TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

# Recent developments in concentrating solar thermal technology for high temperature processing

Christian Sattler
Christian.sattler@dlr.de


DLR

# DLR - German Aerospace Center


- Research Institution
- Space Agency
- Project Management Agency

- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Defence and Security
- Space Administration
- Project Management Agency

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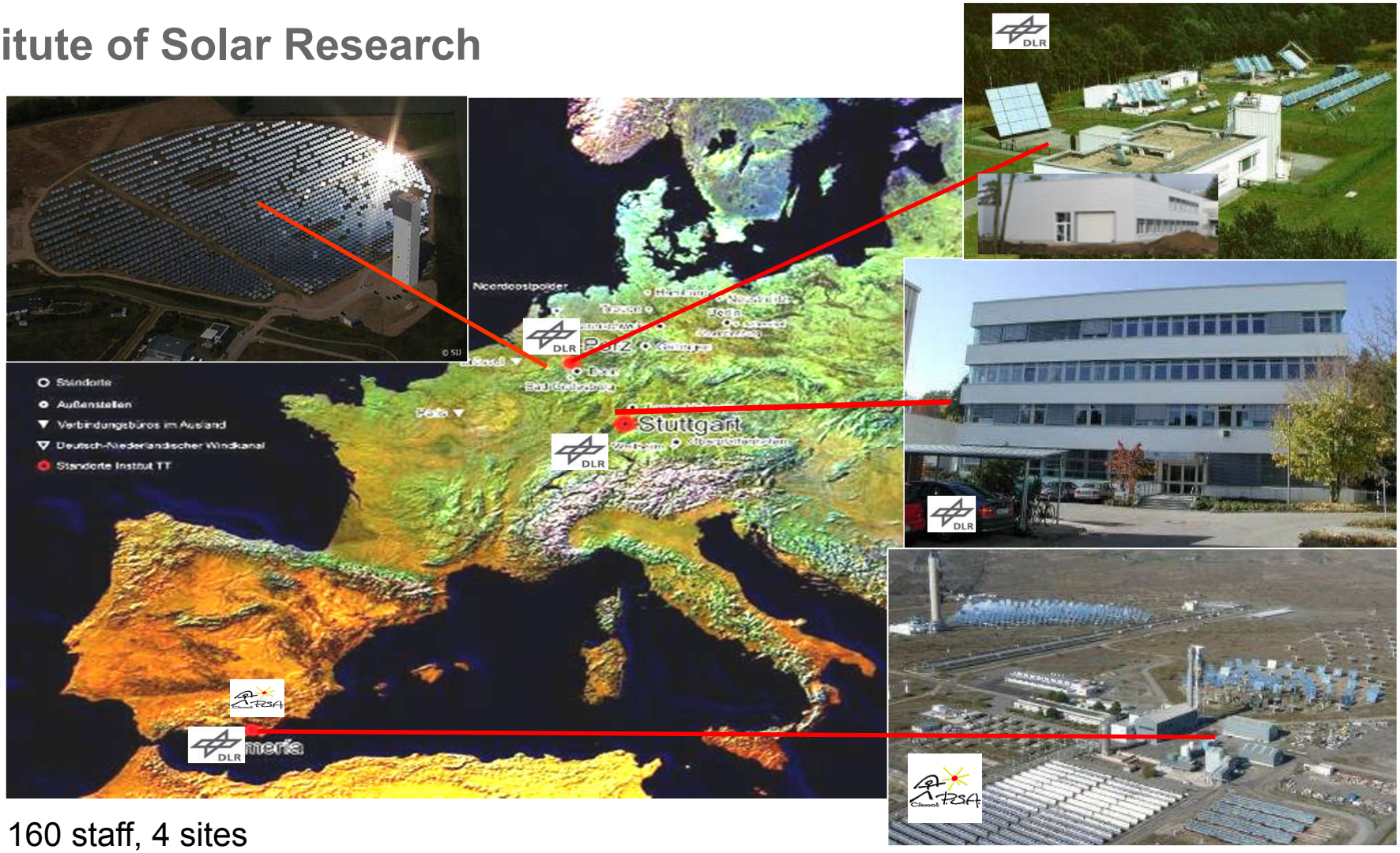
# Locations and employees

Approx. 8000 employees across
33 institutes and facilities at 20 sites.

Offices in Brussels, Paris,
Tokyo and Washington.

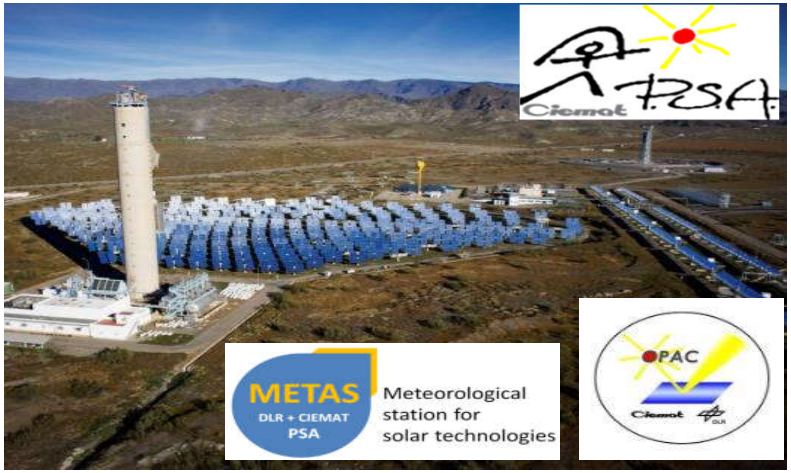
Permanent delegation on the Plataforma
Solar de Almería, Spain

