Solare Brennstoffe aus solarthermischen Kraftwerken

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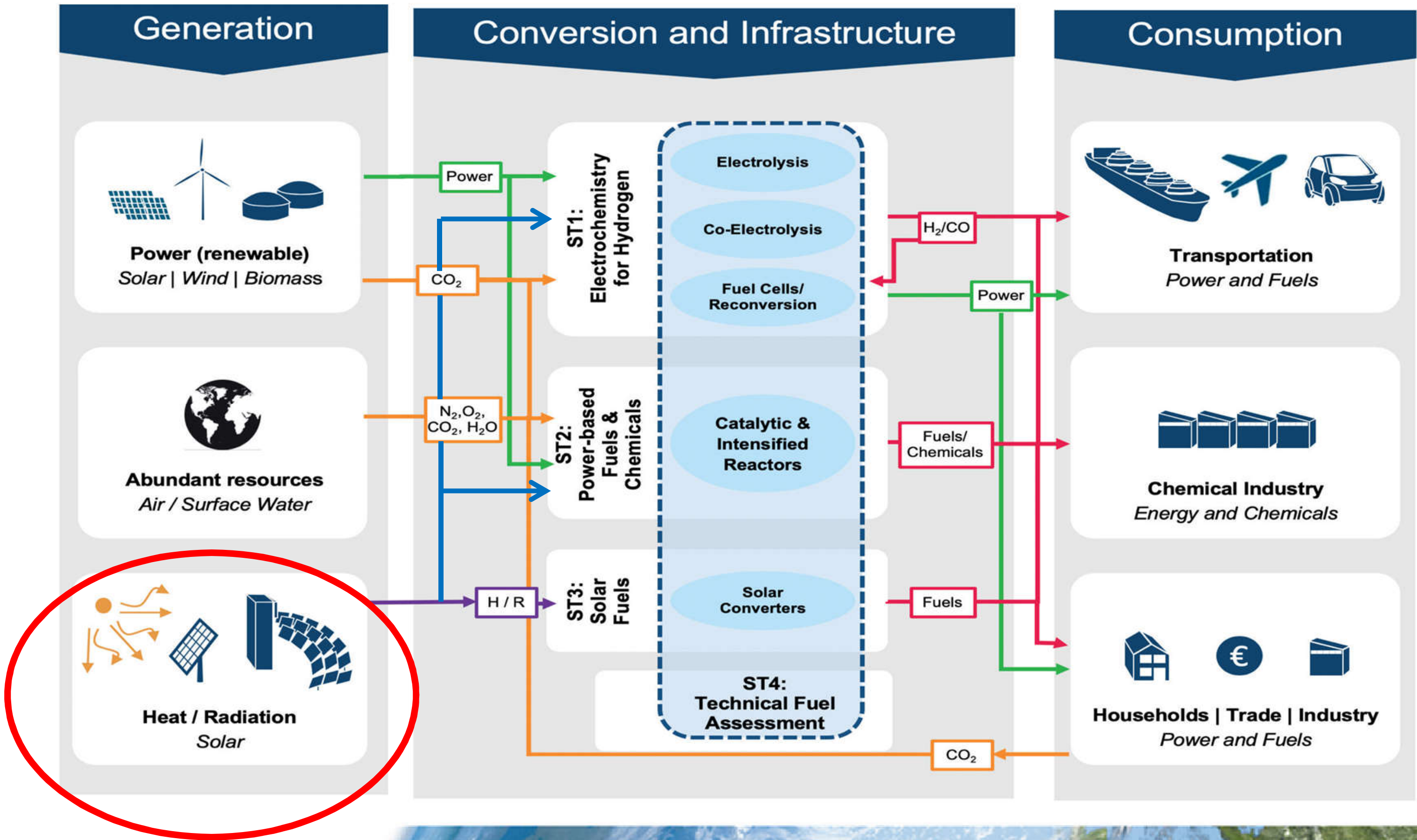
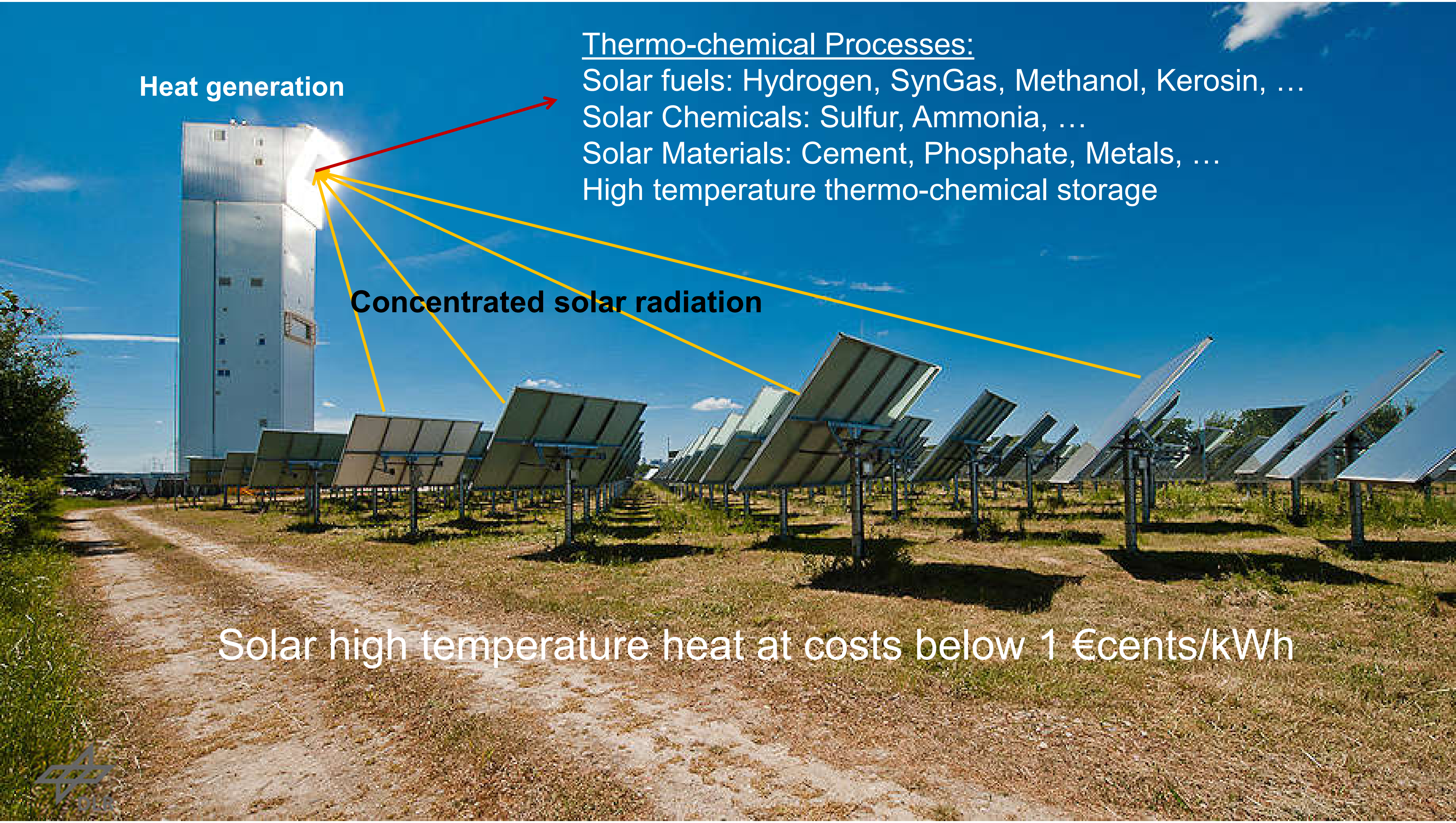
DLR

