# Nutzung von solarer Hochtemperaturwärme zur Erzeugung von Chemikalien und Grundstoffen

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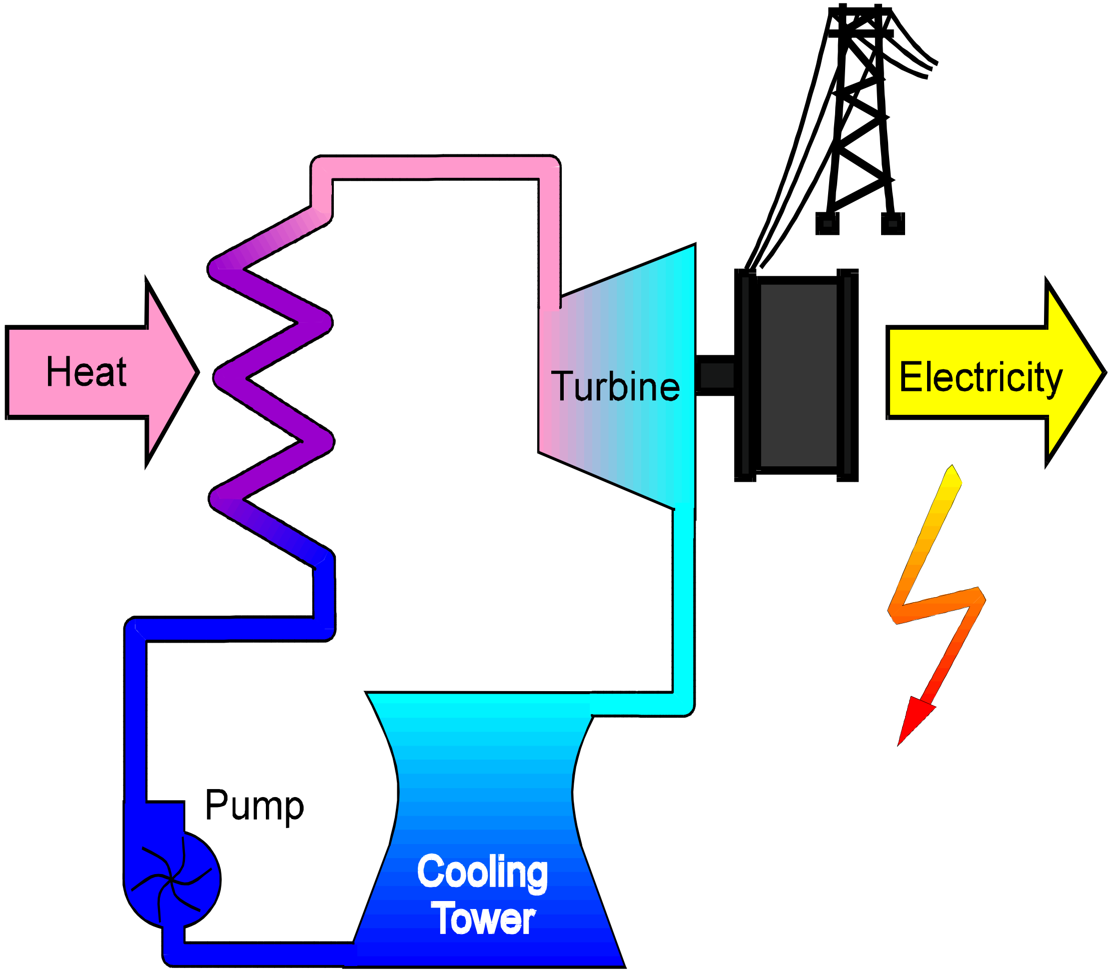
# Übersicht:

- Entwicklungen im Bereich CSP
- Prinzip solarchemischer Prozesse
- Typische Anwendungen
- Projektbeispiele
- Zusammenfassung

