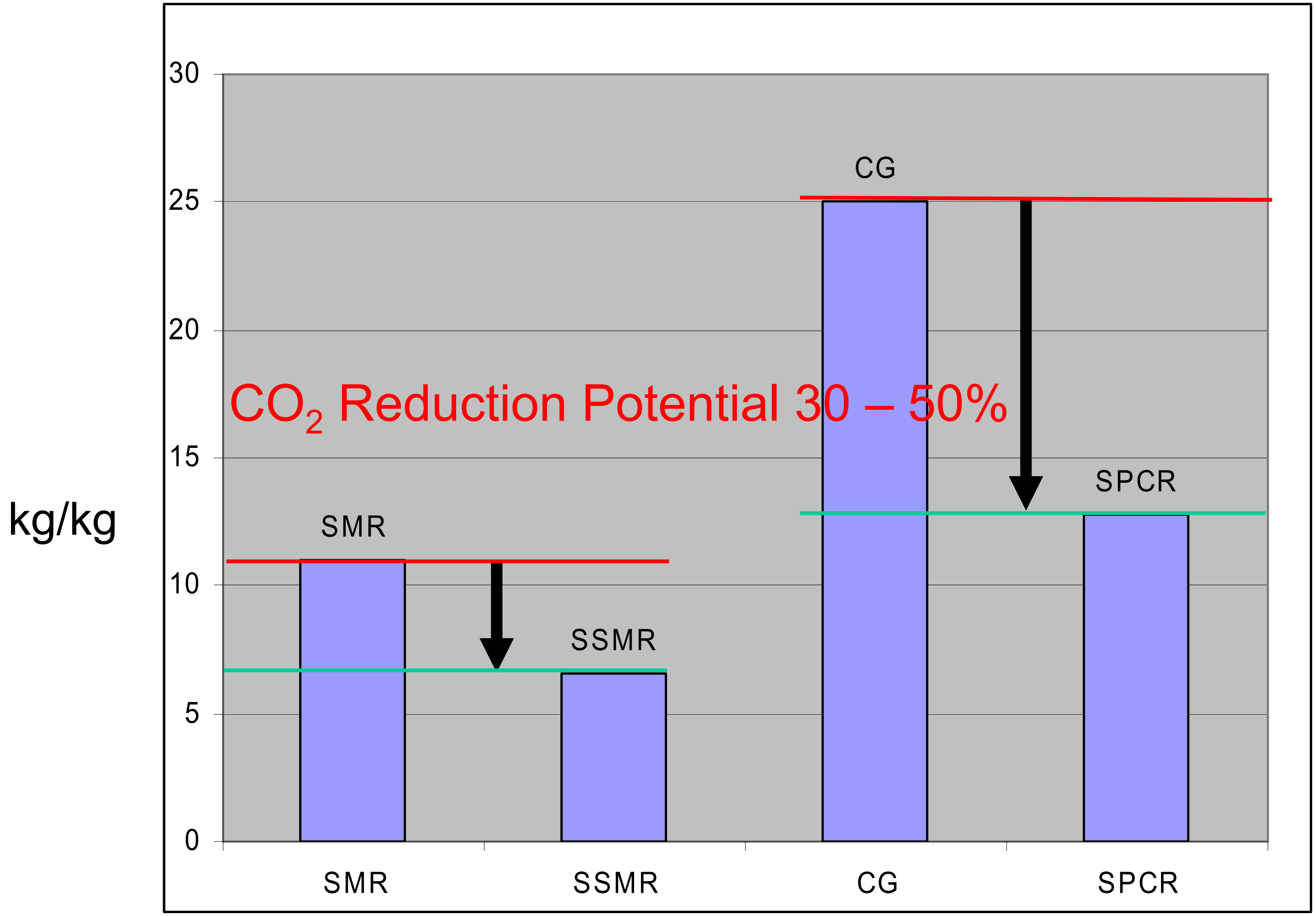
Solar Fuels: Hydrogen in the Long-Term Future



