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Lecture:
Solar Heat for Industrial Processes at high temperatures

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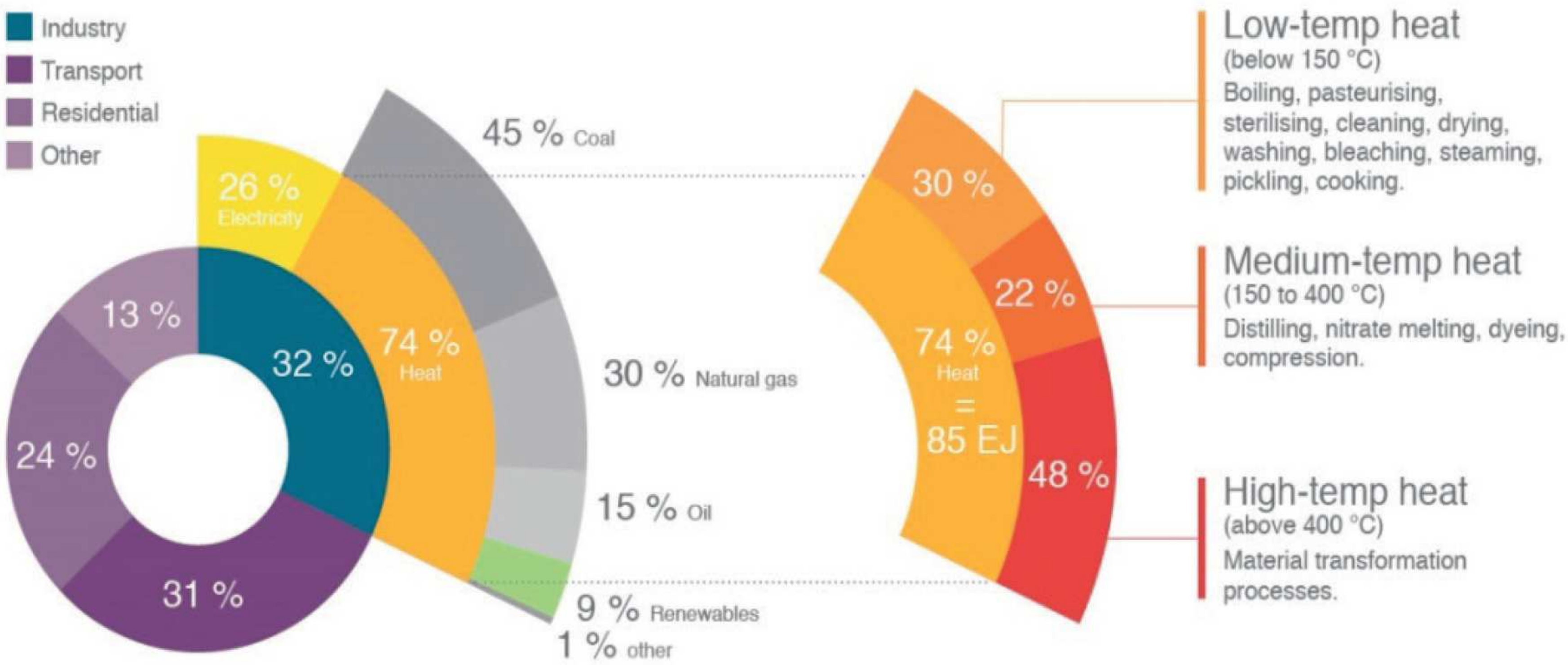
Content:

- Introduction
- Objectives and Motivation
- Identification of high-temperature endothermic processes in the mineral processing; lime production, etc
- Project experiences : SOLSYN, Hydrosol, SOLPART
- Evaluation of solar chemical reactor concepts and designs; optical requirements.
- SWOT analysis

Technology and applications to high temperature SHIP

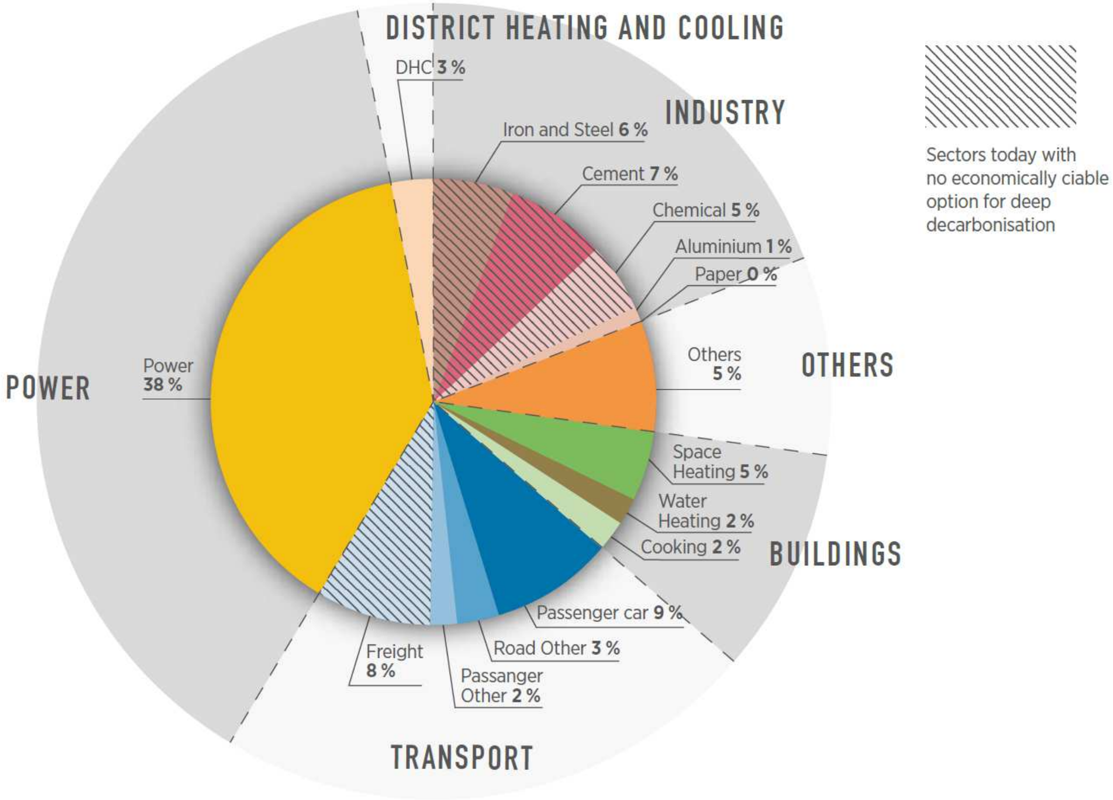
Share and breakdown of heat demand in industry



<u>**Total global final energy use in 2018**</u>

Technology and applications to high temperature SHIP (400ºC to 1500°C)

Breakdown of global energy-related CO2 emissions by sector in 2015.



