Components' and Materials' Performance for Advanced Solar Supercritical CO_2 Powerplants

COMPASsCO$_2$

Project Presentation for Processes4Planet Forum

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Presentation Structure

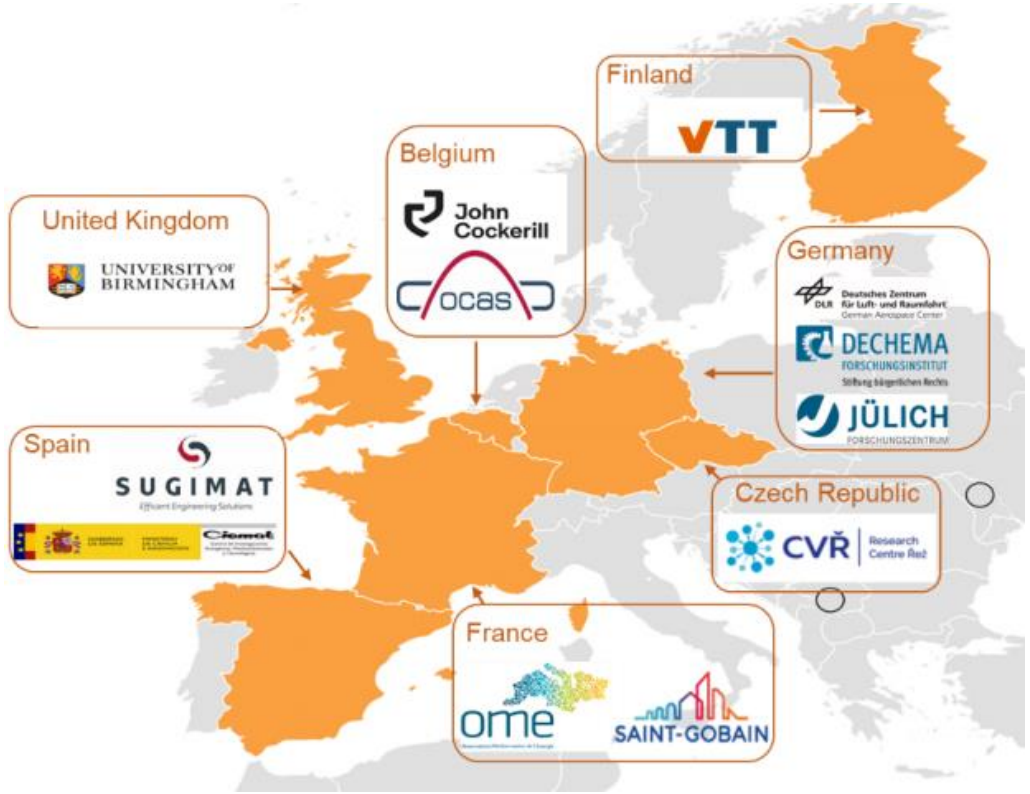
- About COMPASsCO2
- Main objectives
- Expected impact and KPIs
- Activities and progress so far
- Project's contribution to the Processes4Planet objectives