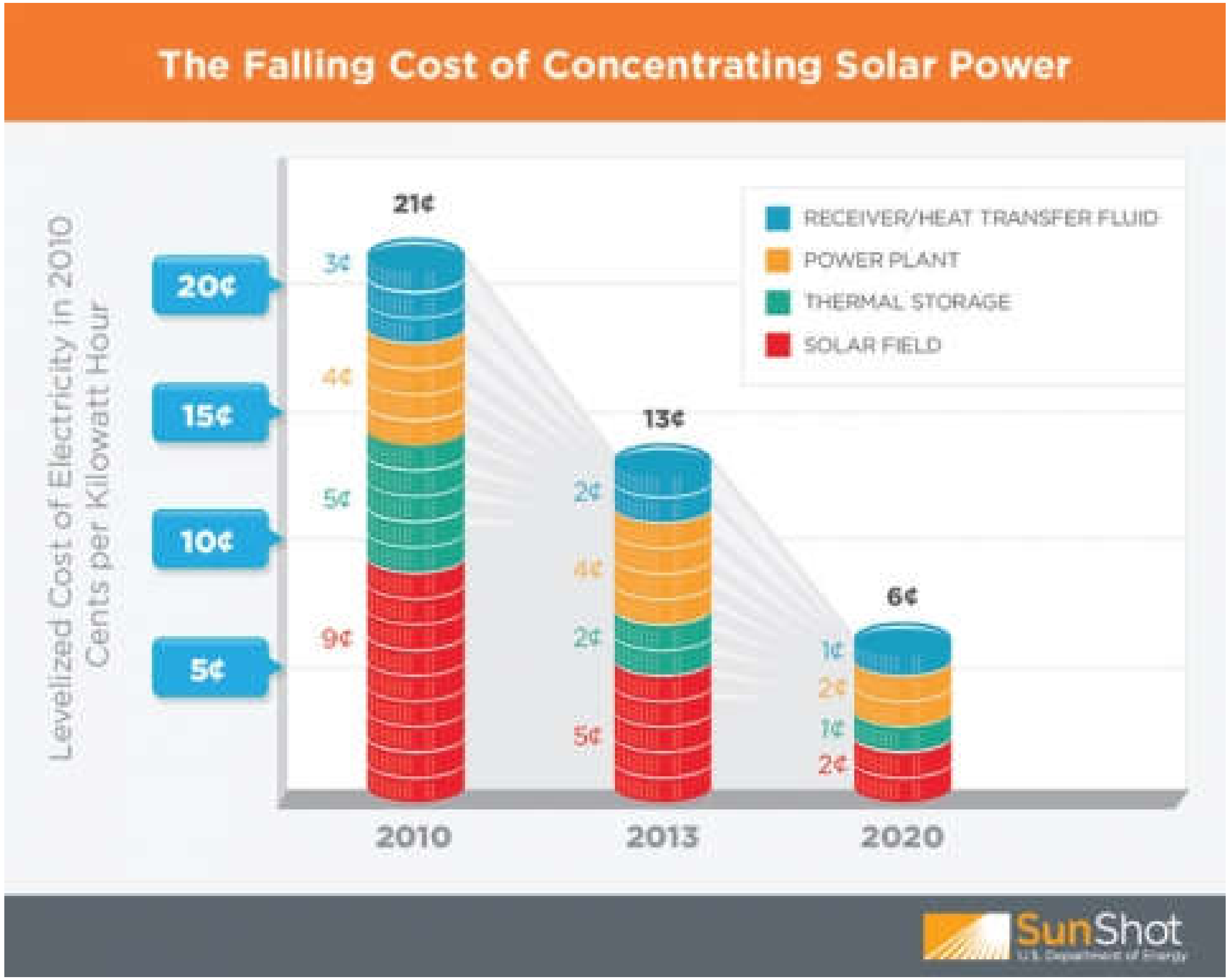
DLR Solarturm, Jülich

# Strom durch CSP

**Solar thermal power plants**



# DOE‘s target for LCOE of CSP

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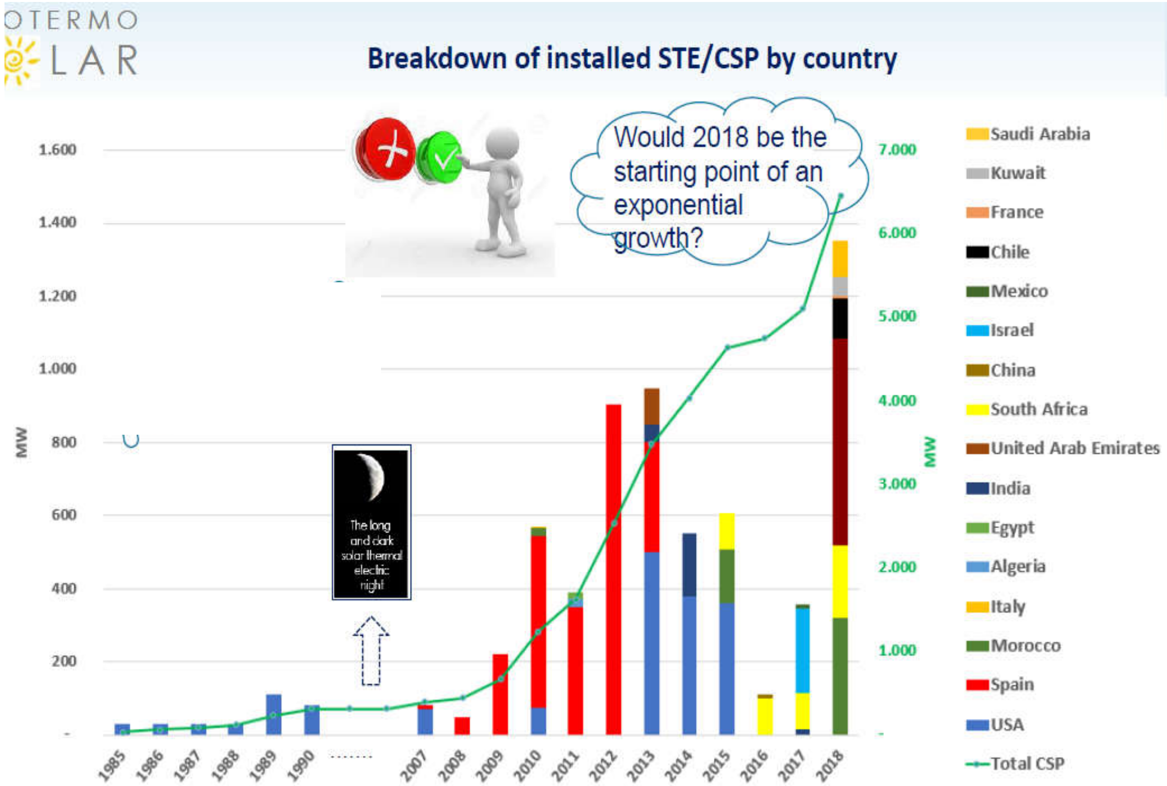
# Installed/planned STE/CSP per country*




Expansion happened in three phases, **each driven by a specific policy regime:**
1984-1990 in California;
2007-2013 in Spain;
2013-today in several countries.**

* L. Crespo CSP-Today 2017Conference
** Lillestam et al, Nature Energy 2017

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# CSP now:

**The price records for dispatchable solar broken last year:**

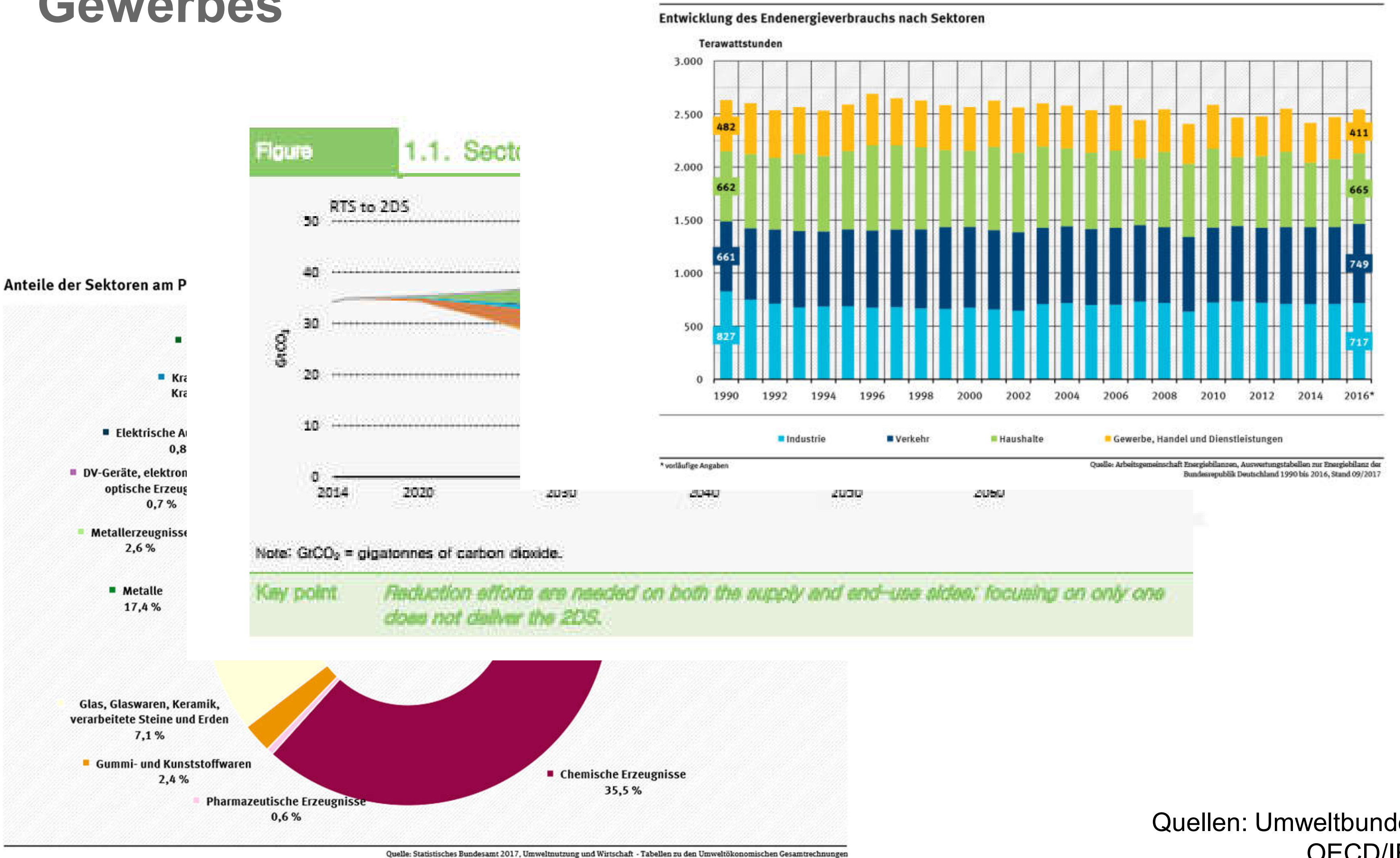
TuNur proposed shipping solar from Tunisia at **10 cents**/kWh

In May, Dubai's DEWA received a solar bid at just **9.4 cents**/kWh.

In September, DEWA awarded a new low contract for solar at just **7.3 cents**/kWh

In August, SolarReserve won a solar contract at **6.1 cents**/kWh.

