PEGASUS Project Overview: Objectives and Challenges

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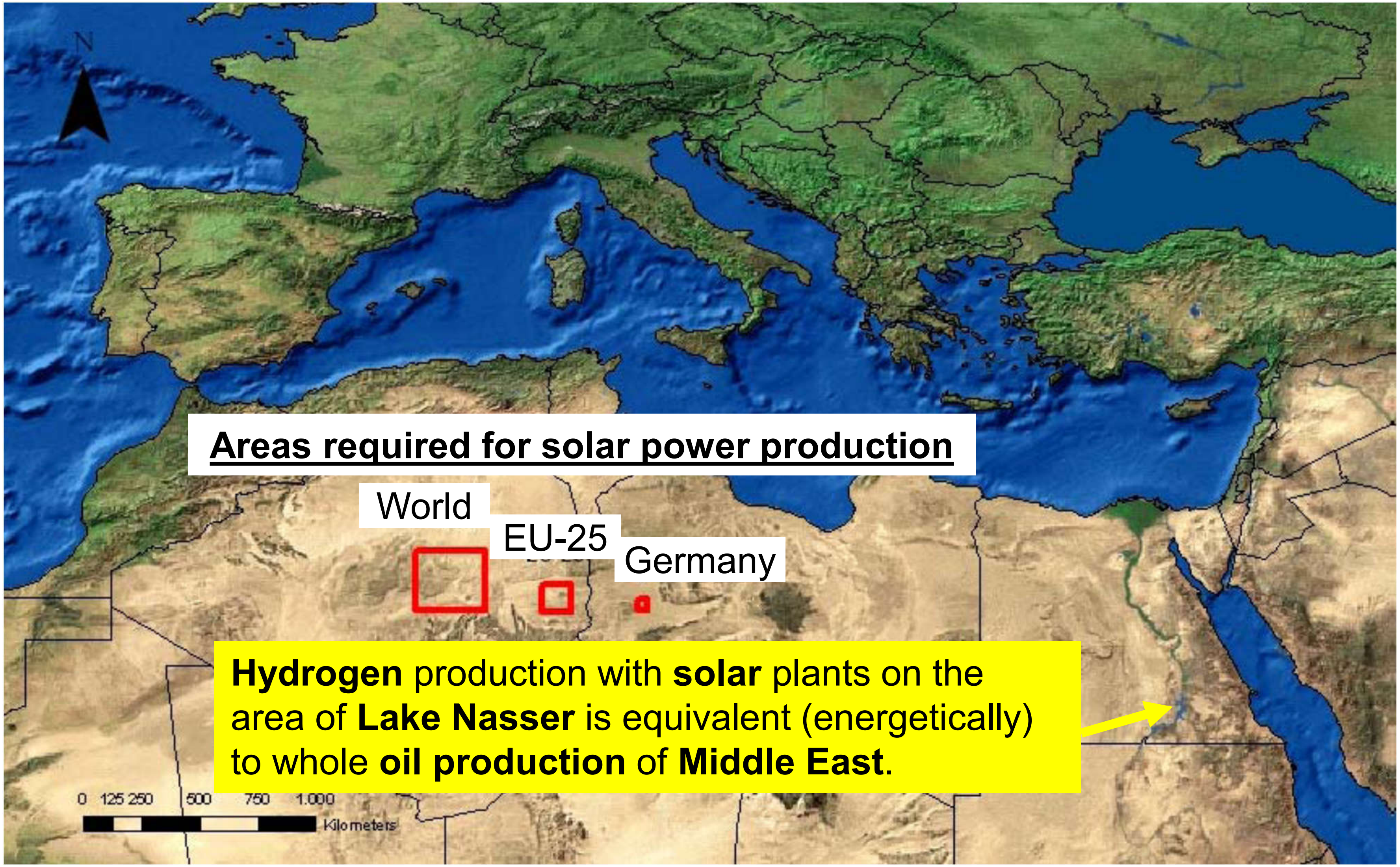
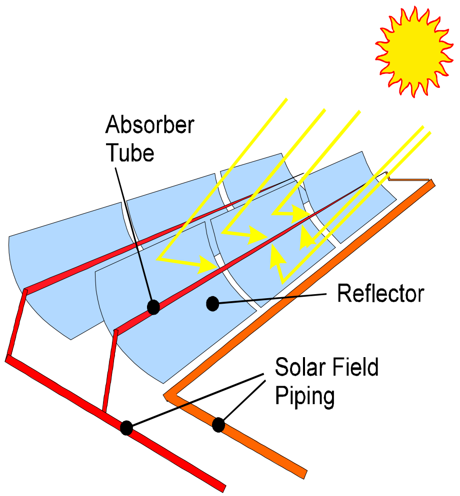
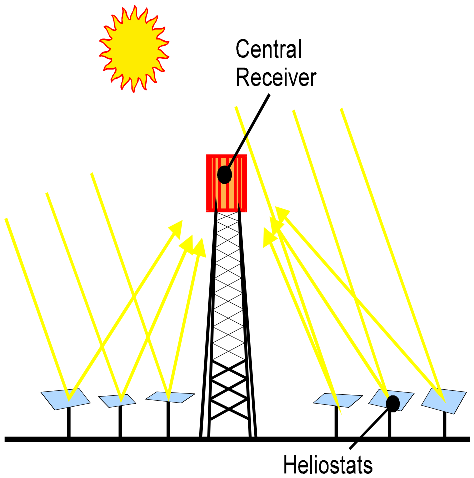
Potential of solar energy