Complete decarbonisation requires lowering net CO2 emissions not only from the electricity sector, but also from industrial processes and transport

Technology and applications to high temperature SHIP

The extractive metallurgical industry is the major contributor of CO_2 emissions derived from the combustion of fossil fuels for heat and electricity generation.

Iron and steel is the second-largest industry energy consumer, claiming 23% of total global industry final energy demand, but it is the largest industrial CO_2 emitter, with 28% of the sector's total direct CO_2 emissions in 2014 .

This share accounts for 7% of total energy-related CO_2 emissions, and is projected to increase to 10% by 2050 under the 2DS (IEA, 2017a).

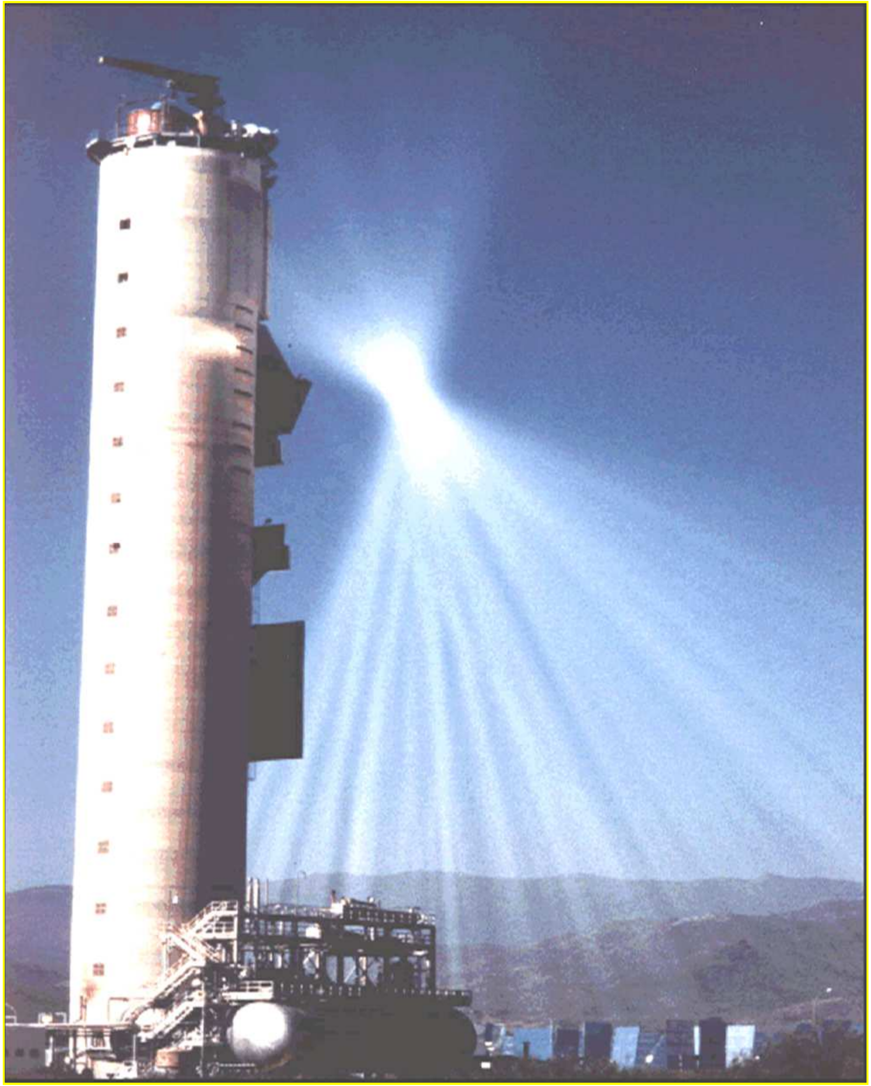
Cement is the third-largest energy consumer in the industry sector, accounting for 7% of total final industrial energy use, but due to important process emissions, cement has the second-largest share of CO_2 emissions from industry at 27%, i.e. 6.5% of total energy-related CO_2 emissions.

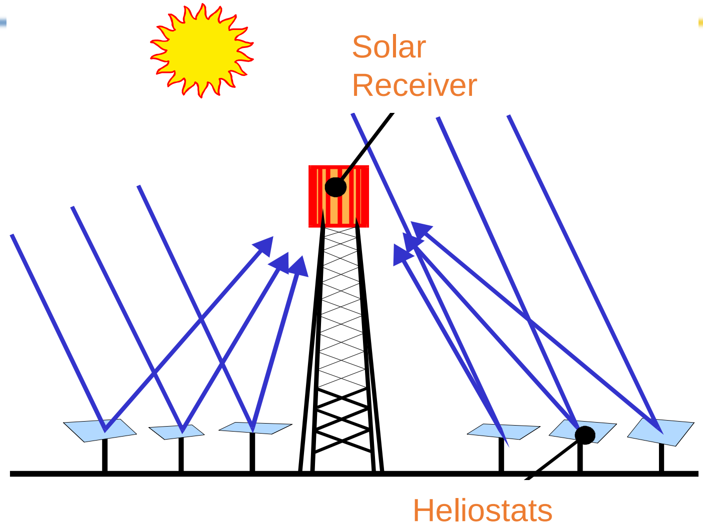
This share is projected to double by 2050 under the 2DS, putting the cement subsector in first place.

Currently, over 95% of hydrogen, a global production of about 70 Mt/y, is generated from fossil fuels: from natural gas through steam methane reforming (SMR), from cracking oil products in refineries, and from coal gasification, mainly in China.

According to the hydrogen economy concept, hydrogen will gradually replace fossil fuels and become the main energy carrier in the second half of the 21st century Energy-related hydrogen production and consumption between 2050 and 2100 may exceed the current level by tens or even hundreds of times.

