TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Concentrated Solar Radiation
More than just a power source

MENAREC 6
04. - 06.04.2016, Kuwait

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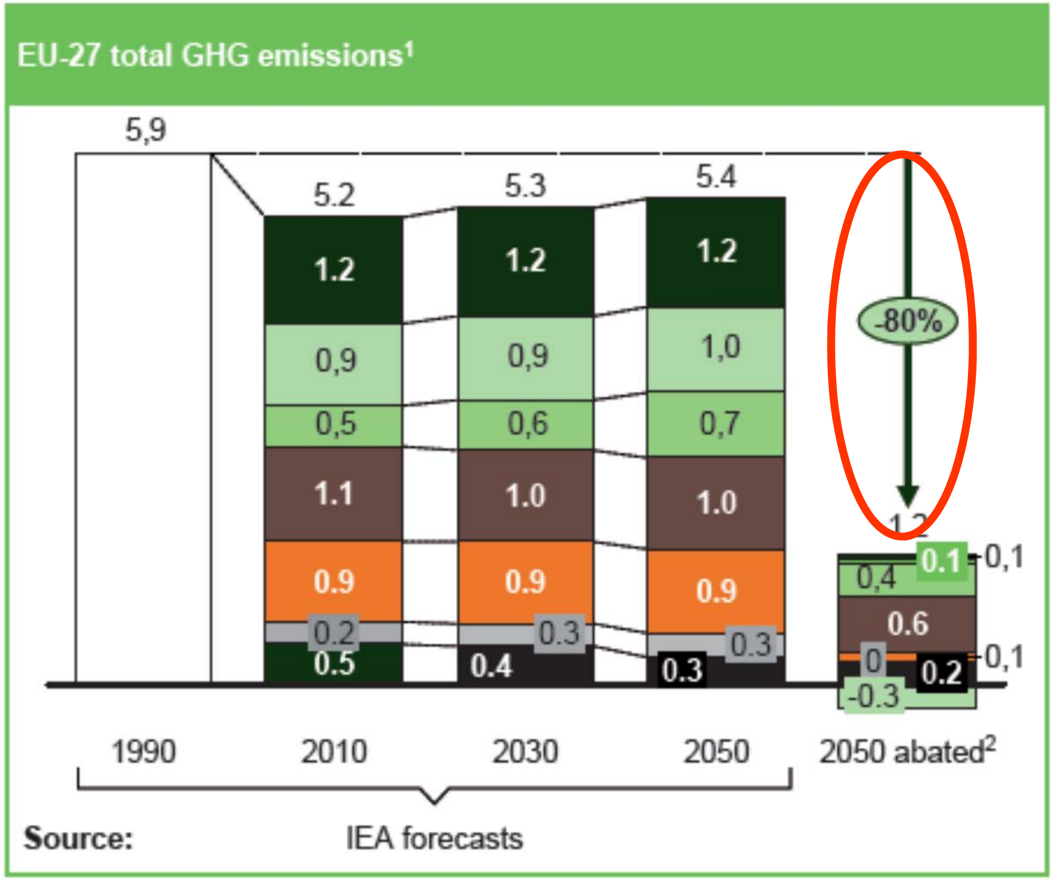
DLR

Overview

- Drivers:
  - Technical, Political, Economical, Ecological,
- Concentrating Solar Systems
- Solar technology developments and demonstrations
  - Thermochemicl heat storage
  - Thermochemical fuels
  - Chemicals and materials
- Outlook

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

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 1990
- **G7 Goals, Elmau, Germany**
  - **100%** Decarbonisation until 2100
  - ***100 bln $/year*** *for climate actions in developing countries, large share by industrial investment from 2020*

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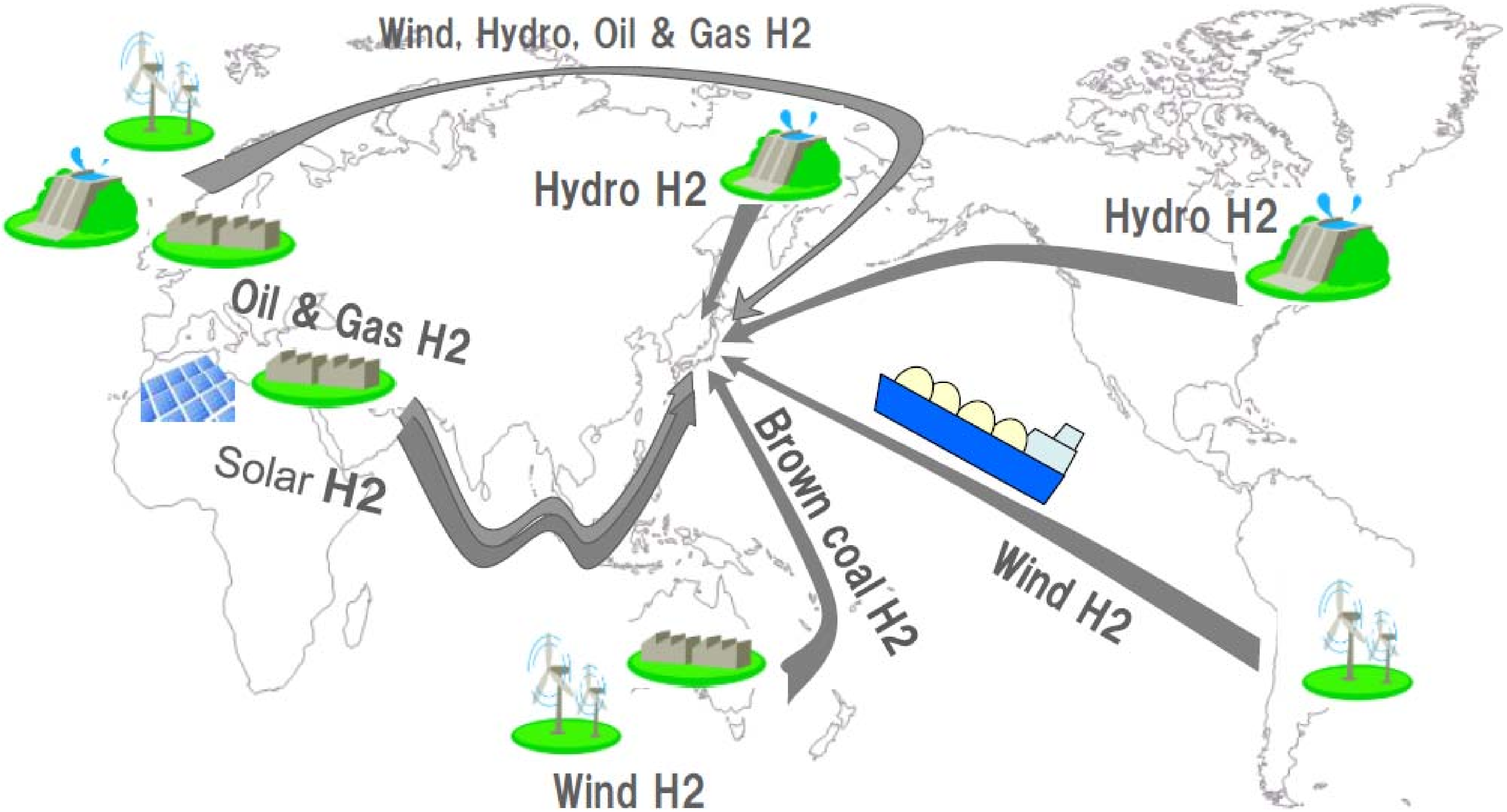
Kawasaki Vision – Hydrogen Potential from Overseas



Kawasaki

Kawasaki vision for the cryogenic liquid hydrogen market – team-up with Shell (March 15, 2016)

Kawasaki 川崎重工業株式会社

川崎重工グループは、国内で有数の大型水素貯蔵タンクや水素運搬車を製造している技術と経験を活かし、未来社会に向けての新しいエネルギー構想として「CO_2フリー水素コンセプト」を提案しています。

http://global.kawasaki.com/en/stories/hydrogen/

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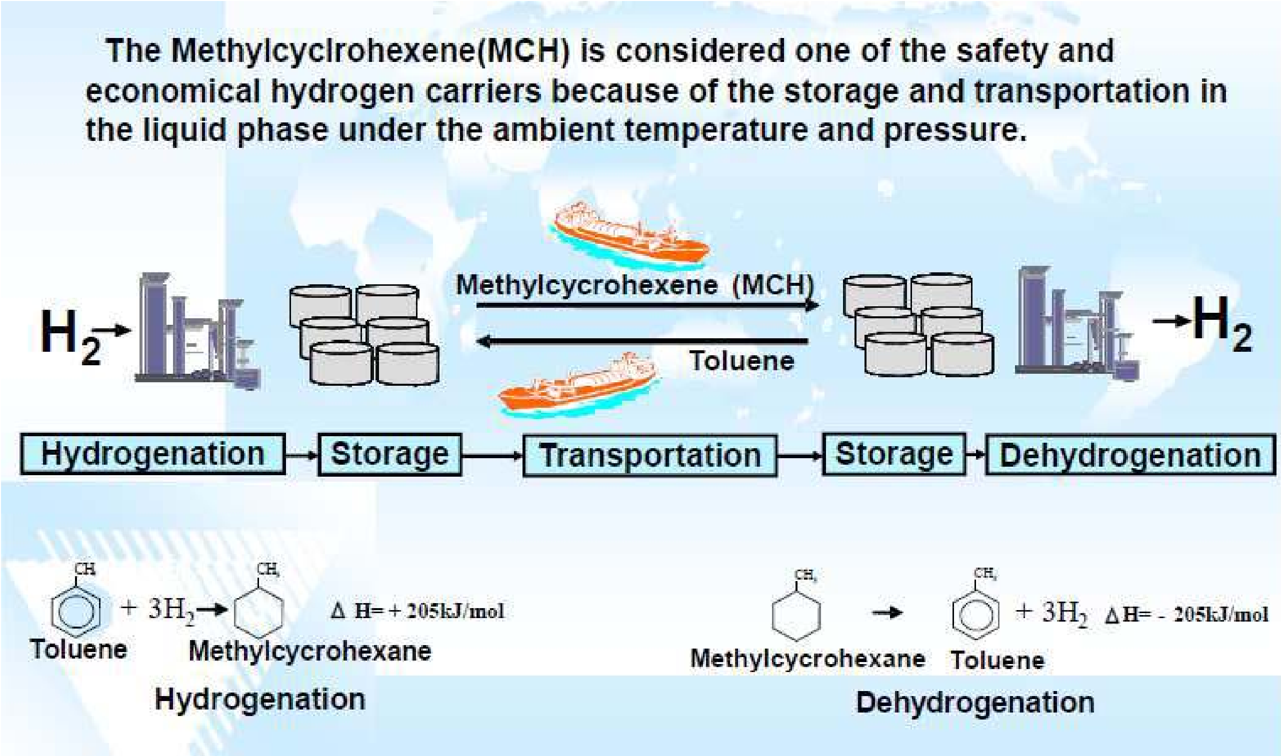
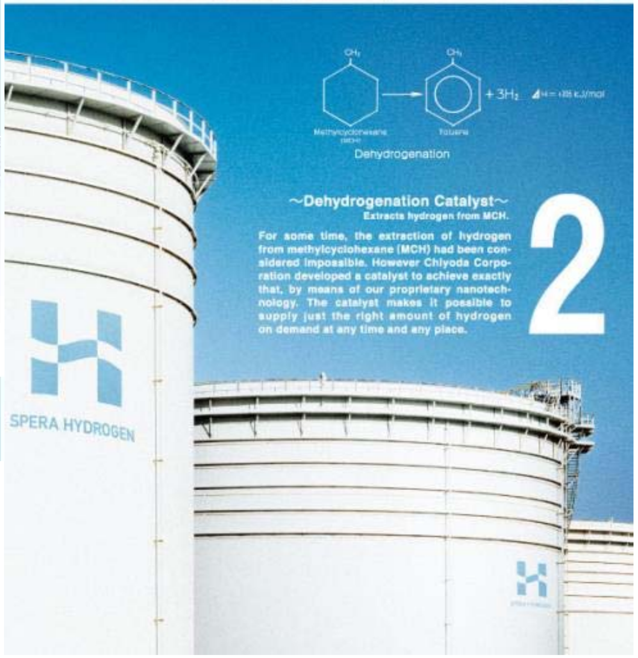
CHIYODA – Hydrogen Vision





