# The production of solar fuels including hydrogen using Concentrated Solar Power

Dr. Martin Roeb

Vereniging voor Zonnekrachtcentrales, Mini-Symposium Hydrogen from the Desert, 8th June 2018


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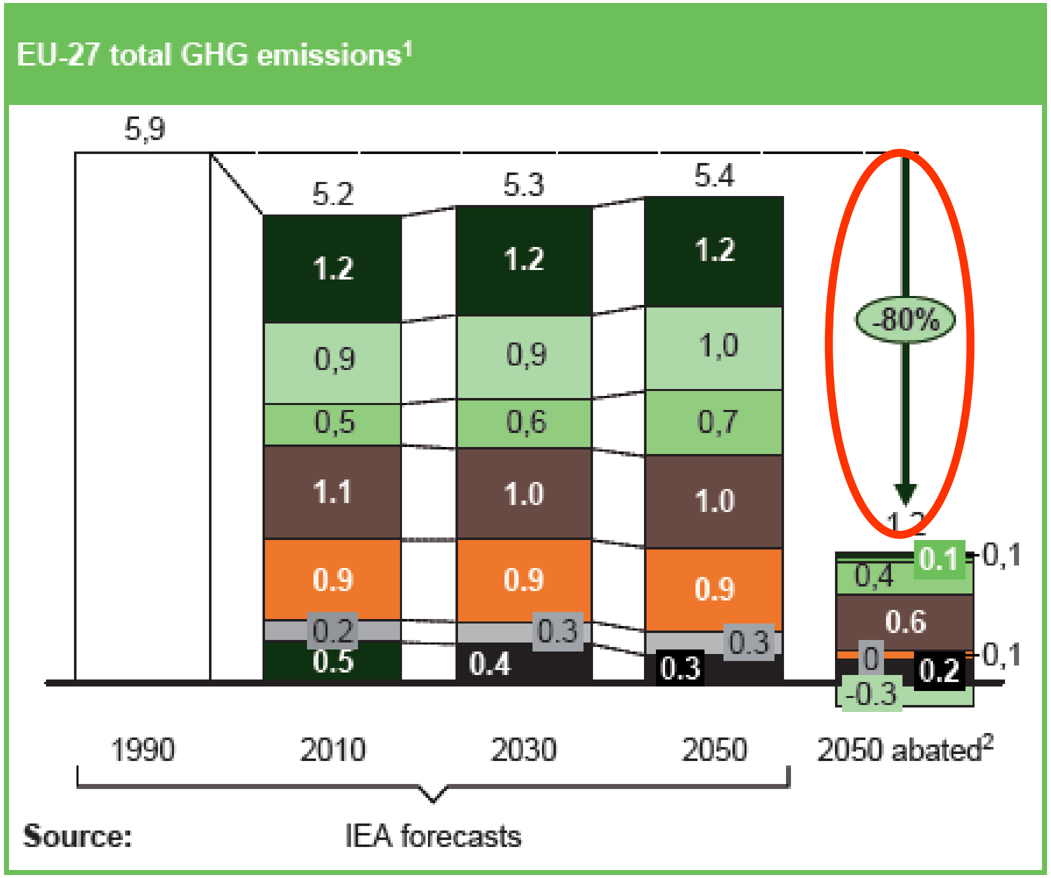
# Outline

- International Goals for Decarbonisation of Energy Economy
- Hydrogen Production and Applications
- Potential of Solar Resources
- Solar Hydrogen Production Routes
- Technology and Project Examples
- Summary

# Political Drivers: Examples – EU Sustainable Energy Technology Plan (SET-Plan 2007) G7 Goals (2015)

- **Goals of the EU until 2020 (20/20/20)**
  - **20%** higher energy efficiency
  - **20%** less GHG emission
  - **20%** renewable energy
- **Goal of the EU until 2050:**
  - **80%** less $CO_2$ emissions than in 1990
- **G7 Goals, Elmau, Germany**
  - **100%** Decarbonisation until 2100
  - **100 bln $/year** for climate actions in developing countries, large share by industrial investment


# Development of EU GHG emissions [Gt $CO_2e$]




| Sector | Total abatement |
|---|---|
| Power | 95-100% |
| Road transport | 95% |
| Air & sea transport | 50% |
| Industry[3] | 40% |
| Buildings | 95% |
| Waste | 100% |
| Agriculture | 20% |
| Forestry | -0.25 Gt $CO_2e$ |

1 Large efficiency improvements are already included in the baseline based on the International Energy Agency, World Energy Outlook 2009, especially for industry
2 Abatement estimates within sector based on Global GHG Cost Curve
3 CCS applied to 50% of large industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

SOURCE: www.roadmap2050.eu

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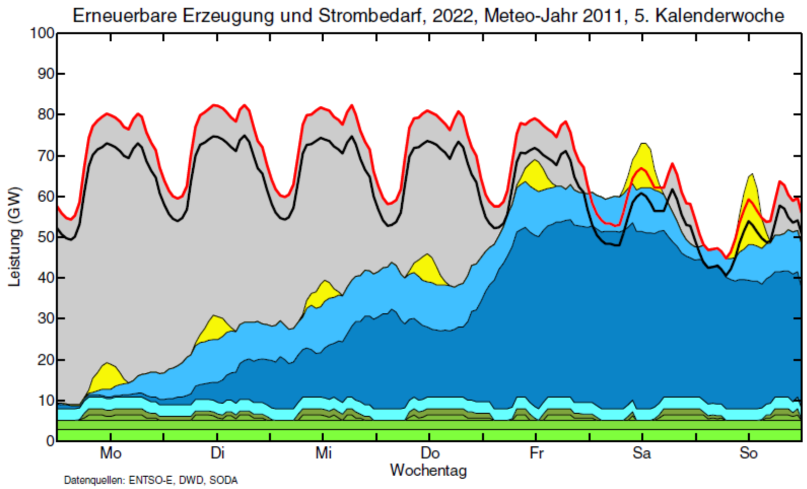
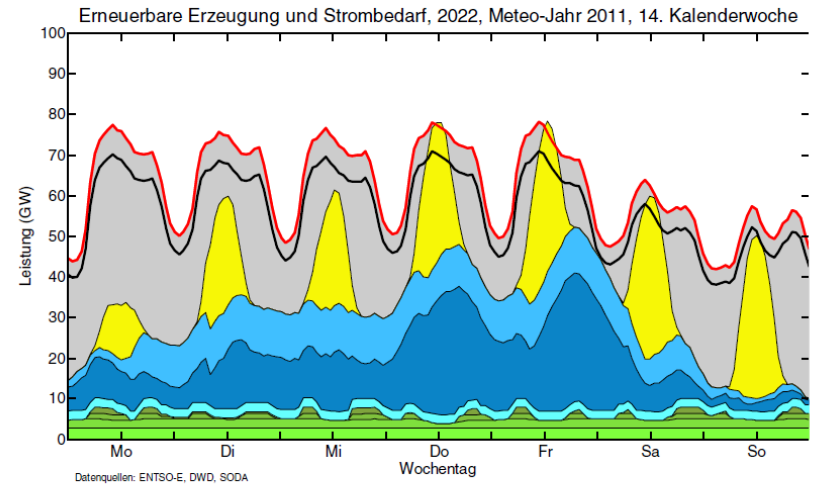
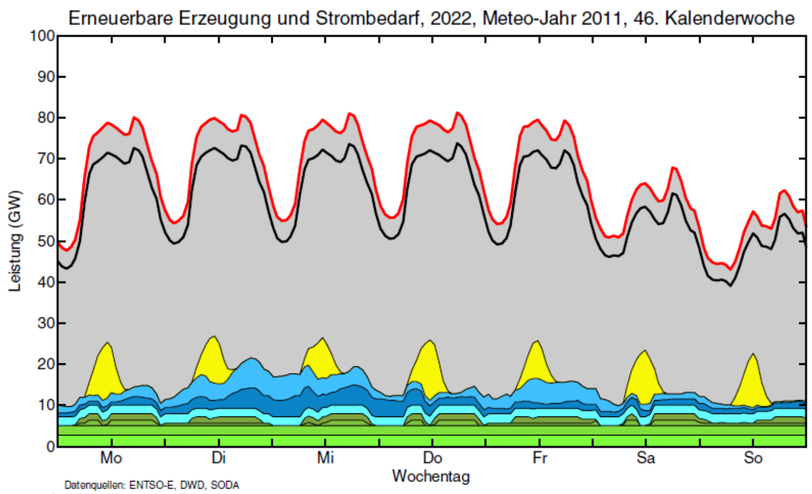
# Importance of Storage for Renewable Energy

## Forecast: Renewable Energy and Electricity Demand




- Biomasse Grundlast
- Biomasse wärmegeführt
- Biogas flexibel
- Biomethan flexibel
- Wasserkraft
- Onshore-Wind
- Offshore-Wind
- Photovoltaik
- konv. Kraftwerke
- Strombedarf
- ohne Bahnstrom und Arealnetze