Point-focus technologies





Key technologies

- **Direct use of concentrated solar thermal (CST) heat:** Technologies are under development with a realistic expectation to supply heat at 800 – 1000ºC for $8/GJ.

- **Solar fuels, such as hydrogen and syngas:** New technologies are needed to produce solar hydrogen and/or syngas at costs competitive with fossil fuels.

- **Refuse derived fuels:** These fuels are well established in industries such as cement and lime. They are also a potential feedstock for more valuable products, such as plastics and liquid fuels, via solar gasification and other processes.

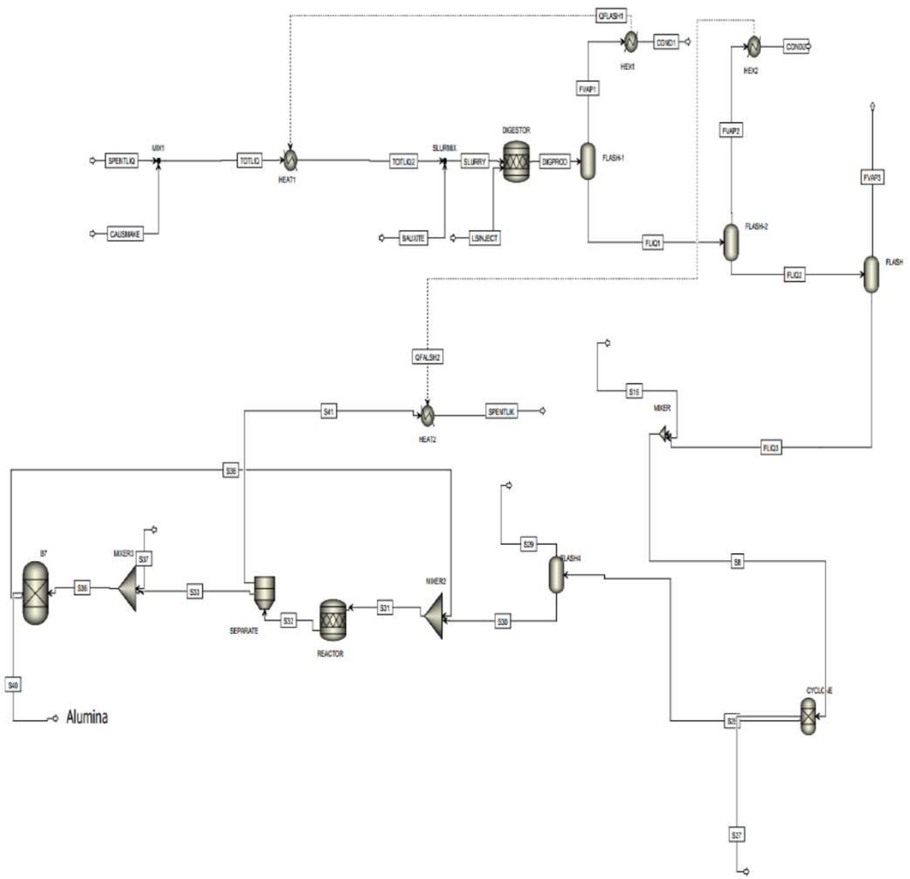
Technology and applications to high temperature SHIP (400ºC to 1500°C)

Strategy to be developed:

- Identification of high-temperature endothermic processes in the mineral processing and extractive metallurgical industry; lime production, hydrogen production, etc

- Definition of receiver requirements (including approaches to batch vs. continuous process operation) and optics system requirements; Evaluation of solar chemical reactor concepts and designs
  - SOLPART
  - Hydrosol
  - SolSyn

Technology and applications to high temperature SHIP (400ºC to 1500°C)



METHODOLOGY

Accomplished:

- Obtaining mass and energy balances for the specific industry

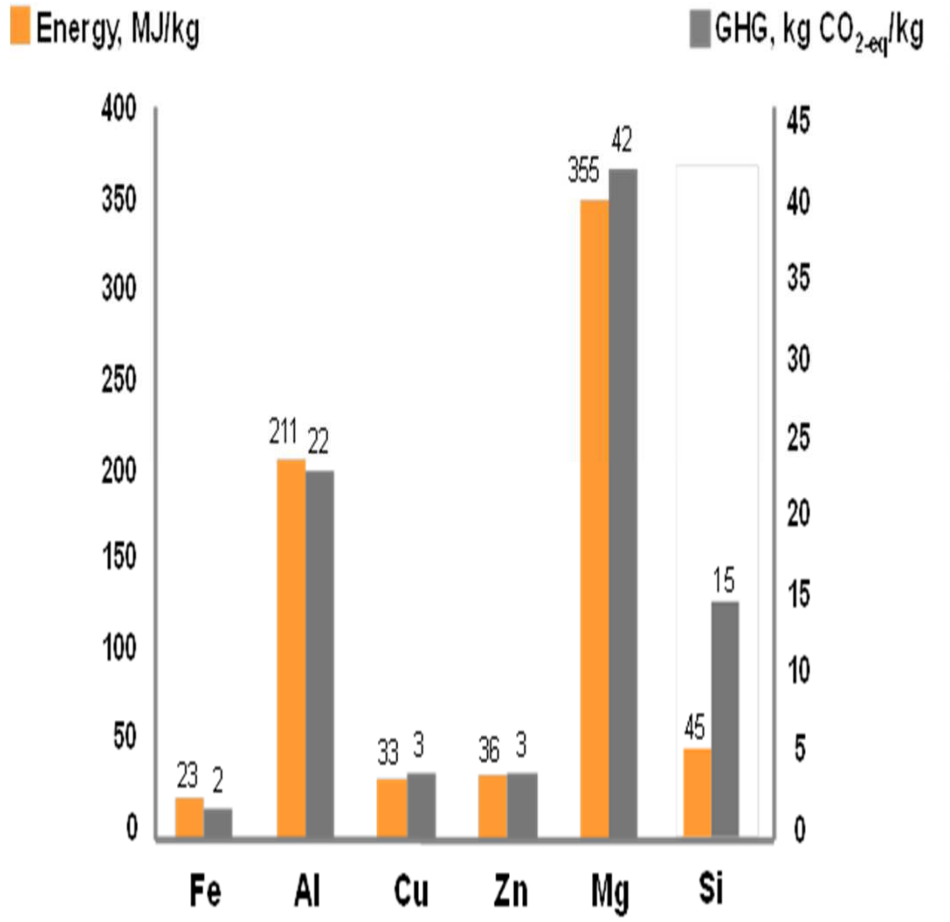
Ongoing:

- Through simulations determining possible paths for solar energy use
- By utilizing simulation results and further **expanding the developed models**, investigating solar hybridization and heat recovery options.