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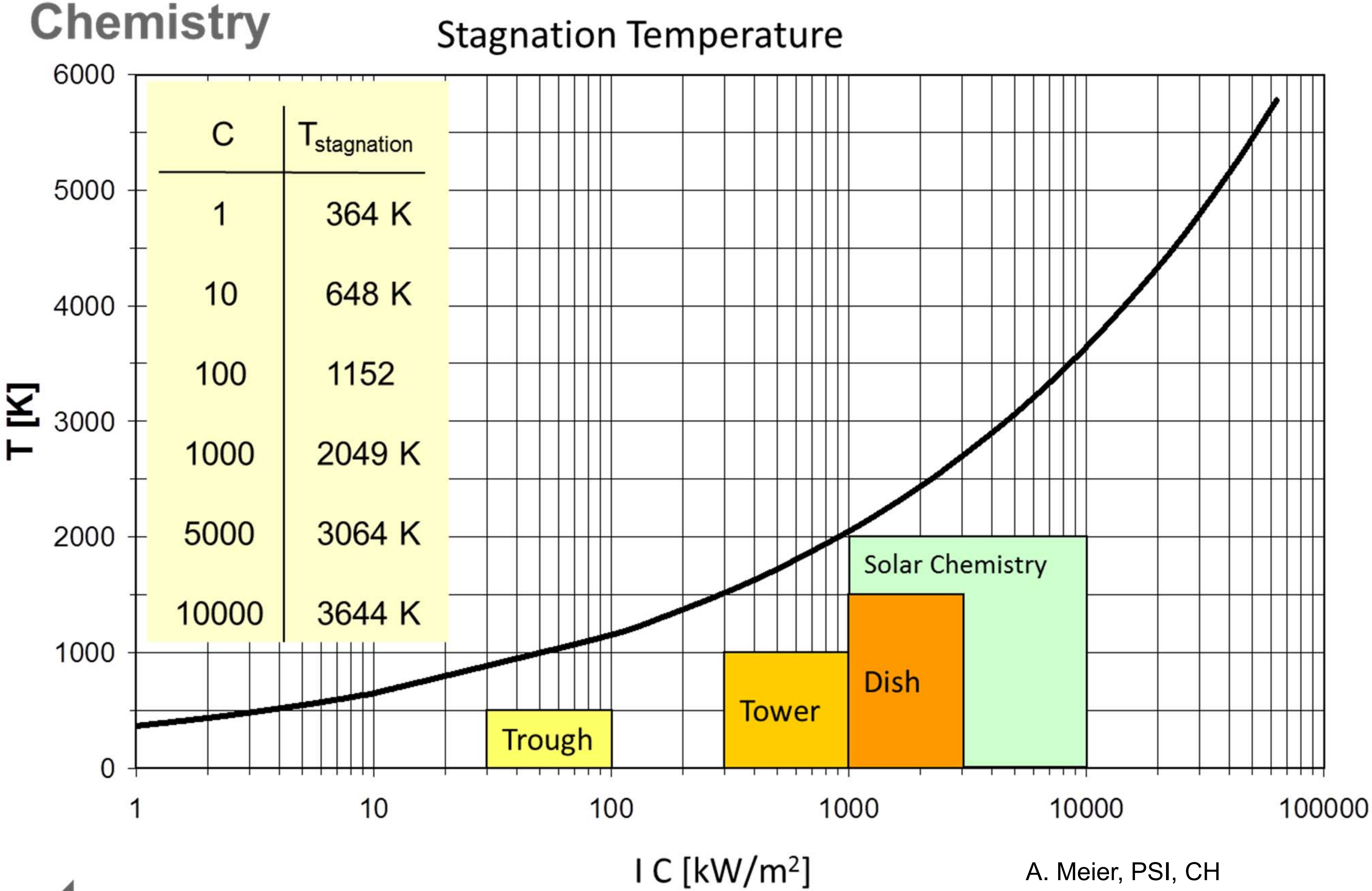
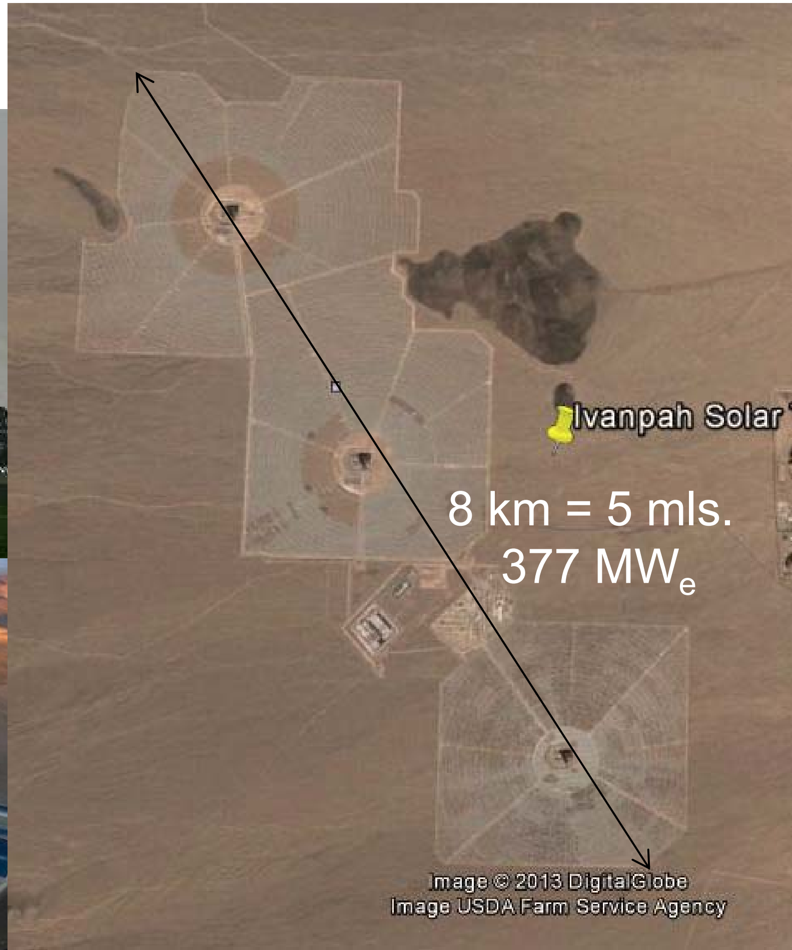
Principle of Concentrating Solar Energy for Power and Chemistry



A. Meier, PSI, CH

Solar Towers



On the Web:

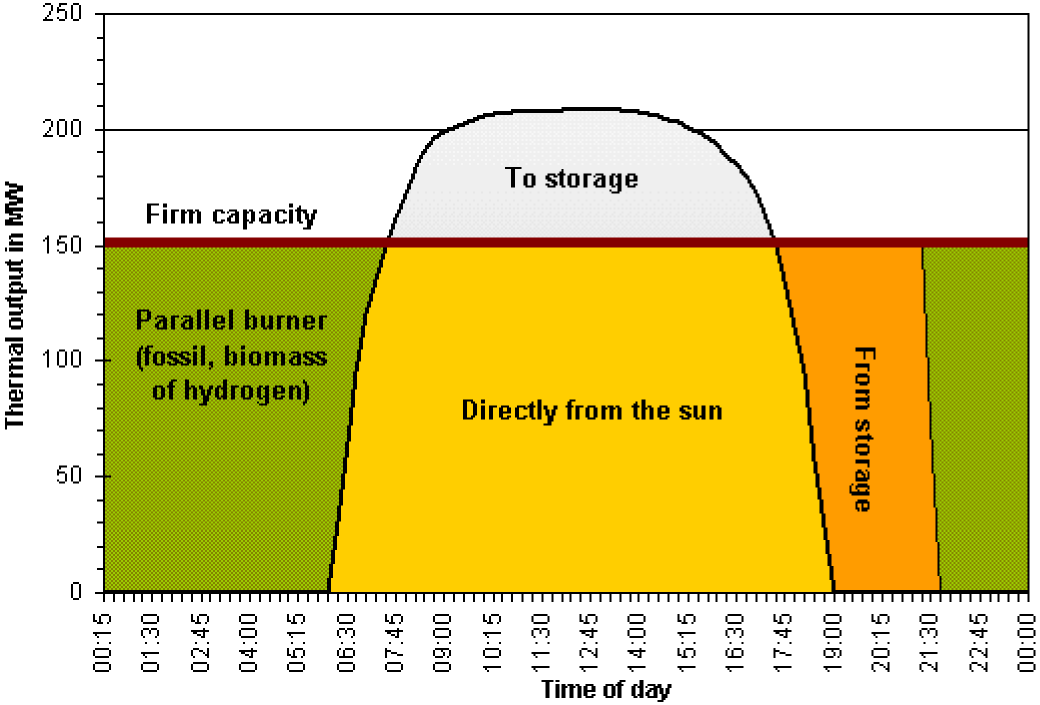
http://www.ivanpahsolar.com/
http://www.psa.es/webeng/index.php
http://www.torresolenergy.com/TORRESOL/home/en
http://www.solarreserve.com/en/global-projects/csp/crescent-dunes
http://www.abengoasolar.com/web/en/plantas_solares/plantas_para_terceros/espana/

Centralized Energy Supply – Solar Troughs and Towers

Main Features

- Typical plant size: 10 – 200 MW_e
- Conv. thermal cycle efficiency: 35-42%

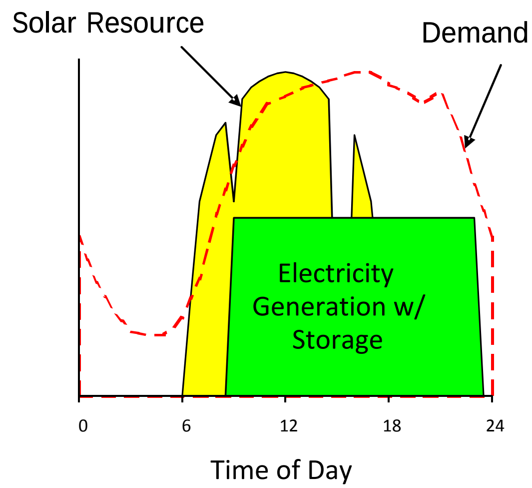
Typical solar plant operation



Thermal Energy Storage (TES)