# Primärenergiebedarf und CO2 Emissionen des produz. Gewerbes




Quellen: Umweltbundesamt
OECD/IEA

# Solar Towers







## On the Web:

http://www.ivanpahsolar.com/
http://www.psa.es/webeng/index.php
http://www.torresolenergy.com/TORRESOL/home/en
http://www.solarreserve.com/en/global-projects/csp/crescent-dunes
http://www.abengoasolar.com/web/en/plantas_solares/plantas_para_terceros/espana/

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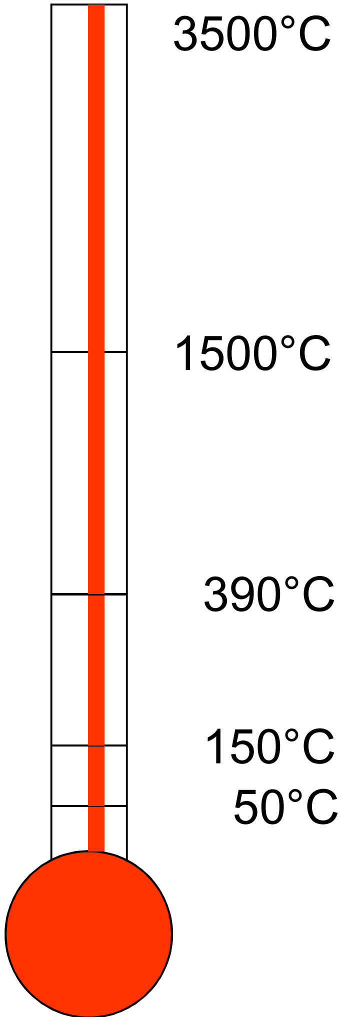
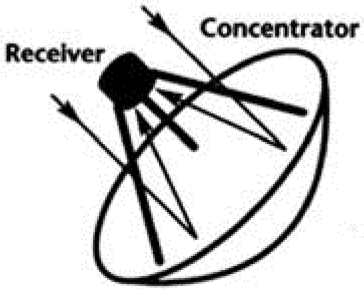
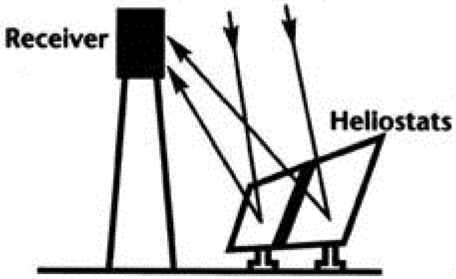
# Temperature Levels of CSP Technologies

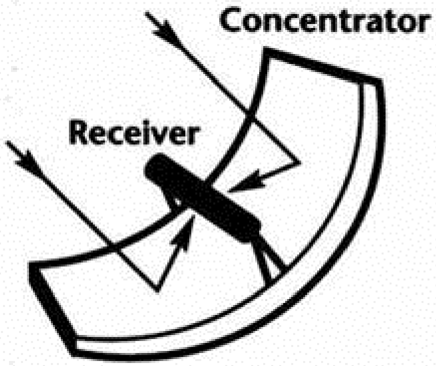



Paraboloid:
„Dish“




Solar Tower
(Central Receiver
System)




Parabolic Trough /
Linear Fresnel

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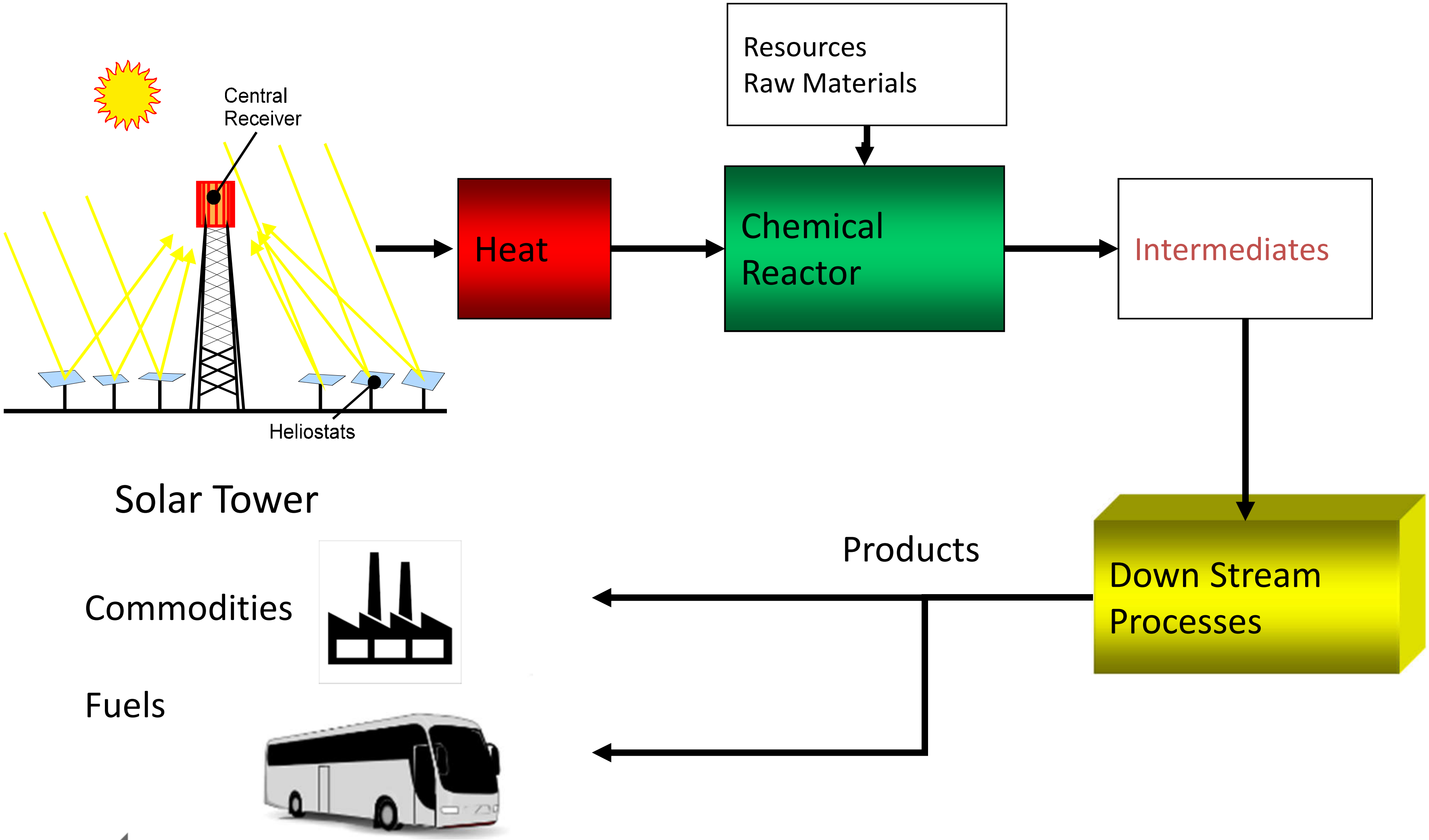
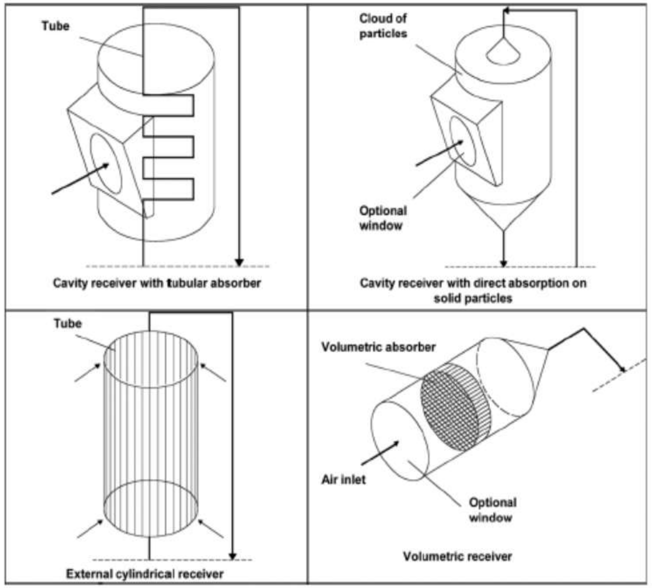
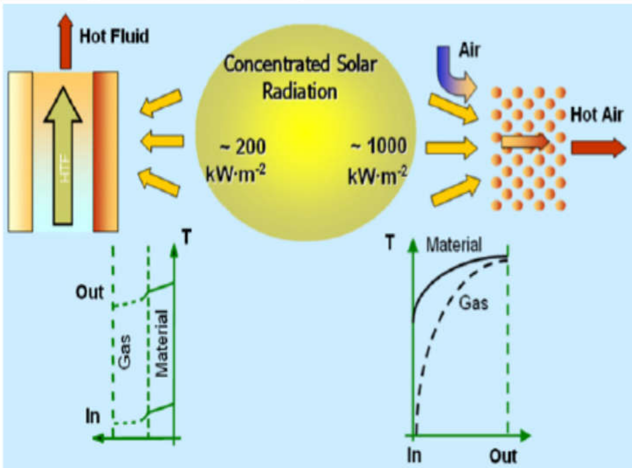
# Prinzip solar thermochemischer Prozesse