Planned:

- The possible hybridization paths are then simulated on TRNSYS for transient <u>analysis of the hybridized path</u>
- Evaluating large scale implementation, economic analysis and CO2 mitigation of solar assisted specific production

Solar metals production for the metallurgical industry



DEVELOPMENT LINES

Accomplished:

- Obtaining mass and energy balances for the aluminium industry

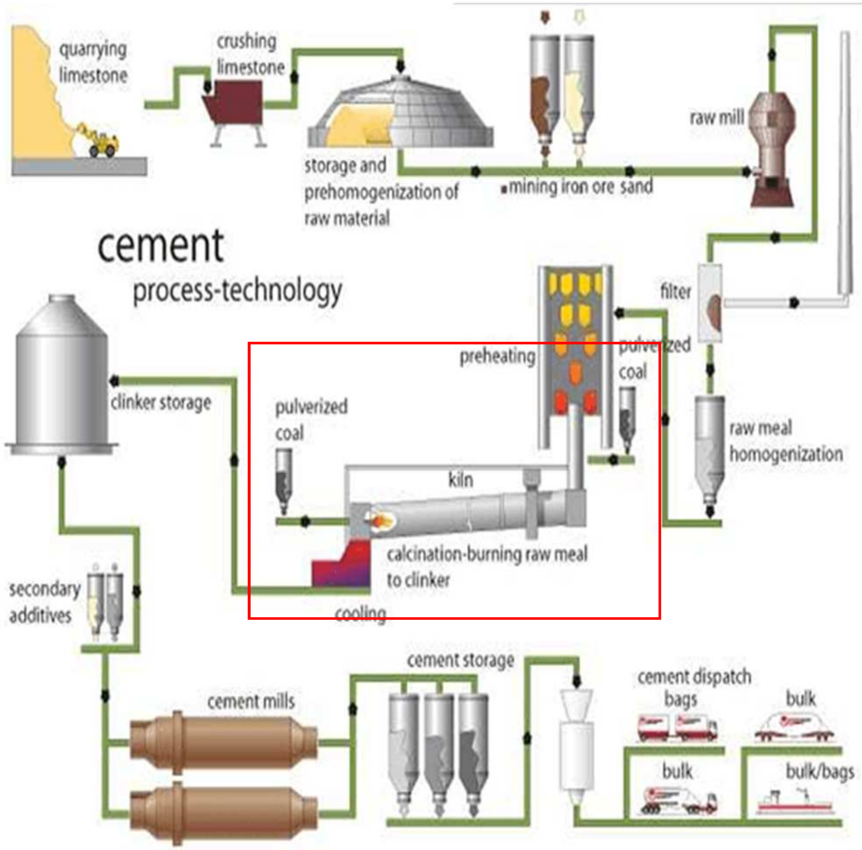
Ongoing:

- Through simulations determining possible paths for solar energy use
- By utilizing simulation results and further expanding the developed models, investigating solar hybridization and heat recovery options.

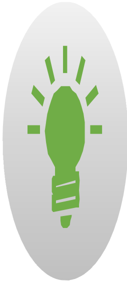
Planned:

- The possible hybridization paths are then simulated on TRNSYS for transient analysis of the hybridized path
- Evaluating large scale implementation, economic analysis and CO2 mitigation of solar assisted aluminium production

Solar lime production for the cement industry



$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$



DEVELOPMENT LINES

Accomplished:

- Obtaining mass and energy balances for the cement industry

Ongoing:

- Through simulations determining possible paths for solar energy use
- By utilizing simulation results and further expanding the developed models, investigating solar hybridization and heat recovery options.

Planned:

- The possible hybridization paths are then simulated on TRNSYS for transient analysis of the hybridized path
- Evaluating large scale implementation, economic analysis and CO2 mitigation of solar assisted cement production

Technology and applications to high temperature SHIP (400ºC to 1500°C)

Strategy to be developed:

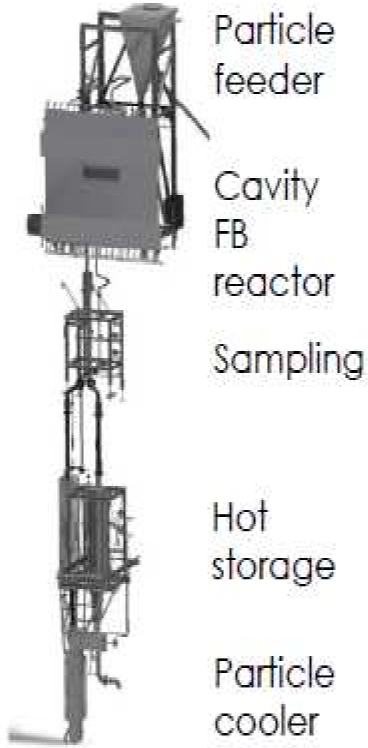
- Identification of high-temperature endothermic processes in the mineral processing and extractive metallurgical industry; lime production, hydrogen production, etc

- Definition of receiver requirements (including approaches to batch vs. continuous process operation); Evaluation of solar chemical reactor concepts and designs
  - SOLPART
  - Hydrosol
  - SolSyn

SOLPART H2020 Project

"High temperature Solar-Heated Reactors for Industrials Production of Reactive Particulates"

Develop, at a pilot scale, **a high temperature (800-1000°C) 24h/day solar process suitable for particle treatment for mineral calcination**.



Technology:

- High temperature solar reactor,
- Transport of high-temperature solid materials
- High temperature thermal storage.