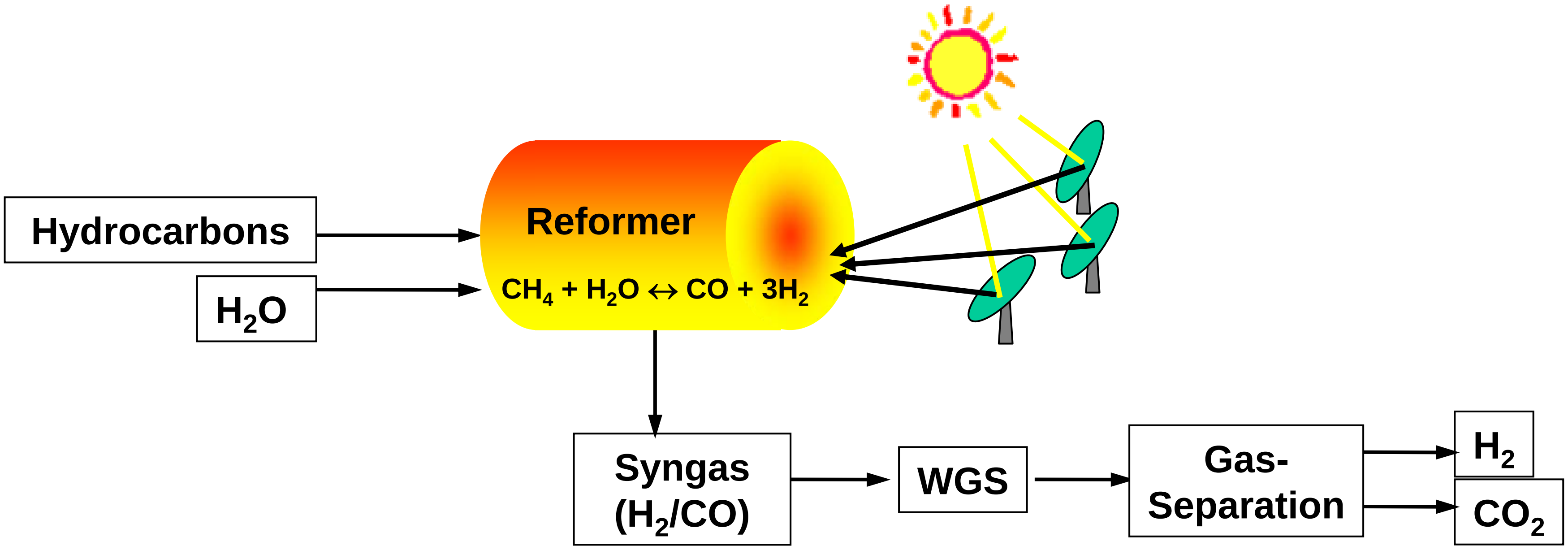
Solar Thermal Hydrogen Generation
Criteria for Process Selection

- Feasible Operation Temperature.
  Between 800 and 1600 K.
- Fast Reactions.
- Availability of Materials.
- High Efficiency.
- Hydrogen Production Cost
- → Bench Mark: H_2 by Electrolysis with Renewable Power.

CO_2 Reduction Potential by "Solarization" of Established Processes



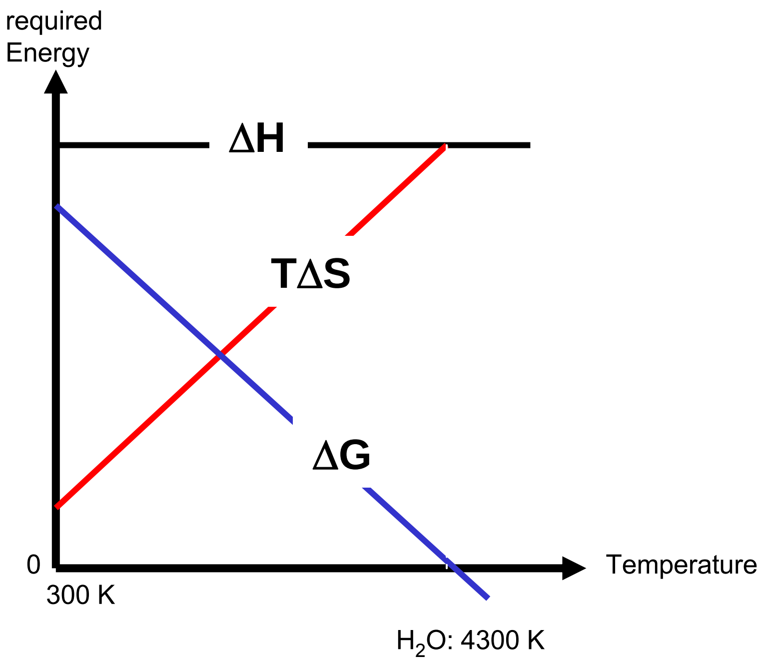
H_2-Production by Solar Reforming of Hydrocarbons