Sustainable production of fuels and chemicals




Thermo-chemical Processes:
Solar fuels: Hydrogen, SynGas, Methanol, Kerosin, …
Solar Chemicals: Sulfur, Ammonia, …
Solar Materials: Cement, Phosphate, Metals, …
High temperature thermo-chemical storage
Heat generation
Concentrated solar radiation
Solar high temperature heat at costs below 1 €cents/kWh

Fuels from water, CO_2 and solar radiation

CO_2

H_2O

Heat & electricity from solar energy

Synthesis gas

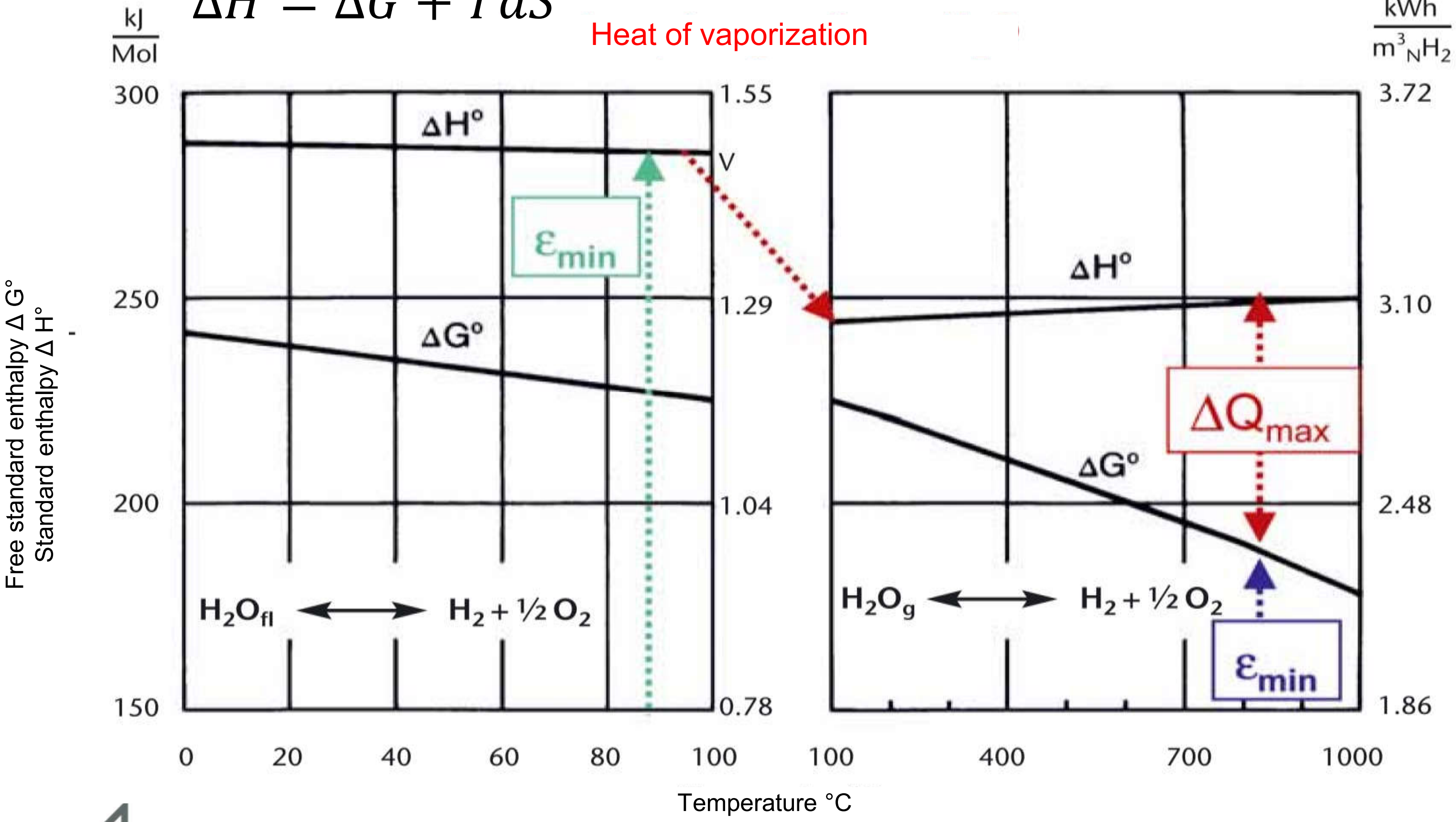
(H_2 + CO)