Fraunhofer IWES

Agora Energiewende

- **Demand ≠ Production**
  **⇒ Storage needed**

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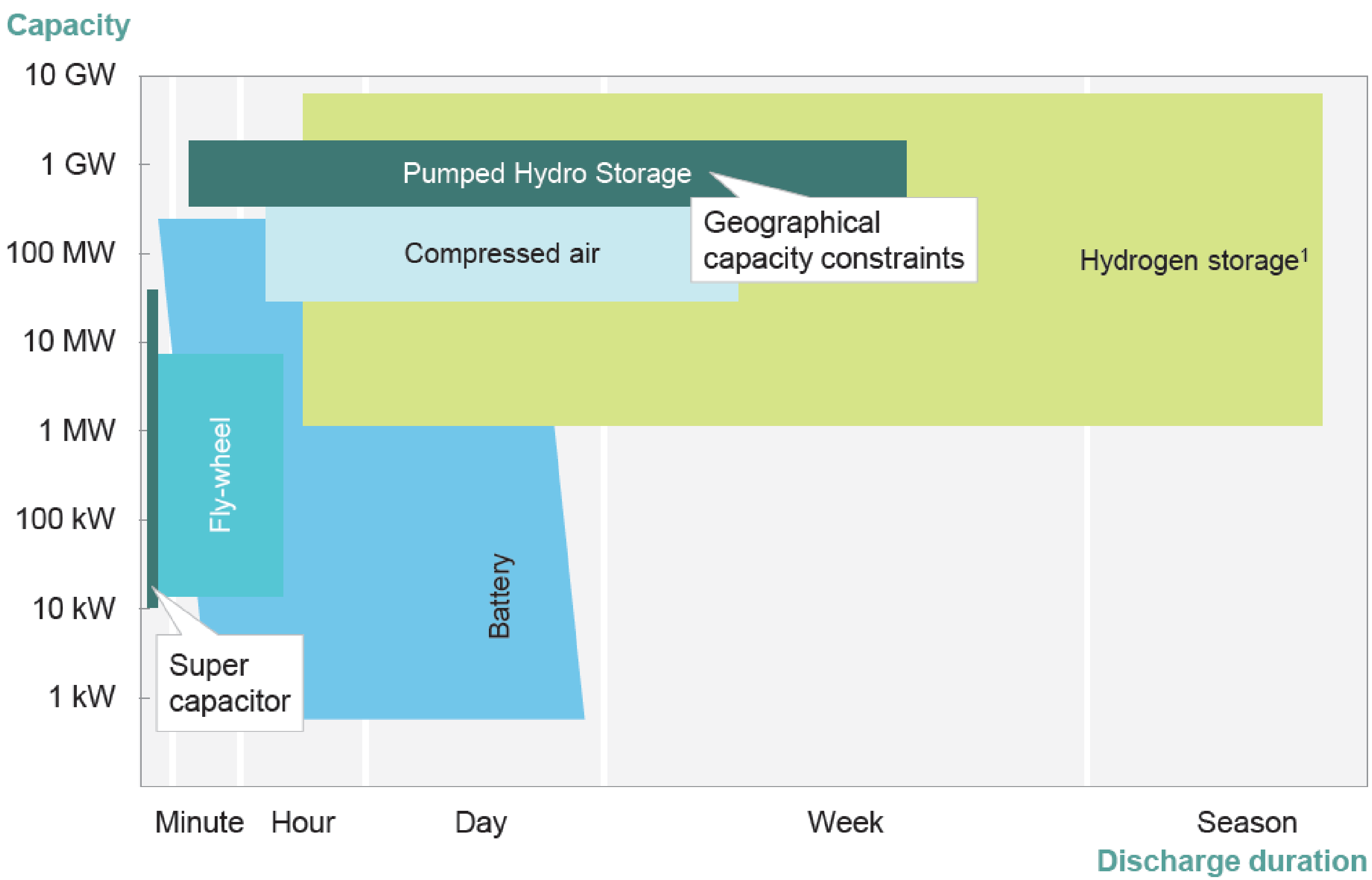
# Available Energy Storage Technologies

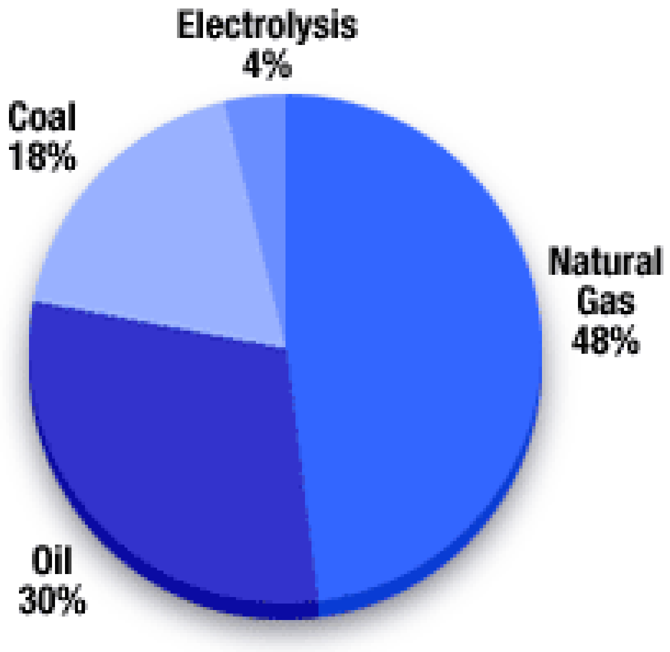



1 IEA data updated due to recent developments in building numerous 1MW hydrogen storage tanks

Source: IEA Energy Technology Roadmap Hydrogen and Fuel Cells, JRC Scientific and Policy Report 2013

# Options and Boundary Conditions for a Hydrogen Economy

# Origin of Hydrogen Today




Production Methods

- Steam and mixed reforming
- Partial oxidation
- Gasification

# Hydrogen in Space Transport

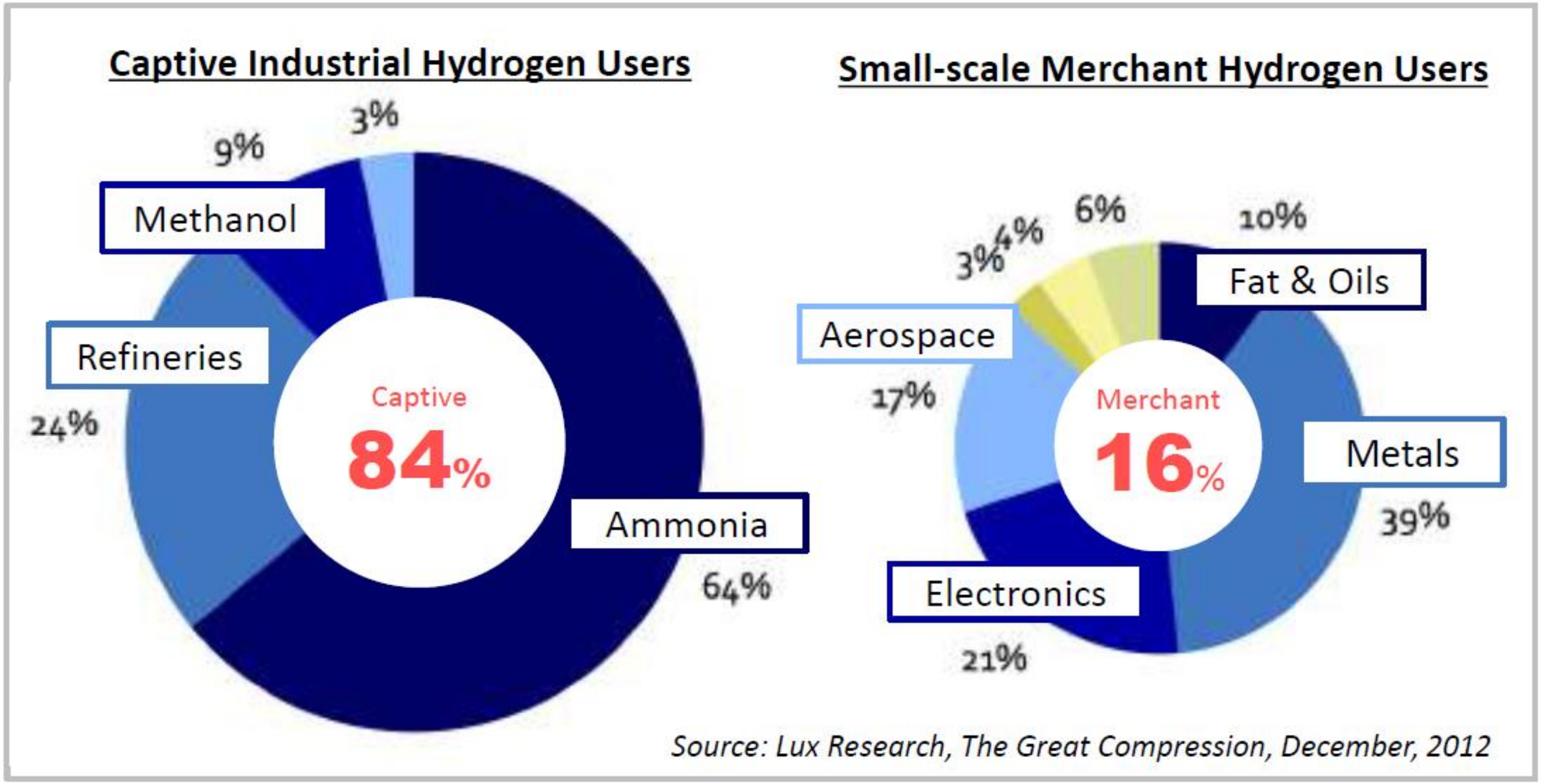
Space Shuttle Discovery
Start from Launch Pad 39B
Kennedy Space Center, FL
4. Juli 2006