Storage provides

- decoupling of energy collection and electricity generation
- helping *grid stability*
- higher value: power production can match utility needs



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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**

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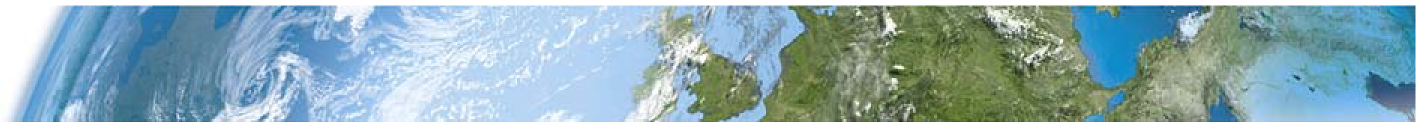
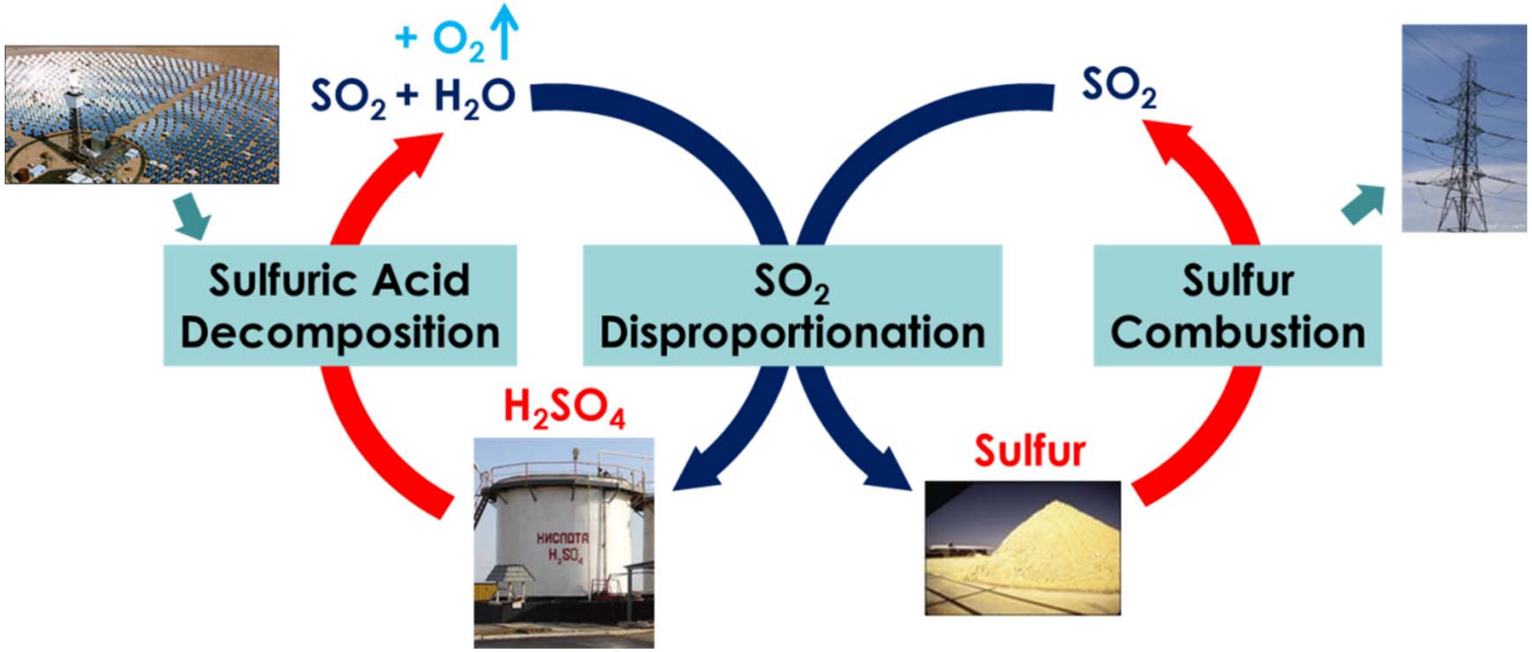


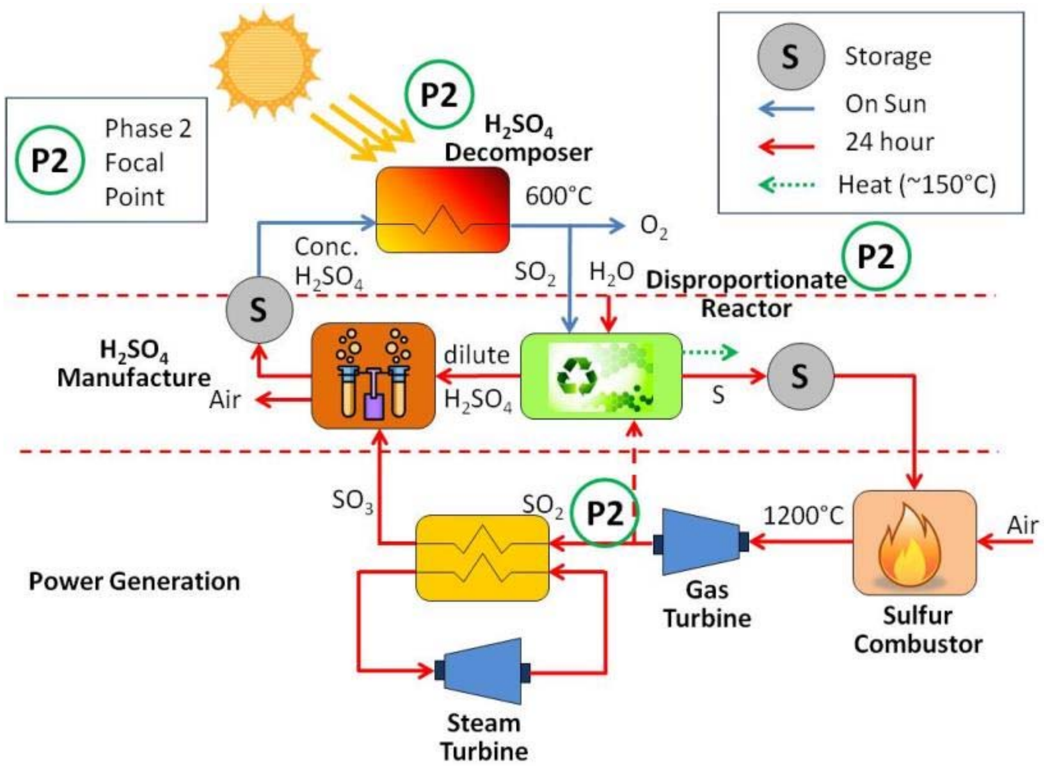
Solar energy can be stored in elemental sulfur via a three step thermochemical cycle



	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

An improved flowsheet was established based on modeling and experimental

- **Plant design incorporated established processes from sulfuric acid manufacturing plant**



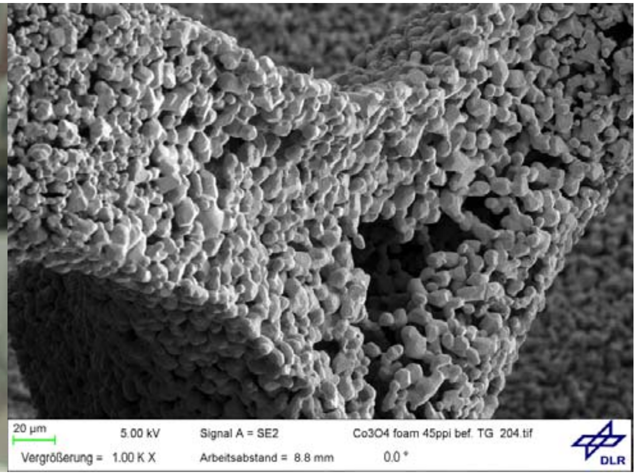
DOE Metric	LCOE (¢/kWh$_e$)
DOE Target	6.5
CSP w/Sulfur Storage	8.1*

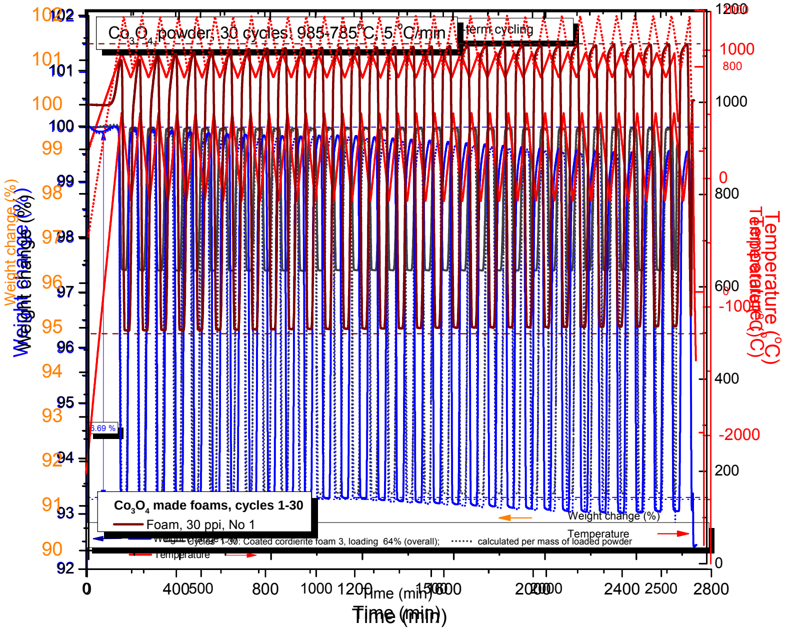
*SAM (NREL) using 2012 costs

- **Storage cost is < $2/kWh**
- **LCOE is ~6¢/kWh$_e$ based on proposed Sunshot targets**