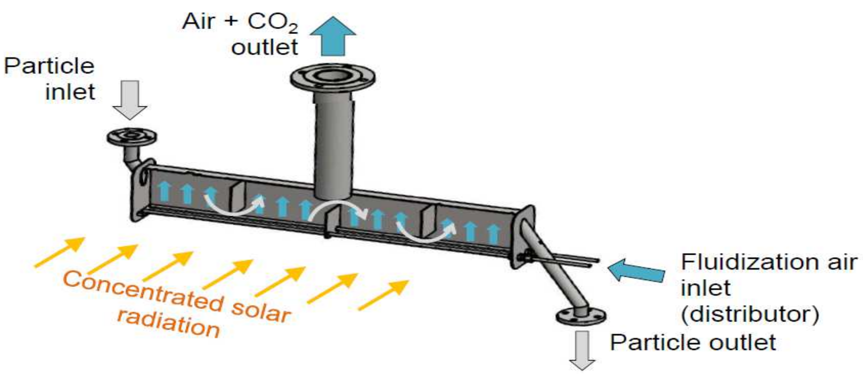
- Industry sectors: fuels, cement, glass, waste management

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

SOLPART H2020 Project
Solar reactor for mineral calcination

Solar reactors for mineral calcination

Pilot scale reactor tested at the CNRS 1 MW solar furnace



SOLPART calcination system has the potential to reduce greenhouse gas emissions by nearly 40% and the fossil energy use by 57%.

https://www.solpart-project.eu/

Technology: Solar Particle receiver

HYDROSOL-Beyond

Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond

Funding : H2020-JTI-FCH-2018-1

Period: January 2019 – December 2023

AEROSOL & PARTICLE TECHNOLOGY LABORATORY

HYGEAR

ABENGOA

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

cea

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

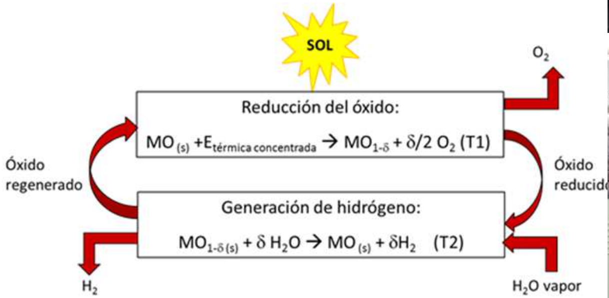
EngiCer

SUPSI

HYDROSOL-Beyond

Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond

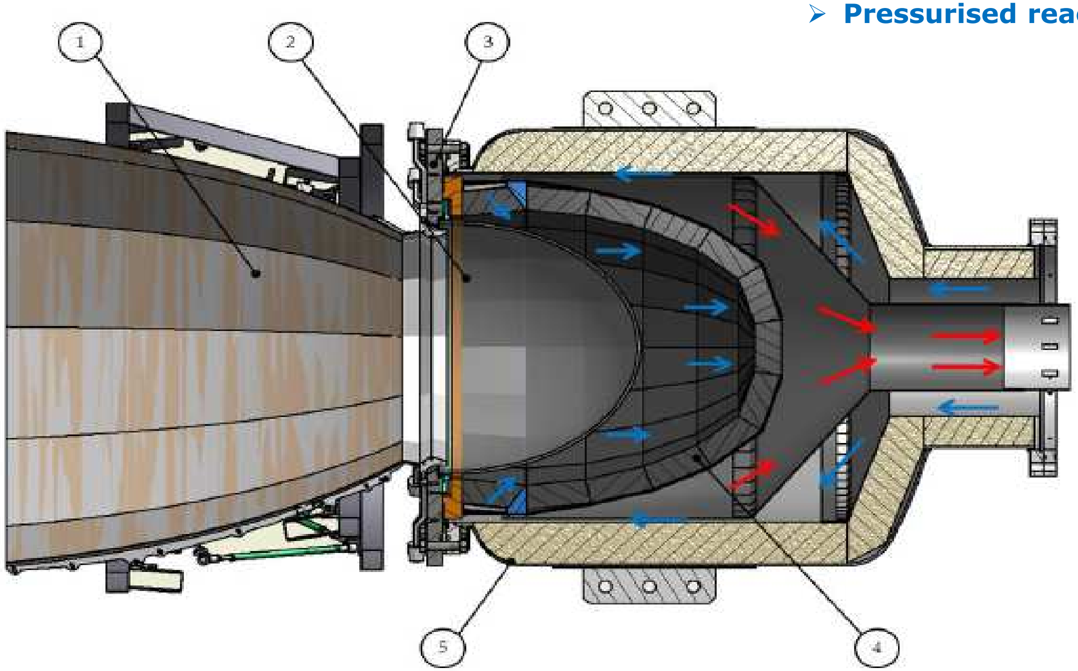
- Scaling-up the HYDROSOL reactor design while advancing the state-of-the-art (redox materials, monolithic honeycomb fabrication and functionalization) for optimum products yield.
- Construct a solar hydrogen production demonstration plant in the 750 kW range to verify the developed technologies for solar thermochemical H2O splitting.
- Design the overall chemical process, covering reactants and products conditioning, heat exchange/recovery, use of excess/waste heat, storage, monitoring and control.
- Improvement of the stability, cyclability and performance of the redox materials and redox structures (1000 cycles or 5000 hours of operation)
- Operate the plant and demonstrate hydrogen production (at levels > 7 Nm3/day)



HYDROSOL-Beyond

Thermochemical HYDROgen production in a SOLar monolithic reactor: construction and operation of a 750 kW PLANT

- **Porous monoliths of pure nickel-ferrite**
- **Secondary concentrator to reduce thermal losses**
- **Pressurised reactor**

