ETH
Swiss Federal Institute of Technology Zurich
Institute of Energy Technology

PAUL SCHERRER INSTITUT
PSI
Solar Technology Laboratory

Project MAGHREB-EUROPE

Solar Thermochemical Production of H_2

Aldo Steinfeld

ETH
Swiss Federal Institute of Technology Zurich

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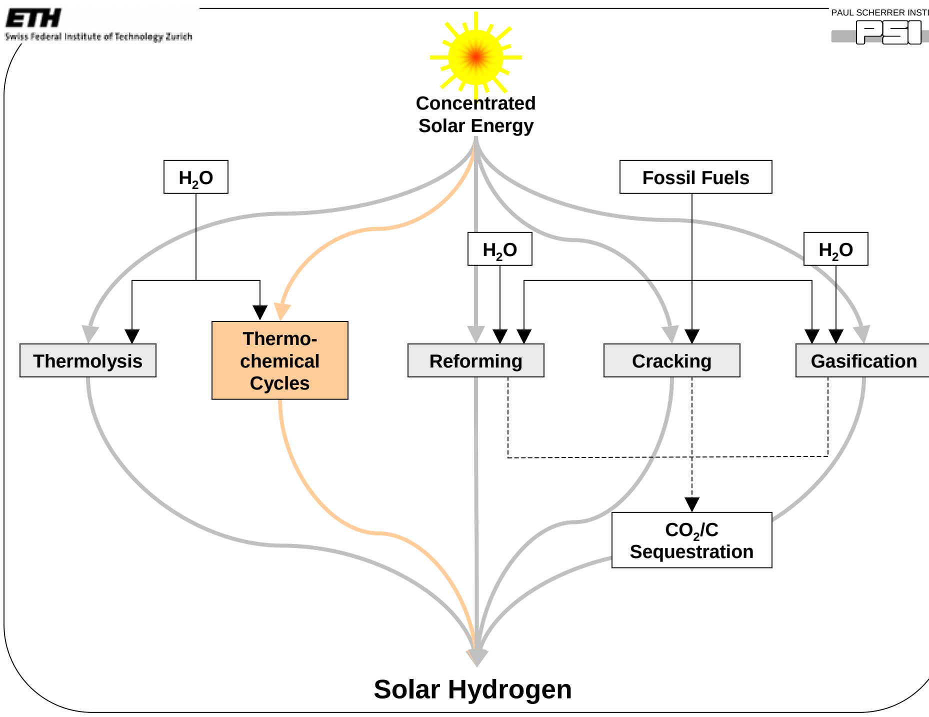