Vulcain-1

Vulcain-2

Rocket engine tests
DLR Lampoldshausen

# Applications of Hydrogen



# Applications of Hydrogen today and tomorrow


- Raw material of chemical industry
    - e.g. fertiliser production, mineral oil refineries

- Fuels for mobile and stationary applications

<u>Hydrogen vehicles</u>

RVK-Hydrogen Bus



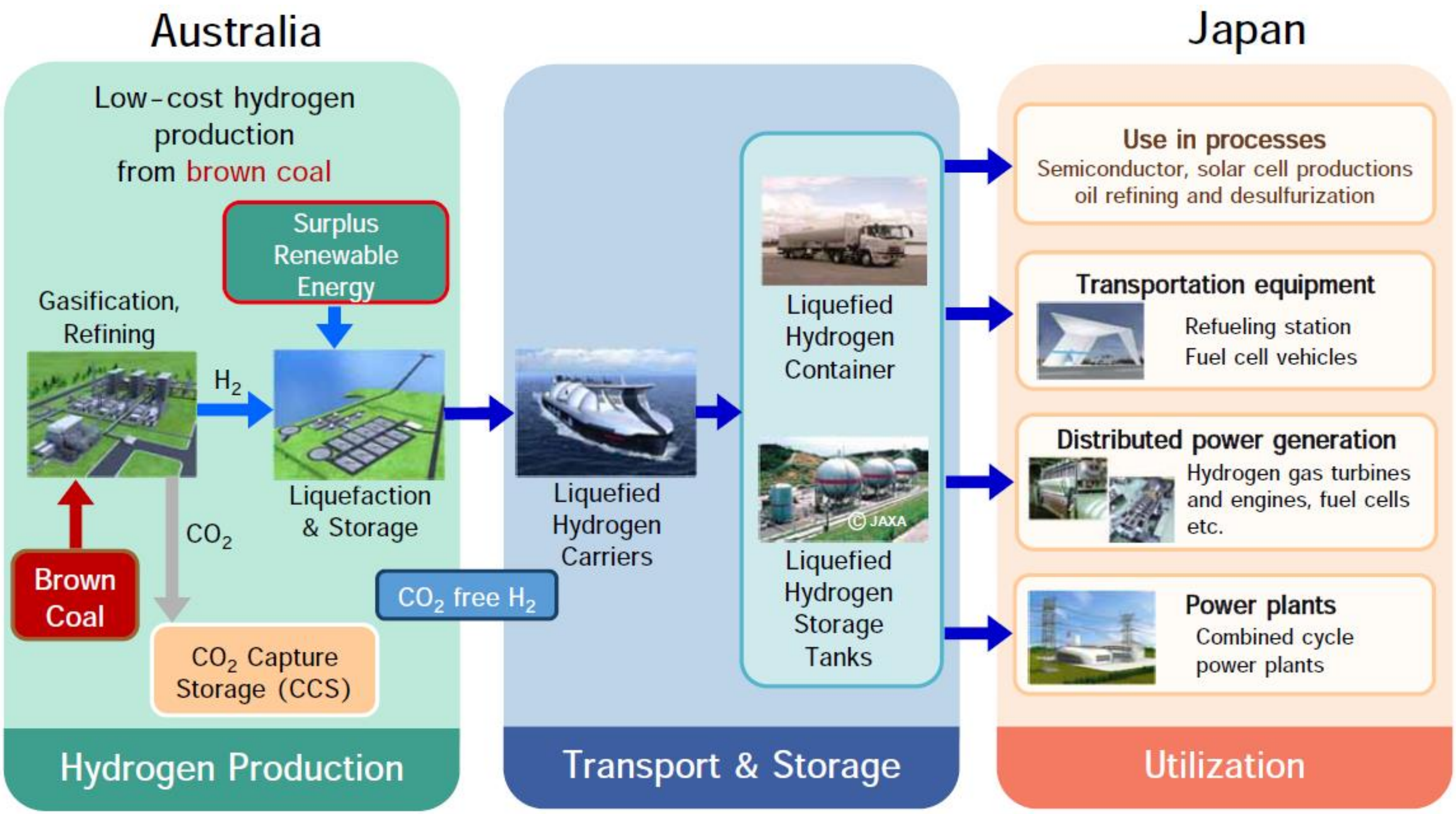
Hydrogen Cars

<u>Fuels cell power plants</u>

4,8 MW-Plant by UTC Power

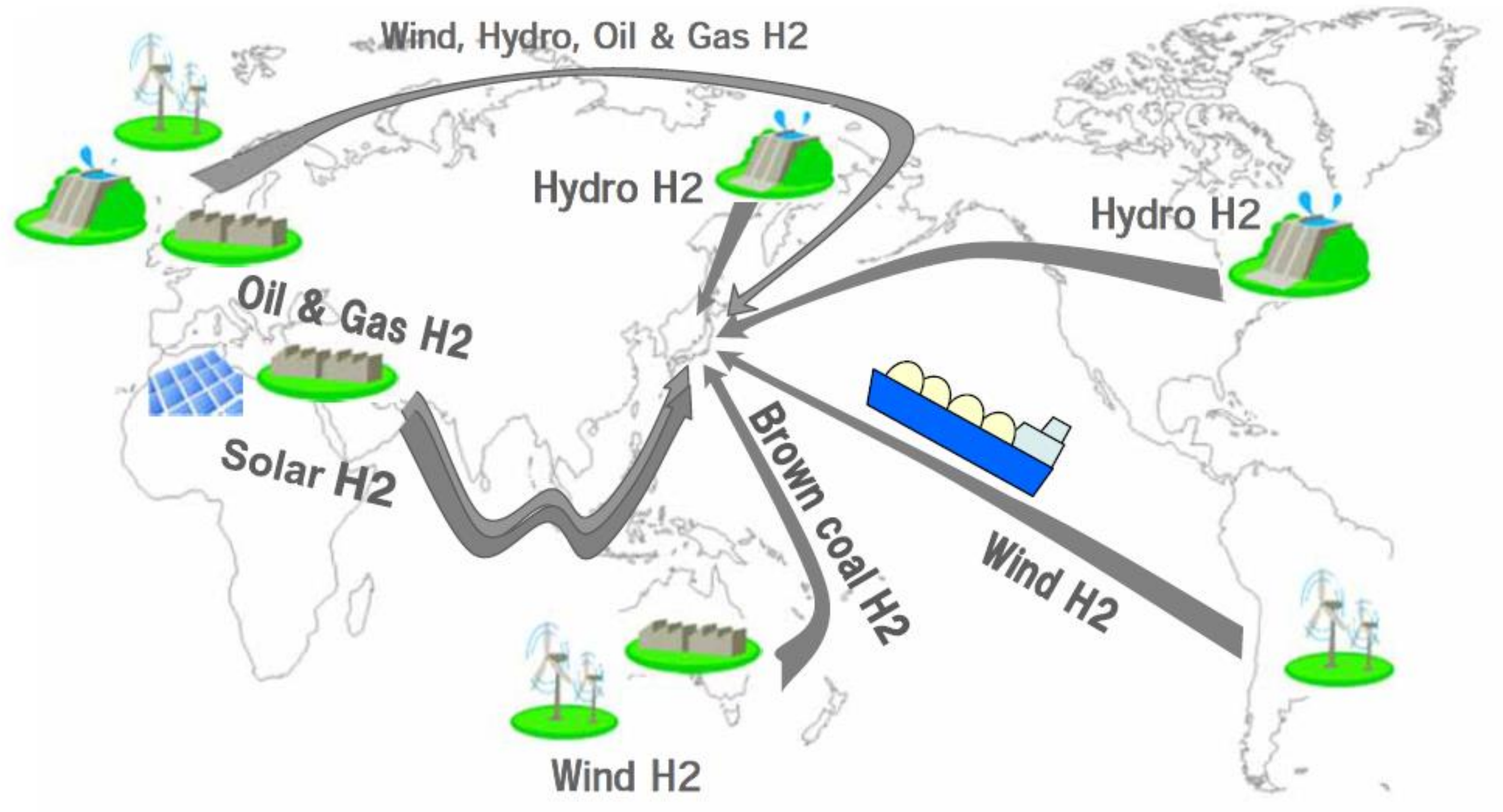
- Generation of liquid hydrocarbons (e.g. **Kerosene**) from hydrogen and CO via **Fischer-Tropsch-Synthesis**