e.g. Fischer-Tropsch-Plant

Future Fuels…

Heat demand in electrochemical water splitting

$$\Delta H = \Delta G + TdS$$



Electrolysis at 20°C

Electricity Demand : 286 kJ/mol

Heat Demand 0

Electrolysis at 800°C

Electricity Demand : 187 kJ/mol

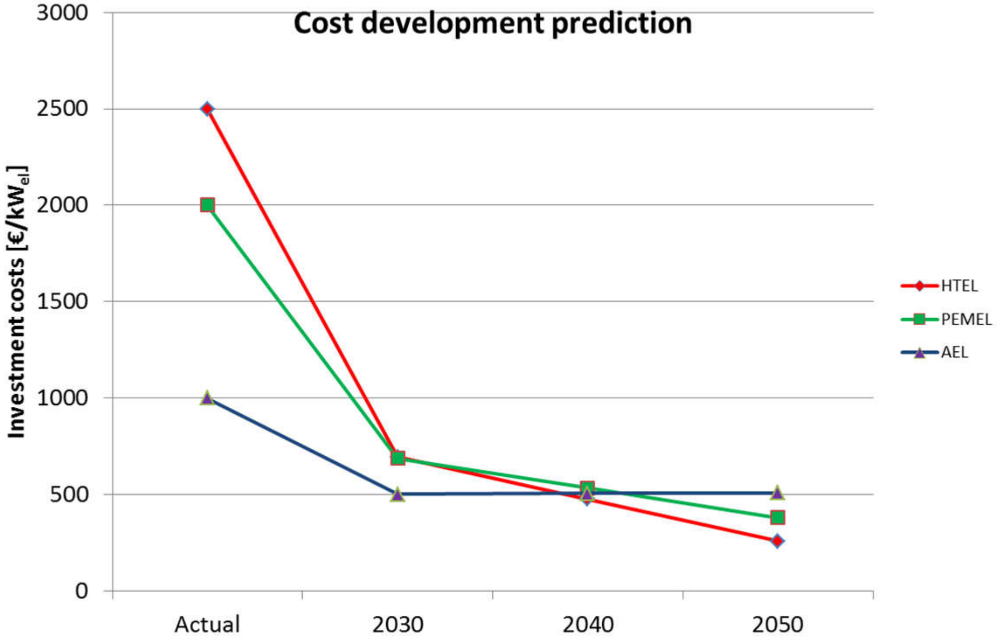
Heat for vaporization 40,7kJ/mol

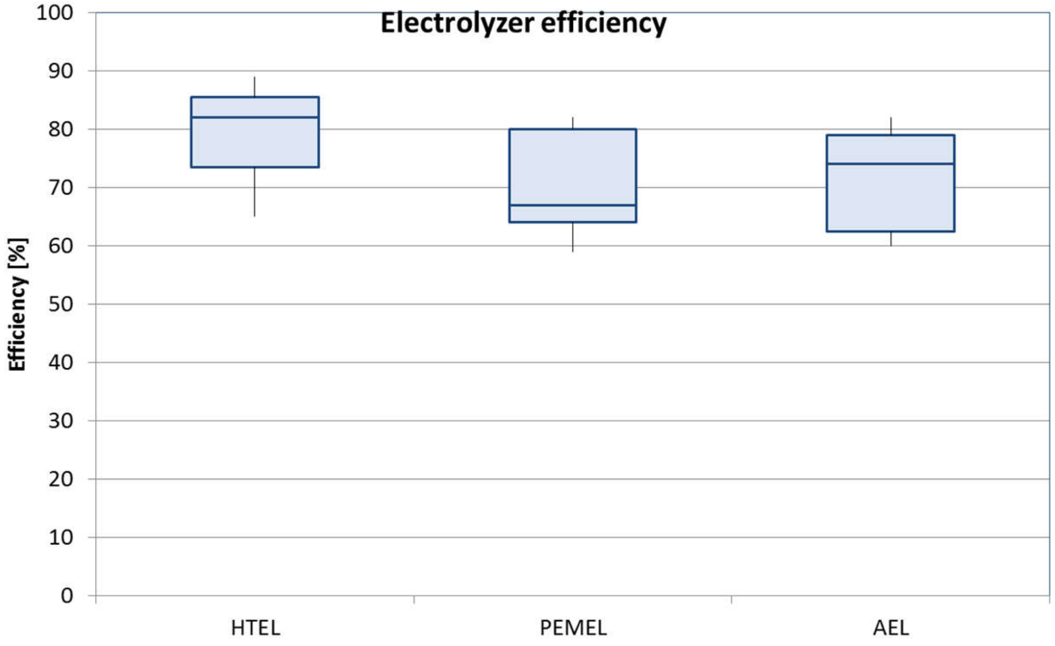
Heat at 800°C 58,3 kJ/mol

Rel. electricity demand

= 187/286 = 65%

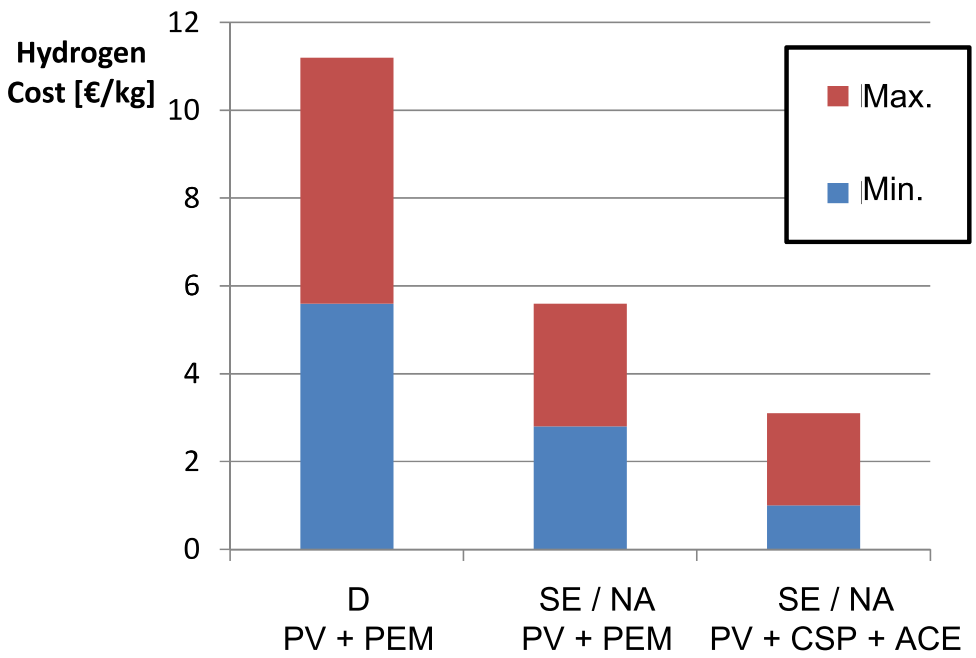
Cost Perspectives for High Temperature Electrolysis