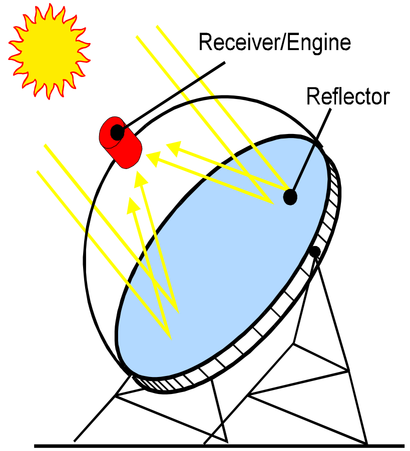


M. Schmitz, TSK Flagsol

Concentrated Solar Power (CSP) Plants







Parabolic Trough **400 °C**

Solar Tower **1000 °C**

Solar Dish **2000 °C**


Noor III, Ouarzazate, Morocco
150 MW, 7.5 h Storage, 2018


Gemasolar
Seville, Spain (2011)
20 MW, 15 h Storage


Ivanpah Solar
8 km
Image © 2013 DigitalGlobe


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

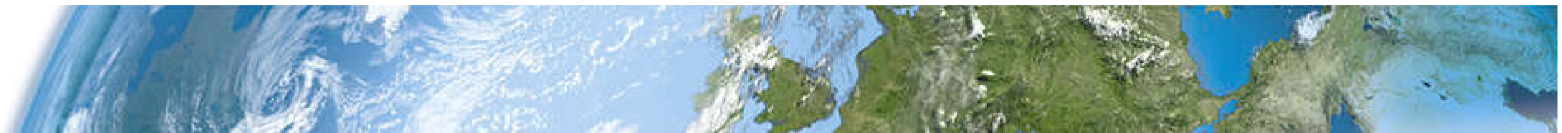

PS10
11 MW, 2007
PS20
20 MW, 2009
Seville, Spain


Ivanpah, California, USA (2014)
377 MW, serves >140.000 homes

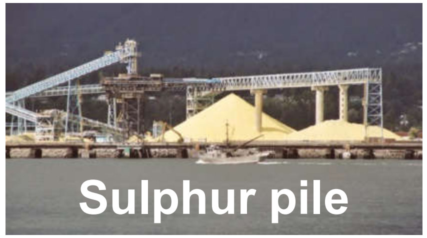
Comparison of energy storage densities

Technology	Energy density (kJ/kg)	Volumetric energy density (kJ/l)
Hydrogen	141,886 [1]	~6,700 *
Gasoline	47,357 [1]	~35,000
Sulphur	**9,281** [2]	**~18,000**
Lithium Ion Battery	580 [2]	~730
Molten Salt	282 [2]	~540
Elevated water Dam (100m)	1 [2]	~1

[1]College of the Desert
[2]General Atomics
*at 700 bar

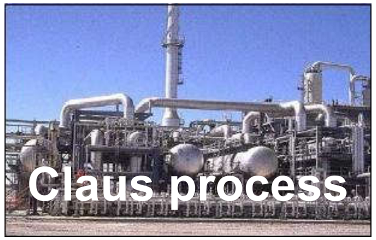


Sulphur in industrial processes



- Sulphur is required for **sulphuric acid** (SA) production
  - SA is world's most produced chemical
    ⇒ Global annual rate **>200 Mio. tons**
  - SA is measure of industrial development
  - SA is mainly needed for **fertiliser production**