# Concept of a CO2-free Hydrogen Supply for Japan



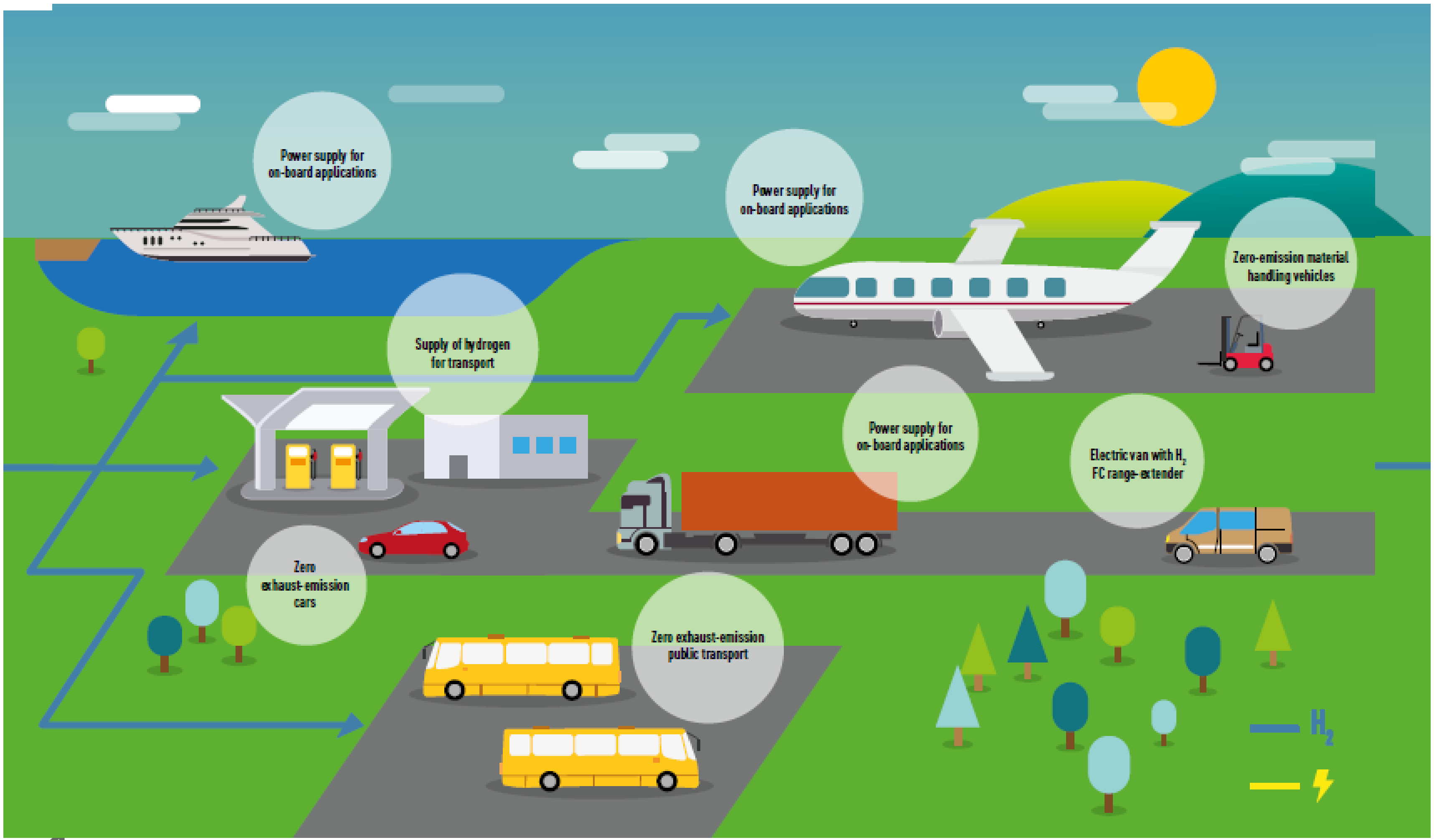

Source: Kawasaki Heavy Ind.

# Japan‘s Vision of Future Energy Import




Source: Japan Ministry of Economics (METI)

# Europe‘s vision on the future hydrogen economy
## (source FCH-JU)



# Hydrogen R&D in Europe

## Fuel Cells & Hydrogen Joint Undertaking

**Industry Grouping Hydrogen Europe**
105 members

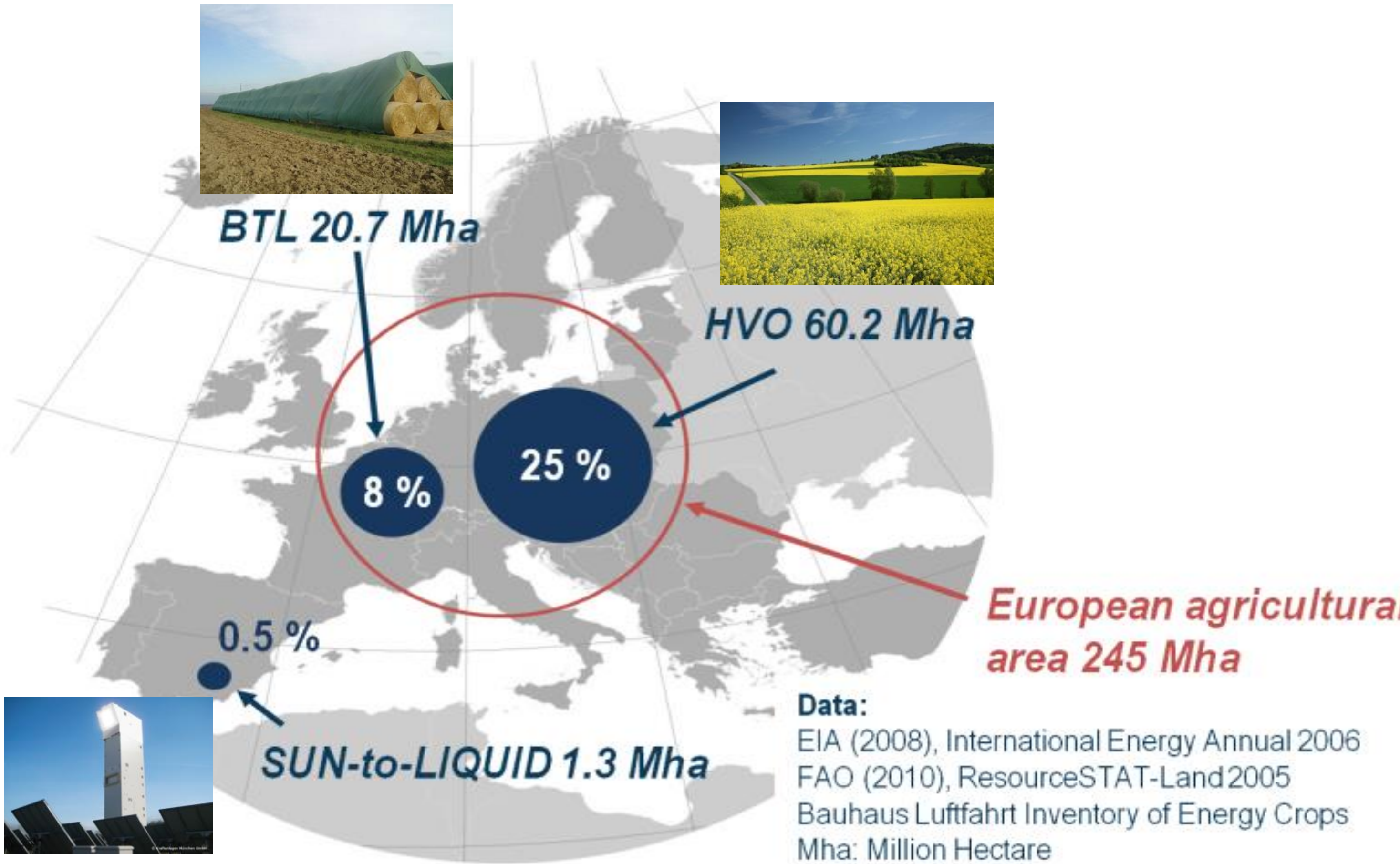
**European Union**
represented by the European Commission