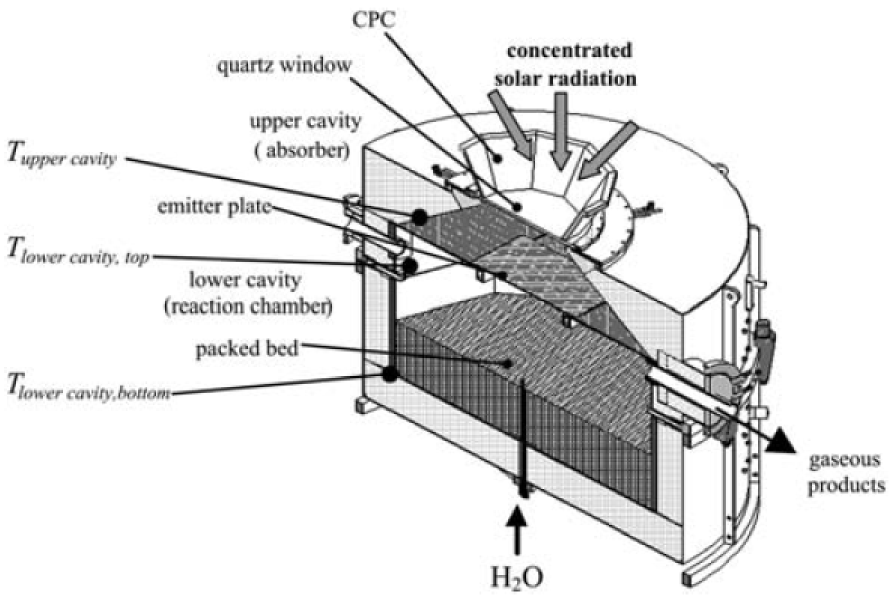


1. Secondary concentrator extension
2. Quartz window
3. Front flange
4. Volumetric absorber
5. Vessel

SOLSYN Project
Solar reactor for biomass gasification

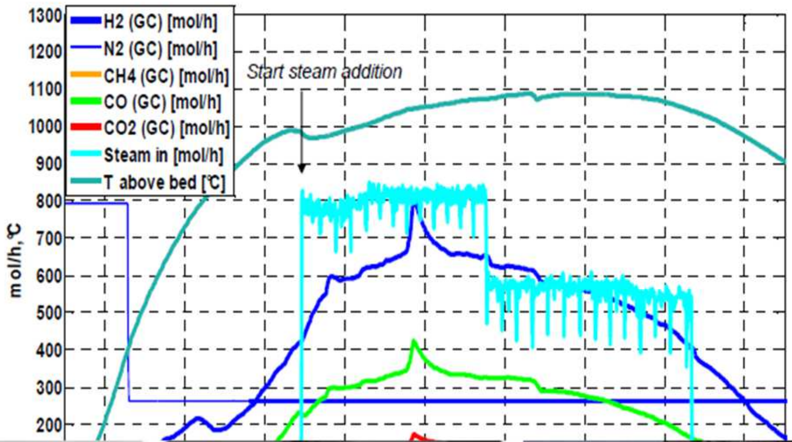
Project title: Pilot Scale Syngas Production via Solar Gasification of Carbonaceous Feedstock (SOLSYN)
Participants: ETH-PSI- HOLCIM-CIEMAT-PSA
Funding: Private
Period: January 2007 - June 2011.

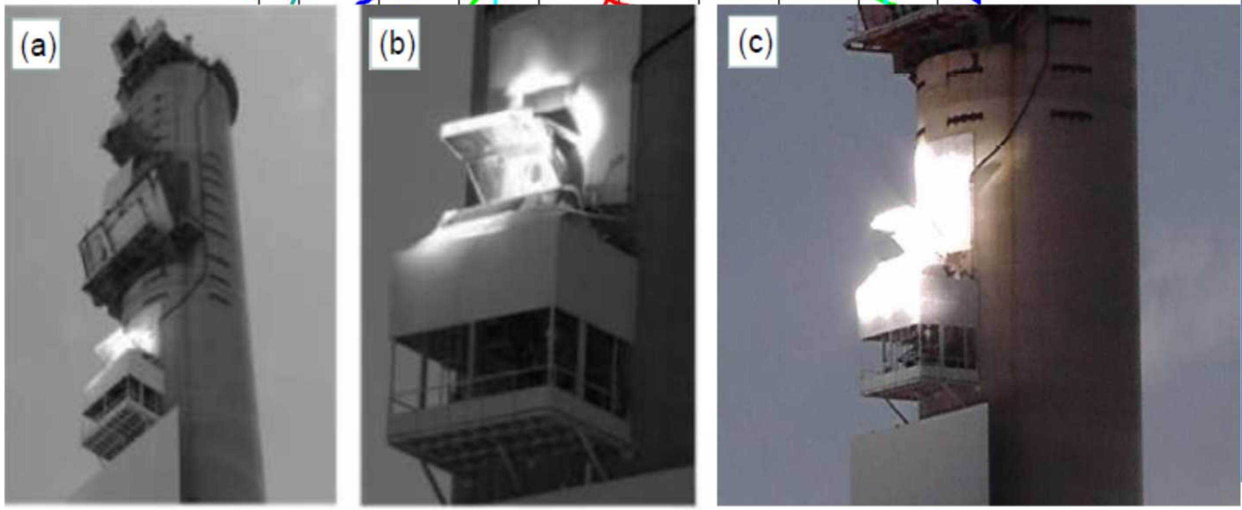
Beech charcoal
Low rank coal Coal
Dried sewage sludge
Industrial sludge
Tire chips (TDF=Tire Derived Fuel)
Fluff (Plastics)