- Sulphur from **desulphurisation of hydrocarbons** via Claus process



- Sulphur is by-product of **metallurgic processes**

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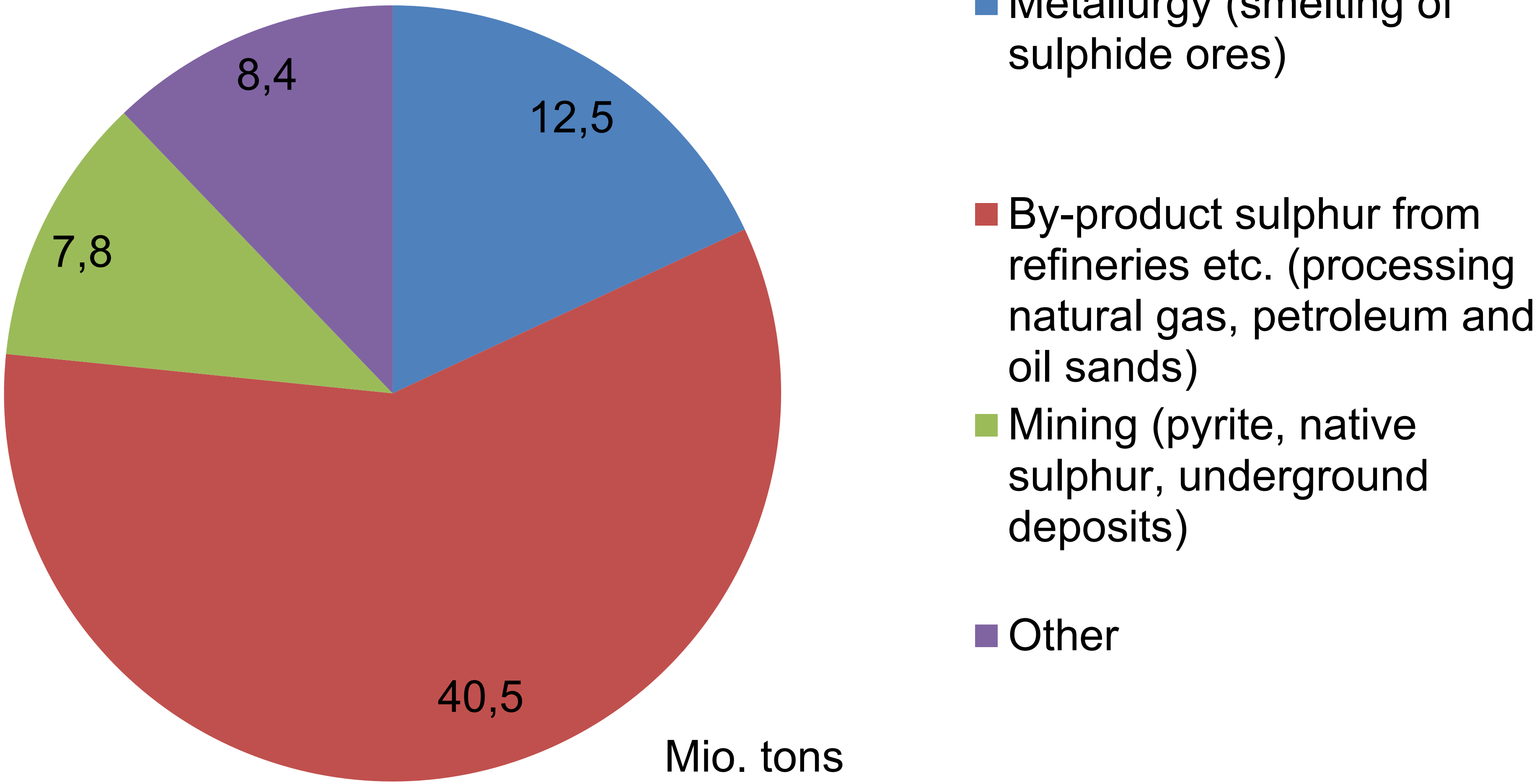
Sulphur world production 2014

Total of 69.1 Mio. tons (avg. world price of US$160 per ton)



Source: 2014 Minerals Yearbook, SULFUR, U.S. Geological Survey

Transportation and storage of sulphur

In solid or liquid form

Pipeline

Molten sulphur in heated pipelines (~140 °C)