**Research Grouping N.ERGHY**
65 members

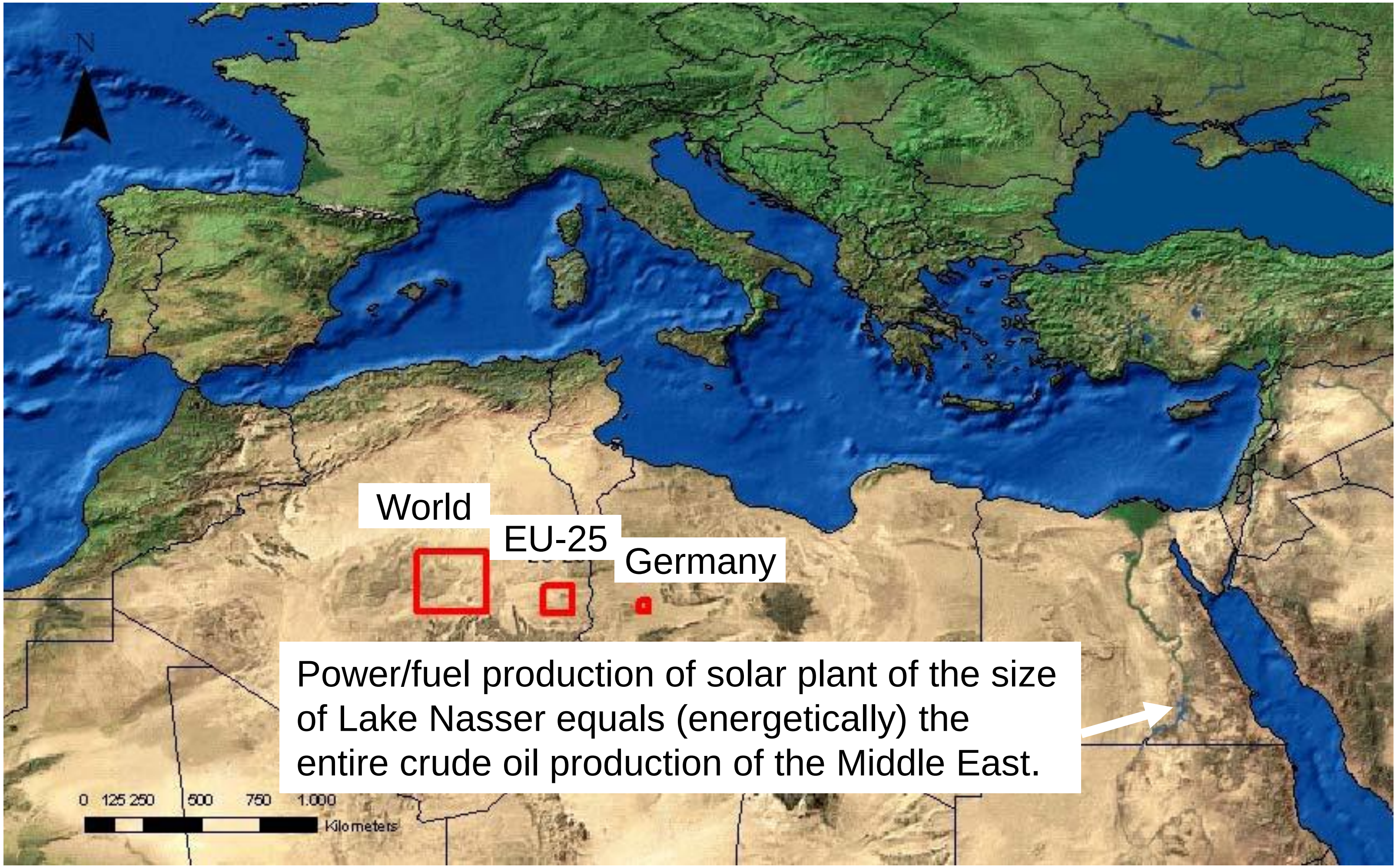
The Joint Undertaking is managed by a **Governing Board** composed of representatives of all three partners and lead by the Industry.

***A portfolio of clean, efficient and competitive solutions*** *based on fuel cells and hydrogen technologies in energy and transport*

# Fraction of E27 agricultural surface to provide European Kerosene demand of 2005:



# Potential of Solar Energy



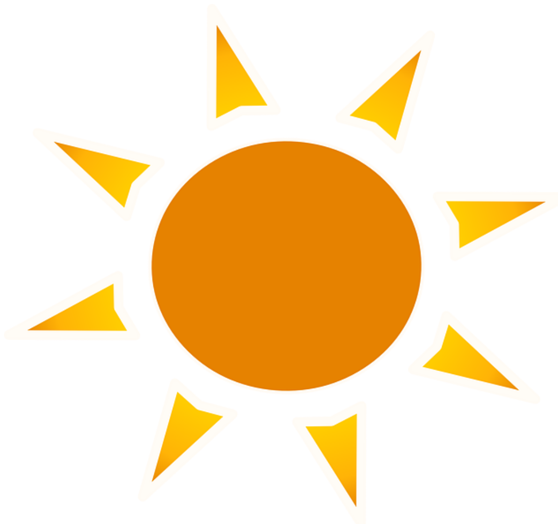

M. Schmitz, TSK Flagsol

# Solar Hydrogen Production

# Principle of Solar Fuel Production from Water and $CO_2$

Carbon dioxide ($CO_2$) →

Water ($H_2O$)



→ Synthesis gas ($H_2$ + CO)

↓

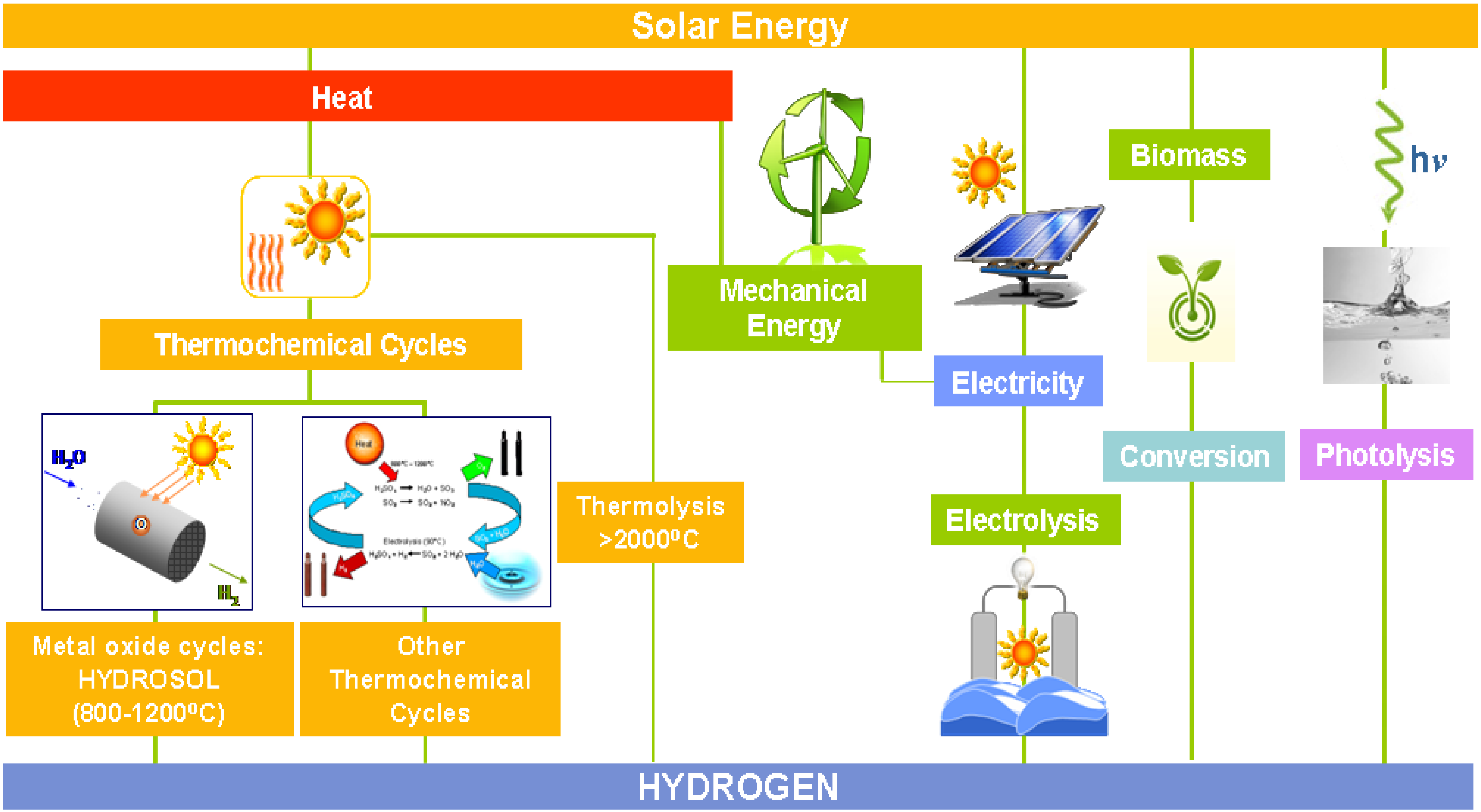
e.g. Fischer-Tropsch-Plant

←

Sustainable synthetic petrol,
diesel, kerosene
hydrogen, methanol,
(fertilisers, polymers)…

←

# Solar Pathways from Water to Hydrogen Fuel

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# Electrolyser: State of the Art


IHT: 750 Nm3/h

Hydrogenics: 60 Nm3/h

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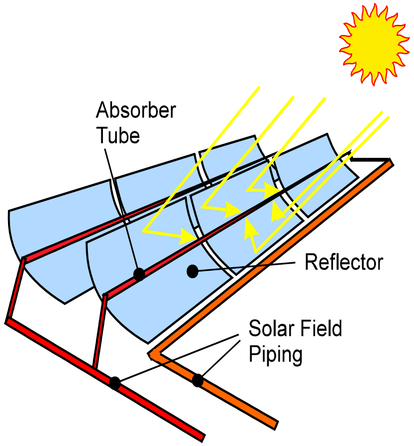
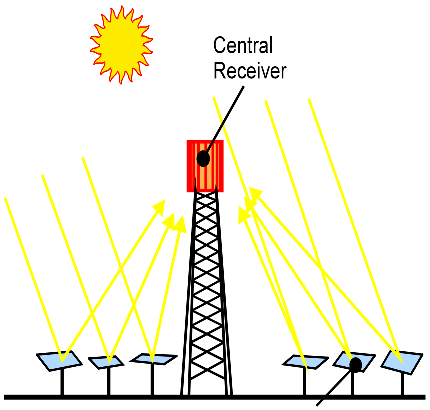
# Comparison of Efficiencies of Solar Hydrogen Production from Hydrogen