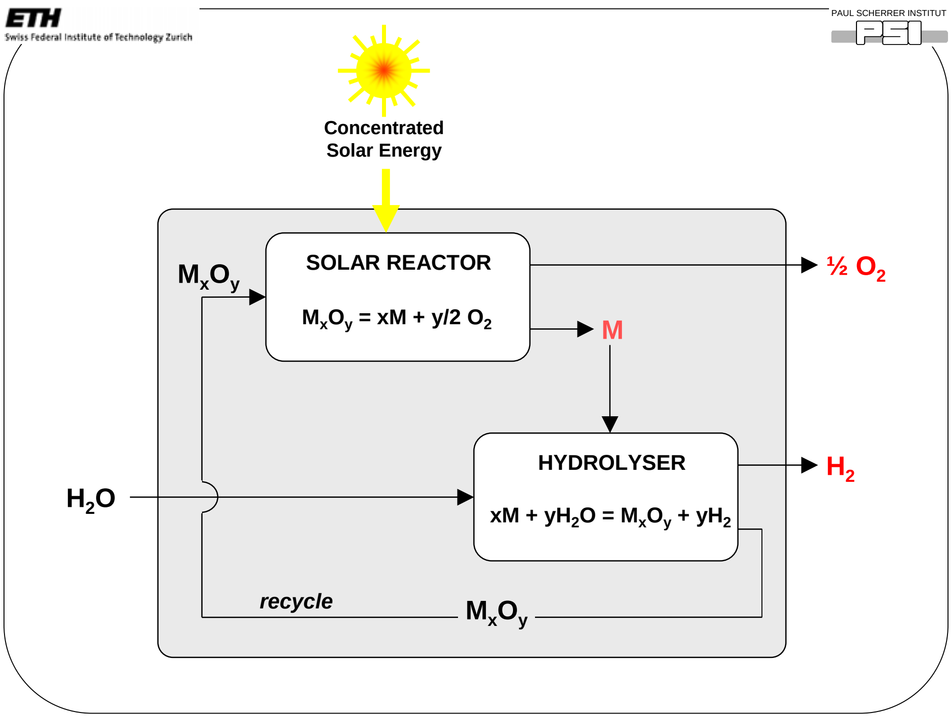
ETH
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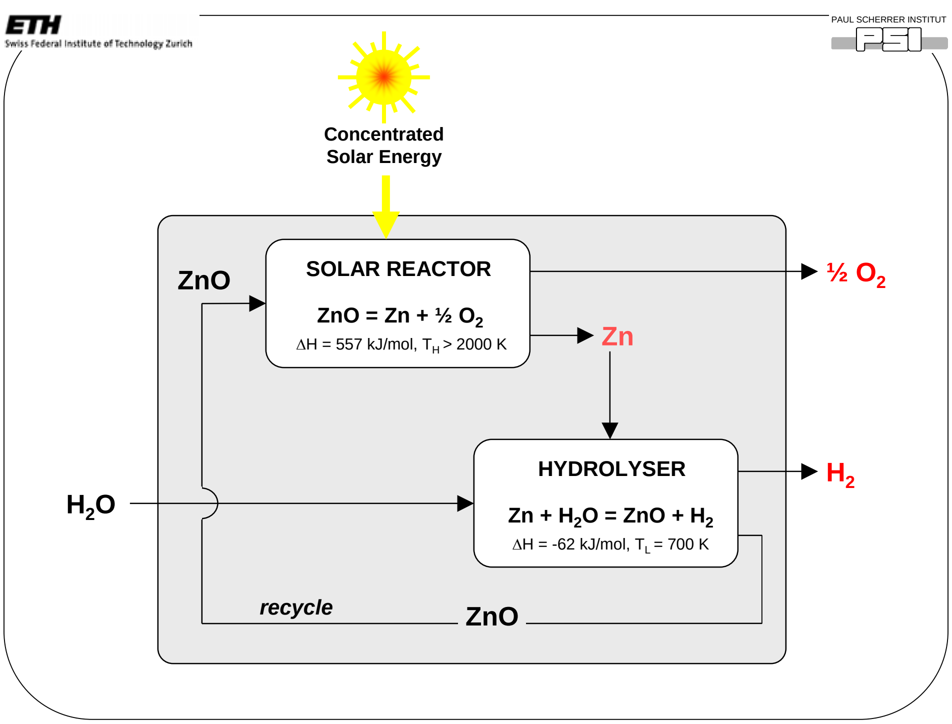
Concentrated Solar Energy
SOLAR REACTOR
$M_xO_y = xM + y/2\ O_2$
M_xO_y
½ O_2
M
HYDROLYSER
$xM + yH_2O = M_xO_y + yH_2$
H_2O
H_2
recycle
M_xO_y


ETH
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Concentrated Solar Energy
SOLAR REACTOR
ZnO = Zn + ½ O_2
ΔH = 557 kJ/mol, T_H > 2000 K
ZnO
½ O_2
Zn
HYDROLYSER
Zn + H_2O = ZnO + H_2
ΔH = -62 kJ/mol, T_L = 700 K
H_2O
H_2
recycle
ZnO

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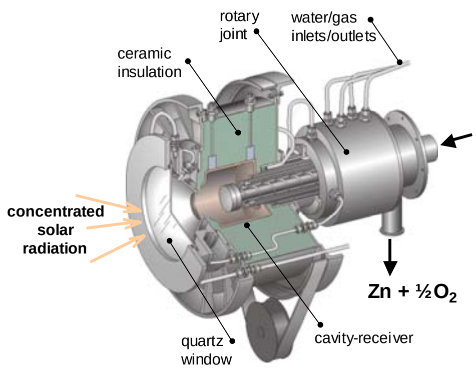
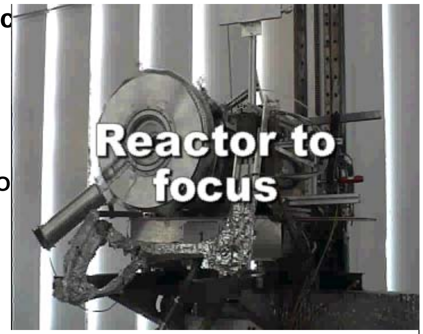
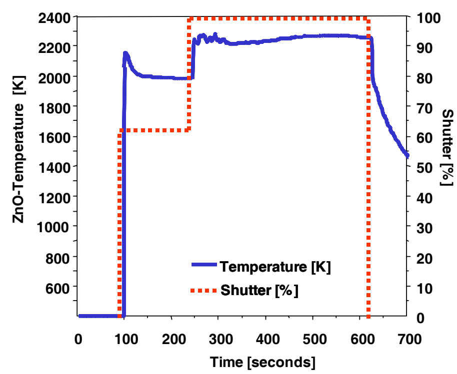
ZnO/Zn Cyc