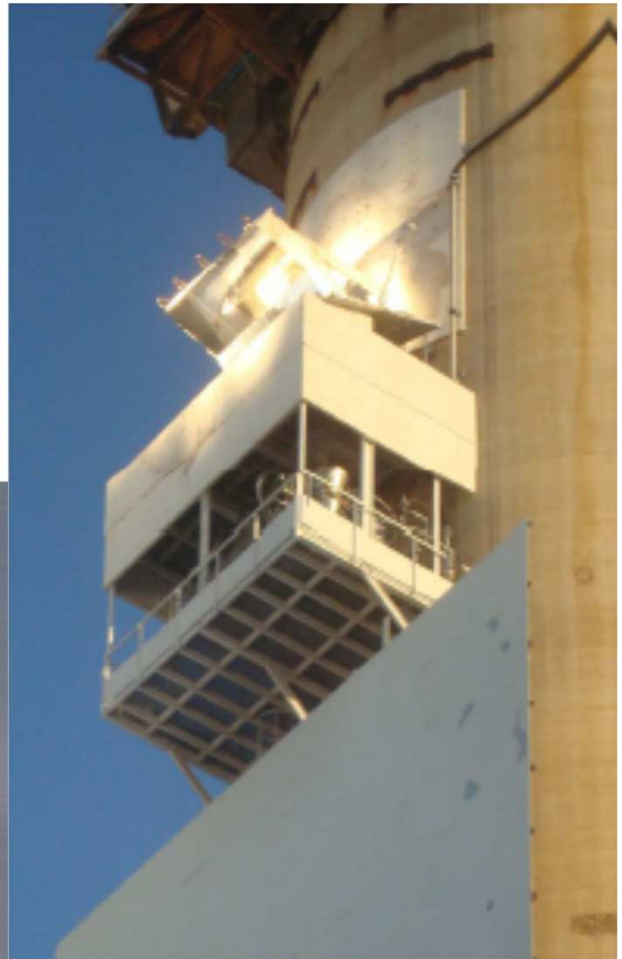


SOLSYN Project
Solar reactor for biomass gasification

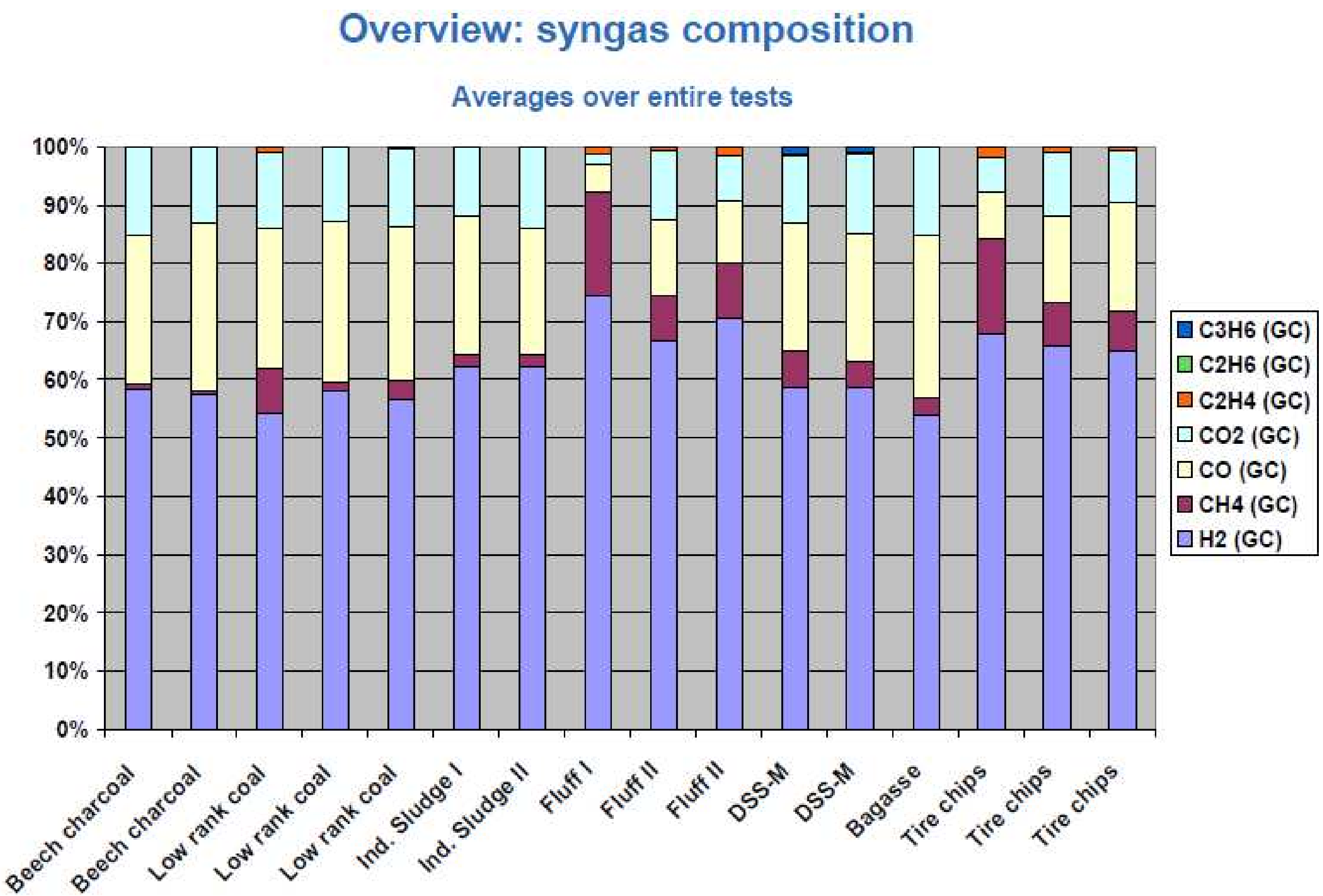
Test example: 180 kg wet low rank coal







SOLSYN Project
Solar reactor for biomass gasification

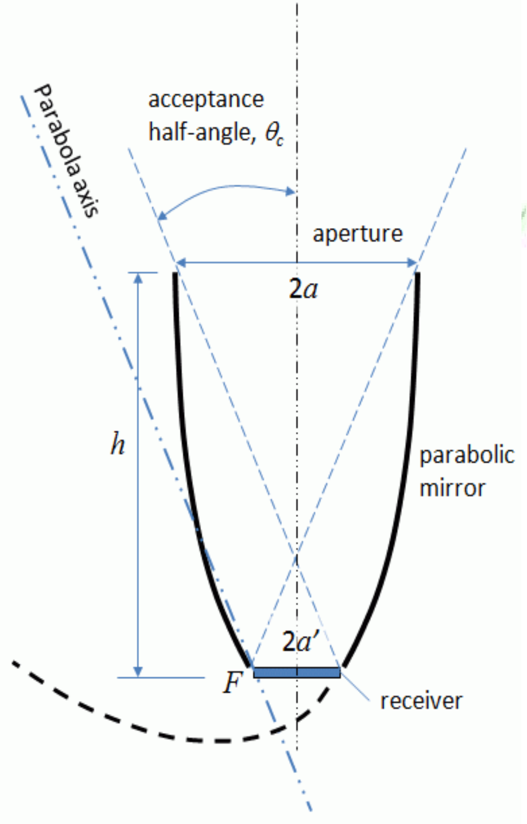


Technology and applications to high temperature SHIP (400ºC to 1500°C)

Strategy to be developed:

- Identification and energy analysis of high-temperature endothermic processes in the mineral processing and extractive metallurgical industry; lime production, hydrogen production, etc
- Definition of receiver requirements (including approaches to batch vs. continuous process operation) and optics system requirements;
  - Non-imaging optics
  - Simulation tools for high concentration optics