Co_3O_4 /CoO

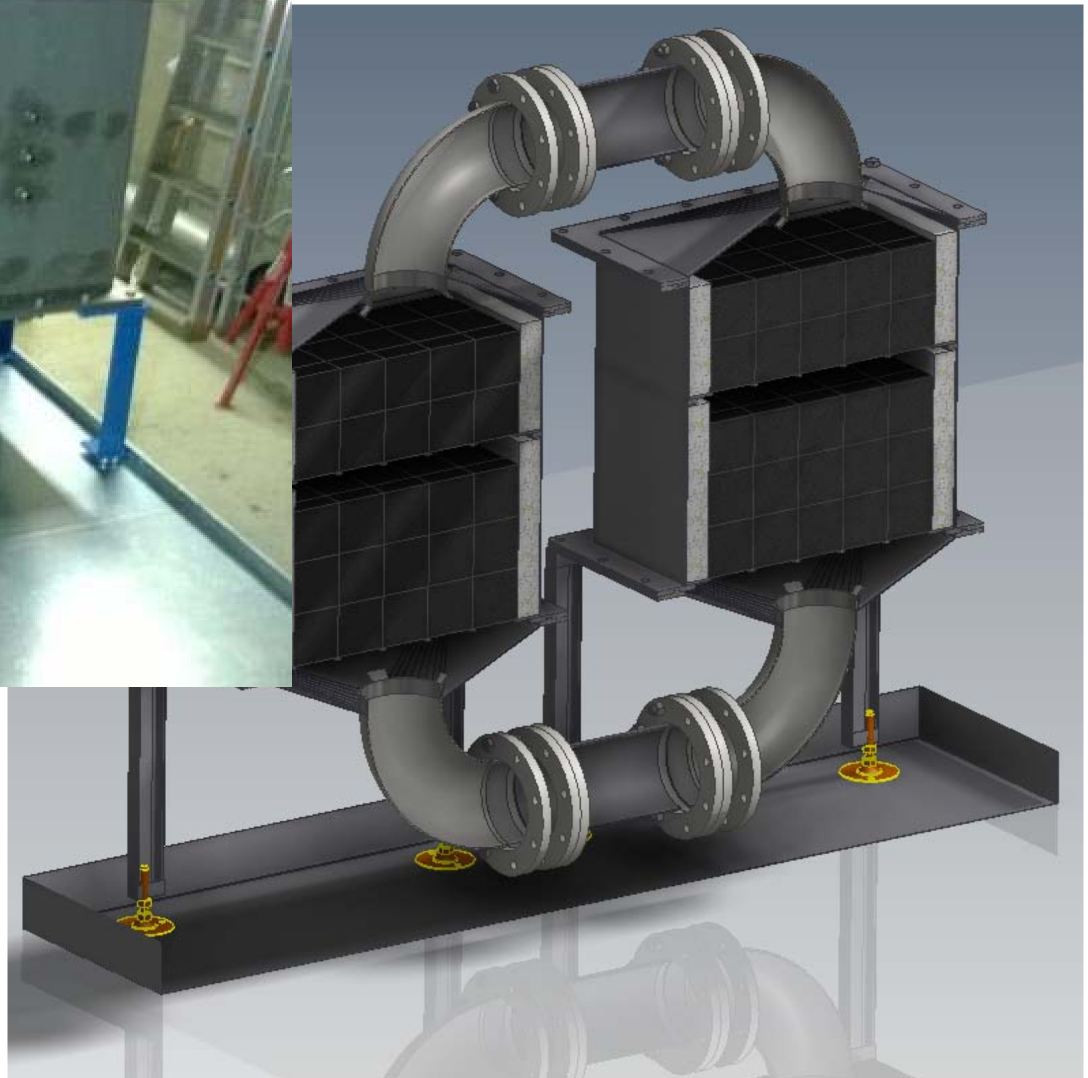
- Co_3O_4 can operate in a quantitative, cyclic and fully reversible reduction/ oxidation mode within 800-1000°C (950°C).
- As powder, coated on honeycombs/ foams or shaped in foams.





Agrafiotis, Roeb, Schmücker, Sattler, Solar Energy, (2014), (2015).

nstration



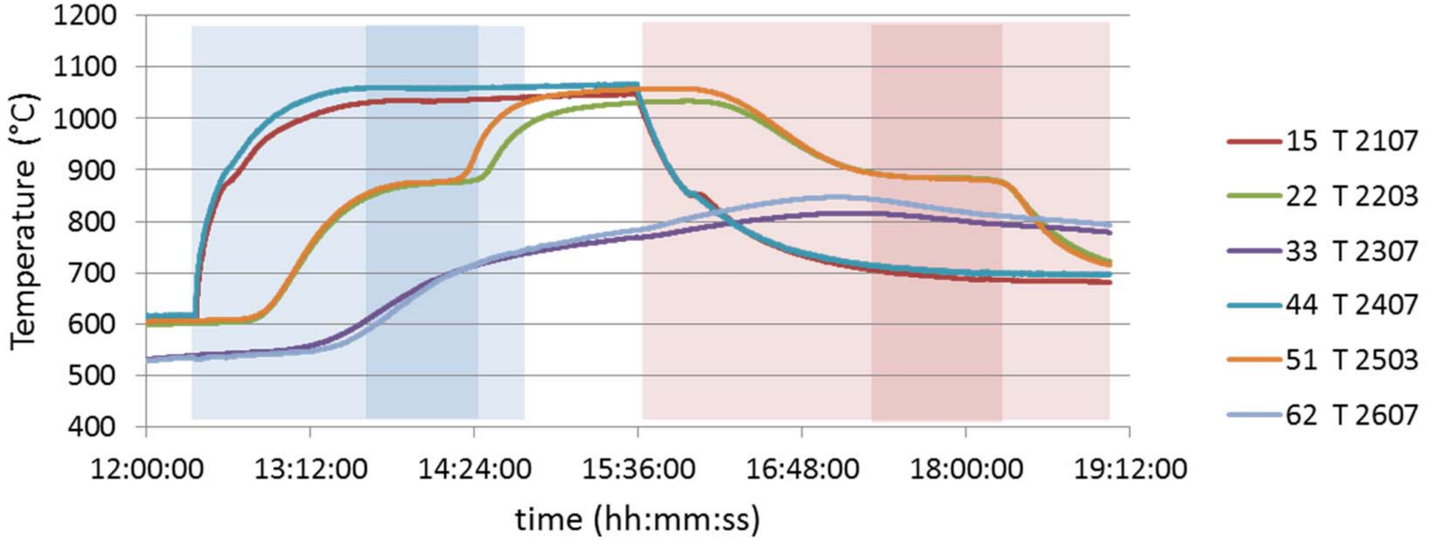
DLR solar tower Jülich,

Germany

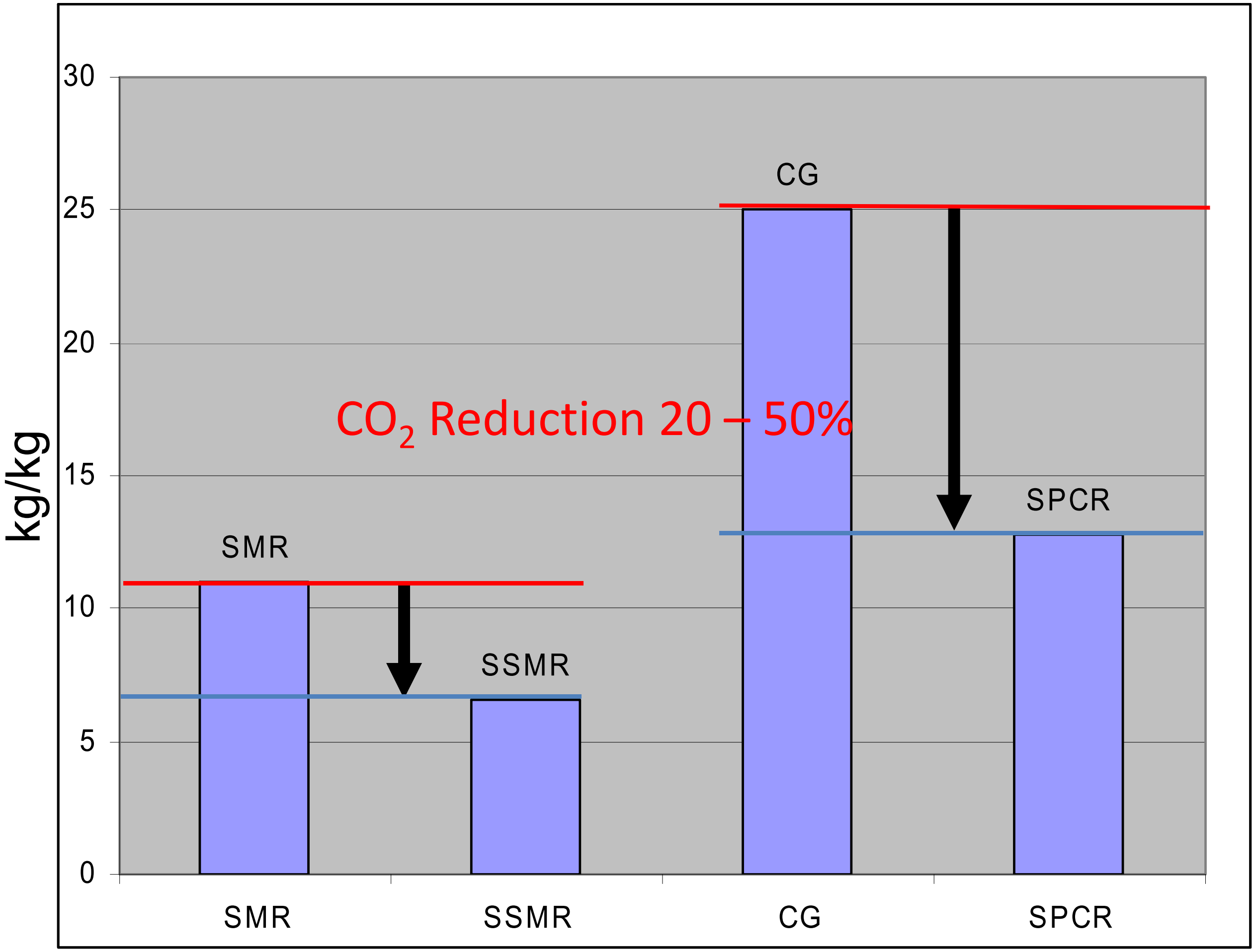
Chemical Tests

considering half of one chamber (≈25kg cobalt)

	Energy stored (kWh)	Average Power (kW)	time	at constant temperature
Charge	38	11.2	3.5 h	1 h
Discharge	32	9.6	3.25 h	1 h



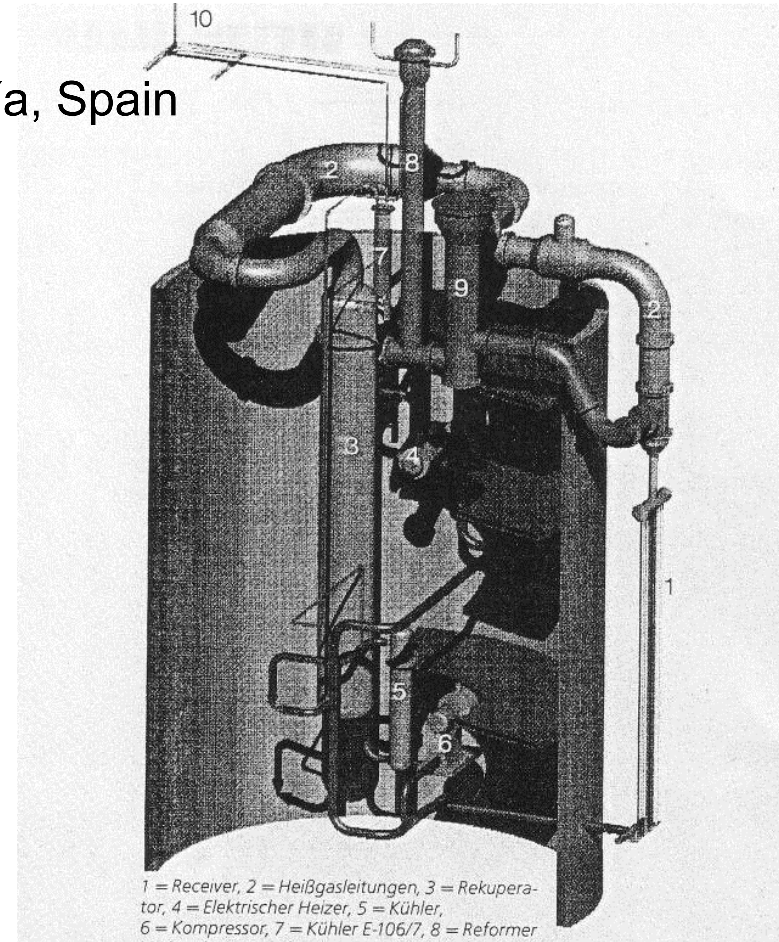
CO_2 Reduction by solar heating of state of the art processes like steam methane reforming and coal gasification



ASTERIX: Allothermal Steam Reforming of Methan

- DLR, Steinmüller, CIEMAT
- 180 kW plant at the Plataforma Solar de Almería, Spain (1990)
- Convective heated tube cracker as reformer
- Tubular receiver for air heating

CESA-1, PSA, Spain. The solar radiation is collected by a field of heliostats and redirected to a tower, where different platforms allow the tests of various receiver technologies.