Train

Truck

Ship

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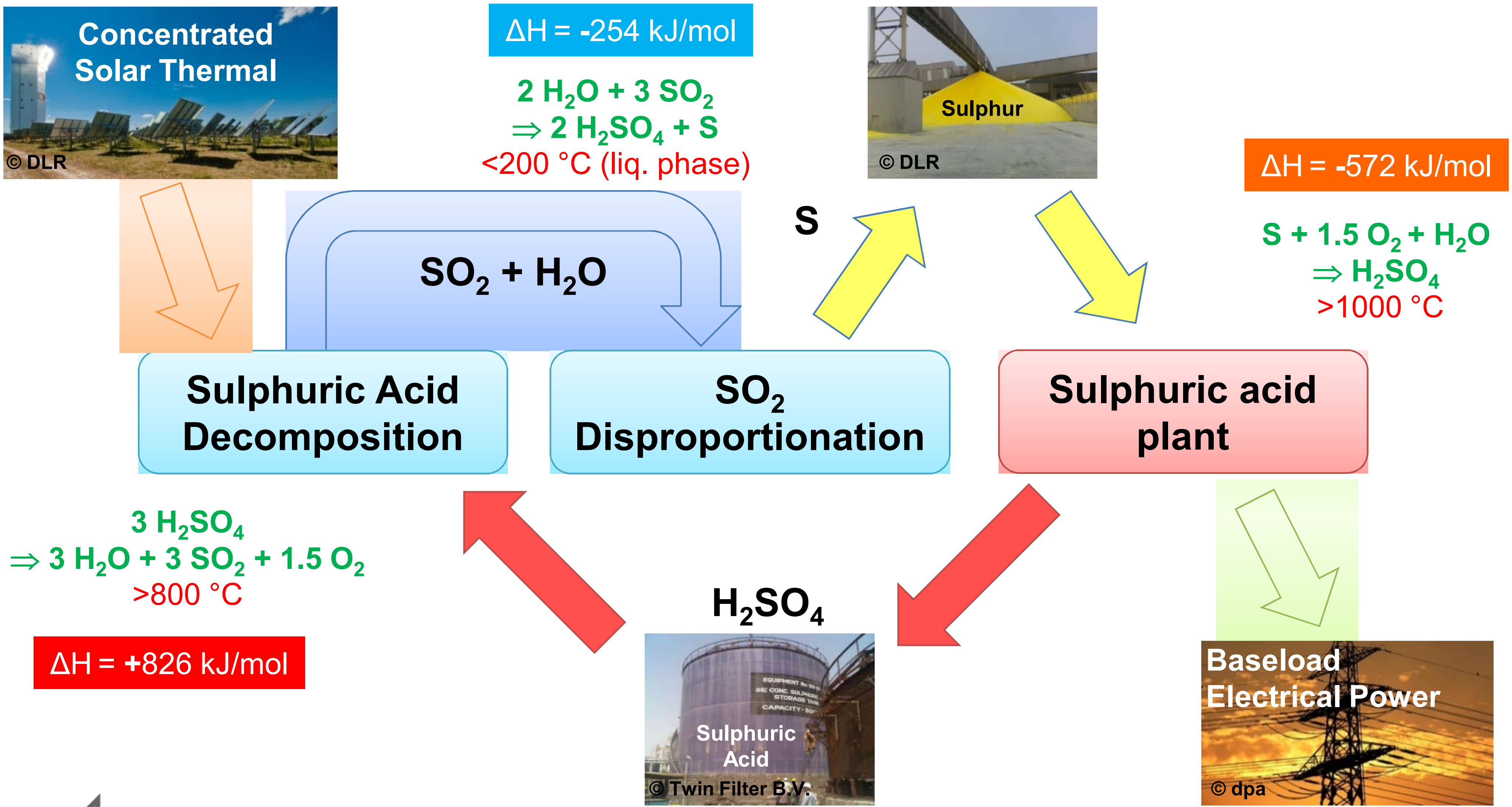
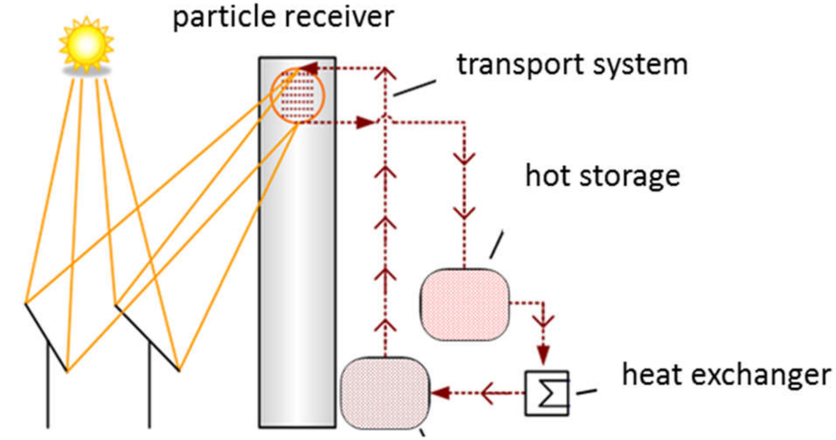
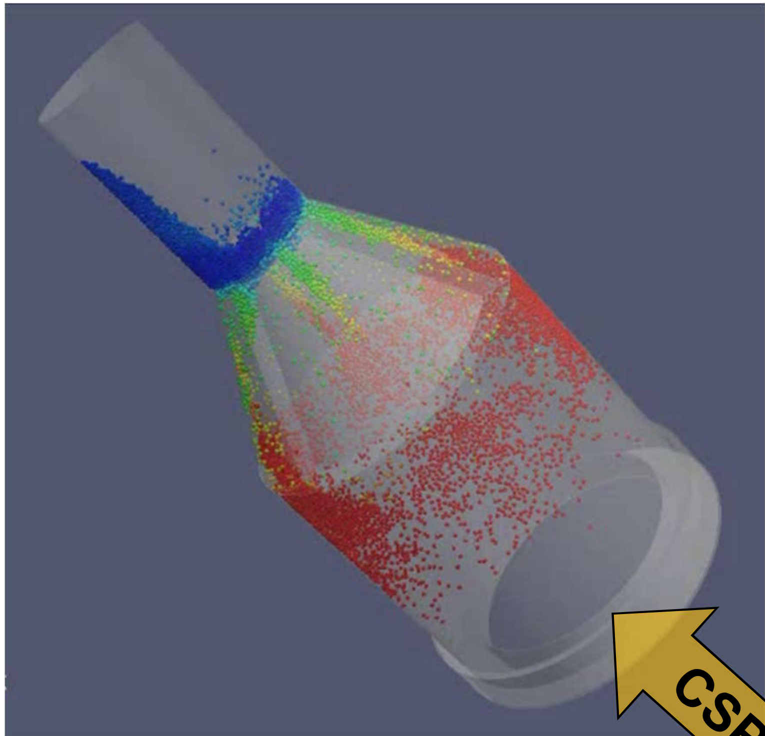
Thermochemical sulfur storage cycle for baseload solar power production