- $T_{reactor}$ = 2000 K
- Q_{solar} = 5 kW
- C_{peak} = 4000 suns
- m_{ZnO} = 11 g/min
- Zn yield = 61%



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ZnO/Zn Cycle

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Thermal Dissociation

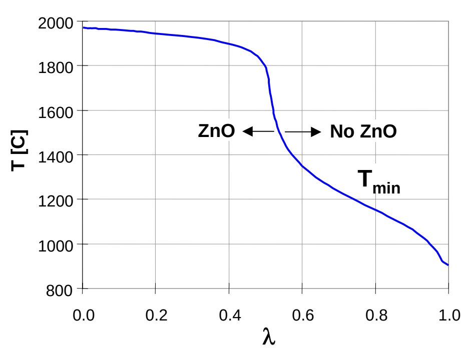
$ZnO \rightarrow Zn + \frac{1}{2} O_2$

Carbothermic (coke, biomass, …)

$ZnO + C \rightarrow Zn + CO$

H_2

$$ZnO + \lambda C \rightarrow Zn + (2\lambda - 1)CO + (1-\lambda)CO_2$$



Carbothermic ZnO/Zn Cycle

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Thermal Dissociation

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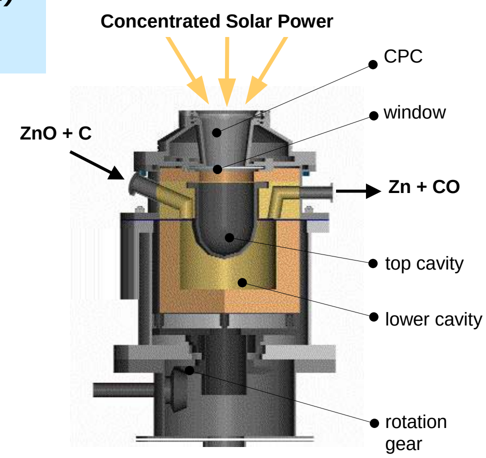

- Osinga et al., *J. Solar Energy Engineering* **126**, 633-637, 2004.
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Carbothermic ZnO/Zn Cycle

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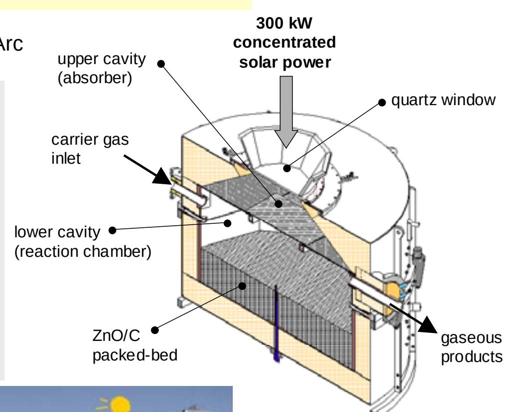
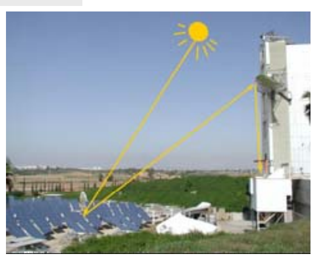
EU-SOLZINC: 300 kW Solar Reactor