# DLR Institute of Solar Research



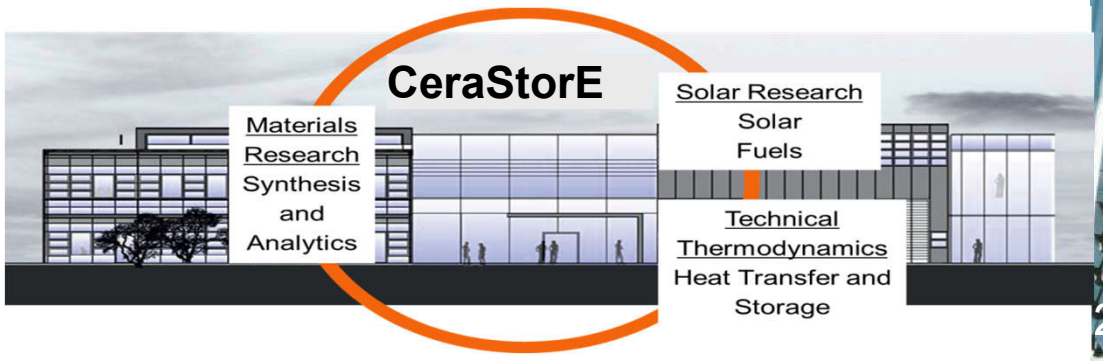

160 staff, 4 sites

# Large scale facilities











# HiTemp Forum - Key Questions

1. **Success**: What would successes look like in the path to reducing carbon emissions for heavy industry in 3, 10, 20 and 40 years?
2. **Enablers**: What role do government, researchers and industry play in enabling the pathway to decarbonise heavy industry?
3. **Barriers**: What are the key barriers to the uptake of renewable energy or other low-carbon processes into high temperature minerals processing?
4. **Key Opportunities**: What opportunities have strong potential for $CO_2$ mitigation for relevant high temperature industrial processing using:
   - Renewable energy
   - Any other process
5. **Pathway**: What role do lower temperature process within the mining and minerals processing sectors, play in the path to enabling low carbon production with high temperature processes?

# G7 Goals, Elmau Germany, June 2015

G7 GERMANY
2015 | Schloss Elmau

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

## 21st Conference of Parties - COP21
## to the United Nations Framework Convention on Climate Change

- COP 1 Berlin 1995, COP 3 Kyoto 1997 – Kyoto Protocol,
  COP 22 Marrakech 2016, COP 23 Bonn 2017, COP 24 Katowice 2018
- 11th meeting of the Parties to the Kyoto Protocol (CMP11)
- Universal agreement by 195 parties (countries) to
  **keep a global temperature rise this century well below 2 degrees Celsius**
- and to drive efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels.

# 21st Conference of Parties - COP21

- Additionally, the agreement aims to strengthen the ability to deal with the impacts of climate change
- **Appropriate financial flows will be put in place**, thus making stronger action by developing countries and the most vulnerable possible, in line with their own national objectives.
- The energy sector is responsible for some 60% of global emissions, making it a top priority for climate action.
- One country decided to withdraw which can formally happen earliest in 2020

## G20 Leader's Declaration 7/8 July 2017
## Shaping an interconnected world

G20 GERMANY 2017
HAMBURG

"We are resolved to **tackle common challenges to the global community**, including terrorism, displacement, poverty, hunger and health threats, **job creation, climate change, energy security**, and inequality including gender inequality, as a basis for **sustainable development and stability**. We will continue to work together with others, including developing countries, to address these challenges, building on the rules based international order."

Next G20 summit: November 30th – December 1st, Buenos Aires

G20
ARGENTINA 2018

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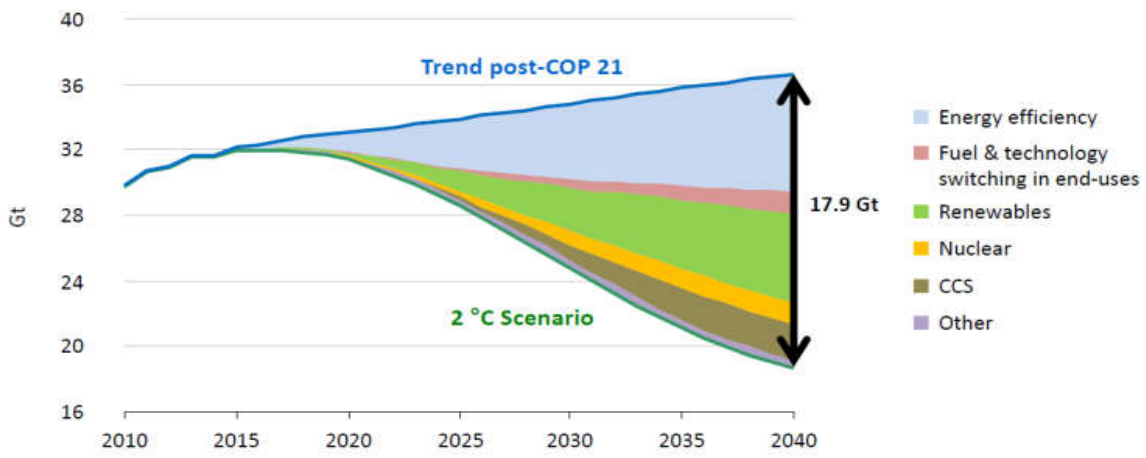
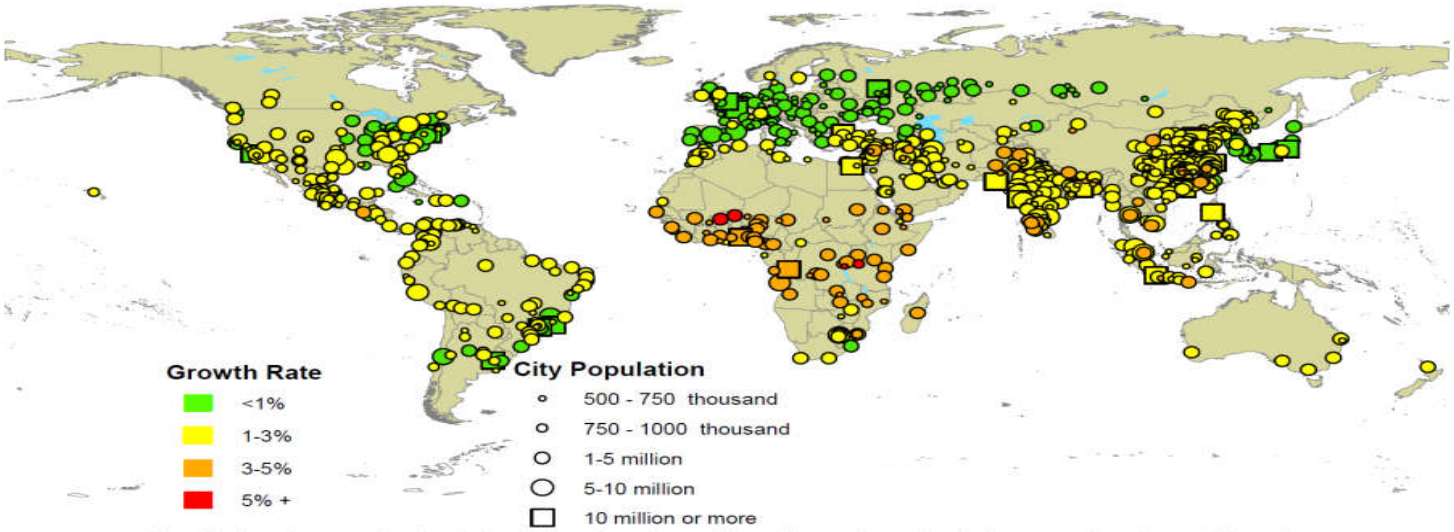
# Global Challenges