Solar particle technology
Centrifugal receiver

- 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

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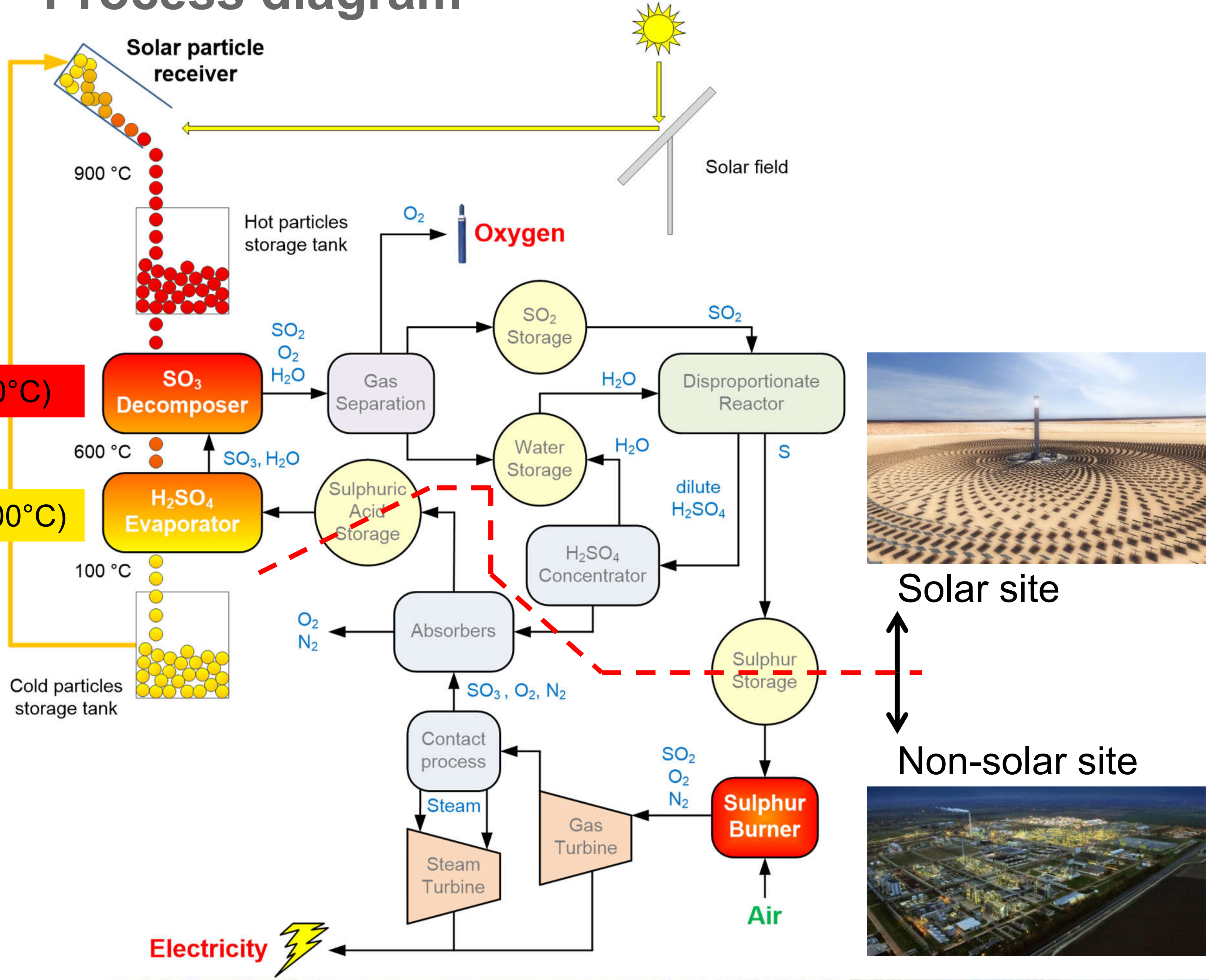
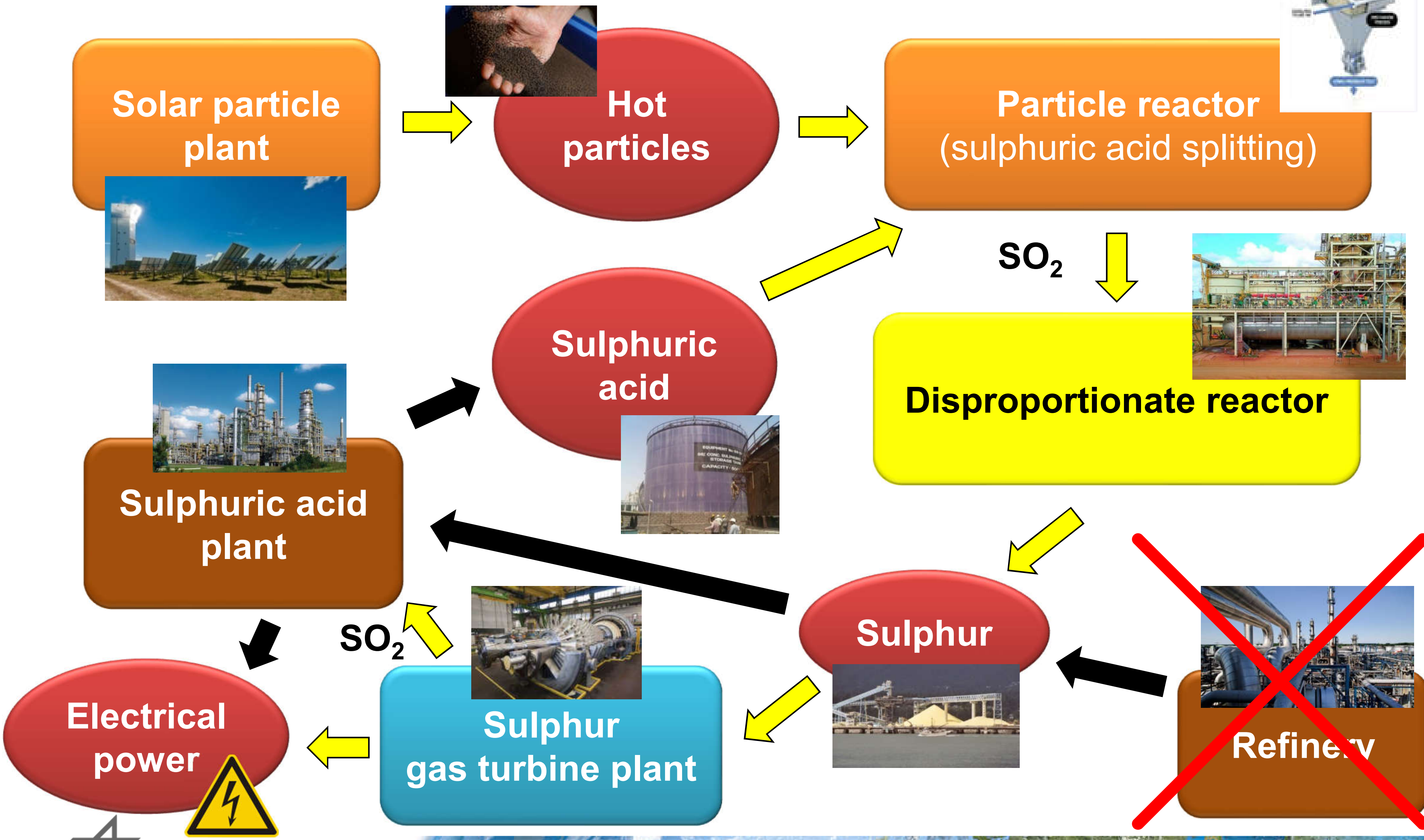
PEGASUS – Process diagram