- Partners: PSI, ETH, WIS, CNRS, ScanArc

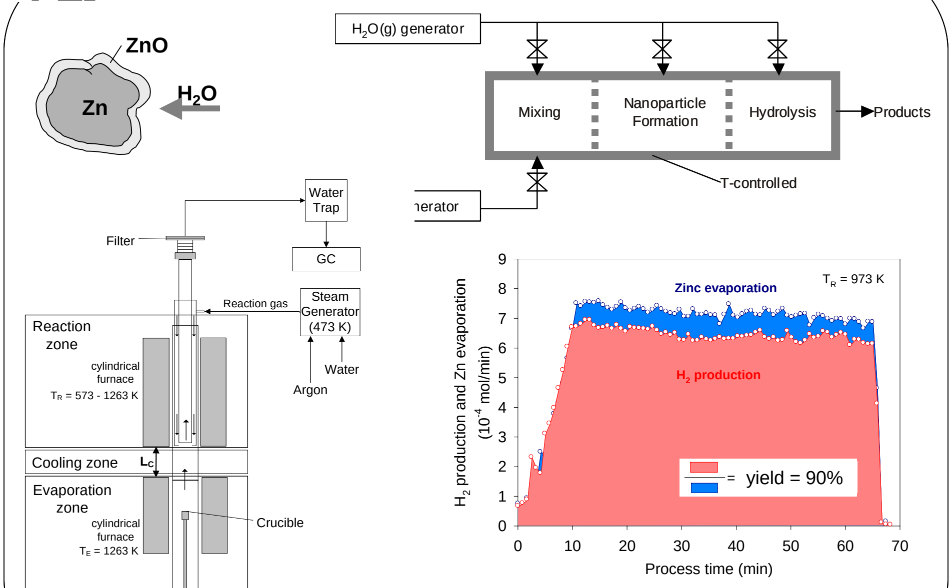
- Solar power input, Q_{solar} = 300 kW
- Solar concentration, C = 1500 suns
- Reactor temperature, $T_{reactor}$ = 1500 K
- Zn production rate = 45 kg/h
- Zn purity = 95%
- Thermal efficiency:

$$\eta_{thermal} = \frac{\Delta H}{Q_{solar} + HV_C} = 30\%$$

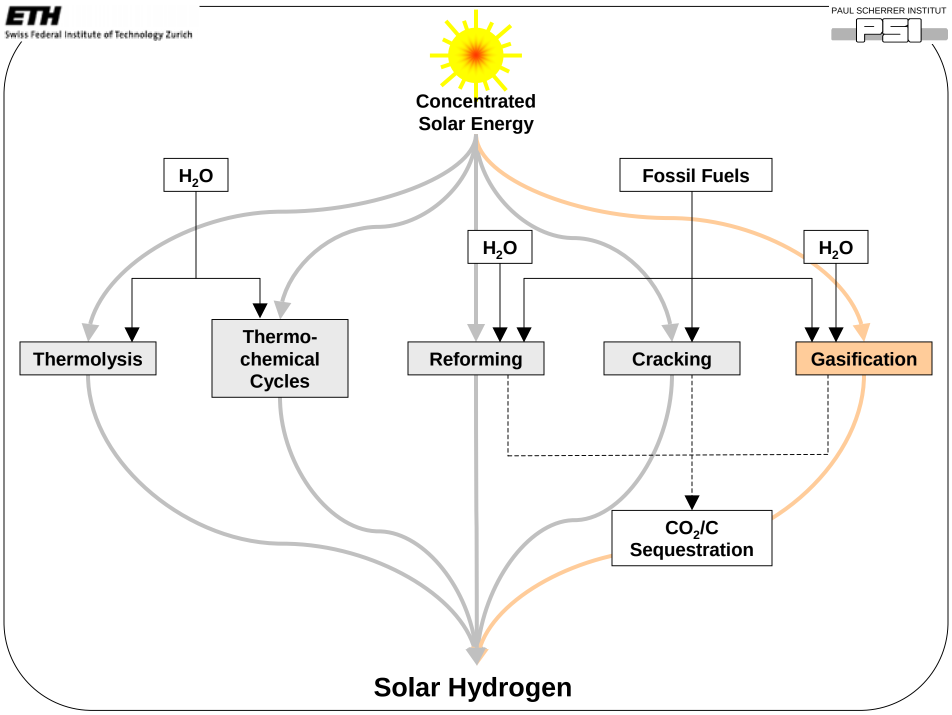




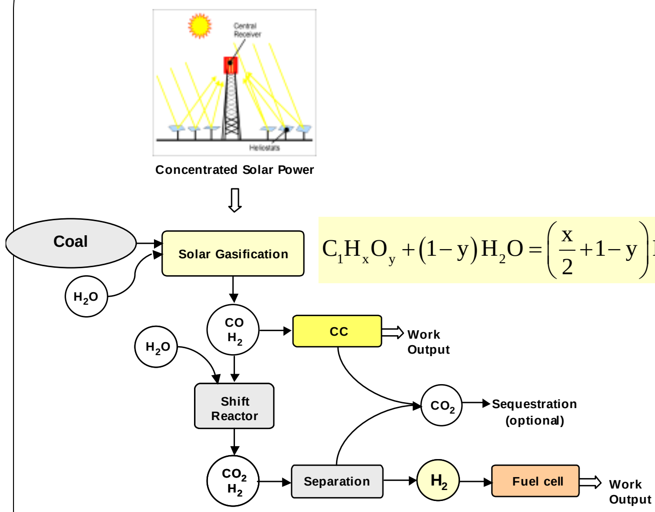
ZnO/Zn-cycle: Hydrolysis



- Weiss et al., *AIChE Journal* **51**, 1966-1970, 2005.
- Wegner et al., *Int. J. Hydrogen Energy* **31**, 55-61, 2006.
- Wegner et al., EU Patent PCT/CH 2005/000315.



Solar Gasification

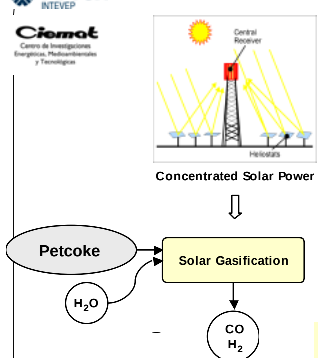


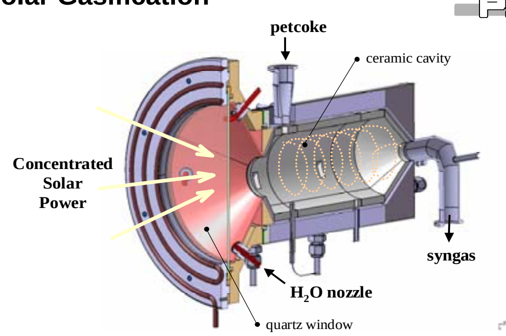
$$C_1H_xO_y + (1-y)H_2O = \left(\frac{x}{2} + 1 - y\right)H_2 + CO$$

Solar Gasification

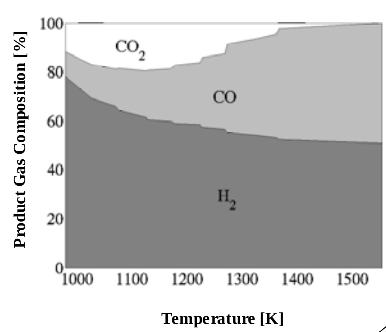
PDVSA INTEVEP

Ciemat





- Q_{solar} = 5 kW
- C = 3000 suns
- m_C = 4 g/min
- $T_{reactor}$ = 1600 K
- x_C = 87 %
- $\eta_{thermal}$ = 19 %