1 = Receiver, 2 = Heißgasleitungen, 3 = Rekuperator, 4 = Elektrischer Heizer, 5 = Kühler, 6 = Kompressor, 7 = Kühler E-106/7, 8 = Reformer V-101 mit Wärmeübertragern E-102/3/4, 9 = Elektrischer Heizer E-105, 10 = Fackel Z-102.

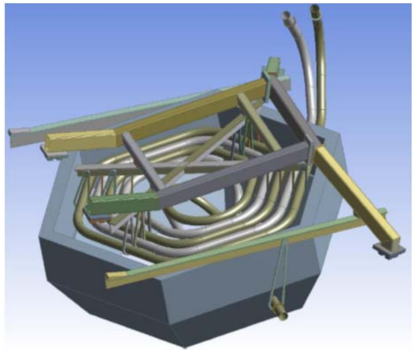
Near-term: Solar Production of Syngas (H_2 and CO)

Solar pilot plants demonstrated in the power range of 200-500 kW_{th}

Solar steam reforming of natural gas / methane

SOLGAS (200 + 600 kW_{th})
CSIRO, Australia

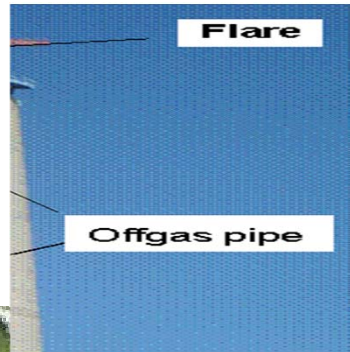
SOLREF (400 kW_{th})
DLR, Germany



Solar steam gasification of carbonaceous feedstock

SYNPET (500 kW_{th})
CIEMAT, Spain

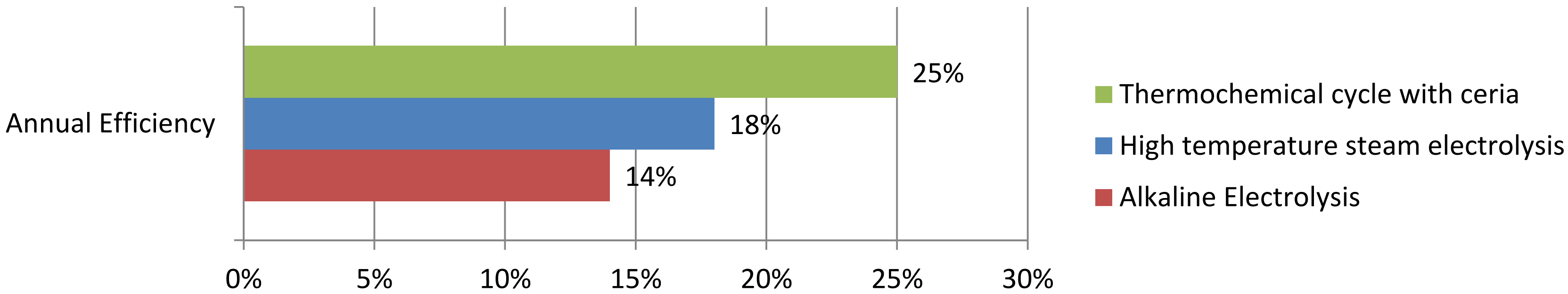
SOLSYN (250 KW_{th})
PSI, Switzerland

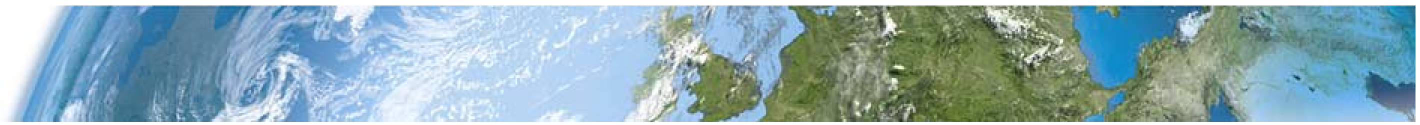


Solar Fuels: Efficiency Comparison vs. Benchmark

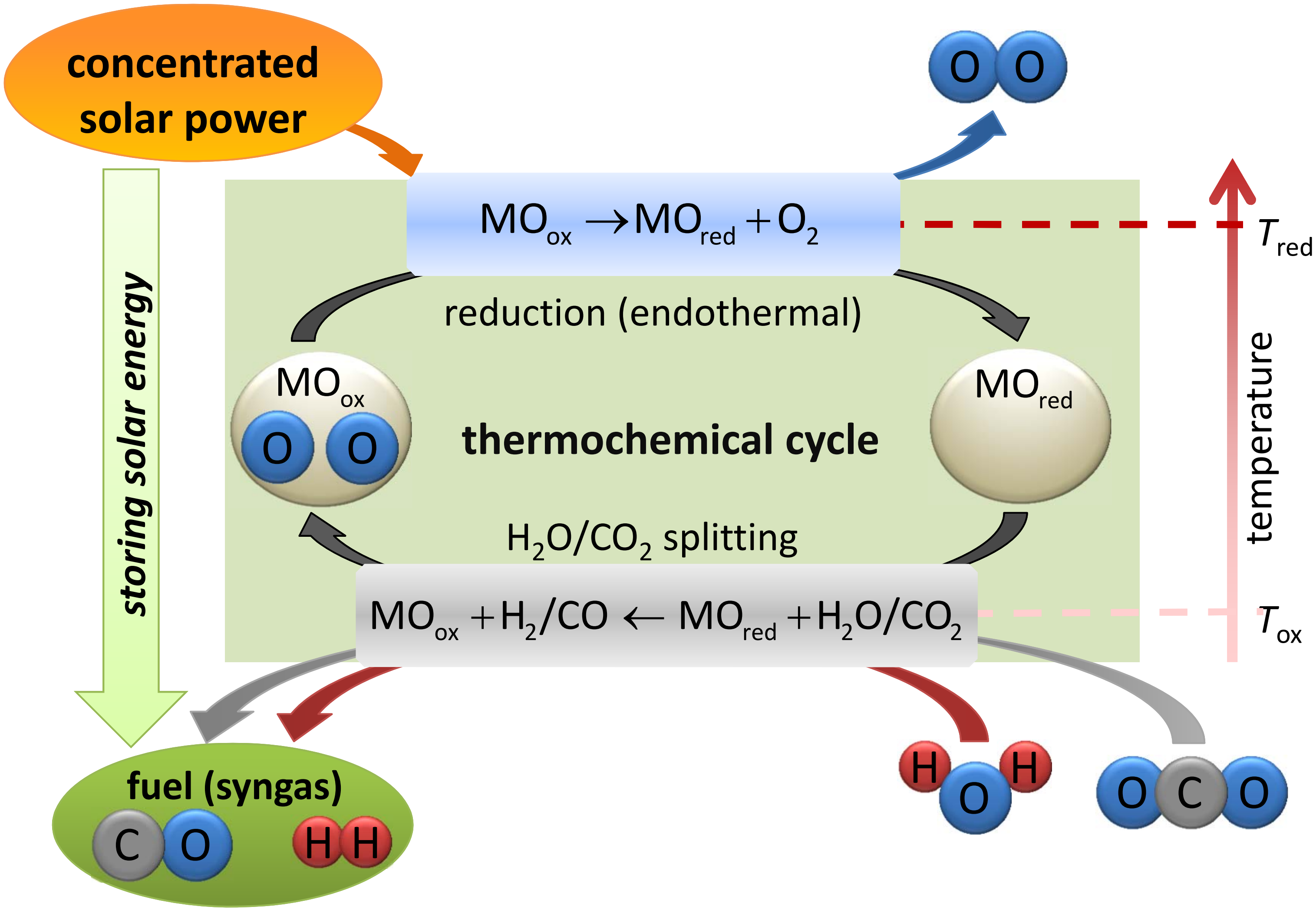
Process	temperature of the chemical reaction	Solar interface receiver temperature
Alkaline Electrolysis	25°C	Solar PV
High temperature steam electrolysis	850°C	Future solar tower 1200°C
Thermochemical cycle with ceria	1500 / 1150°C	Future solar dish 1500°C