- Climat change
- Urbanization
- Ressources
- Markets




Source: World Energy Outlook 2015




Note: Designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

LABEL PARIS2015 COP21·CMP11

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Hydrogen Council

# The Hydrogen Council

- **Global initiative of leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition**
- Launched at the World Economic Forum 2017, in Davos, the growing coalition of CEOs have the ambition to:
  - Accelerate their significant investment in the development and commercialization of the hydrogen and fuel cell sectors.
  - Encourage key stakeholders increase their backing of hydrogen as part of the future energy mix with appropriate policies and supporting schemes
- http://hydrogencouncil.com/

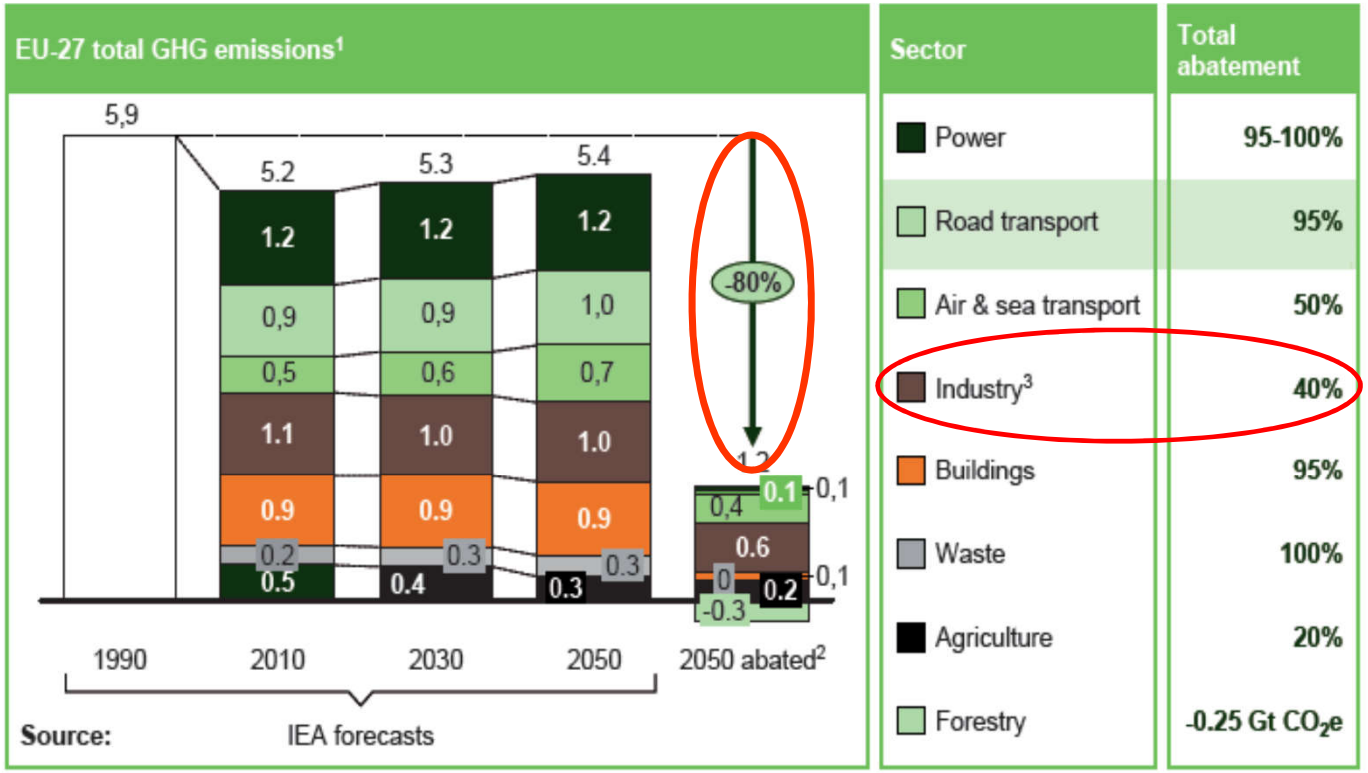
## 2050 Vision


## Since 2007
## European Strategic Energy Technology Plan – The SET-Plan

- aims to accelerate the **development and deployment of low-carbon technologies**
- **improve new technologies** and **bring down costs** by coordinating national research efforts and helping to finance projects
- **promotes research and innovation efforts** across Europe by supporting the most impactful technologies in the EU's transformation to a low-carbon energy system
- **promotes cooperation** amongst EU countries, companies, research institutions, and the EU itself.
- comprises the SET-Plan Steering Group, the European Technology and Innovation Platforms, the European Energy Research Alliance (EERA), and the SET-Plan Information System (SETIS).
- https://publications.europa.eu/en/publication-detail/-/publication/064a025d-0703-11e8-b8f5-01aa75ed71a1/language-en/format-PDF/source-search

# Development of EU GHG emissions [Gt $CO_2$e] Roadmap2050 https://ec.europa.eu/clima/policies/strategies/2050_en

- By 2050, the EU should cut greenhouse gas emissions to 80% below 1990 levels
- Milestones to achieve this are:
  - 40% emissions cuts by 2030
  - 60% by 2040
- All sectors need to contribute
- The low-carbon transition is feasible & affordable.