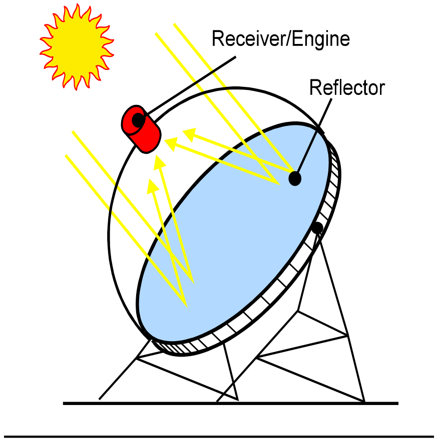
| Process | T [°C] | Solar plant | Solar-receiver + power [$MW_{th}$] | η T/C (HHV) | η Optical | η Receiver | η Annual Efficiency Solar – $H_2$ |
|---|---|---|---|---|---|---|---|
| Electrolysis (+CSP or PV) | NA | Actual Solar tower | Molten Salt 700 | 30% | 57% | 83% | 13% |
| High temperature steam electrolysis | 850 | Future Solar tower | Particle 700 | 45% | 57% | 76,2% | 20% |
| Hybrid Sulfur-process | 850 | Future Solar tower | Particle 700 | 50% | 57% | 76% | 22% |
| Hybrid Copper Chlorine-process | 600 | Future Solar tower | Molten Salt 700 | 44% | 57% | 83% | 21% |
| Metaloxide two step Cycle | 1800 | Future Solar dish | Particle Reactor | 52% | 77% | 62% | 25% |

Siegel, et al. (2013) *Ind Eng Chem Res*

# Solar Concentrating Technologies
# CSP (Concentrated Solar Power)




Parabolic Trough **400 °C**

Solar tower **>1000 °C**

Solar Dish **2000 °C**


**Crescent Dunes**, Nevada, USA
110 MW, 10 h Storage, 2015
©SolarReserve


**Khi Solar One**, South Africa
50 MW, 2h Storage, 2016

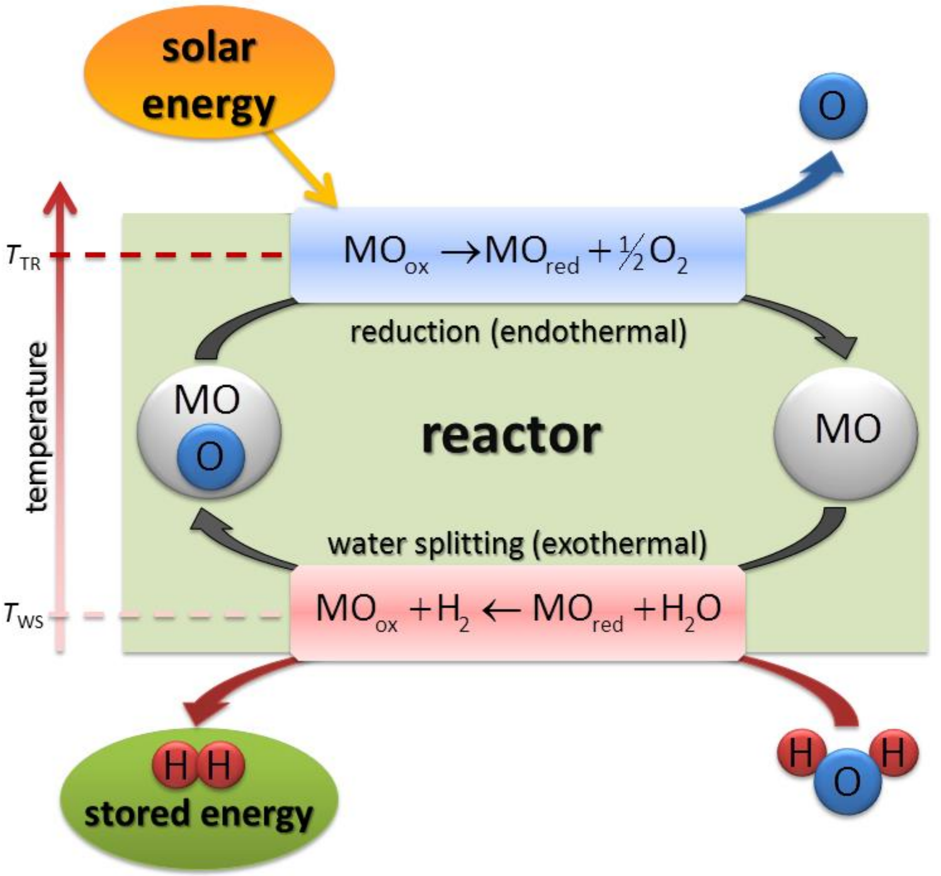

**Gemasolar**
Sevilla, Spain (2011)
20 MW, 15 h Storage


Ivanpah Solar
8 km
Image © 2013 DigitalGlobe


**PS10**
11 MW, 2007
**PS20**
20 MW, 2009
Sevilla, Spain


**Ivanpah**, California, USA (2014)
377 MW, supplies 140.000 households

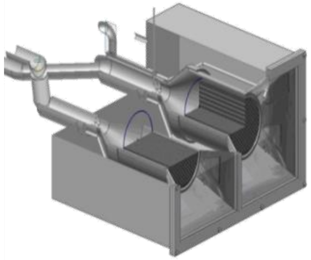
# Principle of solar thermal Water Splitting



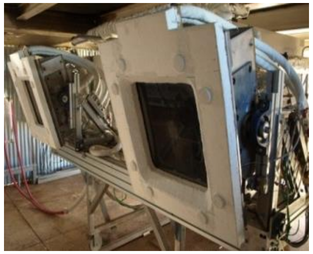

MO = ferrites, ceria, perovskites…

# Development of HYDROSOL-Technology

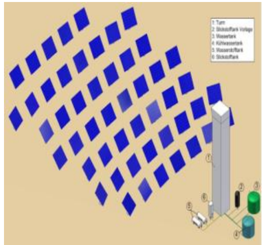
<u>Hydrosol I</u>
2002 – 2005
**< 10 kW**

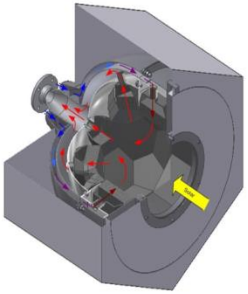


<u>Hydrosol II</u>
2006 – 2009
**100 kW**

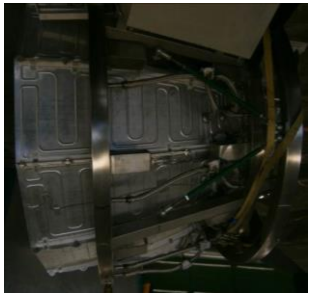


<u>Hydrosol 3D</u>
2010 – 2013
**design**





<u>Hydrosol Plant</u>
2013 – 2017
**750 kW**

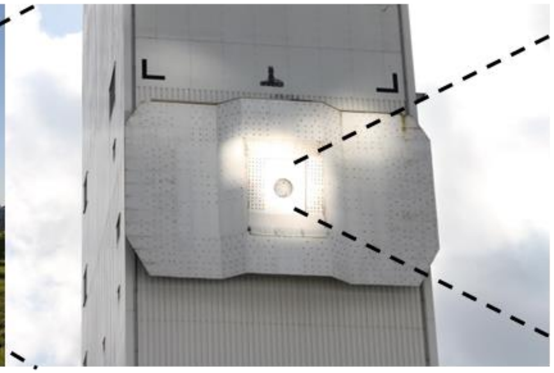


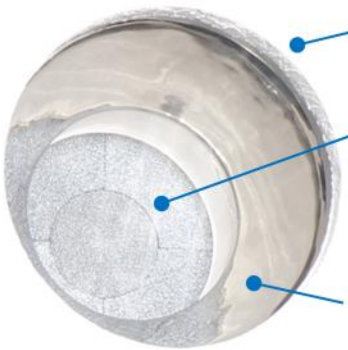
# Hydrogen by thermochemical water splitting