*G.J. Kolb, R.B. Diver SAND 2008-1900 / N. Siegel et al. I&EC Research May 2013



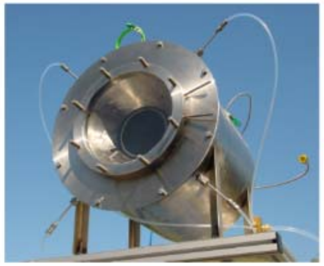


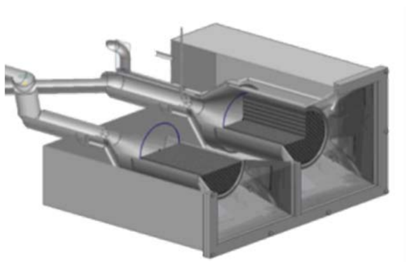
Thermochemical Cycles



HYDROSOL Development

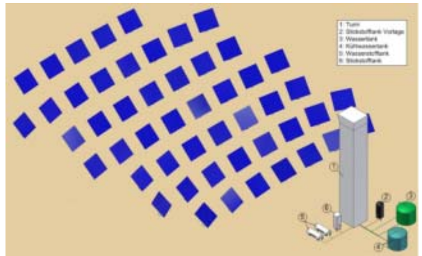
Hydrosol I
2002 – 2005
< 10 kW

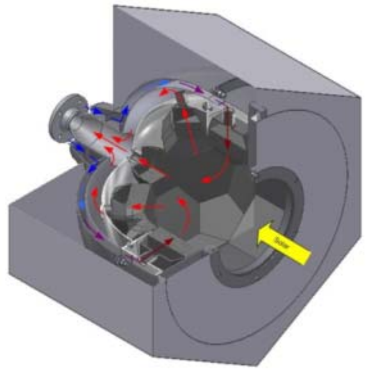




Hydrosol II
2006 – 2009
100 kW

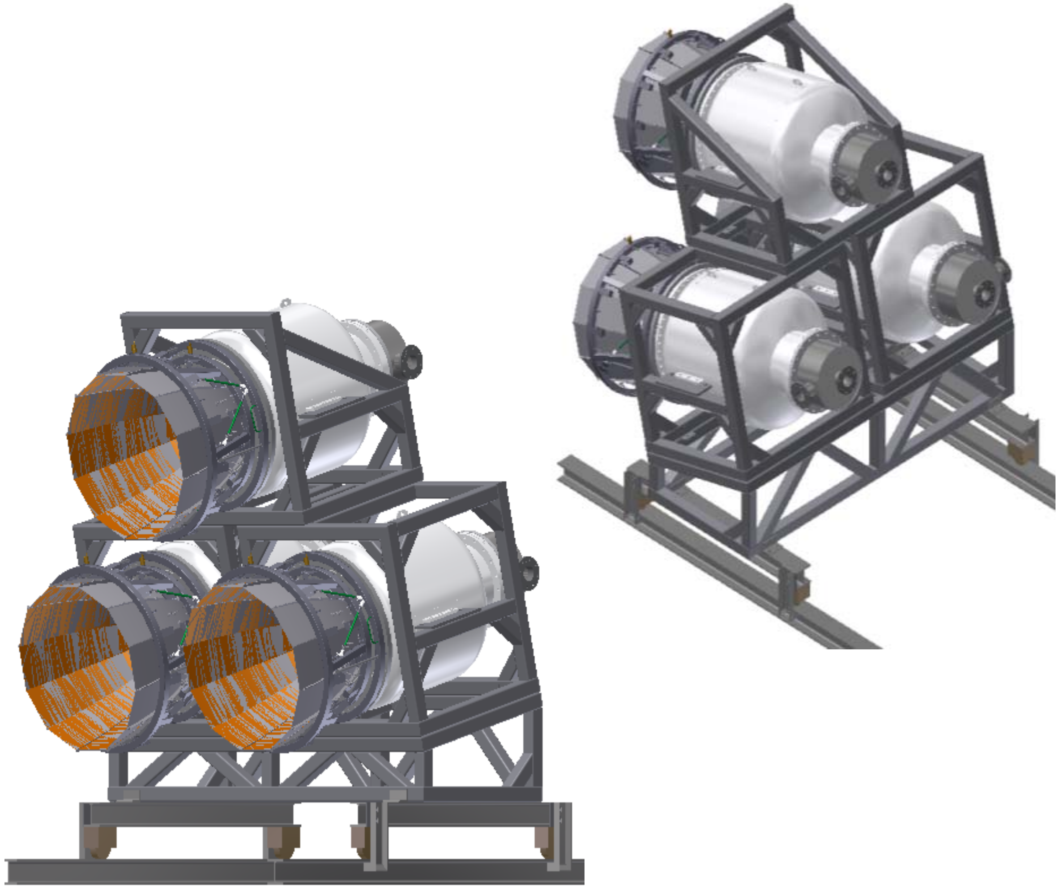
Hydrosol 3D
2010 – 2012
1 MW





Hydrosol Plant - Design for CRS tower PSA, Spain

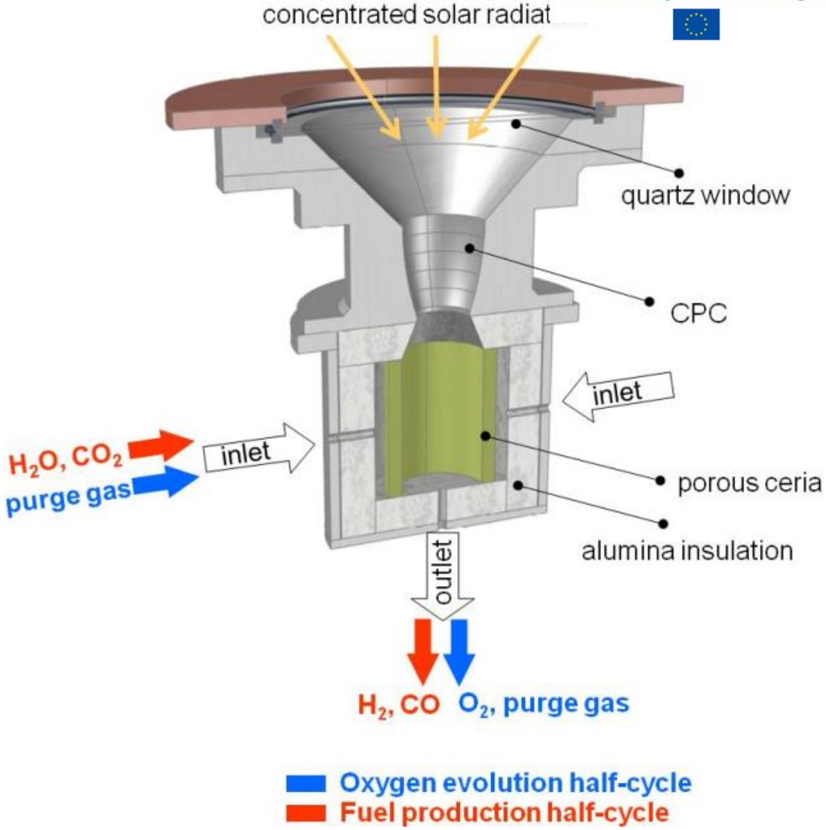
- European FCH-JU project
- Partner: APTL (GR), HELPE (GR), CIEMAT (ES), HYGEAR (NL)
- 3 * 750 kW_{th} demonstration of thermochemical water splitting
- Location: Plataforma Solar de Almería, Spain, 2016
- Reactor set-up on the CRS tower
- Storage tanks and PSA on the ground



H_2O/CO_2-Splitting Thermochemical Cycles

Solar Production of Jet Fuel

- EU-FP7 Project SOLAR-JET (2011-2015)
- SOLAR-JET aims to ascertain the potential for producing jet fuel from concentrated sunlight, CO_2, and water.
- SOLAR-JET will optimize a two-step solar thermochemical cycle based on ceria redox reactions to produce synthesis gas (syngas) from CO_2 and water, achieving higher solar-to-fuel energy conversion efficiency over current bio and solar fuel processes.
- **First jet fuel produced in Fischer-Tropsch (FT) unit from solar-produced syngas**!

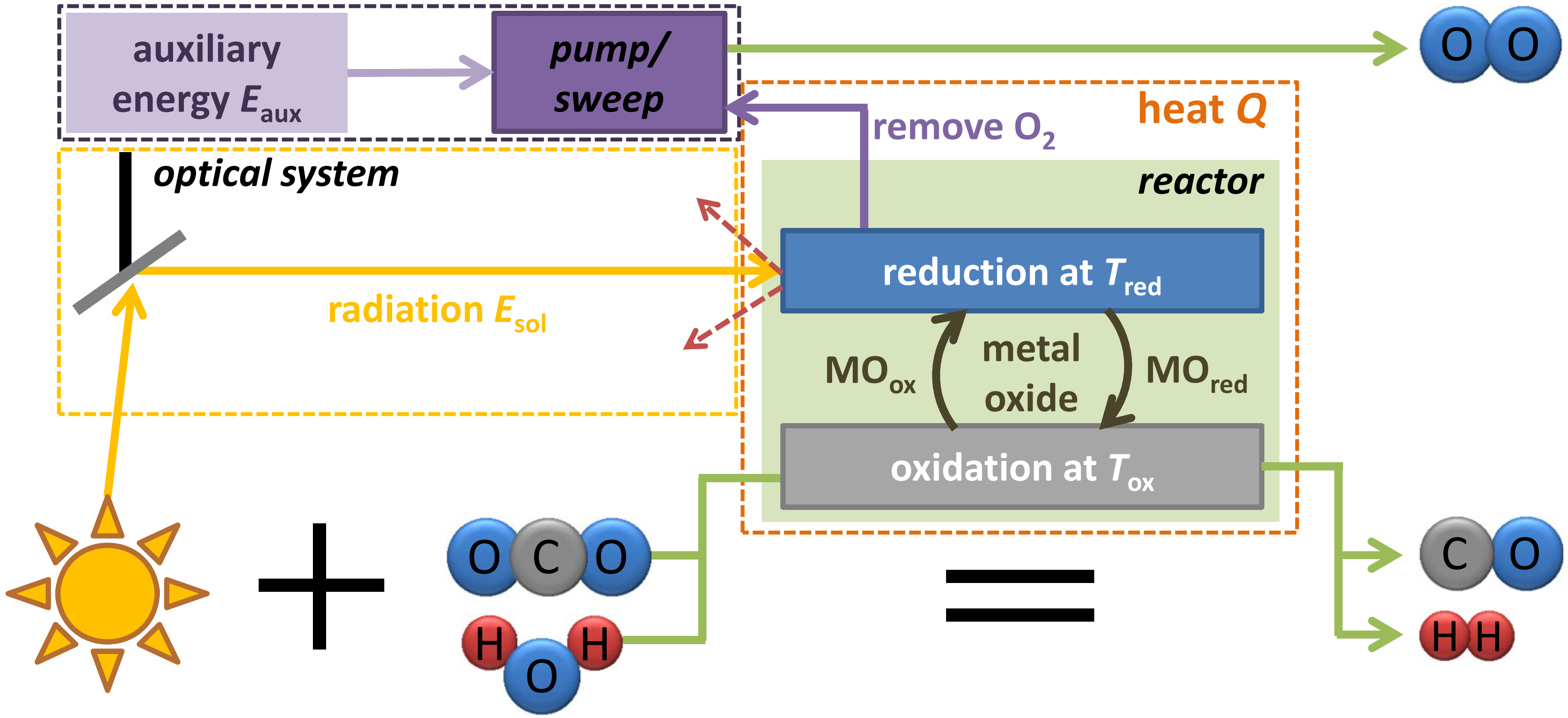


Int. J. Heat & Fluid Flow 29, 315-326, 2008.
Materials 5, 192-209, 2012.