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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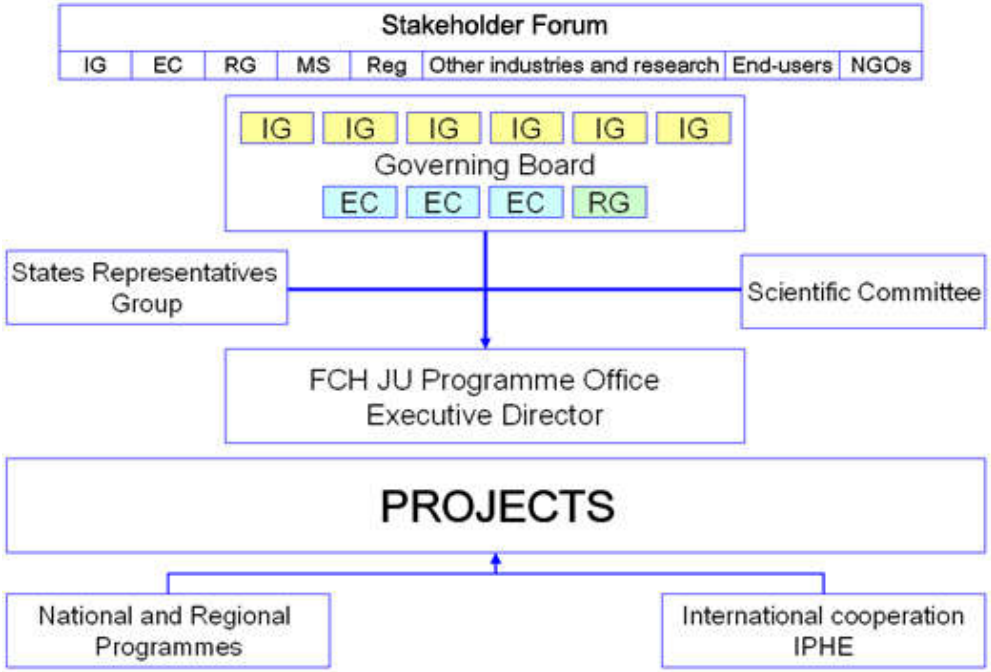
# European Fuel Cell and Hydrogen Joint Undertaking – Getting Industry in the lead for a faster deployment (established 2008)


Over 250 projects are funded already



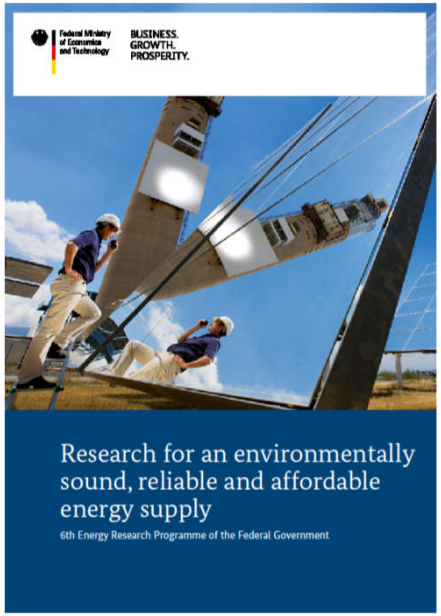
# Project REFHYNE - Clean Refinery Hydrogen for Europe

- 10MW electrolyser from ITM Power at a large refinery in Rhineland, Germany, which is operated by Shell Deutschland Oils.
- The REFHYNE electrolyser will be the largest in the world and has been designed as the building block for future electrolysers up to 100MW and beyond. REFHYNE includes a design study into the options for a 100MW electrolyser at the Rhineland refinery, which will help prepare the market for deployments at this scale.

- **Project Information**
- **Type of project :** Demonstration
- **Timing :** 01/01/2018 > 31/12/2022
- **Project Budget :** 16.058.562 €

# German „Energiewende“

- The goal:
  **Reach the age of renewable energy as fast as possible while keeping the price for electricity competive**
- Redesign energy conversion for the sake of everyone
- Support the conmpetition
- Development of a flexible electricity market
- Planning of appropriate power grids
- Save energy and use it more efficiently
- Electromobility - instantly cleaner
- 6th Energy Research Programme (since 2011, € 1,01 bln in 2017)
- https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/0-Buehne/buehnenartikel-links-energiewende-im-ueberblick.html;jsessionid=4E95071A286F0D56A72536D8A64BE226.s7t2



# Solar-thermal Industrial Production

- Concentrated solar radiation can be used as **heat or power** in thermal and thermochemical processes
- Temperature and **energy demand need to fit to the concentrator** system
- Possible products (other than fuels) are **inorganic solids** (e.g. minerals, metals, ceramics, sulphur), or **gases** (e.g. $SO_2$, $N_2$, $O_2$)
- Implementation of new technologies is difficult and not proven (**valley of death**)
- Research community is not as big and well connected as for CSP
  - **Implementation in many research programmes is missing**
- DLR recently worked on: Hydrogen, Synthesis Gas, Kerosene, Carbon Black, Aluminium, Ore Roasting, Sulphur, Sulphuric Acid, Cement, Phosphate, Nitrogen, Oxygen, Ammonia, …

# Example $H_2$ Production

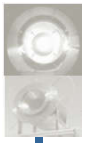
HYSOLAR: PV + Alkaline Electrolyser
10 kW Demonstration,
DLR Stuttgart, Germany 1990

HYDROSOL: Concentrated solar radiation + thermochemical cycle, 10 kW Demonstration,
DLR Cologne, Germany 2005

# HYDROSOL – 20 years development

**HYDROSOL** | **HYDROSOL-II** | **HYDROSOL-3D** | **HYDROSOL-PLANT** | **HYDROSOL-beyond**

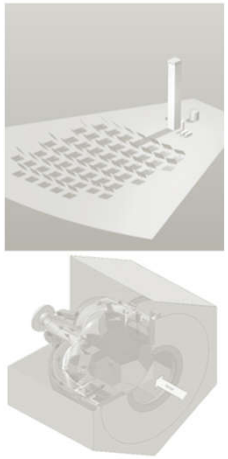
3 $kW_{th}$, first solar $H_2$ production



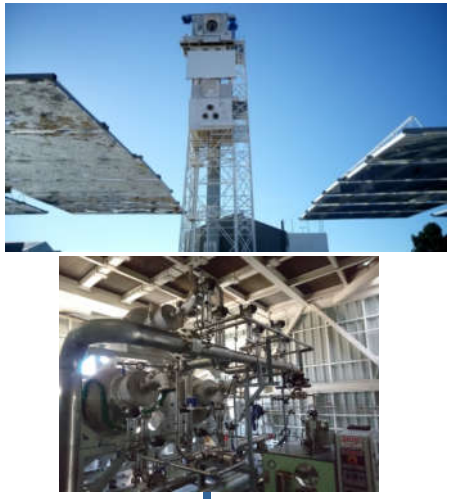
3 $kW_{th}$ x 2, continuous $H_2$ production