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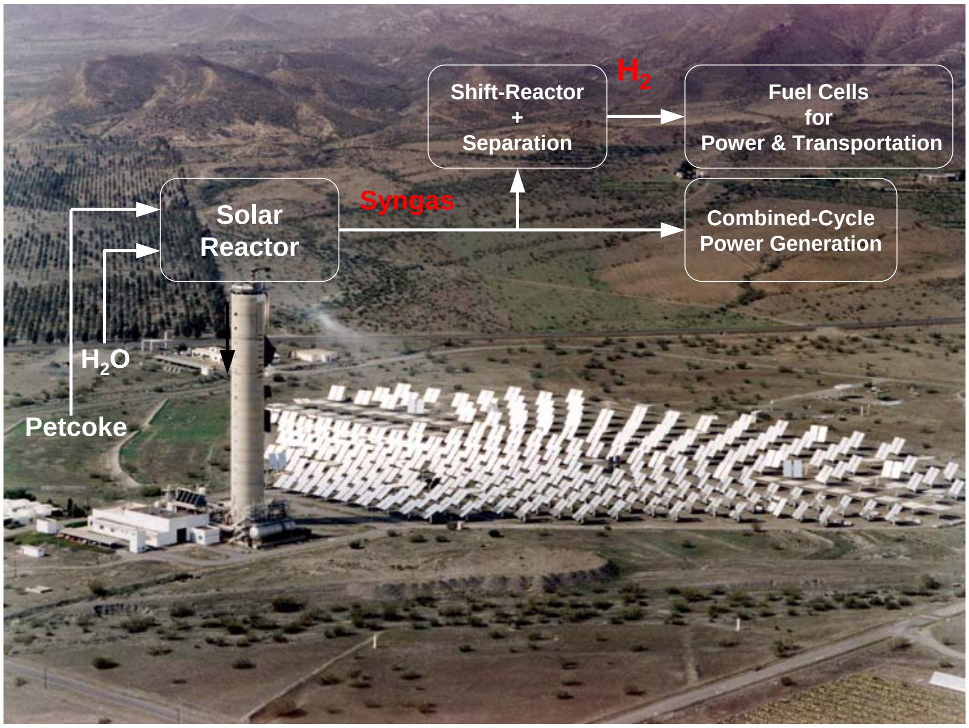
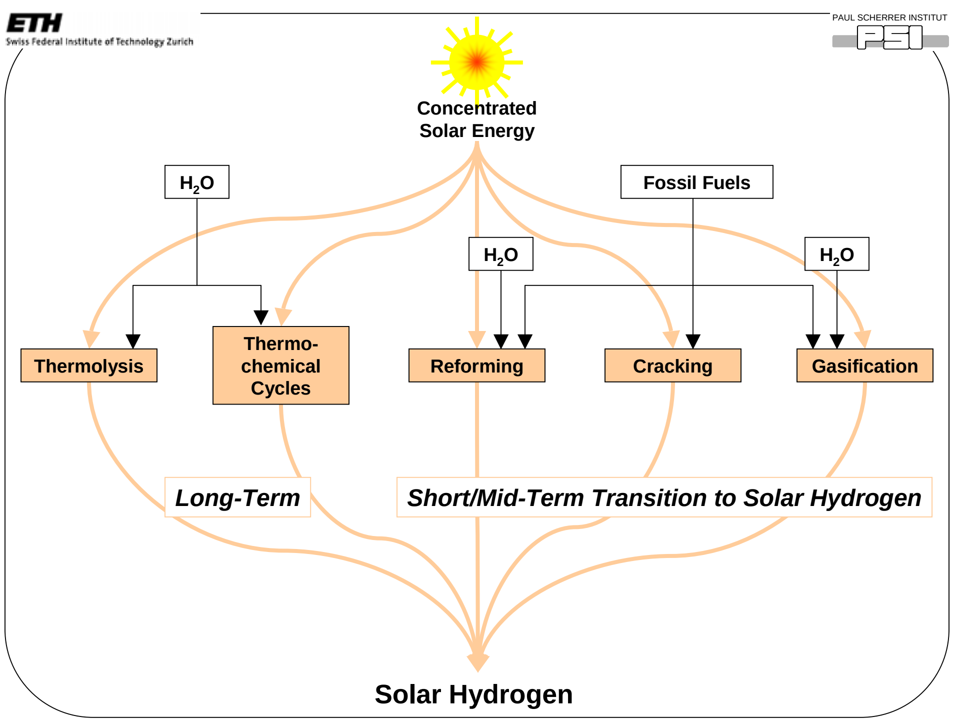
• v. Zedtwitz et al., *Ind. Eng. Chem. Res.* **44**, 3852-3861, 2005.


Shift-Reactor
+
Separation
H_2
Fuel Cells
for
Power & Transportation
Solar
Reactor
Syngas
Combined-Cycle
Power Generation
H_2O
Petcoke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PSI
Concentrated
Solar Energy
H_2O
Fossil Fuels
H_2O
H_2O
Thermolysis
Thermo-
chemical
Cycles
Reforming
Cracking
Gasification
Long-Term
Short/Mid-Term Transition to Solar Hydrogen
Solar Hydrogen

- **"Solar Thermochemical Process Technology"**
  Encyclopedia of Physical Science and Technology
  Academic Press, Vol. 15, 2001.

- **www.pre.ethz.ch**