VIDEO

# Hydrogen Production through solar HyS-Process

## FCH-JU Projekt SOL2HY2



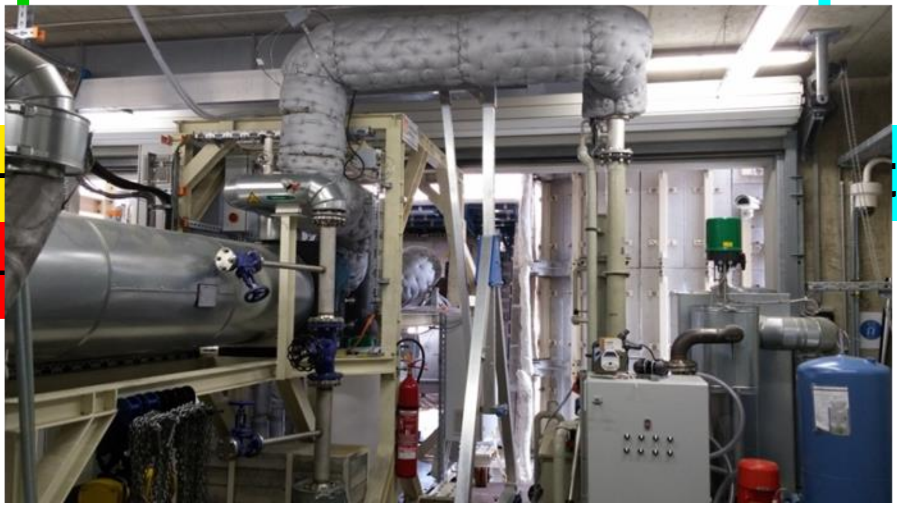



ydrogen

Electricity

$H_2SO_4 \Rightarrow SO_3 +$

$SO_3 \Rightarrow SO_2 +$

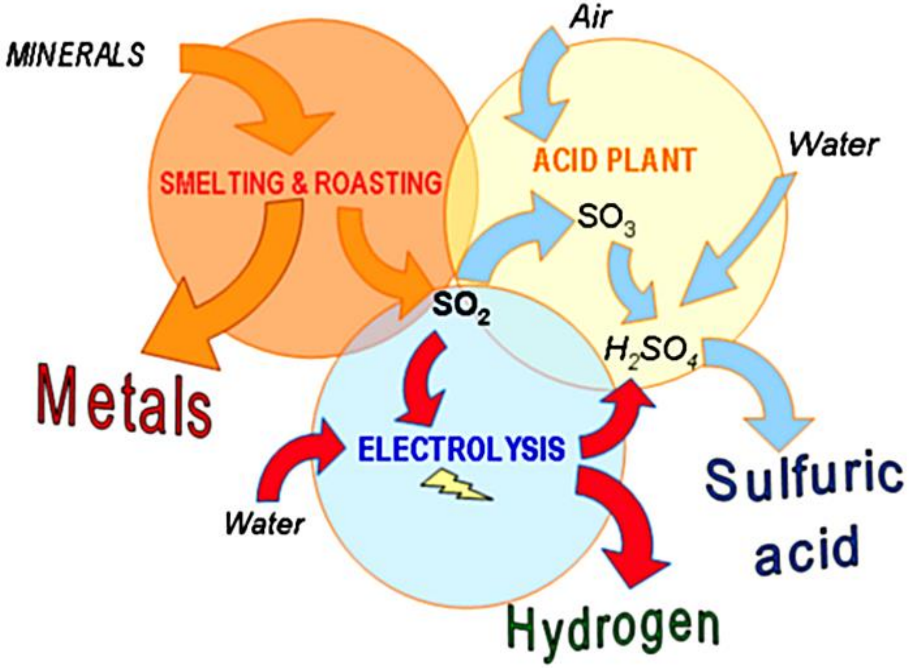


trolysis

# SOL2HY2 – Solar To Hydrogen Hybrid Cycles

- FCH JU project on the solar driven Utilization of waste $SO_2$ from fossil sources for co-production of hydrogen and sulphuric acid
- Hybridization by usage of renewable energy for electrolysis
- Partners:
  - **Industry: EngineSoft (IT), Outotec (FI), Erbicol (CH), Oy Woikoski (FI)**
  - Research: Aalto University (FI), DLR (DE), ENEA (IT),

## Outotec[TM] Open Cycle (OOC)



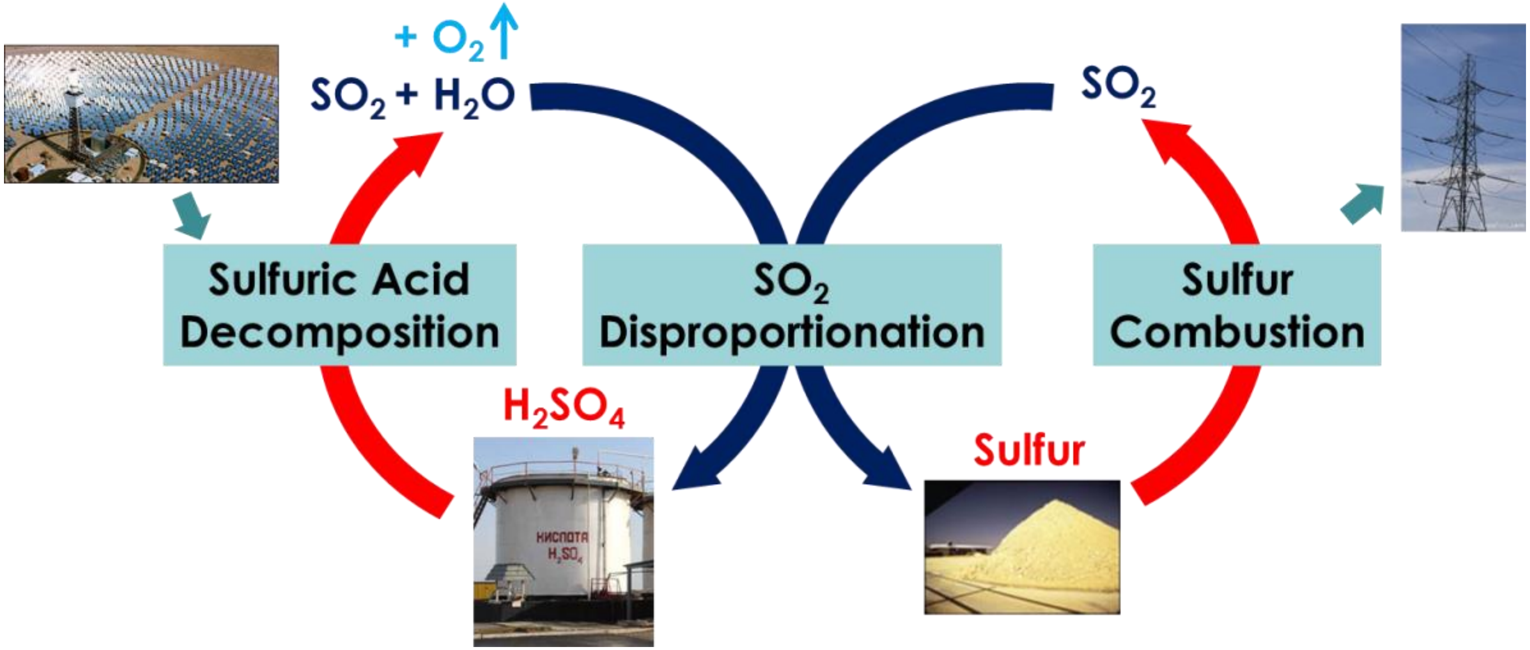

- Utilization of waste $SO_2$ from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis

# Thermochemical heat storage can provide very high energy storage densities

| Technology | Energy Density (kJ/kg) |
|---|---|
| Gasoline | 45000 |
| **Sulfur** | 12500 |
| **Cobalt Oxide** | 850 |
| Molten Salt (Phase Change) | 230 |
| Molten Salt (Sensible) | 155 |
| Lithium Ion Battery | 580 |
| Elevated water Dam (100m) | 1 |

- **High energy densities with low storage cost**
- **Ambient and long term storage**
- **Transportability**

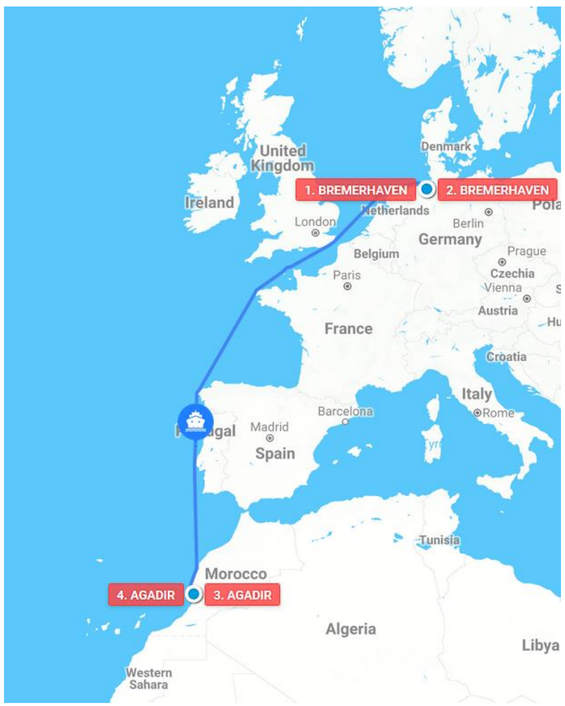
# Solar energy can be stored in elemental sulfur via a three step thermochemical cycle