100 $kW_{th}$ X 2, pilot plant

1 $MW_{th}$ plant design



750 $kW_{th}$ solar $H_2$ reactor



- Improvement of heat recovery
- 5% efficiency of the 750 kW plant
- > 1000 cycles

2002 | 2005 | 2008 | 2010 | 2014 | 2018 | 2022

**HYDROSOL:** APTL/CERTH, DLR, JM, STOBBE

**HYDROSOL-II:** APTL/CERTH, DLR, CIEMAT, STOBBE

**HYDROSOL-3D:** APTL/CERTH, DLR, CIEMAT, HYGEAR, TOTAL

**HYDROSOL-PLANT:** APTL/CERTH, DLR, CIEMAT, HYGEAR, HELPE

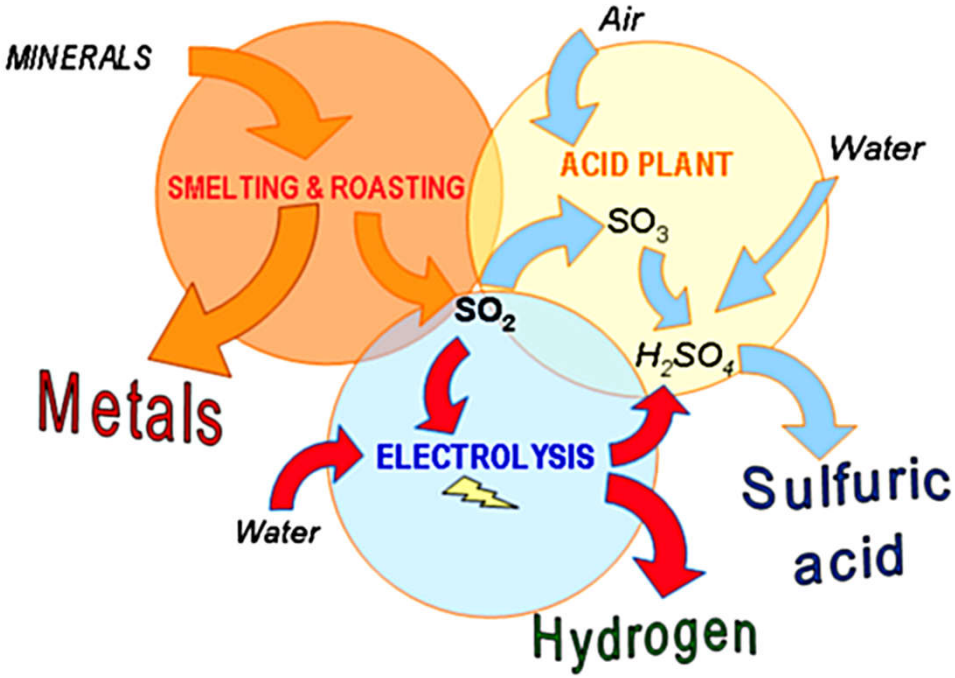
**HYDROSOL-beyond:** APTL/CERTH, DLR, CIEMAT, HYGEAR, ENGICER, SUPSI, CEA, ABENGOA

**Agreement between 16 partners for a 10 MW demonstration based on the IPHE pushed by DoE**

# Example Sulphur in Mining: 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

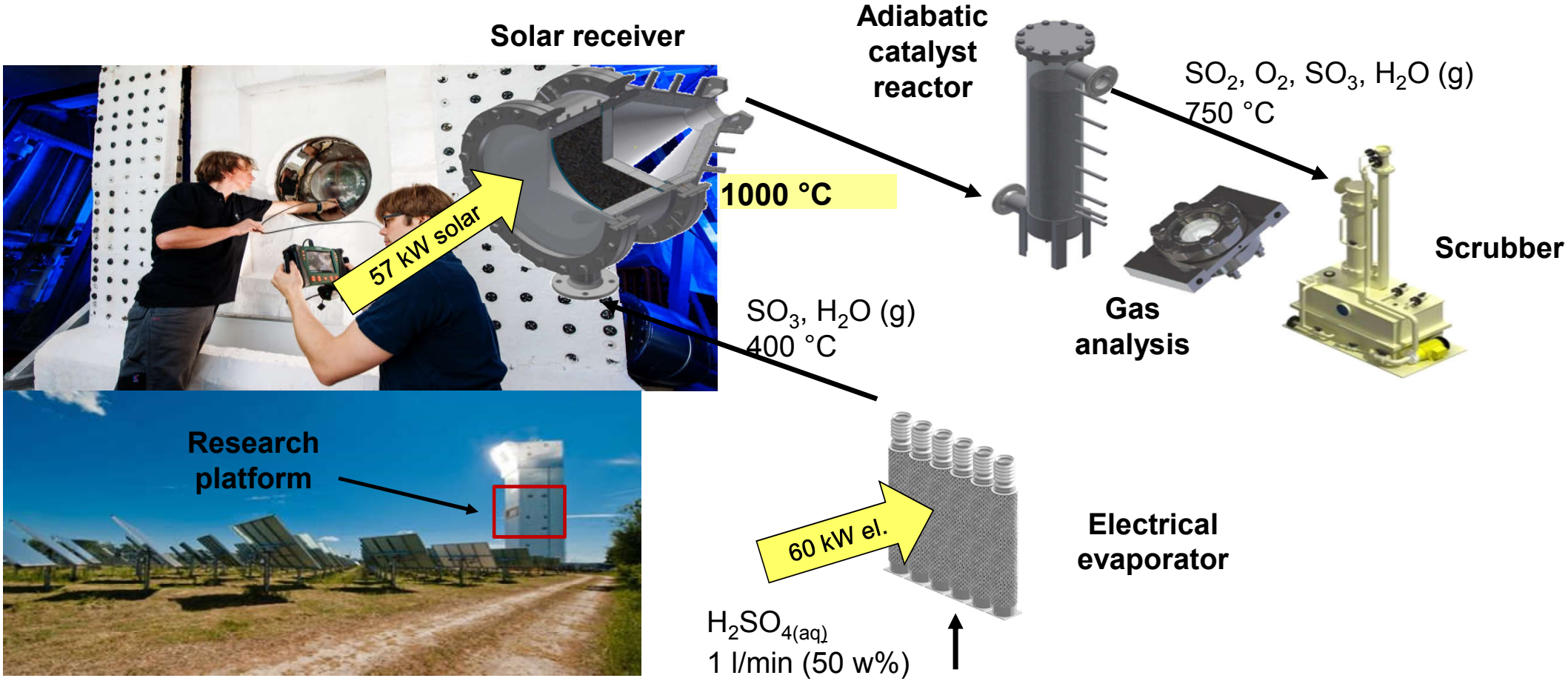
## Outotec™ Open Cycle (OOC)