source data : [7] Milanzi (2018)

Solar-Hydrogen-Potential today based on PEM and ACE Elctrolyser
Location Comparison Germany (D): Southern Europe/ Northern Africa (SE/NA)



Power cost for the electrolyzer

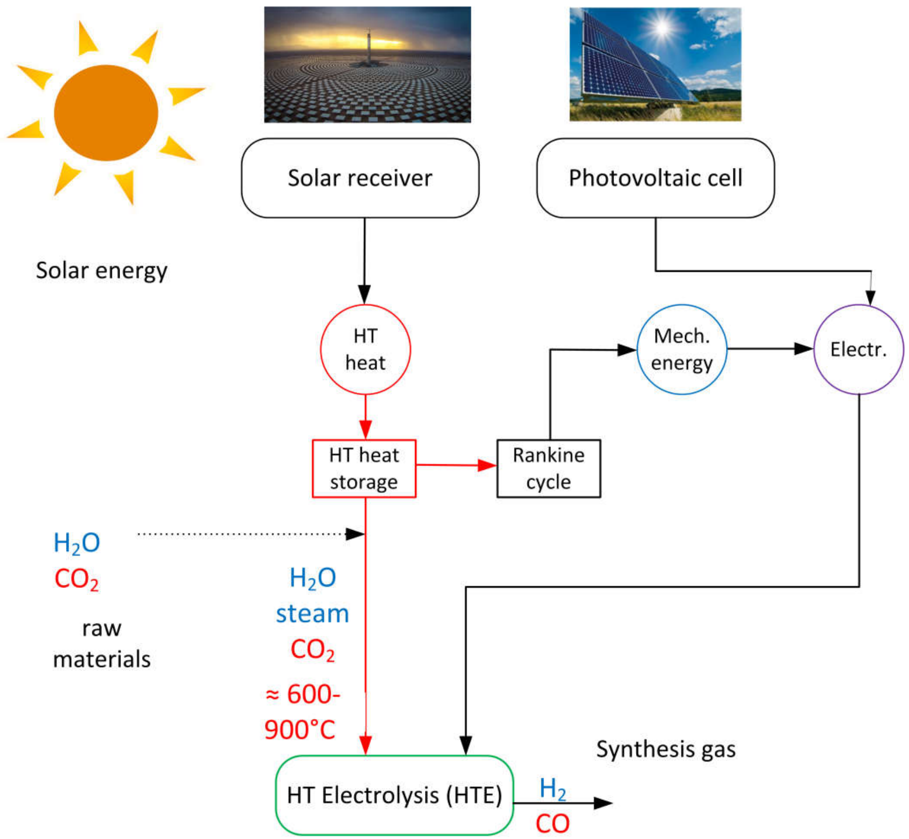
- PV D 1000 h: 6,0 → 5,0 €Ct/kWh
- PV SE/NA 2000 h: 3,0 → 2,5 €Ct/kWh
- PV+CSP SE/NA 6000 h: 5,4 → 3,8 €Ct/kWh

Invest cost for the electrolyzer

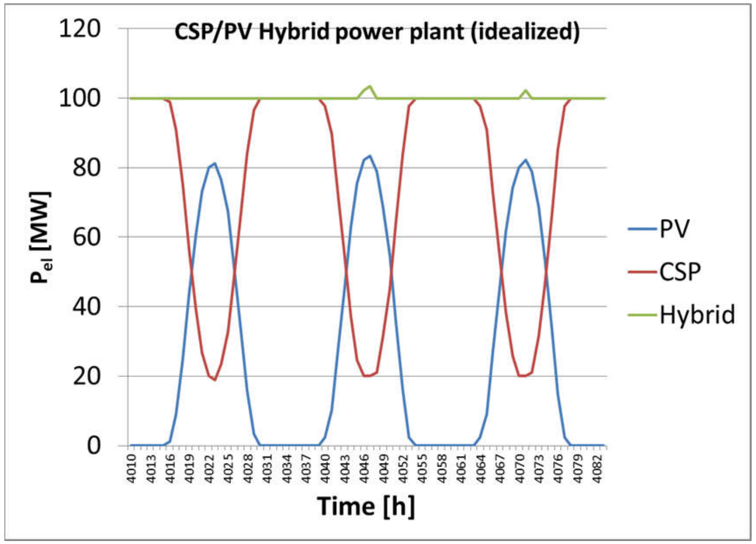
- PEM 1000 h 60% 12,6 → 5,2 €Ct/kWh
- PEM 2000 h 60% 6,3 → 2,6 €Ct/kWh
- ACE 6000 h 65% 0,7 → 0,4 €Ct/kWh

CSP + PV + ACE
25-40 % cheaper than PV PEM at the same location
60-70 % cheaper than PV PEM in Germany