# Solarreceiver - Solarstrom oder chemische Reaktion




→ Dampf/Gasturbine

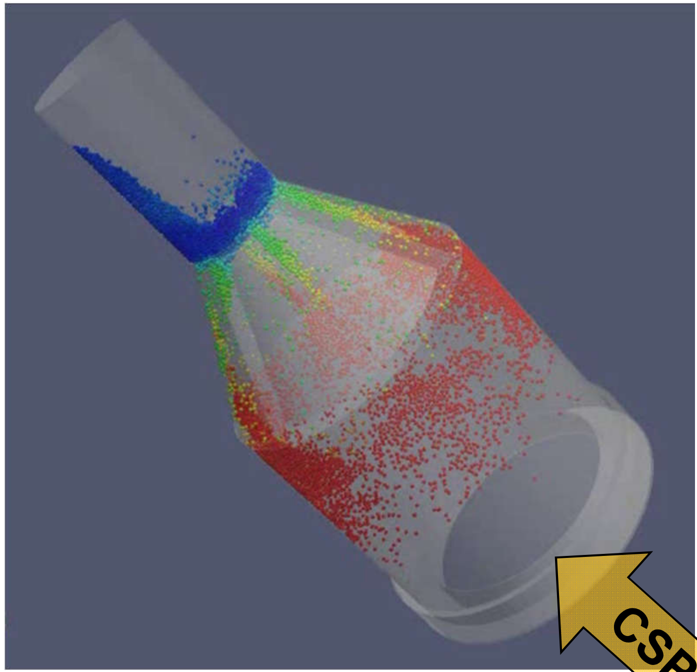
→ Stromerzeugung

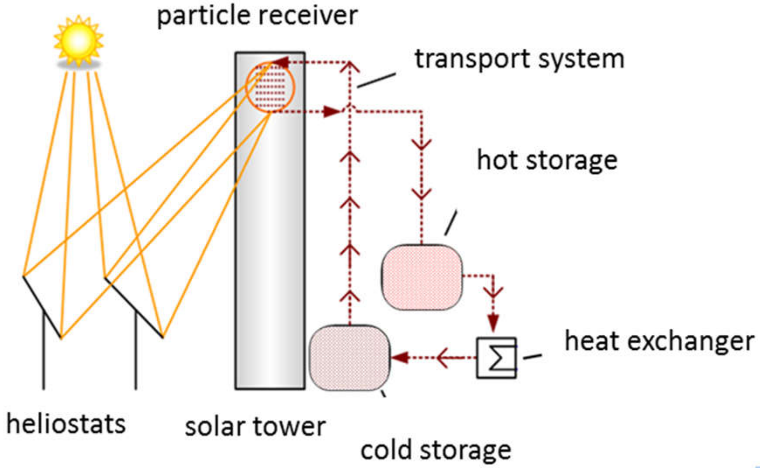
→ Reaktor/Ofen

→ Erzeugung von Chemikalien und Grundstoffen

# Solar Partikeltechnologie
## Zentrifugalreceiver

- Direct absorption ⇒ high efficiency and energy density
- Direct storage
- Receiver and storage at ambient pressure
- No freezing and no decomposition
- Low parasitic
- Low security requirements






CSP

# Solarisierung von industriellen Hochtemperaturprozessen

Thermochemische Spaltung von Wasser und Kohlendioxid

Hochtemperaturelektrolyse

Reformierung von Erdgas

Kohlevergasung

Cracken von Methan

Stahlgewinnung

Aufbereitung von Erzen
(z.B. Eisen, Aluminium, Mangan, Kupfer)