Experimental Results of SOLASYS (EU FP4) Currently Continued in SOLREF (EU FP6)

- Power to Gas: up to 220 kW_{th} (400 kW_{th})
- Reforming Temperature:
  up to 765°C (1000°C)
- Operation Pressure: up to 9 bar (15 bar)
- Degree of Methane Conversion: max. 78 %
  acc. to theoretical equilibrium

H_2-Production in TC Cycles



TC: 1000-2500K

Direct Thermal Dissociation of Water Only Possible at Very High Temperatures:

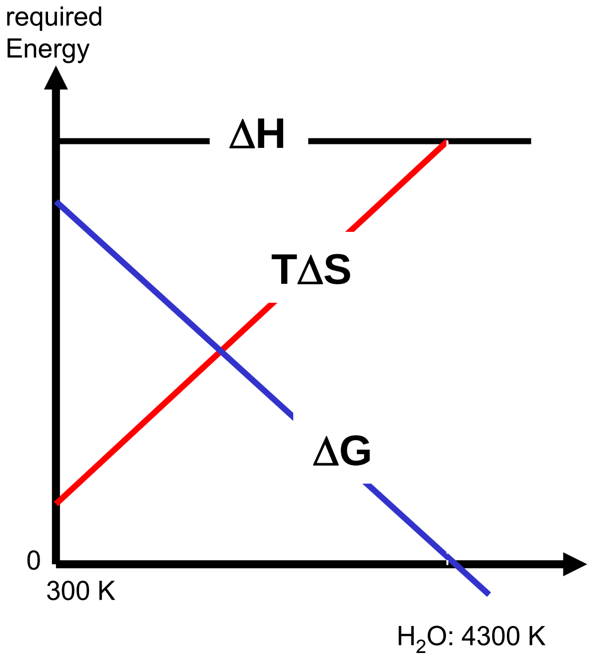
>> 2000°C .

$$H_2O \leftrightarrow H_2 + ½O_2$$

Problems:

- Constant Generation of High Temperatures over Extended Periods
- Materials
- Separation of Products