$SO_3 \Rightarrow SO_2 + ½ O_2$ (850°C)

$H_2SO_4 \Rightarrow SO_3 + H_2O$ (400°C)



Integration of solar sulphur power generation



EU-Project PEGASUS (2016-2021)

Renewable **P**ow**e**r **G**eneration by Solar P**a**rticle Receiver Driven **Su**lphur **S**torage Cycle

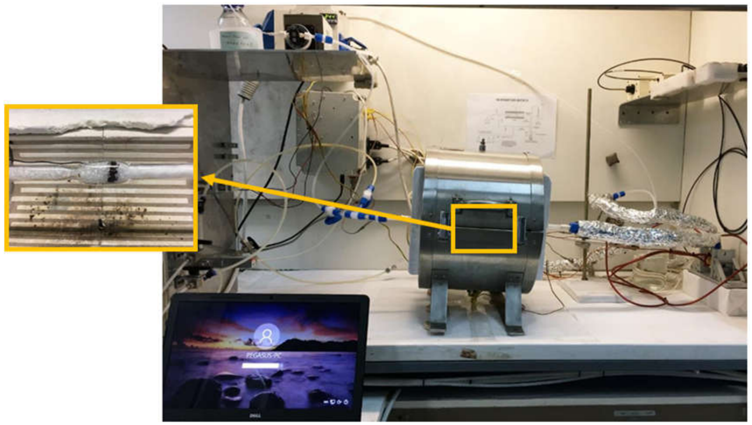
Partners

- **DLR**, Germany (Coordinator)
  - Solar sulphuric acid splitting
- **APTL/CERTH**, Greece
  - Catalyst materials developer
- **KIT**, Germany
  - Combustion specialist
- **Baltic Ceramics***, Poland
  - Advanced ceramics manufacturer
- **NextChem**, Italy
  - Power plant designer/contractor
- **BrightSource**, Israel
  - CSP plant designer/contractor

*) excluded in Aug. 2019

Objectives and challenges
Catalytic particles for H_2SO_4 splitting

- Combine and further improve current state-of-the-art proppant properties and SO_3-splitting catalysts in synthesizing catalytically active particles that can demonstrate in combination:
  - Conversion of SO_3 to SO_2 and O_2 close to respective thermodynamic value
  - Low deactivation of initial catalytic activity at long-term exposure to reaction conditions
  - High solar absorptivity during lifetime
  - Low cost of losses due to abrasion or chemical inactivity.