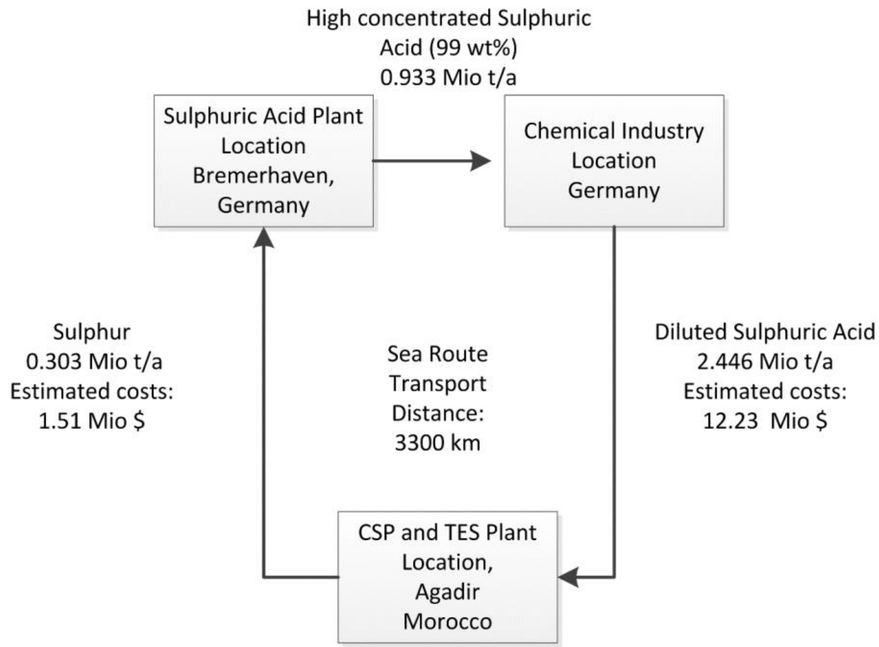



| | Reaction | Temp (°C) |
|---|---|---|
| $H_2SO_4$ Decomposition | $2H_2SO_4 \rightarrow 2H_2O(g) + O_2(g) + 2SO_2(g)$ | 800 |
| $SO_2$ Disproportionation | $2H_2O(l) + 3SO_2(g) \rightarrow 2H_2SO_4(aq) + S(l)$ | 150 |
| Sulfur Combustion | $S(s,l) + O_2(g) \rightarrow SO_2(g)$ | 1200 |

# Process concept: Sulphuric acid recycling

- Sulphuric acid: most produced chemical worldwide (~ 200 Mio t/year)
- Production in Germany (~ 5 Mio t/year)→Usage in chemical industry
- Recyling of $H_2SO_4$ by thermal splitting (~ 1.2 Mio t/year in Germany), currently by fossil fuels

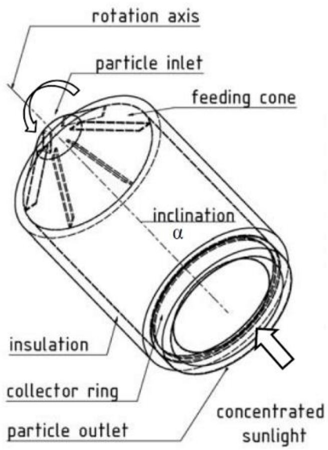


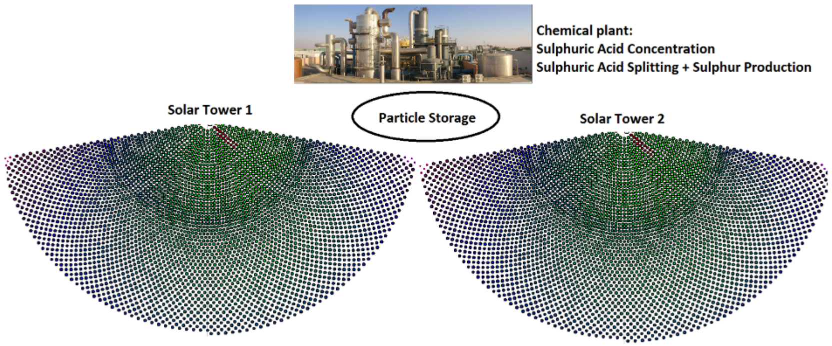



# Process concept

- limitatation for process upscaling: 40 MW CentRec

- Multi-tower concept (24 solar towers and 12 sulphuric
- acid splitting units)




12x Solar sulphur production units


Plant is able to conduct ~¾ of Germany‘s thermal decomposition $H_2SO_4$ recycling

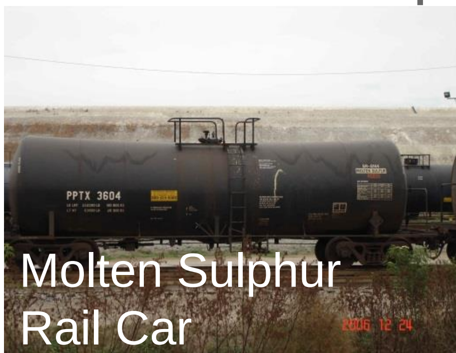
# Transportation and storage of sulphur

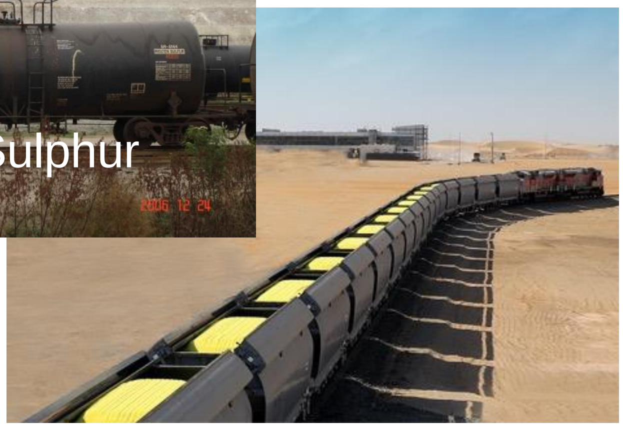
## In solid or liquid form

**Pipeline**

Molten sulphur in heated pipelines (~140 °C)

**Train**



**Truck**


**Ship**

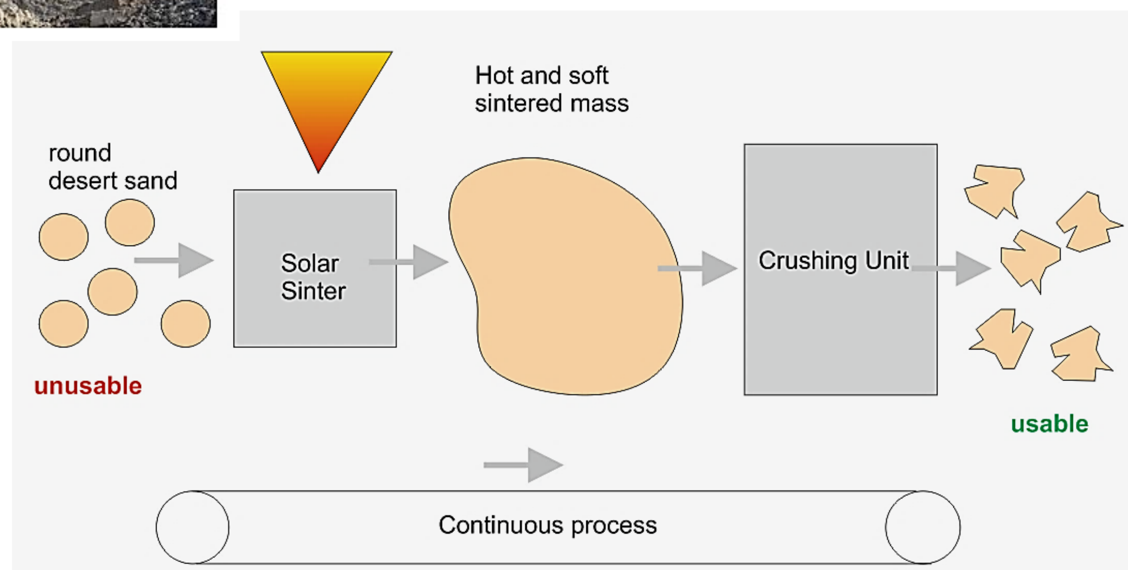
# „Solar Sand from the Desert“

Construction Sand

2000: 3 $/ton

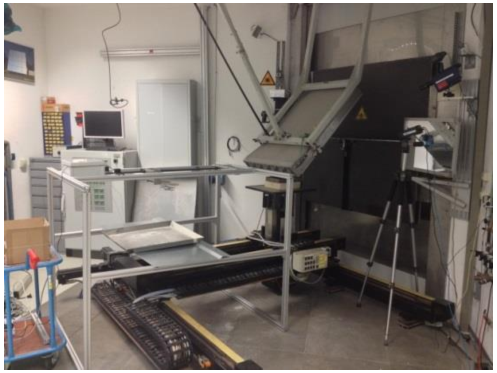
2018: 200 $/ton

**Desert sand is unusable for concrete production**



# Solar 3-D Printing of bricks from sand

- Setup



- Melting and layering

- Final object

# Solar Process Heat for Industry and Ore Processing

- Solar oxygen and nitrogen production
- Solar fertilizer production
- Solar process heat provision (steam, air, particles…)
- Solar calcination
- Solar cement production
- Solar reduction of metal oxides
- Solar smelting and recycling of metals
- …

# Summary

- World energy and fuel demand can be covered by solar energy – driver is the trend to decarbonise the energy economy
- Visions and scenarios for (renewable) hydrogen based energy economy are already there (Japan and EU)
- Several pathways to produce hydrogen without emissions are available
- Solar thermochemical routes are able to split water thermally and highly efficient
- Huge potential to use solar high temperature heat in several industries and mining

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# Thank you very much for your attention!