Thermochemische Speicher

Schwefelsäurerecycling und Schwefelsäurespaltung

Luftzerlegung

Ammoniak und Dünger

Schmelzen von Metallen und Glas

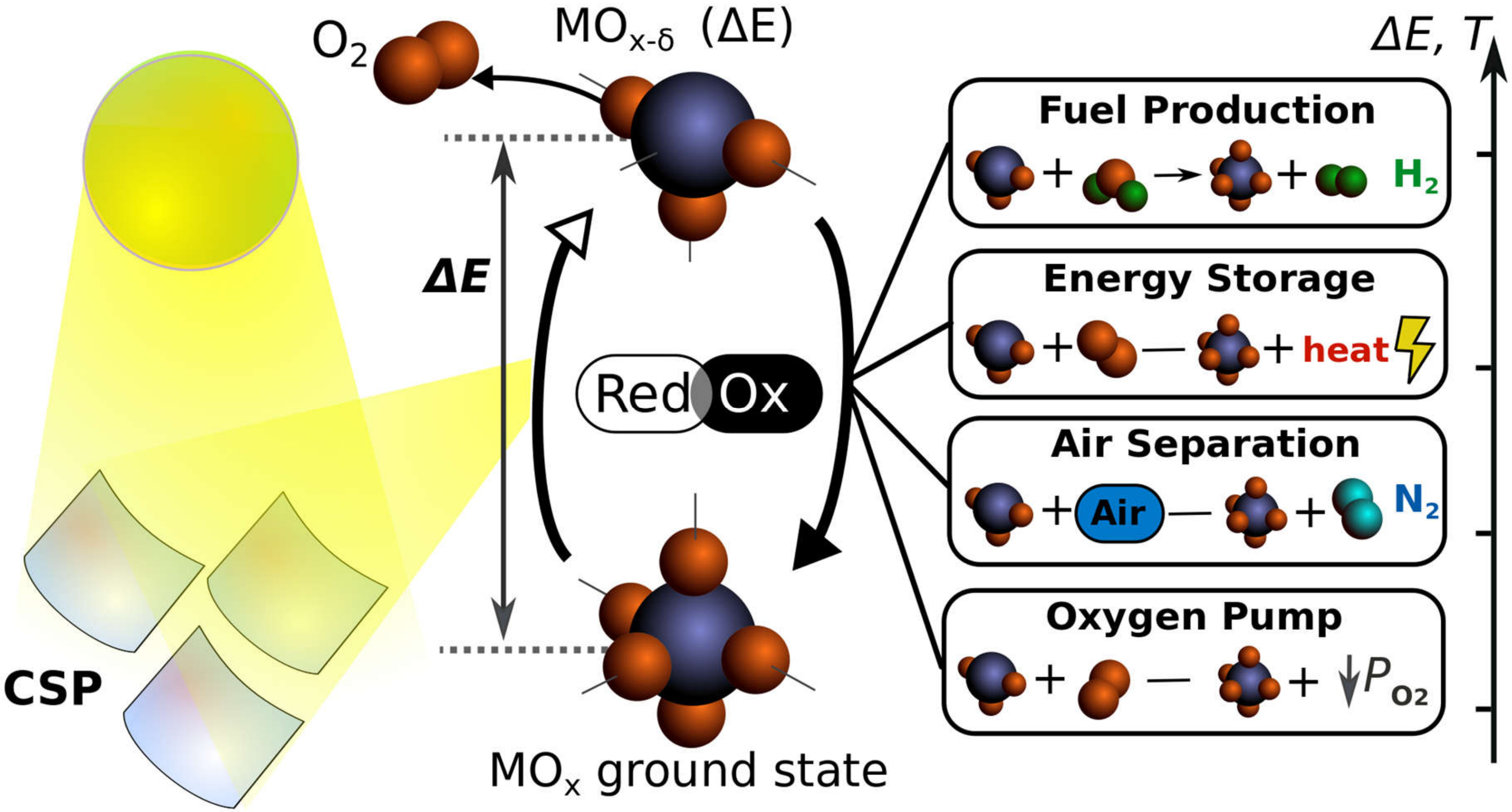
Recycling von Metallschrott

Zement-, Kalk- und Phosphatherstellung

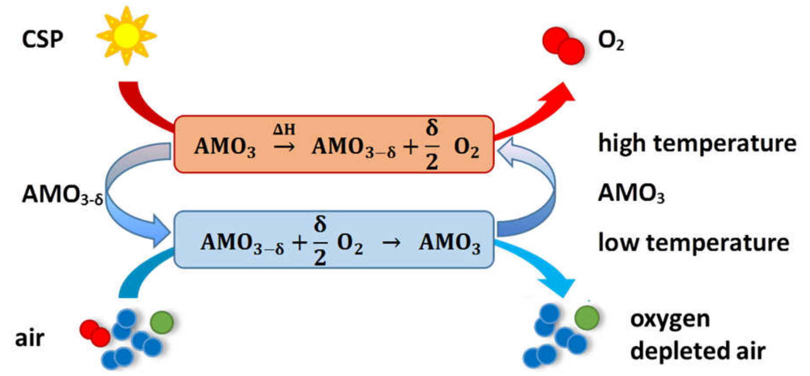
# Anwendungen systematisch

| Kalzinierung | Kohle- und Petrochemie | Stickstoffchemie | Metallgewinnung und Metallurgie | Schwefelchemie |
|---|---|---|---|---|
| Zement | Kohlevergasung | Ammoniak | Schmelzen | Schwefelsäure-recycling |
| Klinker | Kohletrocknung | Nitrate | Recycling | Schwefelsäure-Hybrid-Prozess |
| Kalk | Cracking | Ammonium-Nitrat | Reduktion von Metalloxiden | Schwefelherstellung |
| $CaCO_3$-Looping | Reformierung | Schmelzsalze | Aufbereitung von Metallerzen | Dünger |
| $Ca(OH)_2$-Looping | Gasifizierung | Dünger | Herstellung anorganischer Pigmente | |
| (Phosphat) | | Luftzerlegung | | |

# Redox-Anwendungen



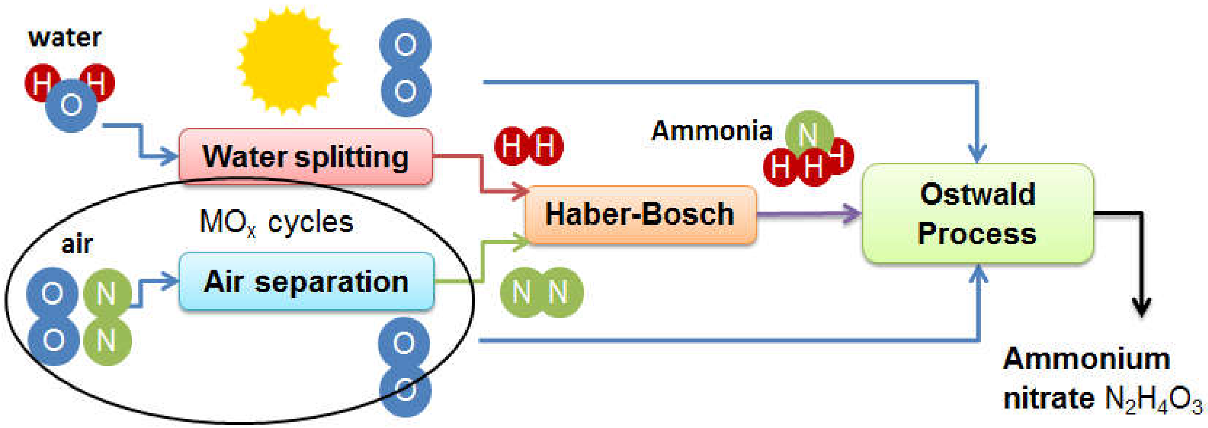
# DÜSOL: Solare Ammoniak und Stickstoffdüngerproduktion




→ production of nitrogen or oxygen for industrial applications

→ nitrogen: application in ammonia production (currently > 1% of world primary energy consumption[1])

[1] Erisman, J. W.; Sutton, M. A.; Galloway, J.; Klimont, Z.; Winiwarter, W., How a century of ammonia synthesis changed the world. Nature Geosci 2008, 1, (10), 636-639.



# DÜSOL: Konsortium und Inhalte

GTT

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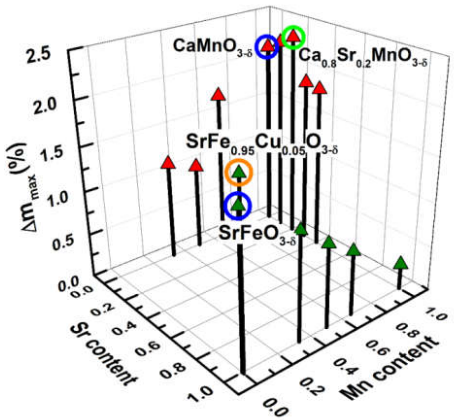
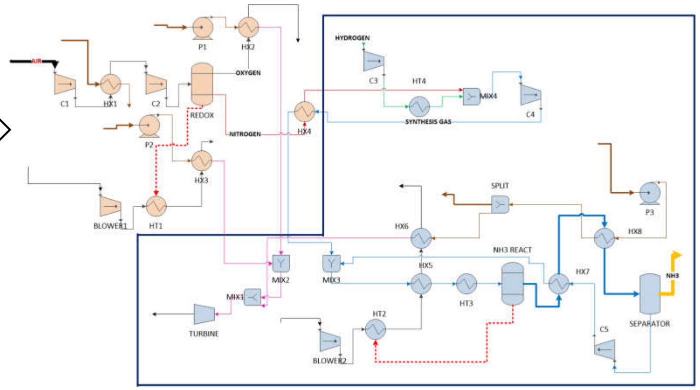
aixprocess