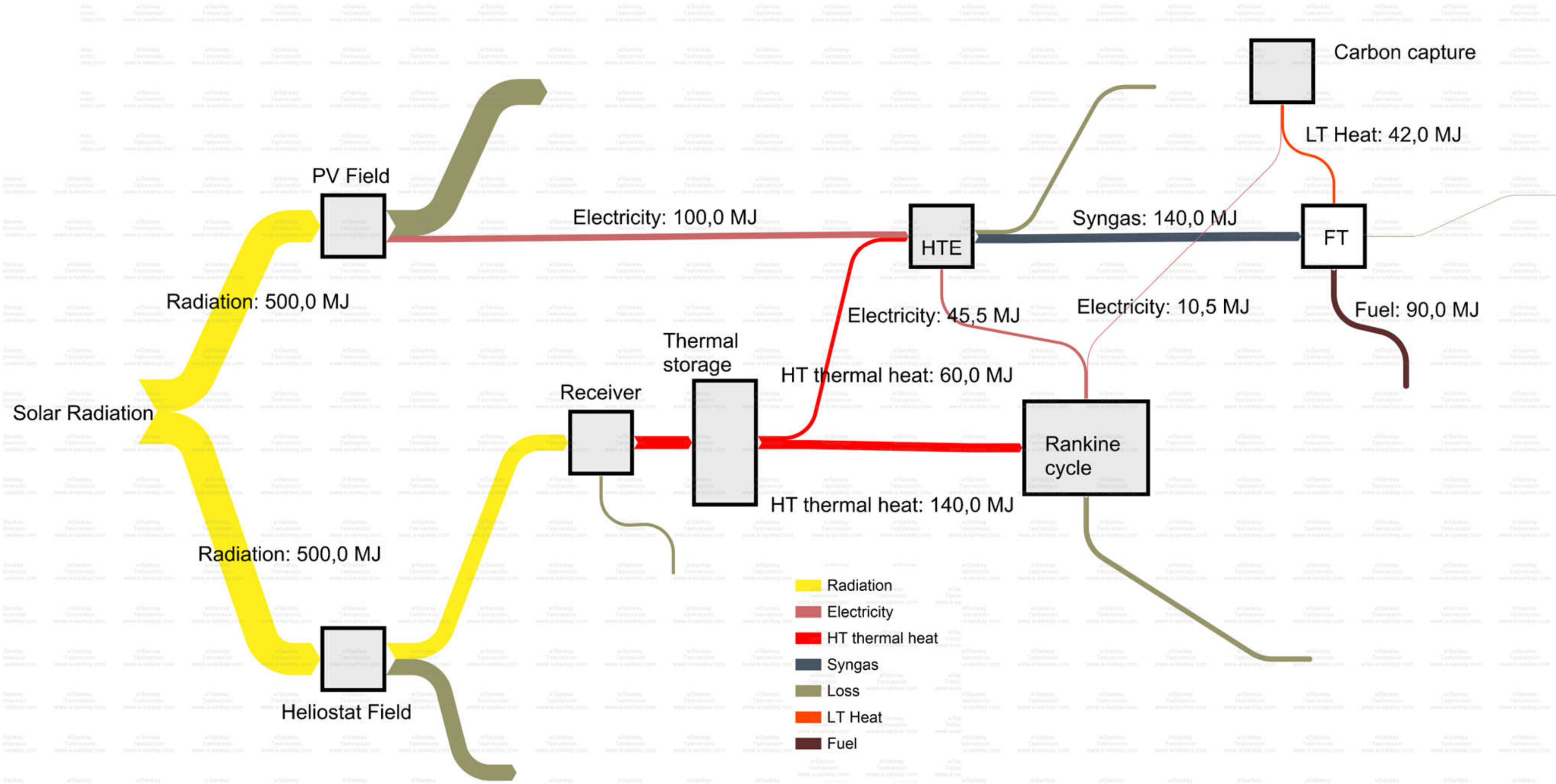
Syngas production with high temperature electrolysis powered by CSP/PV hybrid power station



- ✓ cheap PV + cheap thermal storage
  - ➢ low LCOE and high FLH
  - ➢ HT heat lowers P_{el} demand
  - ➢ η_{HTE} ≈ 0.75-0.85