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Objectives and challenges
Centrifugal particle solar receiver

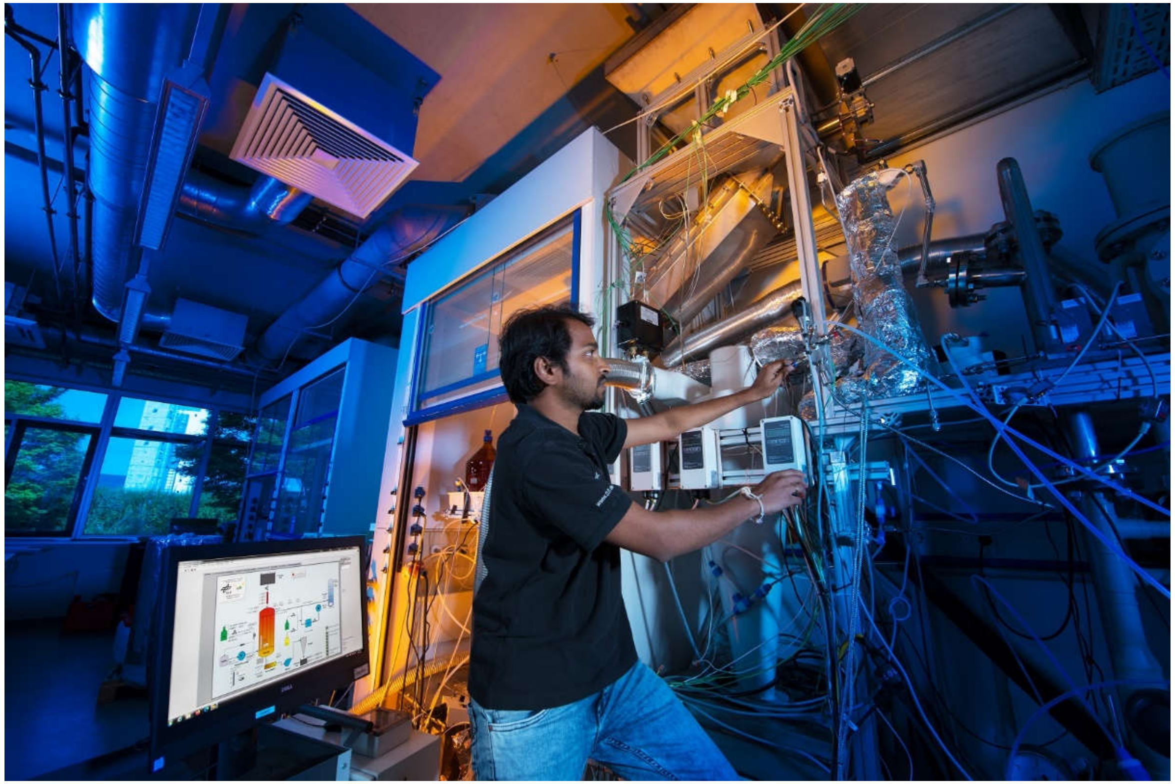
aptL AEROSOL & PARTICLE TECHNOLOGY LABORATORY

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

- Synthesize large-scale quantities of qualified particles and demonstrate on-sun capability of **150 to 500 kW$_{th}$ prototype centrifugal particle solar receiver** for heating such particle streams to temperatures in excess of 900 °C
- Design high-temperature **particle storage system** that can maintain particle temperatures higher than 900 °C for at least 6 hours

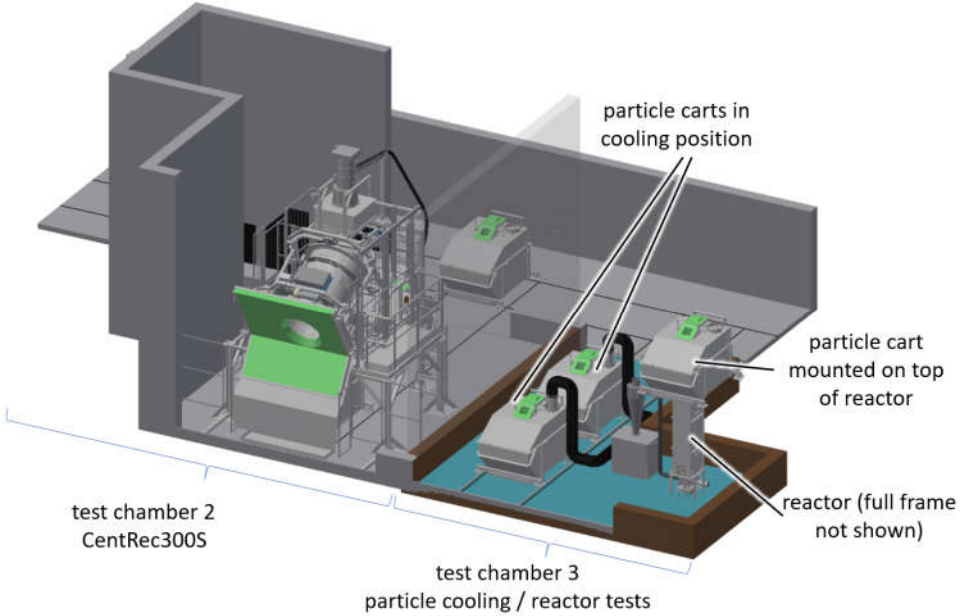
Objectives and challenges
H_2SO_4 splitting particle reactor

- Design, build and operate **laboratory prototype sulphuric acid decomposition cascade** consisting of evaporator and an SO_3 decomposer, employing moving heated particles as heat source