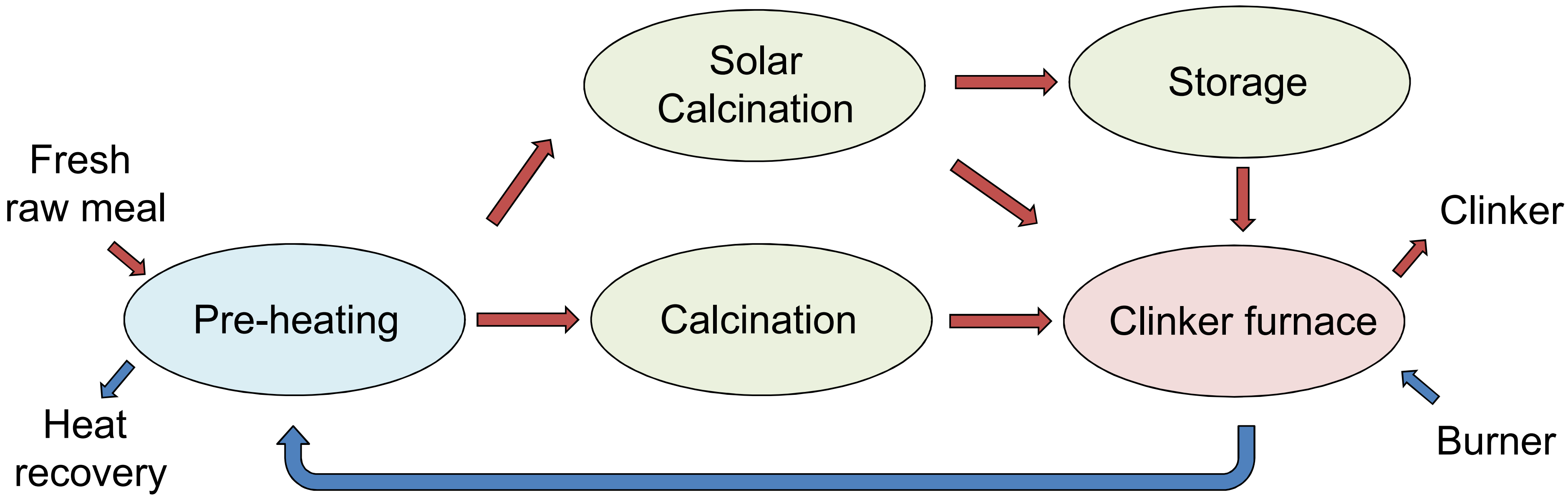

Thyssenkrupp



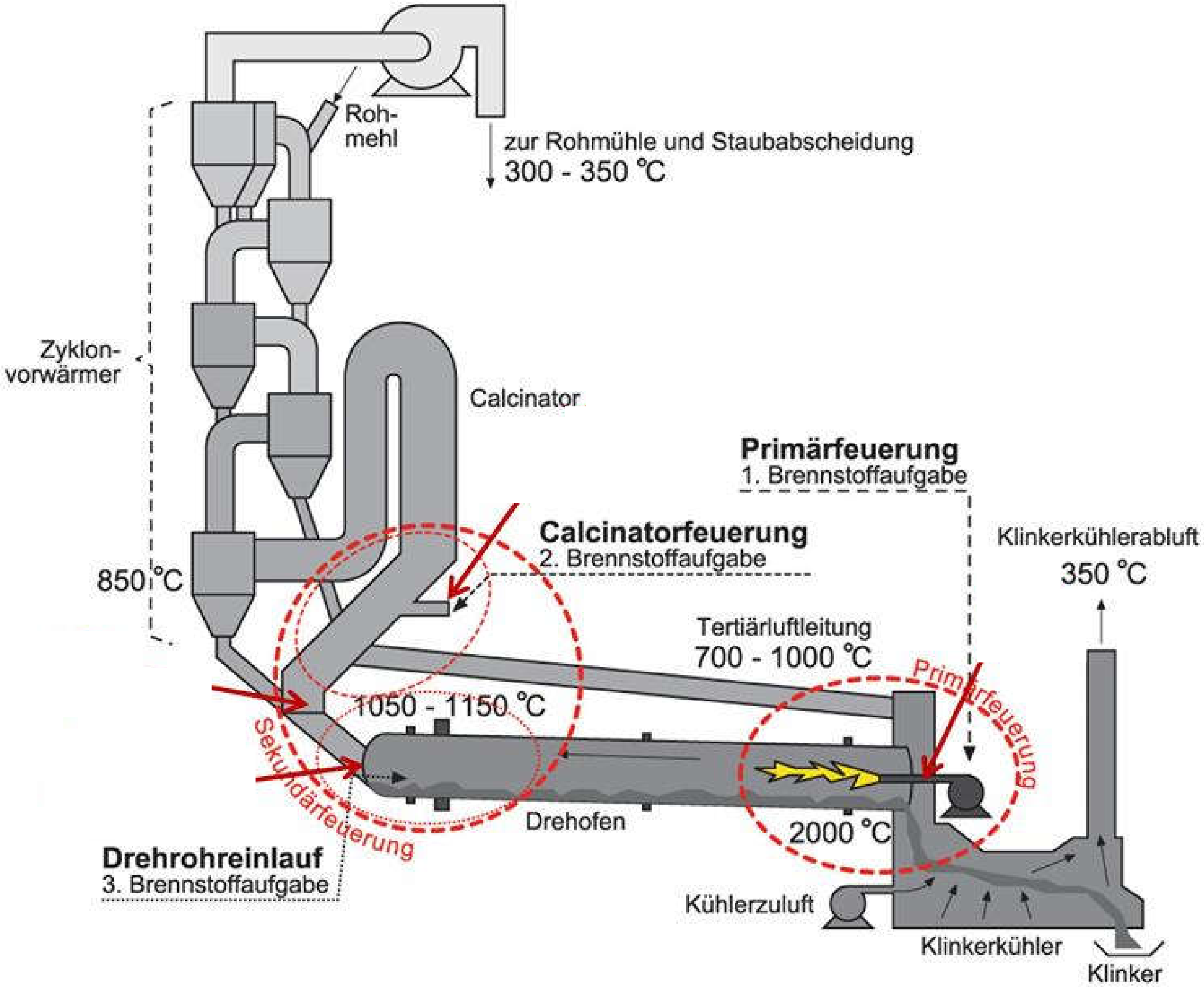
Yara Deutschland

# EU-Projekt SOLPART

Develop, at pilot scale, a high temperature (800-1000°C) solar reactor for particle treatment. The process should work 24 h/day in energy intensive Industries like cement production and phosphate treatment.



# Industrieprozess zur Zementherstellung




[http://www.wtert.eu/default.asp?Menue=13&ShowDok=49]

# The SOLPART Consortium

cnrs dépasser les frontières

DLR

comessa

CEMEX

forlime.be

MANCHESTER 1824
The University of Manchester

ABENGOA

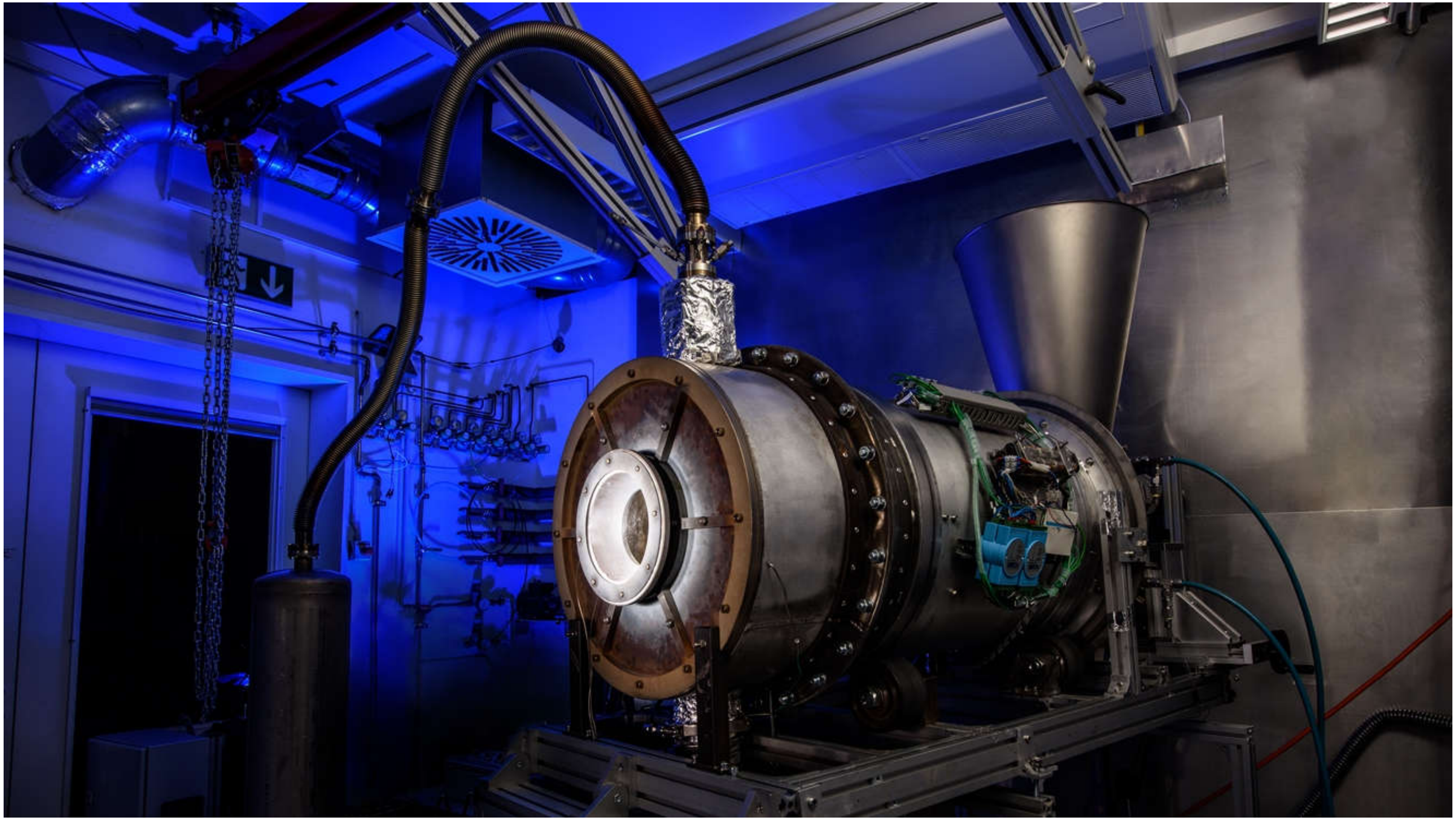
EUROPEAN POWDER & PROCESS TECHNOLOGY
EPPT
BELGIUM