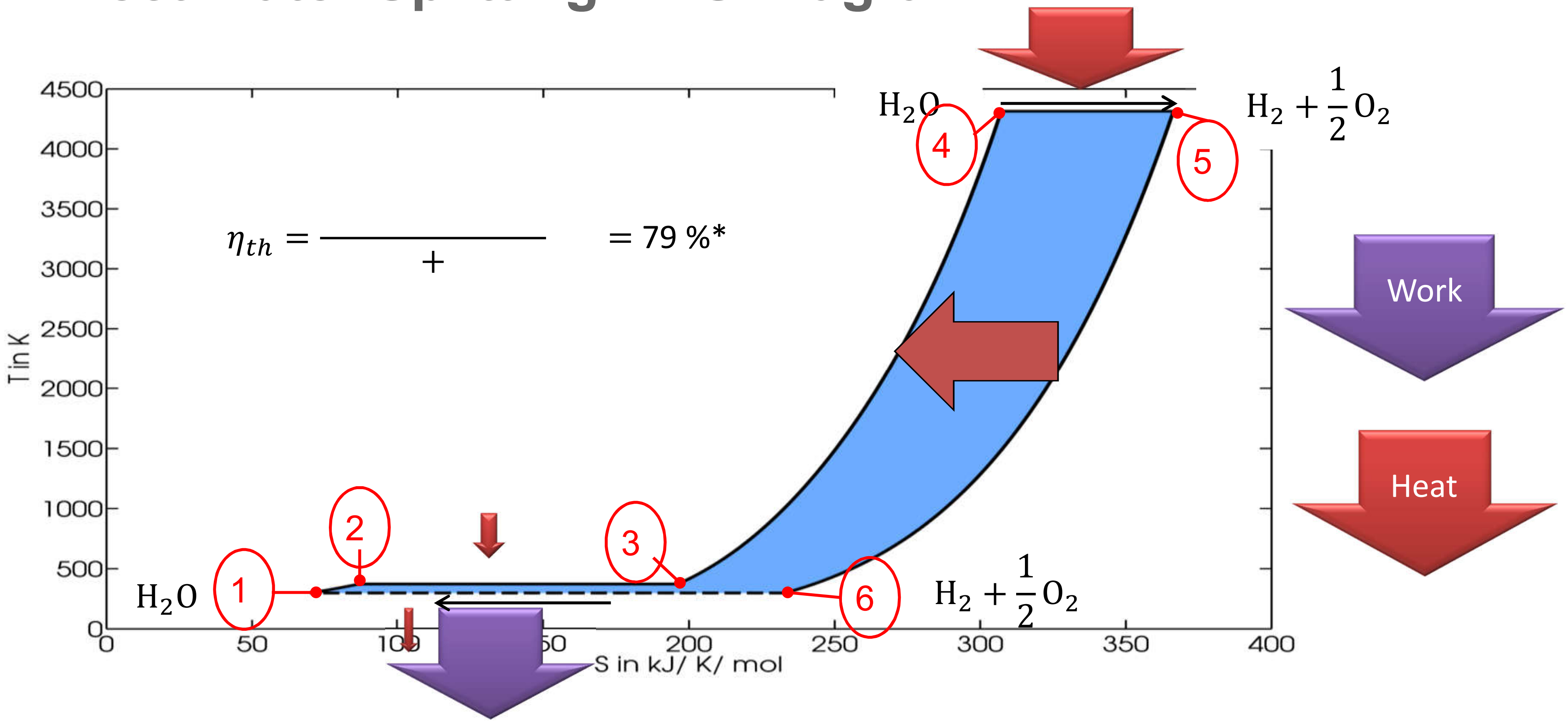


Energy Flow Diagram (preliminary results)