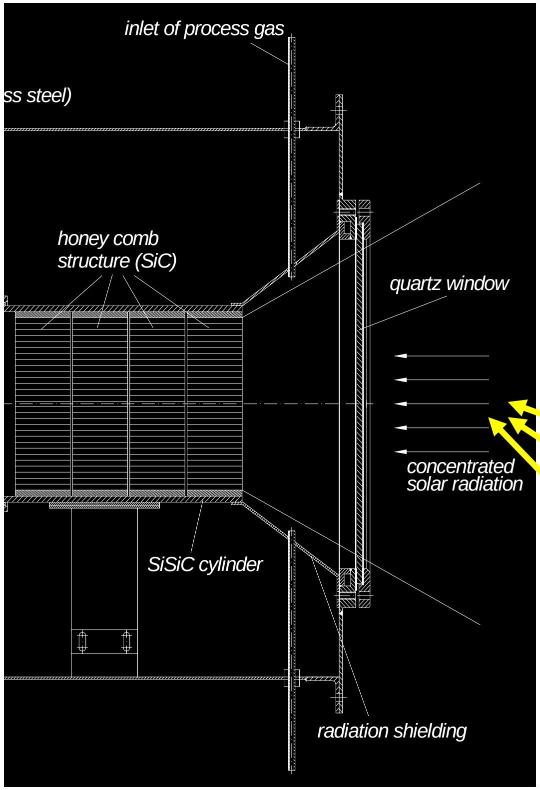
H_2-Production in TC Cycles

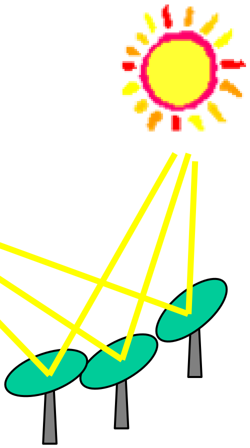


TC: 1000-2500K

- In TC Cycles Splitting of Water in Several Steps:
- e. g. Two Steps
  1) $M_xO_y \leftrightarrow xM + y/2O_2$
  2) $xM + yH_2O \leftrightarrow M_xOy + yH_2$
- Lower Reaction Temperatures than Direct Splitting.
- To Achieve High Efficiencies: not more than three Step Processes.

HYDRSOL + HYDROSOL 2 (EU FP5, FP6)





2 Step Redox Cycle based on Ferritic Materials

1. Endothermal Step (1000-1200°C)

$$MO_{ox} \leftrightarrow MO_{red} + \frac{1}{2} O_2$$

2. Water Dissociation (700 - 1000°C)

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

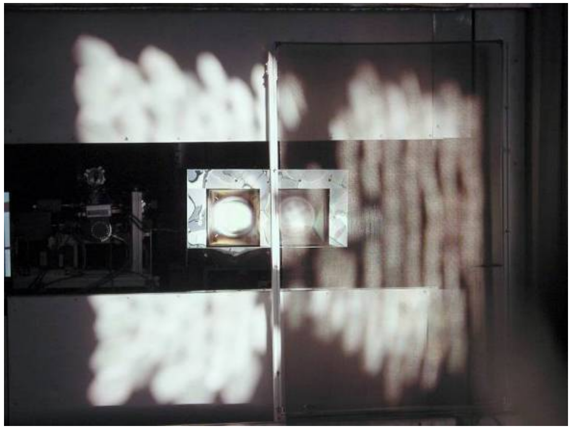
Redox System:

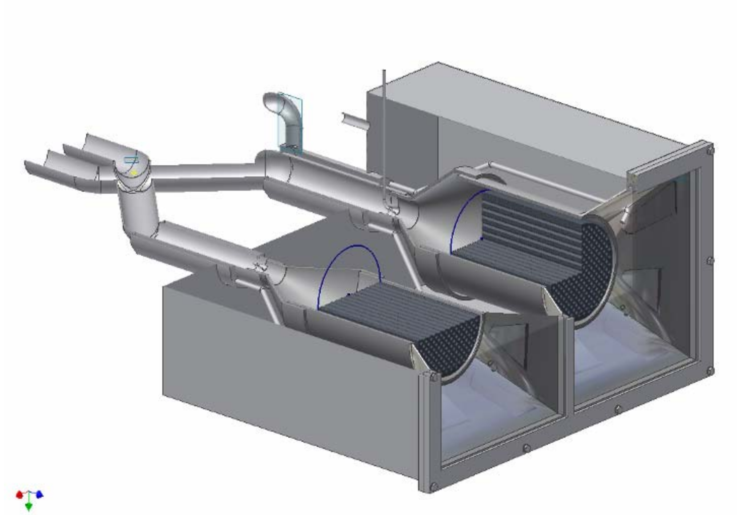
MO = $(Zn,Y)Fe_2O_4$ (black)
Y = Ni or Mn