Objectives and challenges
System integration and operation

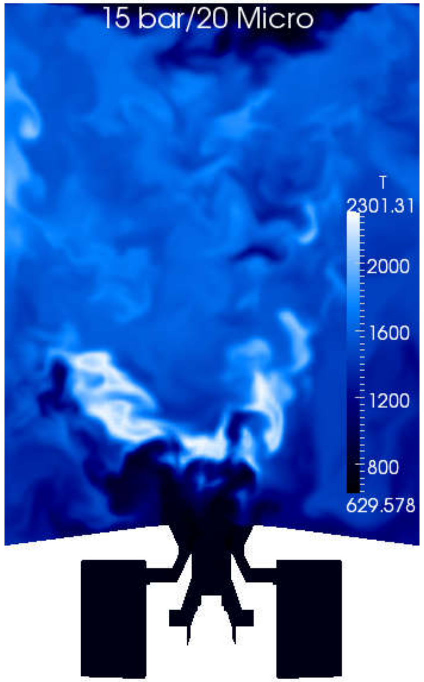
- Transfer sulphuric acid decomposer technology from laboratory- to on-sun conditions and demonstrate its proof-of-concept on 150 to 300 kW_{th}-scale operating it in assembly with centrifugal particle solar receiver, under simulated solar irradiation achieving high thermal efficiency

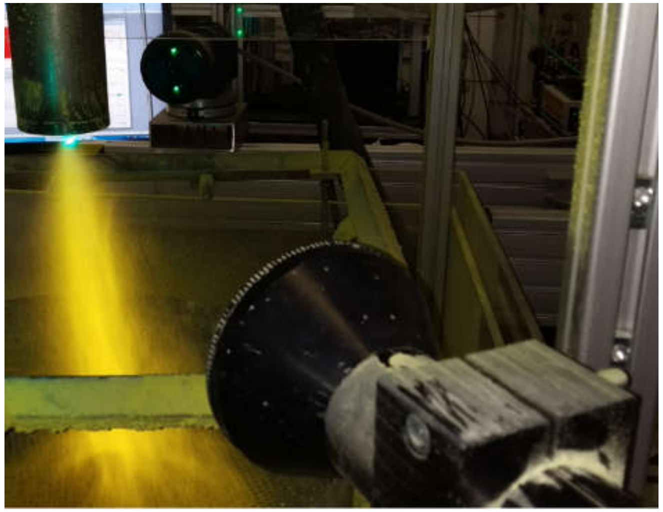


Karlsruhe Institute of Technology

Objectives and challenges
Sulphur burner for gas turbines

- Develop and realize a novel lab-scale sulphur burner in 10 kW range able to modulate up to 15 bar outlet pressure for gas turbine application





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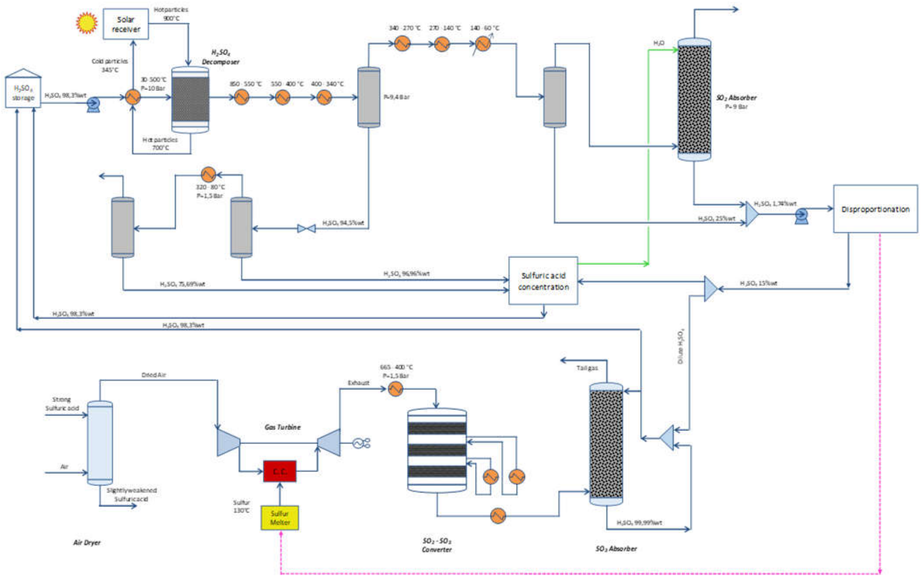
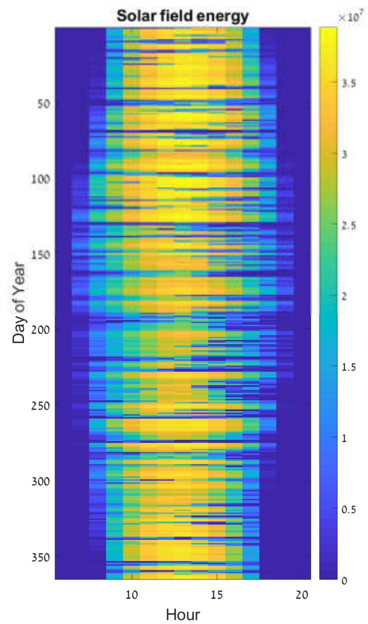
Objectives and challenges
Overall concept evaluation

- Demonstrate feasibility of over-all process, draft **complete flowsheet and techno-economic analysis** of optimized integrated process scaled-up to relevant power levels, assess technology vs. the targets set and evaluate its potential with respect of realizing a sulphur storage cycle enabling solar power production





Thank you for your attention!

www.pegasus-project.eu

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