Non-imaging optics for solar tower and parabolic dish concentrators



Technology: Concentrated Solar Power systems

CHALLENGE

Increase the concentration factor of current solar tower and parabolic dish concentrator to operate at higher temperatures

DEVELOPMENT LINES

Accomplished: First simulation tests using non-imaging concentrators

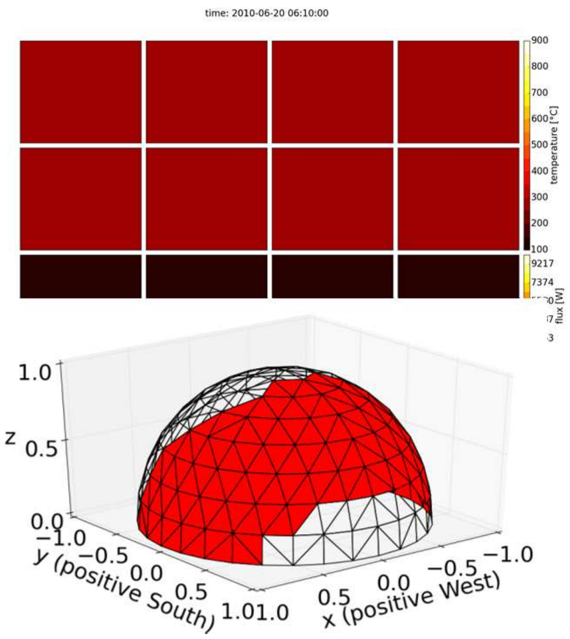
Ongoing: Design of practical solutions for solar tower system with beam-down and parabolic dish systems

Planned: Full optical and thermal performance analysis

EXPECTED BENEFITS

- ✓ Boost in concentration: Concentration factors close or even above 2000 suns are possible
- ✓ Compactness: Tower heights < 50m

Transient Simulation of High-Concentration Beam-Down Optics



Accurate assessment of high-concentration optical systems with transient simulation tools

Research institute: Fraunhofer ISE, Germany

Technology: Simulation tools

Industry sectors: CSP

CHALLENGE

Solar technologies require transient simulation and annual yield assessment due to fluctuation of efficiencies and DNI

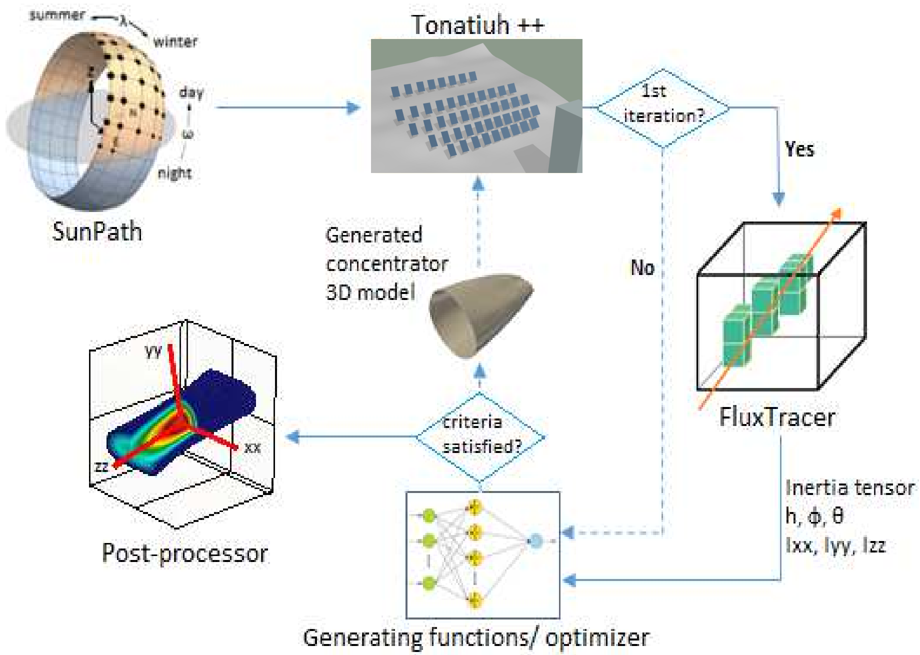
GOALS:

- Raytracing technique to calculate all the most relevant optical properties: optical efficiency, acceptance-angle, effective concentration factor in an hourly/annual basis
- F-ISE's transient optical simulation methodology (simulations will be based on F-ISE's in-house tool Raytrace3D)
- Planned: Implementation of beam-down model in the F-ISE software Raytrace3D

EXPECTED BENEFITS

✓ Developers: Evaluation and comparison of competing technologies accelerated by several orders of magnitude

Open Source Ecosystem for Automatizing the Design of High Concentration Optics



Research institute: The Cyprus Institute, Cyprus

Technology: Open Source Software optimized for use in High Performance Computing (HPC) systems

Industry sectors: fuels, metals, cement, glass, waste management, electricity production

CHALLENGE

Develop an ecosystem of advanced open-source tools to assist in the design of solar concentrators

DEVELOPMENT LINES

SunPath A user friendly program to estimate the annual yield of a solar concentrating system in a given location
Tonatiuh++ HPC-optimized Monte Carlo ray tracer for the modelling, analysis, design and optimization of almost any type of solar concentrating system.

FluxTracer Monte Carlo Ray Tracing post-processor for advance analysis and exploration of ray tracing results

SolarWolf Specialized AI-enhanced and HPC-optimized Scientific Workflow System for the automatized optimization of solar concentrators

EXPECTED BENEFITS

- ✓ Capability to automatize the exploration of the optimization space, undertake ambitious optimization problems, and achieve better designs.

SWOT analysis for High T°C SHIP technology

STRENGHTS

- Utilize entire spectrum of incident solar radiation.
- Readily hybridizable with existing combustion pathways & other thermal renewable technologies
- Heat-to-heat: no intermediate energy conversion

WEAKNESSES

- Requires direct solar energy
- Raising awareness of the social and environmental aspects of the benefits of CSP
- Development of these technologies on a small scale

OPPORTUNITIES

- Enhance research on high-temperature storage and thermochemical storage technology.
- Raise global awareness on climate change

THREATS

- Dominant position of fossil fuels
- Potential ecological impact with the development of concentrating solar technologies
- Discontinuity of energy policies

Solar Facilities for the European Research Area

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End of Presentation

- Thank you for your attention
- Questions ?