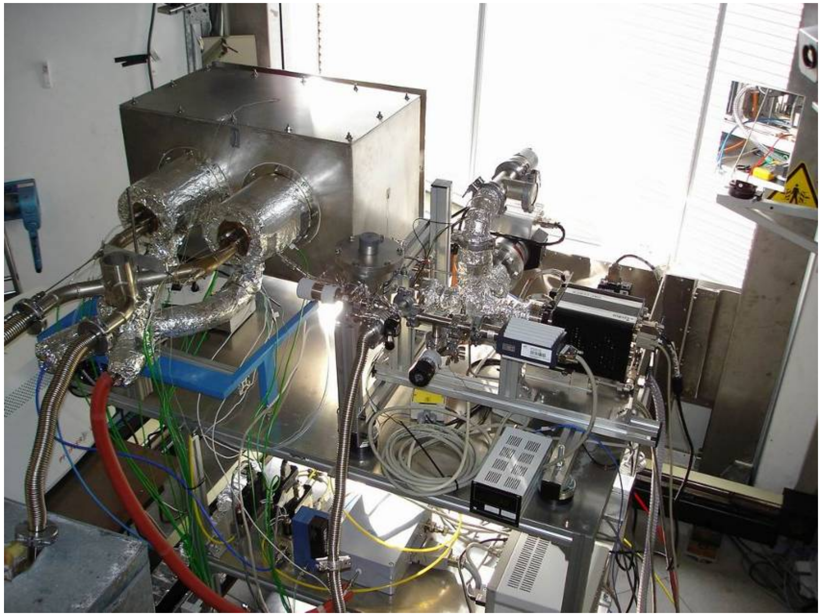
Cost Estimate:

- Batch-Process 7 €/kg
- Conti-Process 3,5 €/kg

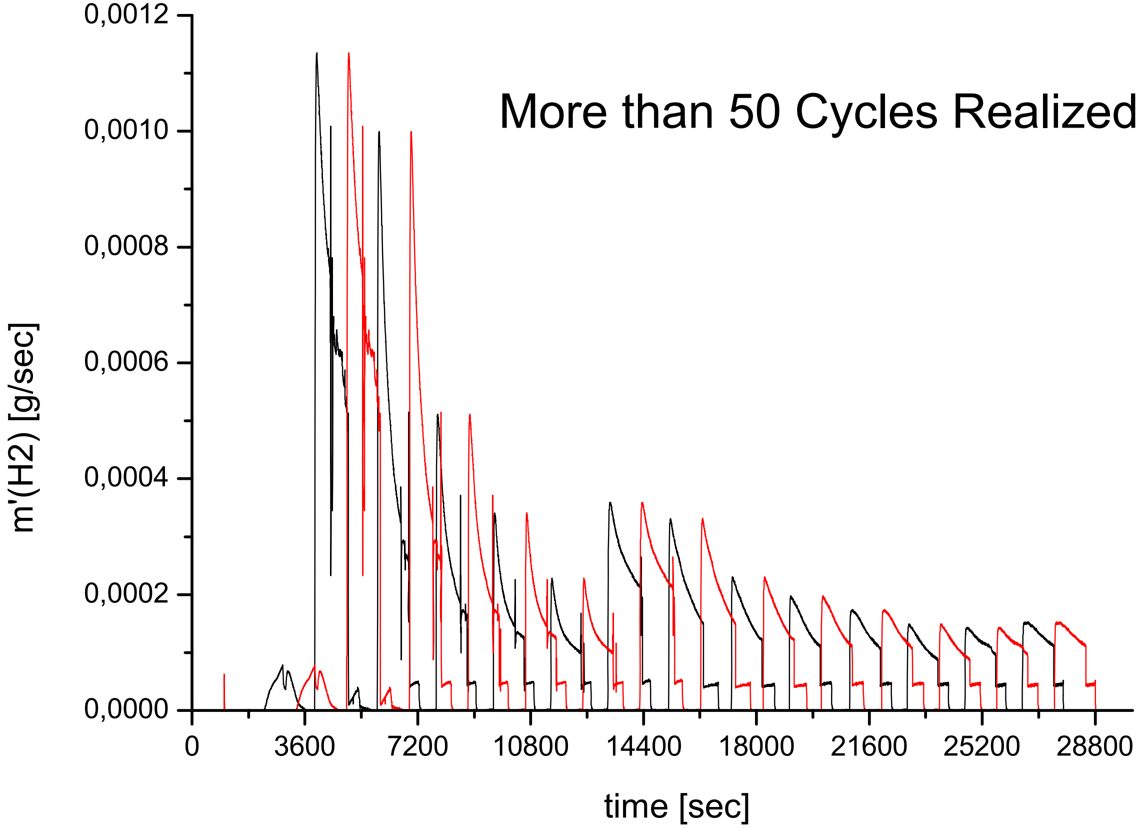
Conti-Reactor Test in DLR‘s Solar Furnace