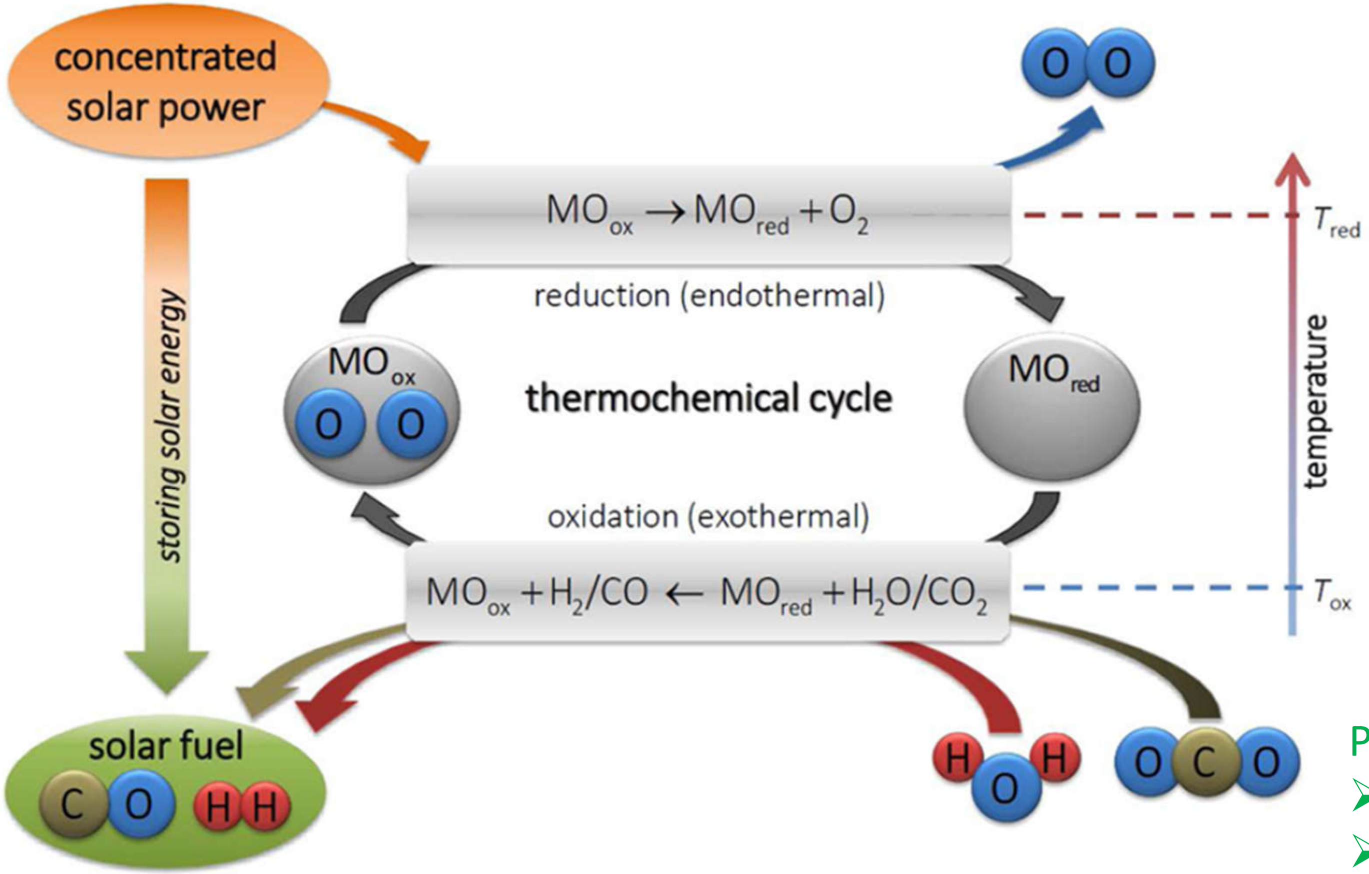
$$dQ_{rev} = T\,dS$$

Direct Water Splitting: T–S Diagram



* Including ideal heat recovery

Thermochemical syngas production

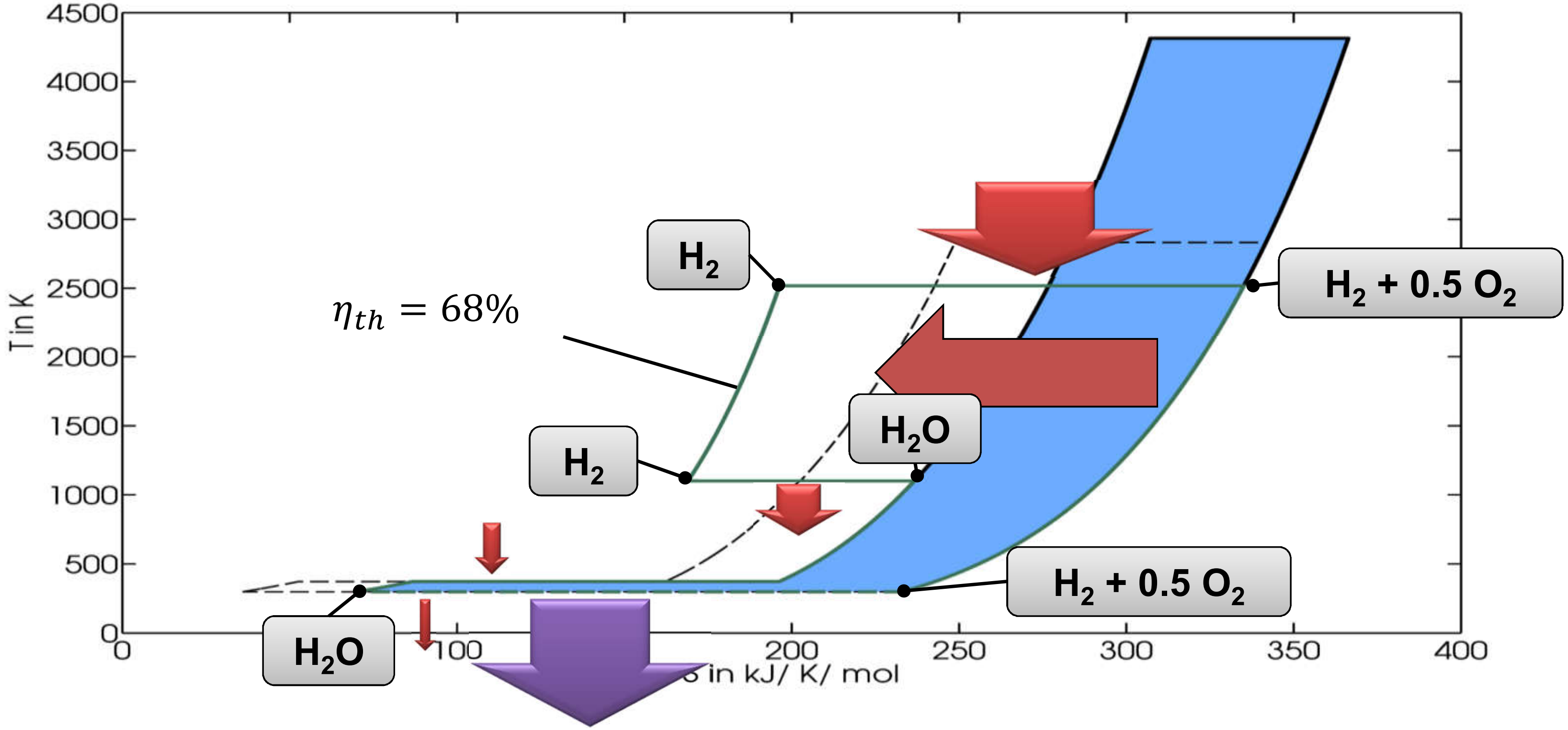


source: DLR

source: sun-to-liquid.eu

Possiblities to increase efficiency:
- Heat storage between Red/Ox [3]
- Co-generation of electricity [4]

Theorecticaal Efficiency Two Step – Gas Phase Only



SUNLight-to-LIQUID: Integrated solar thermochemical synthesis of liquid hydrocarbon fuels

Aim

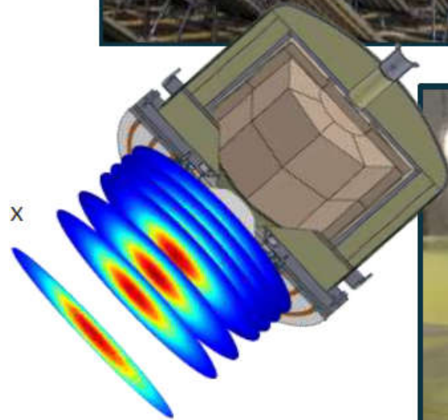
- Demonstration of ceria redox cycle for liquid hydrocarbon production at at 50kW scale
- Follow up of EU Solar-Jet

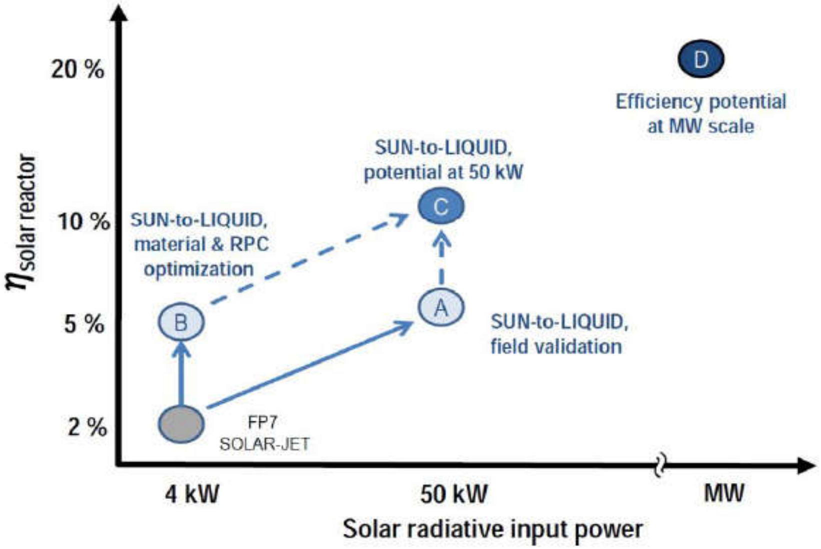
Main Tasks

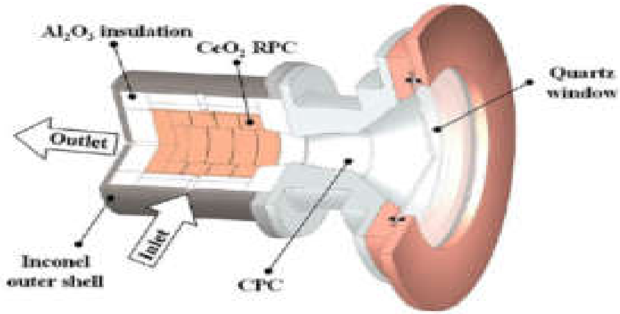
- Techno-economic analysis
- Design and construction
- Experimental demonstration
- Optimization (Thermal & Material)
- Plant modeling