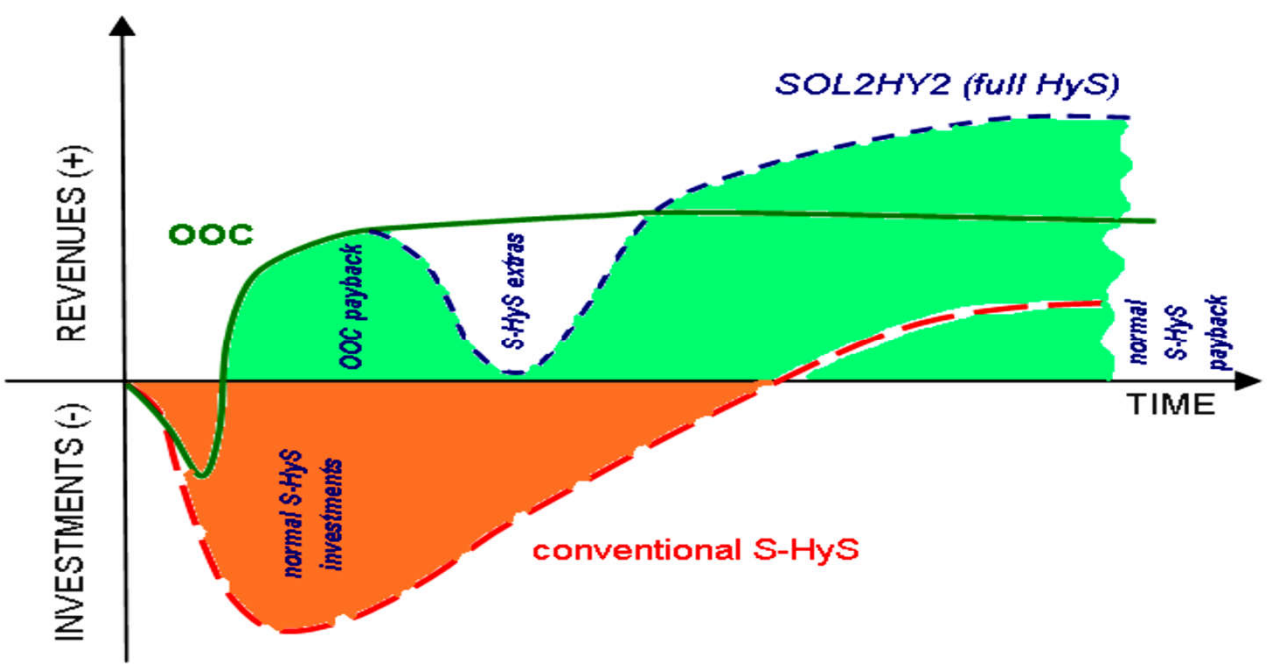

- Utilization of waste $SO_2$ from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis

https://sol2hy2.eurocoord.com

# Design of SOL2HY2 pilot plant



# Investments vs. revenues



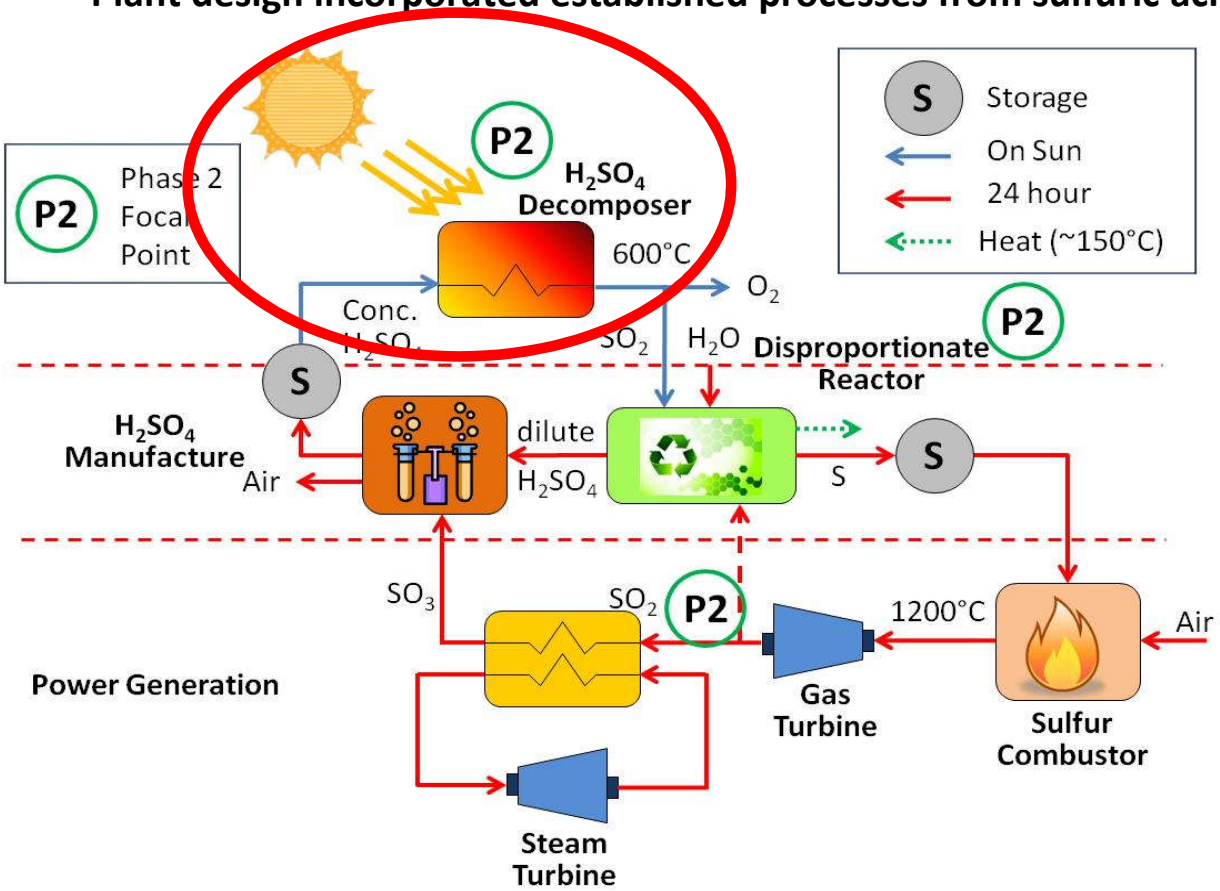

- Reduction of initial investments
- Financing of HyS development by payback of OOC
- Increase of total revenues