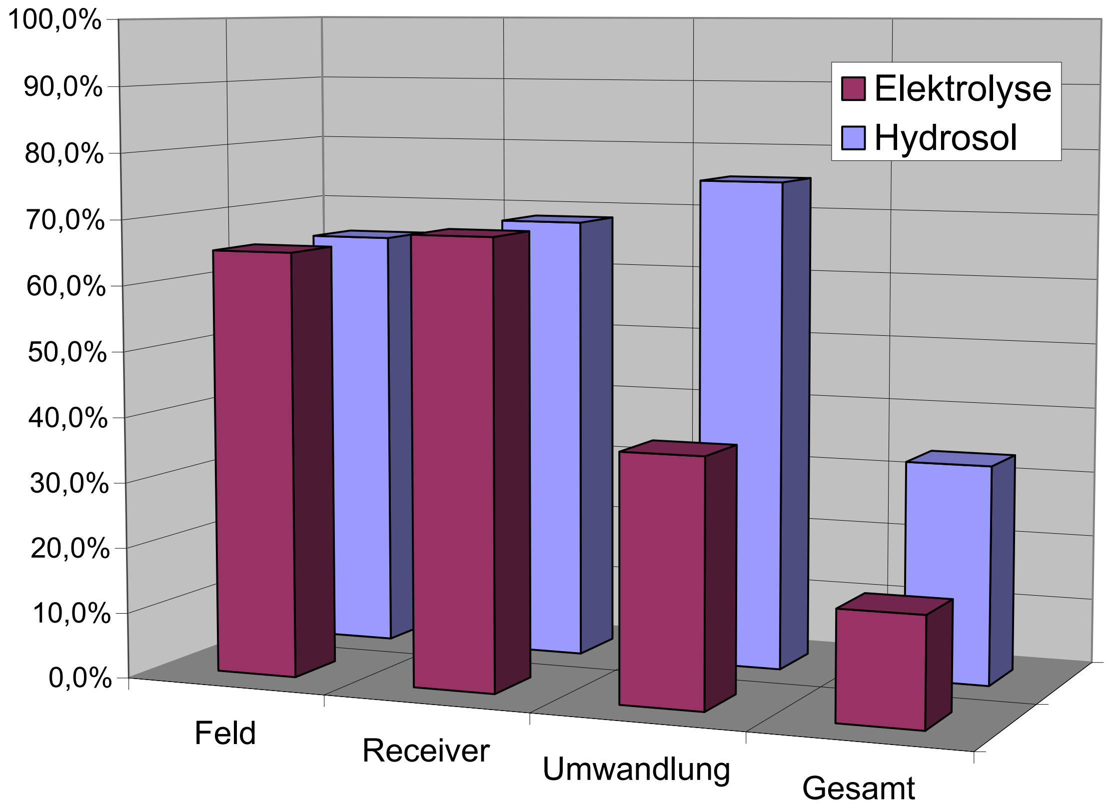




Quasi-continuous Hydrogen Production in DLR's Solar Furnace



Efficiency Potential: HYDROSOL vs. Electrolysis



Summary

- Solar Fuels, in particular Hydrogen, Could Contribute to a Renewable Energy Economy Significantly, Provided that:
- Proof of Feasibility in Demo-Scale Required for Industrial Acceptance
    - Solar Thermal Processes Promise High Efficiencies
    - Carbon-Based Transition Processes Facilitate Market Approach
- Hydrogen Storage Essential for Acceptance
- Accepted Energetic Utilization of Hydrogen in a Large Scale (Fuel Cells, Combustion Engines …)

Thank you for your Attention