Partners: Bauhaus Luftfahrt (D), ETH (CH), DLR (D), SHELL (NL), ARTTIC (F)
Funding: EC

http://www.solar-jet.aero/

Challenges of the entire process



Production of CO_2-neutral renewable fuels through solar-driven thermochemical cycles ($ + η)

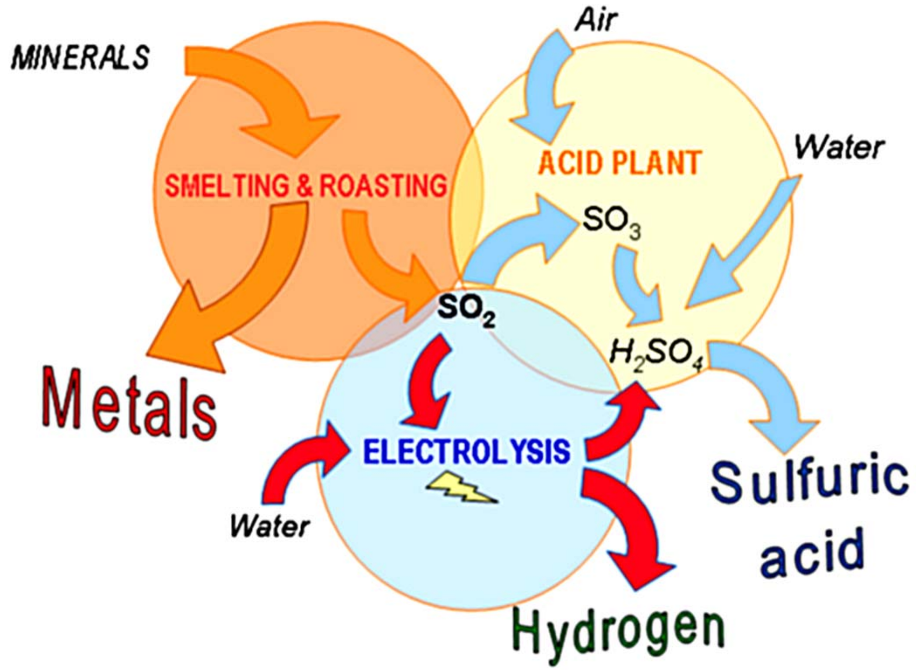
material side	• Determination of atomic mobilities in the redox materials • Identification of methods to enhance long-term stability • Improvement of hydrogen/CO yield per cycle and conversion rate
process side	• Analysis and modelling of heat transfer mechanisms in the solar receiver • Solar heat incorporation: Matching rates of chemical reaction and heat transfer • Analysis and optimization of transport (conversion rates and residence times)

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: EngineSoft (IT), Aalto University (FI), DLR (DE), ENEA (IT), Outotec (FI), Erbicol (CH), Oy Woikoski (FI)
- >100 kW demonstration plant on the solar tower in Jülich, Germany in 2015

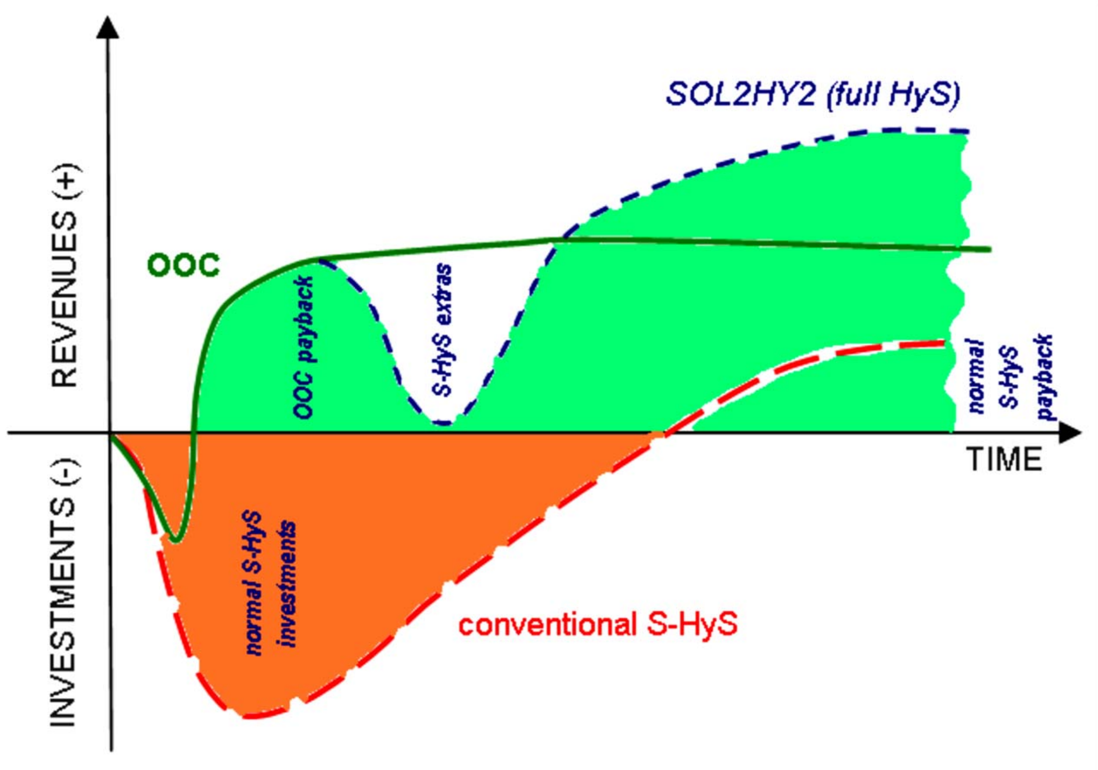
https://sol2hy2.eurocoord.com

Outotec™ Open Cycle (OOC)



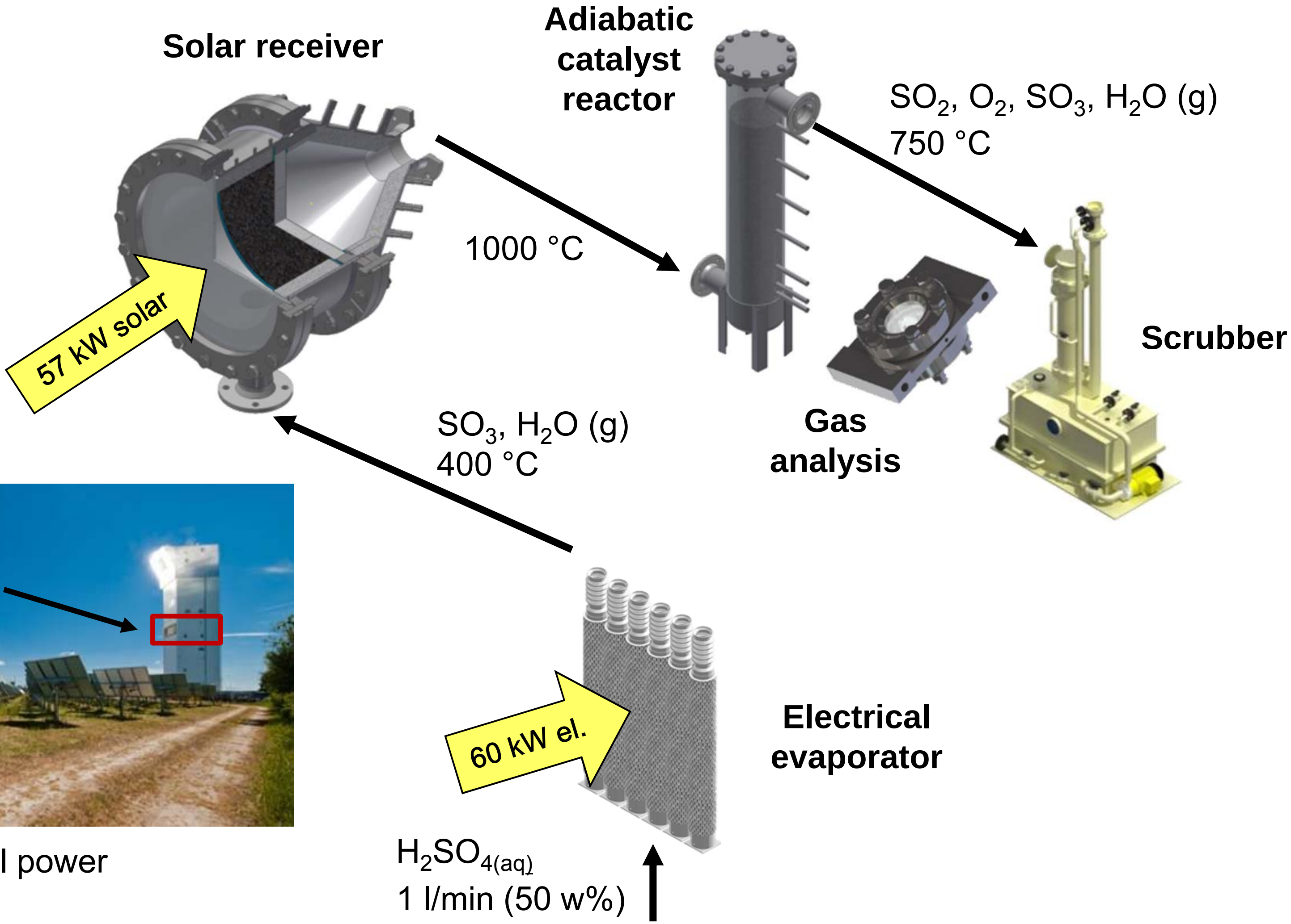
- Utilization of waste SO_2 from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis

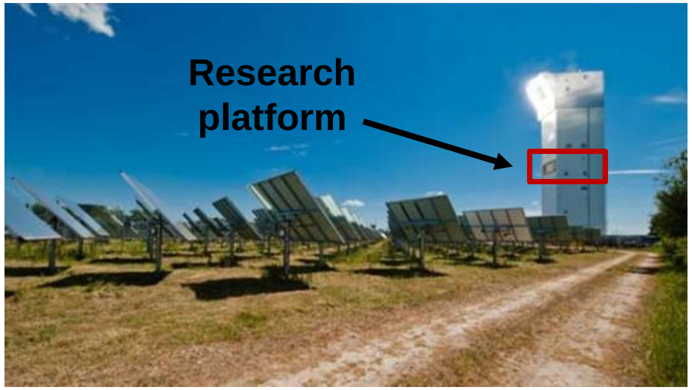
Investments vs. revenues



- Reduction of initial investments
- Financing of HyS development by payback of OOC
- Increase of total revenues

Design of SOL2HY2 pilot plant



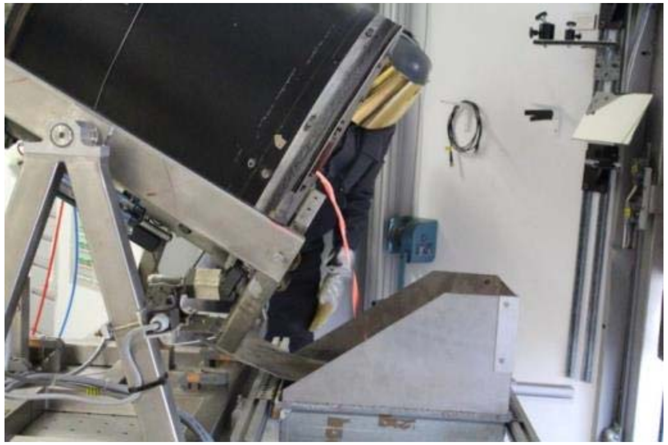


~100 kW total thermal power

SOLAM

Solar Aluminium Melting in a Directly Heated Rotary Kiln

- **Aim**
- Demonstration of solar aluminium recycling in a 20 kW rotary kiln
- Develop process concept for a commercial pilot plant
- Driver: Reduce the electricity demand from the grid



South African partners

CSIR – Council for Scientific and Industrial Research

NFTN – National Foundry Technology Network

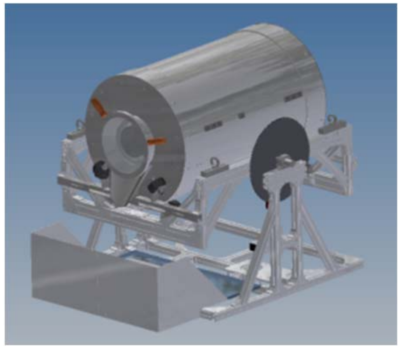
Eskom – South African National Electricity Generator and Distributor

DST – Department of Science and Technology

German partners

aixprocess

DLR



SOWARLA®

SOWARLA Plant, Lampoldshausen, Germany
240 m² Receiver (3*4.5 m³/d)
in operation since 2009!