# Example Sulphur as Storage/Chemical/Fuel


| | 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 |

# Example Sulphur as Storage/Chemical/Fuel
# Flowsheet based on modeling and experimental data for economic calculations

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




Work was carried out by General Atomics under the DoE Sunshot BaseLoad Project

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

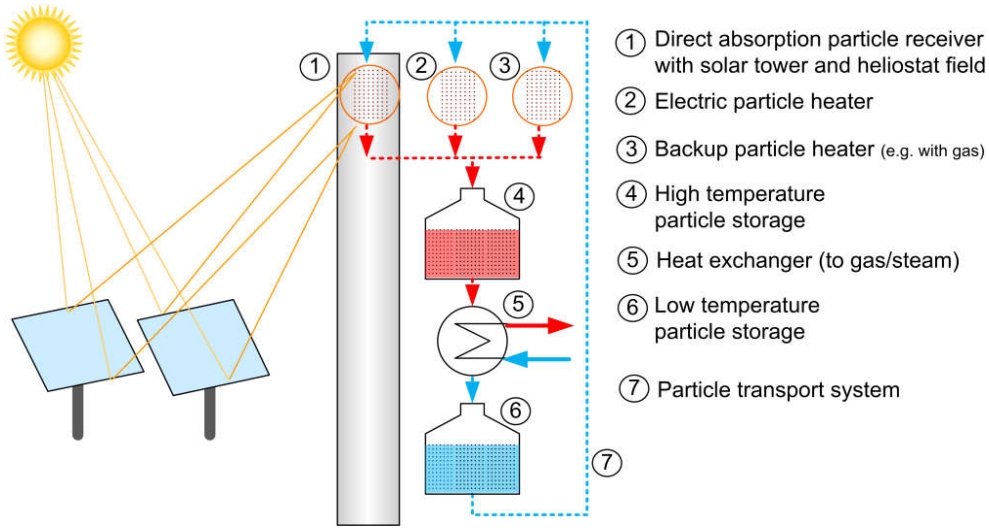
*SAM (NREL) using 2012 costs

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

# Ceramic particles as heat carrier and low-cost thermal storage

**HelioHeat**

*24/7 High Temperature Renewables*



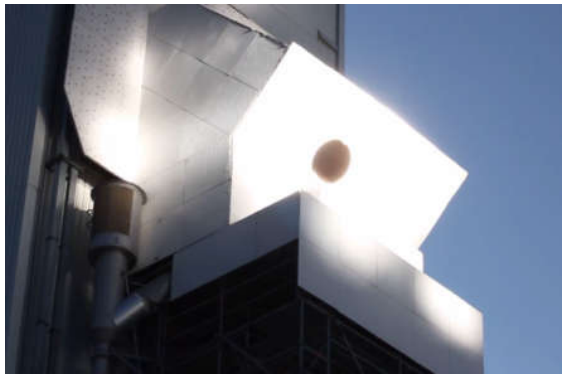

- Ceramic particles enable:
  - Temperatures **up to 1000°C and potentially above**
  - Heat input from **concentrated solar and/or electricity** (wind and/or PV in a in a power to heat configuration)
  - Easy hybridisation with e.g. biomass or gas for full **security of supply**
  - Direct storage of heat for **24h operation**
  - Heat supply as **hot air or steam** for
    - Process heat
    - Electricity and cogeneration

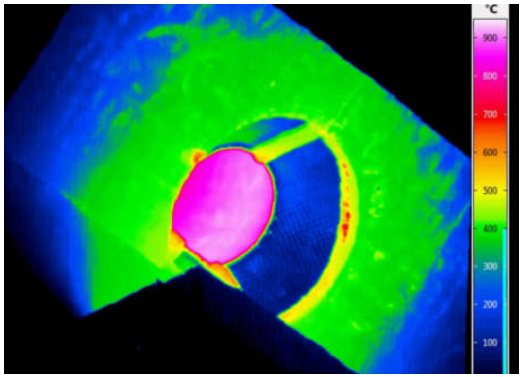
# HelioHeat

*24/7 High Temperature Renewables*

## Development status

- **2.5 $MW_{th}$ solar receiver prototype** achieved **965°C** outlet particle temperature at the Solar Tower Jülich, Germany
- Results of a cost study for a CSP plant in Chile (3583 kWh/m²a DNI, 7% WACC):
  - Levelized heat costs: **18 €/$MWh_{th}$**
  - Share of storage and heat exchanger: **4 €/$MWh_{th}$**