euronovia

MARRAKECH
جامعة القاضي عياض
UNIVERSITÉ CADI AYYAD

OCP

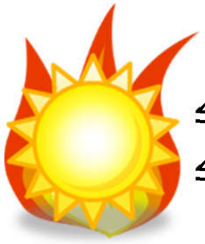
# Aufbau des solaren Drehtrommelofen im Solarsimulator



# Petrochemie: INDIREF

$CH_4 + H_2O +$ [Sonne] $\leftrightharpoons 3H_2 + CO$

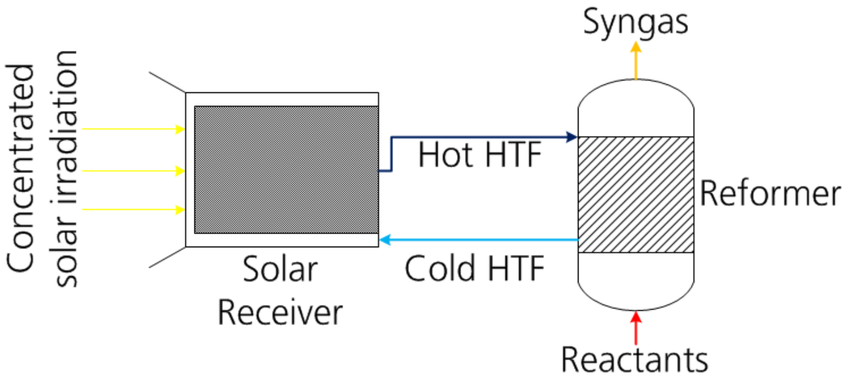
$CH_4 + CO_2 +$ [Sonne] $\leftrightharpoons 2H_2 + 2CO$



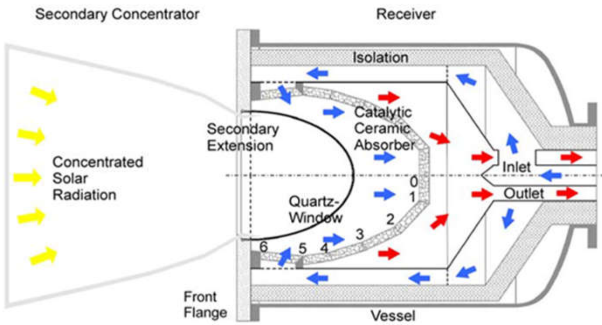
Reduktion des Erdgasverbrauchs

Sonnenenergie wird chemisch gespeichert

Indirekt solar beheizt:



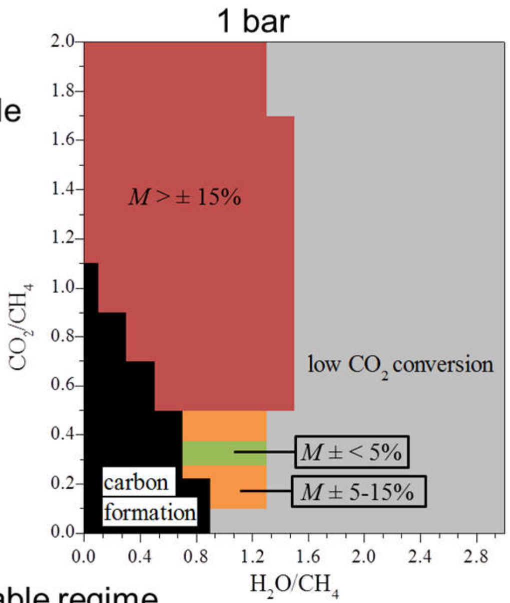

Direkt bestrahlt:

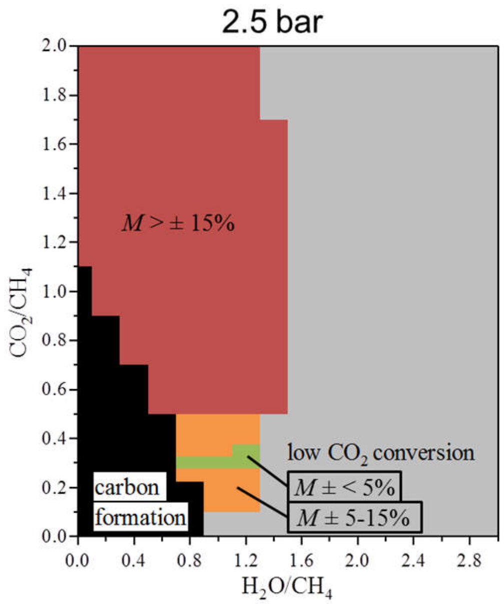



**Flexibilität vs. Effizienz**

# Indiref: Investigations on suitable operation regimes

- Results for 900°C
- Only green area suitable

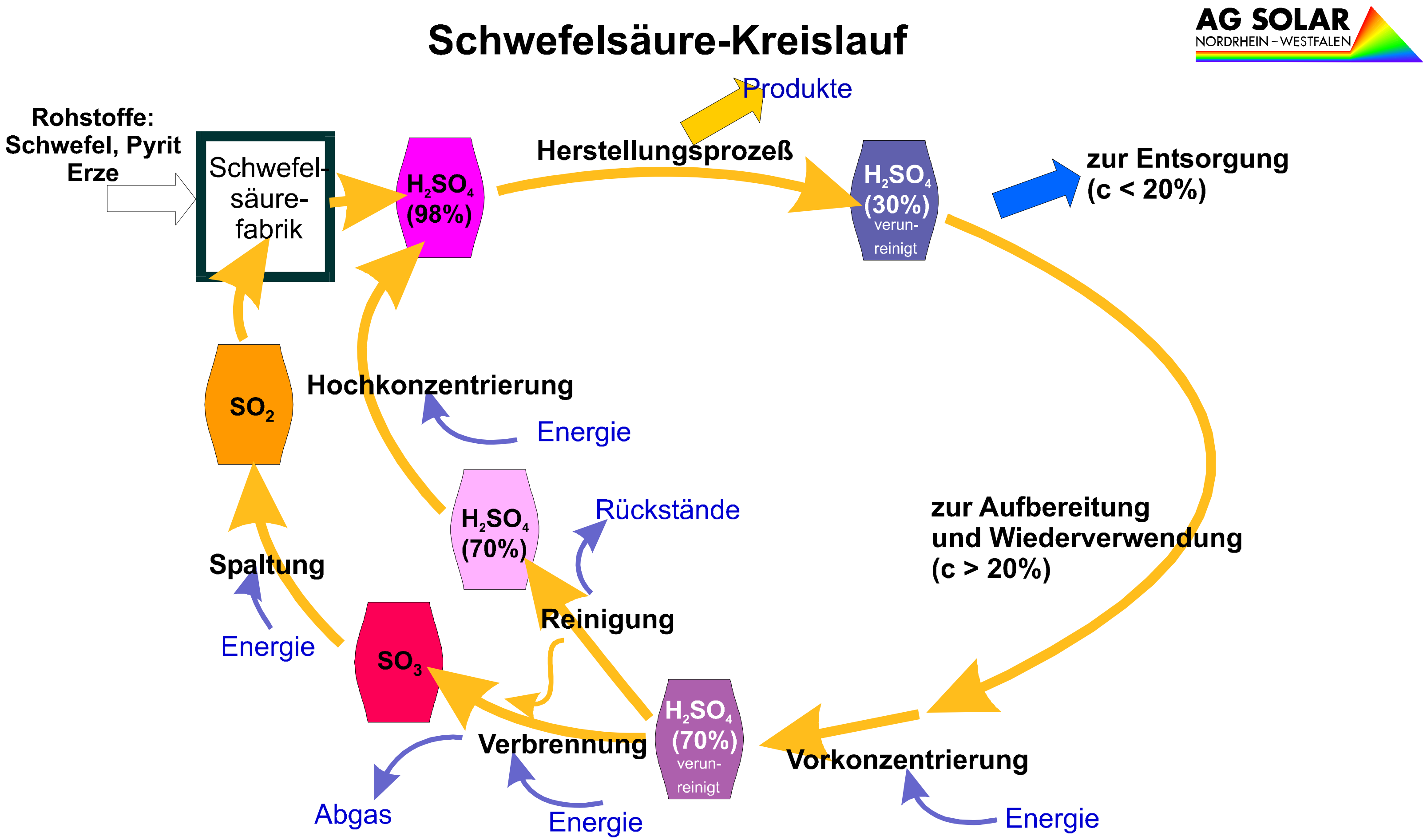


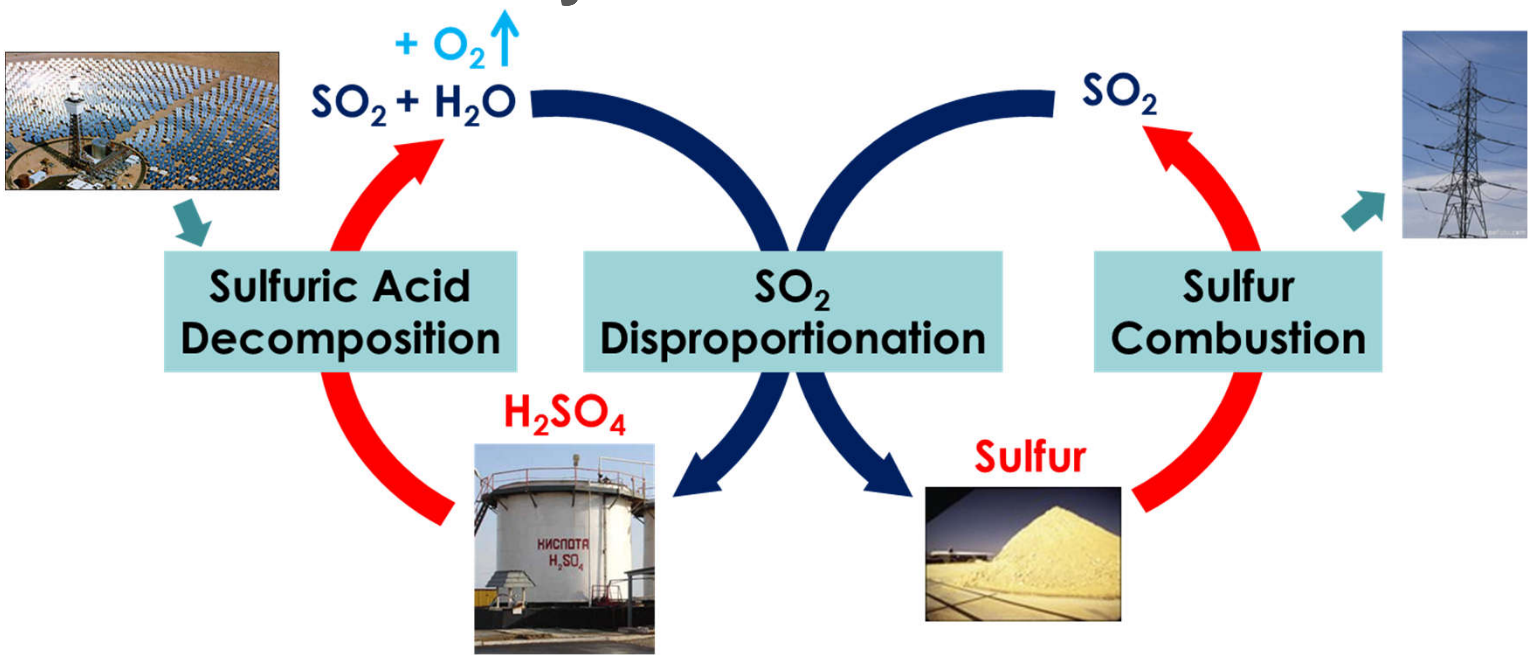

→ Only very narrow suitable regime
→ There is a suitable regime (for low pressure!)

compare Energies 2018, 11, 2537; doi:10.3390/en11102537

# Schwefelsäure-Recycling



# Solar energy can be stored in elemental sulfur via a three step thermochemical cycle




| | Reaction | Temp (°C) |
|---|---|---|
| $H_2SO_4$ Decomposition | $2H_2SO_4 \rightarrow 2H_2O(g) + O_2(g) + 2SO_2(g)$ | 800 |
| $SO_2$ Disproportionation | $2H_2O(l) + 3SO_2(g) \rightarrow 2H_2SO_4(aq) + S(l)$ | 150 |
| Sulfur Combustion | $S(s,l) + O_2(g) \rightarrow SO_2(g)$ | 1200 |

# Solare Schwefelchemie

## Train

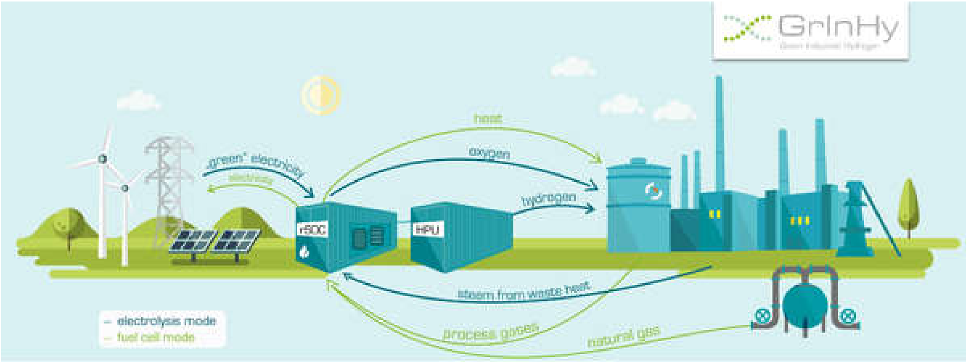

## Pipeline

Molten sulphur in heated pipelines (~140 °C)

## Ship

## Truck

# GrinHY: Renewable hydrogen for direct reduction of iron ore




This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700300.

This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

# Zusammenfassung

- Neben den Brennstoffes enormes Potential zur Deckung von Wärmebedarf für (chemische) energieintensive Industriepozesse aus Erneuerbaren
- Anwendungen: Metall, Glas, Baustoffe, Dünger, chemische und petrochemische Industrie, Schwefelsäure und Schwefel, Bergbau und Erzverarbeitung…
- teils Integration in bestehende Anlagentechnik, teils neue Prozesstechnologie notwendig
- Zuwachs des Industrieinteresse (Technologie- und Komponentenentwickler, Generalunternehmer, Anlagenbetreiber, Nutzer)

# Danksagung


- der EU für die Co-Finanzierung der Projekte SOLPART (Contract-No. 654663) und PEGASUS (Contract-No. 727540) .
- Dem BMBF für die Co-Finanzierung des Projekts SOLAM (Vertrag Nr. 033R121A).
- Dem Land NRW im Leitmarkt- und Klimaschutzwettbewerb „ErneuerbareEnergien.NRW" und dem EFRE Programm der EU für die Co-Finanzierung der Projekte DÜSOL (EFRE-0800603), Indiref (EFRE-0800578) und Calypsol (EFRE-0801159).

European Commission
HORIZON 2020

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

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# Thank you very much for your attention!