Treatment cost	
UV Plant	4.52 €/m³
SOWARLA	0.50 €/m³
SOWARLA hybrid	1.06 €/m³

STAGE-STE

Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy (2014-2017)

WP1: Consortium Governance and Management Issues
WP2: Integrating Activities for Long-lasting Research Cooperation
WP3 Enhancement of STE Research Facilities Cooperation
WP4 Capacity Building and Training
WP5 Relationship with Industry & Transfer of Knowledge Activities
WP6 International Cooperation Activities
WP7: Thermal Energy Storage
WP8: Materials for Solar Receivers and STE Components
WP9: Solar Fuels
WP10: STE plus Desalination
WP11: Linear focusing STE Technologies
WP12: Point focusing STE Technologies

- WPs 7 to 12 involve 6 parallel individual research projects dealing with the whole current spectrum of STE research activities.
- Each WP is devoted to address the execution of considered most urgent research activities according to the defined EERA Subprogrames, complemented with the missing elements to address the indicated whole spectrum of research activities

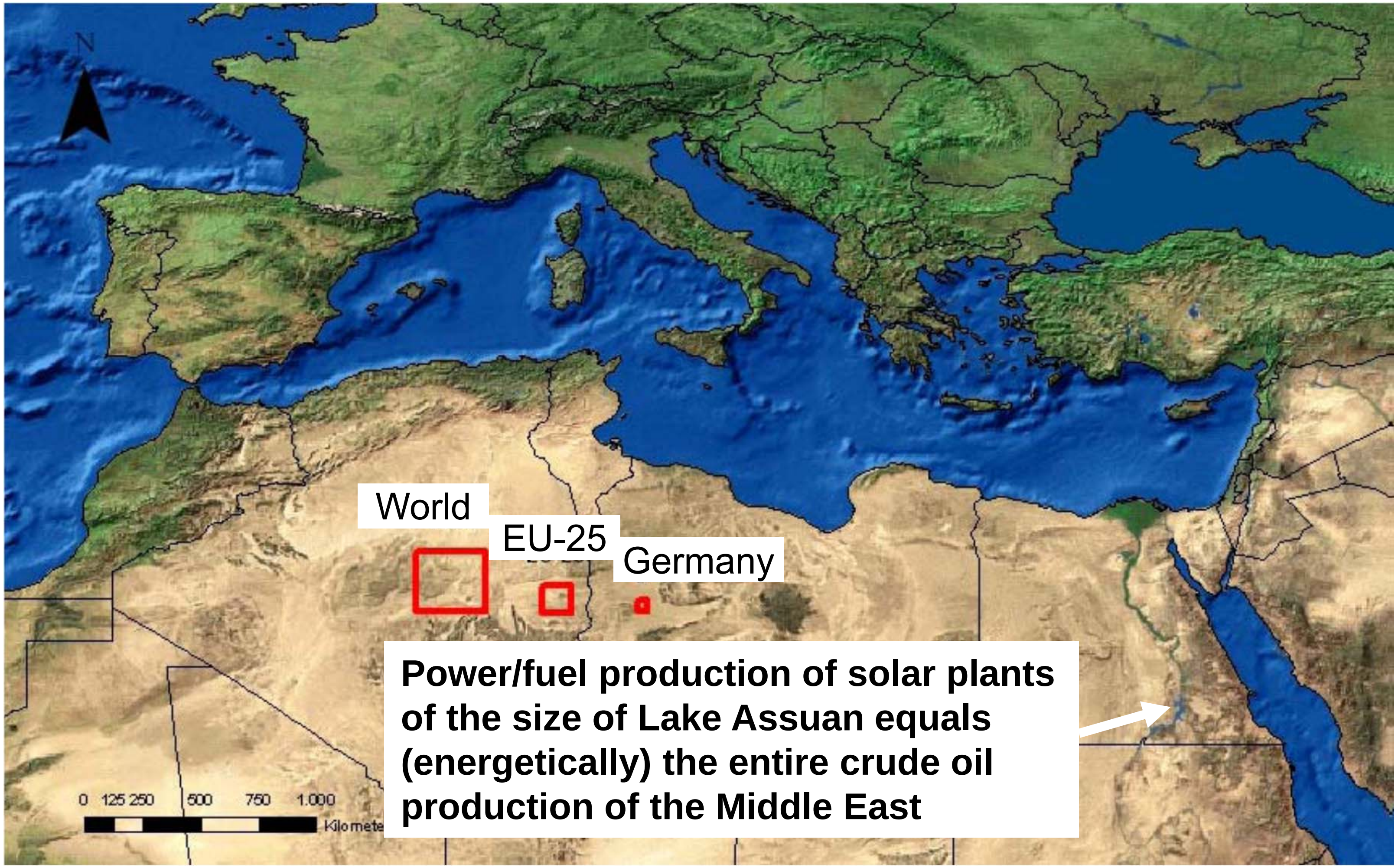
- Contact: Dr. Julian Blanco
- Julian.blanco@psa.es
- http://www.stage-ste.eu/

STAGE-STE Consortium

Participant no.	Organisation name	Country
1 (Coord.)	CIEMAT	SPAIN
2	DLR	GERMANY
3	PSI	SWITZERLAND
4	CNRS	FRANCE
5	FISE	GERMANY
6	ENEA	ITALY
7	ETHZ	SWITZERLAND
8	CEA	FRANCE
9	CYI	CYPRUS
10	LNEG	PORTUGAL
11	CTAER	SPAIN
12	CNR	ITALY
13	CENER	SPAIN
14	TECN	SPAIN
15	UEVORA	PORTUGAL
16	IMDEA	SPAIN
17	CRAN	UK
18	TKN	SPAIN
19	UNIPA	ITALY
20	CRS4	ITALY

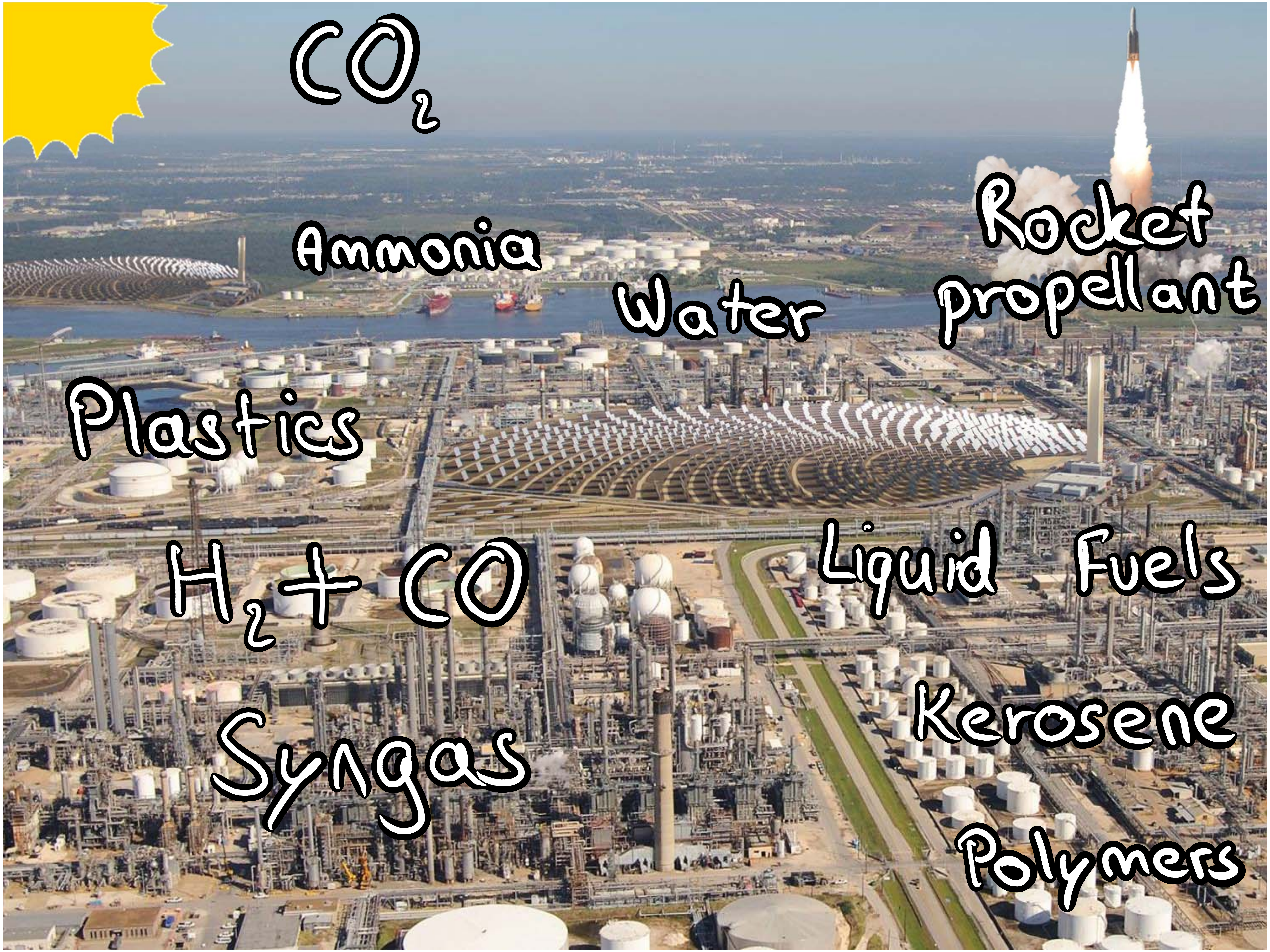
Participant no.	Organisation name	Country
21	INESC-ID	PORTUGAL
22	IST-ID	PORTUGAL
23	SENER	SPAIN
24	CNIM	FRANCE
25	HITIT	TURKEY
26	ACCIONA	SPAIN
27	SCHOTT	GERMANY
28	ASE	ITALY
29	ESTELA	BELGIUM
30	ASNT	SPAIN
31	KSU	**SAUDI ARABIA**
32	UNAM	**MEXICO**
33	SUN	**SOUTH AFRICA**
34	CSERS	**LYBIA**
35	CSIRO	**AUSTRALIA**
36	FUSP	**BRAZIL**
37	IEECAS	**CHINA**
38	UDC	**CHILE**
39	UCAM	**MOROCCO**
40	FBK	ITALY
41	CNIM	France
42	COBRA	Spain

Potential of Solar Energy – the new economy?



M. Schmitz, TSK Flagsol

DLR


CO_2
Ammonia
Water
Rocket propellant
Plastics
$H_2 + CO$
Syngas
Liquid Fuels
Kerosene
Polymers

Thank you very much for your attention!