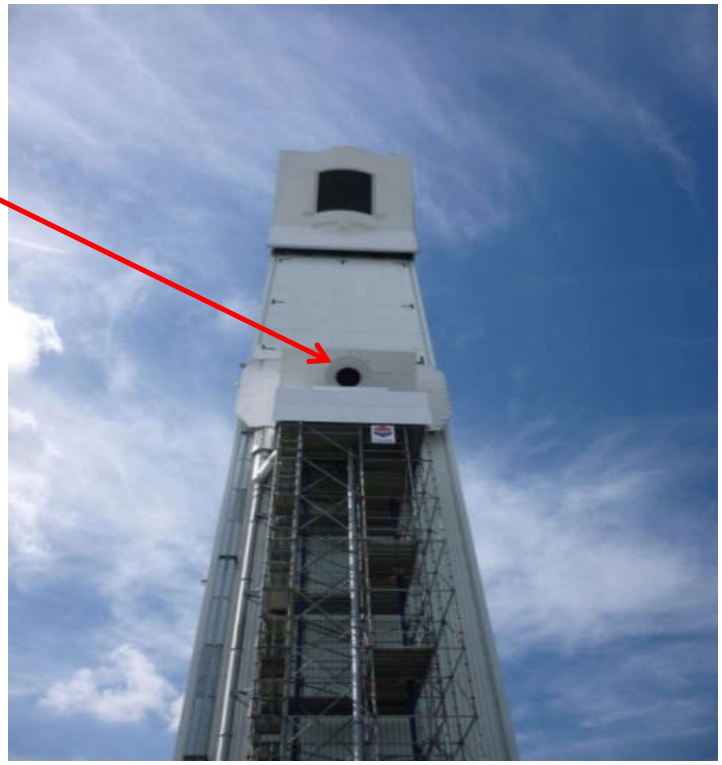



Next step:
**Demonstration plant**

# Centrifugal particle solar receiver optimization

## Application of pilot receiver developed in CentRec project

- Centrifugal particle receiver was erected on scaffold in front of Juelich Solar Tower
  - Nominal power: 2.5 $MW_{th}$
  - Diameter of the aperture: 1.13 m
  - Max. particle temperature: 1000 °C
- Solar testing of CentRec started in autumn 2017

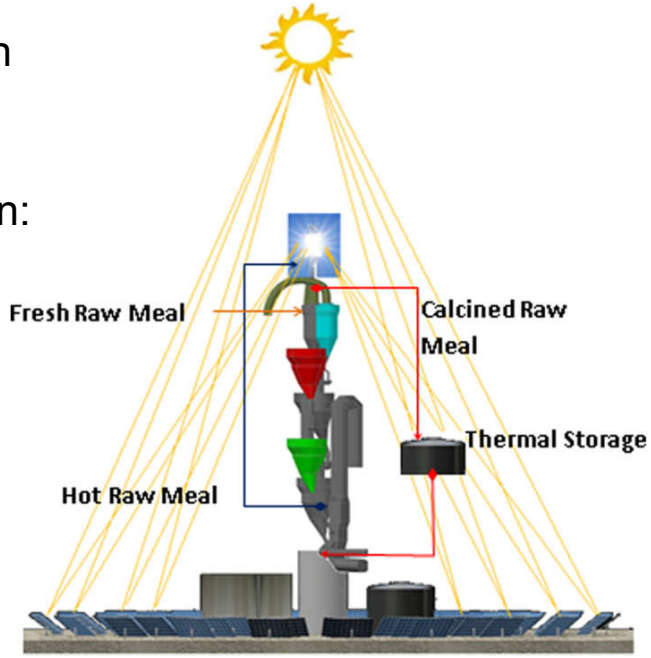


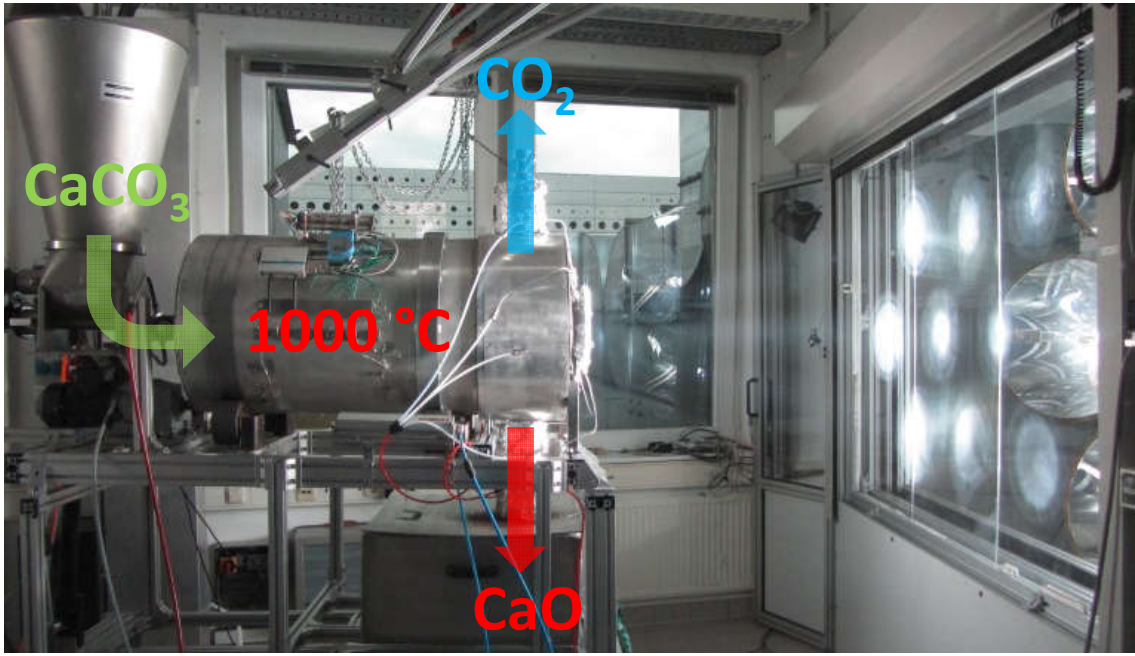
**Project PEGASUS**

- Project partner Baltic Ceramics delivered 3 tons of particles in May 2018
- Pre-testing of particles is underway (i.e. absorptance, pouring angle, flow angle, thermo-shock, crushing resistance, abrasiveness, emissivity)
- Solar testing of catalytic particles in CentRec pilot plant

# SOLPART - High temperature Solar-Heated Reactors for Industrials Production of Reactive Particulates (Cement, Phosphate)

- Solar heated rotary kiln
- High temperature 24h/day solar process e.g Calcination reaction: $CaCO_3 = CaO + CO_2$
- Simulate at prototype scale a 24h/day industrial process (TRL 4-5)
  **Partners:** CNRS, Abengoa, Cemex, OCP, Comessa, UCA, UMAN, EPPT, forlime, Euronovia




| Massflow | Conversion | Ch. Efficiency |
|---|---|---|
| 11.4 kg/h | 45% | 16% |
| 7.4 kg/h | 95% | 20% |

# Solar-thermal Industrial Production – Pros and Cons 2018

+ Huge potential for solar heat and power in industry
+ Long term energy security
+ Independency from varying power or fuel prices
+ No additional emissions ($CO_2$, NOx, SOx …)
+ Low risk on additional taxes
- Long term investment
- Little experience yet
- Finacing without support (governmental) difficult/expensive
- Tough competition on the markets
- Already many other actions in place to reduce $CO_2$ in production processes


Thank you very much for your attention!
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