Partner

- Bauhausluftfahrt, ETH, DLR (SF/VT), IMDEA, HyGear, Abengoa Research, ARTTIC







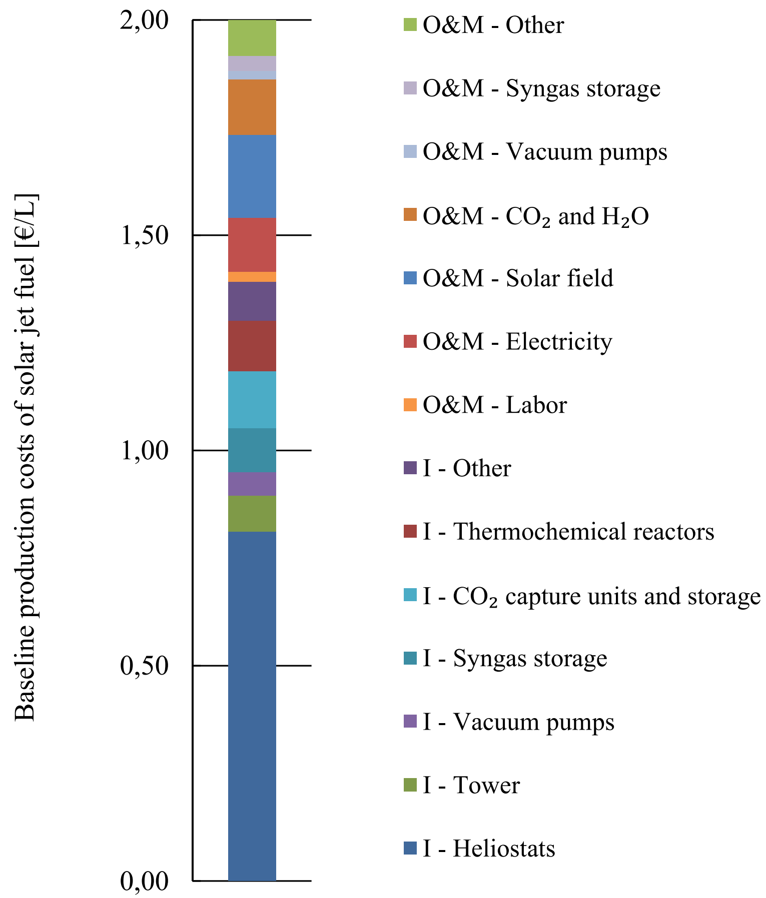
Economic analysis

- Estimation of fuel production costs for solar thermochemical plant (LCOE method)
- Assumptions:
  - Production volume: 1054 bpd of jet fuel and 888 bpd of naphtha
  - Solar plant: Concentration 100 €/m², O&M 2 €/m², DNI: 2500 kWh/(m² a) in Morocco
  - Electricity: 0.04 €/kWh_{el} on site from CSP plant
  - CO_2: 108 €/t from air capture with co-product H_2O
  - Thermochemical energy conversion efficiency: 19%
  - Fischer-Tropsch: 60% efficiency, 23000 €/bpd (investment), 4 €/bbl (O&M)
  - Weighted average cost of capital (nominal): 8%
  - By-product: Price(naphtha) = 80% × price(jet fuel)
  - Inflation: 2%, publicly supported facility, no tax has to be paid

Economic analysis

- Estimated production cost: 2.00 €/L jet fuel

- Cost drivers:
  - Investment costs and O&M of solar concentration
    100 €/m², 2 €/(m² a)
  - Generation of CSP electricity
    0.04 €/kWh_{el}
  - Provision of CO_2 by air capture
    108 €/t
  - Thermochemical efficiency 19.3% (with vacuum pumping and gas separation: 14.7%)



Source: C. Falter, V. Batteiger, A. Sizmann; *Climate Impact and Economic Feasibility of Solar Thermochemical Jet Fuel Production*, Environ. Sci. Technol., 2016, 50 (1)

Conclusion

- Efficient production of fuels based on water and CO_2 can be use both – heat and electricity to run the process
- Low costs can only be achieved if the process is operated for many full load hours
- Solar heat input has two major benefits:
  - Heat storage can be used to provide electricity at high full load hours
  - As heat can be provided at lower cost as electricity, it can replace some electricity input
- Hydrogen cost at good solar sites < 2€/kg (if high full load hours can be achieved)
- Synthetic fuel is 2-3 times more expensive than hydrogen

Fragen für die Podiumsdiskussion

- Kann die Energie für eine vollständige Dekarbonisierung des deutschen Energiesysteme allein in Deutschland durch erneuerbare Energien zur Verfügung gestellt werden?
- Welche Optionen gibt es erneuerbare Energien zu importieren und was sind die Herausforderungen?
- Wie groß sind die Kosten für den Transport gegenüber den Kosten der Herstellung? (Strom, Wasserstoff, Brennstoffe)?
- Wie günstig muss Wasserstoff /Synfuel werden, um mit anderen Brennstoffen (auch Biobrennstoffen) t zu konkurrieren?
- Welche CO_2 Bepreisung benötigt man um mit Erdgas oder Öl konkurrieren zu können?
- Macht es Sinn in Deutschland oder Europa eine Beimischung von nachhaltigen Brennstoffen vorzuschreiben und due Quote sukzessive zu erhöhen
- Unter welchen Bedingungen kann ein globaler Wasserstoffmarkt /Brennstoffmarkt entstehen?