About COMPASsCO2

Project start: November 2020

Duration: 4 years

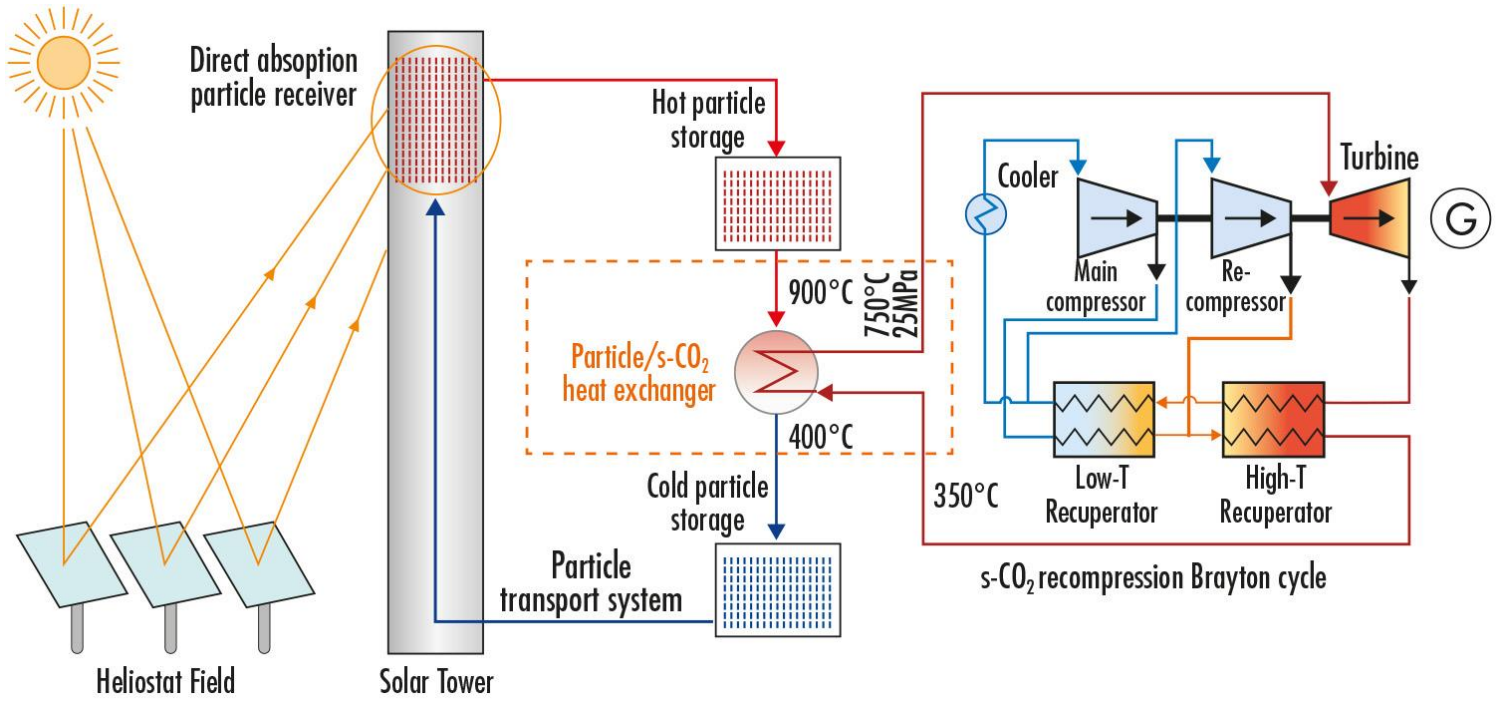
12 Partners, 7 Countries



About COMPASsCO2

The project focus is to develop **new materials for extreme conditions** in order to integrate two innovative systems:

CSP plants with particles and sCO2 Brayton power cycles



CSP: concentrated solar power, sCO2: supercritical carbon dioxide

Project Objectives / Expected Outputs

- Develop highly durable and efficient particles for CSP plants
- Develop optimized structural materials for heat exchanger tubes in contact with particles and sCO2
- Demonstrate material lifetime by measuring and modeling the degradation of the materials
- Design, construct and operate a particle/sCO2 heat exchanger section in order to validate the degradation and heat transfer models
- Evaluate the economic benefits of a CSP-sCO2 plant using the materials and components developed in COMPASsCO2 and compare it with state-of-the-art CSP plants

Expected Impacts

- **Sun-to-electricity efficiency of the overall system improved by 30%** compared to the current state-of-the-art CSP plants
- **100% CO_2-reduction** for electricity production by replacing a fossil power plant with the new sCO_2-solar-tower-system
- **20% longer service life of the particles** compared to absorber coatings of molten salt receivers.

Key Performance Indicators

Heat exchanger tubes

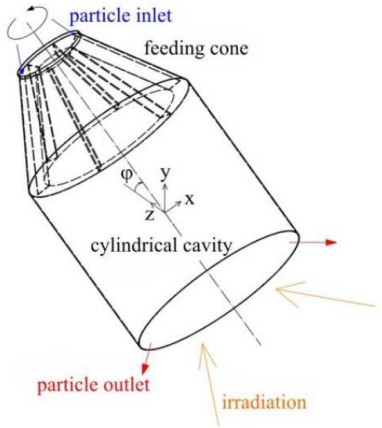
- Operating temperature ≥ 700°C
- Internal pressure ≥ 250 bar,
- Strength > 400 MPa at 23°C, > 200 MPa at 600°C, > 50 MPa at 800°C
- Elongation strain to failure ε_f > 5%
- Minimum creep rate < 10^{-6} 1/s at 200 MPa and 600-800°C
- Wear by particle erosion < 0.5% of material thickness/year
- Oxidation/carburization rate < 0.5% of material thickness/year

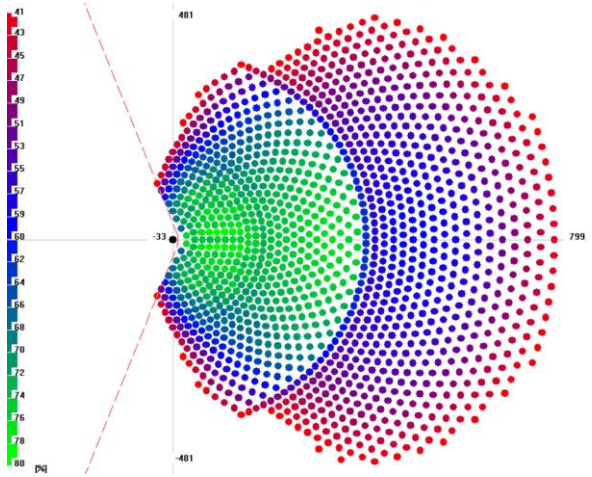
Particles for CSP cycle

- Solar absorptance αs > 95%
- Heat capacity cp > 1.5 J/g K
- Thermal stability > 900°C
- Cost < 1 €/kg
- Mass loss by attrition < 0.5 kg/MWhth,transferred
- Useable lifetime > 10 years
- Decrease in solar absorptance αs < 5%-points

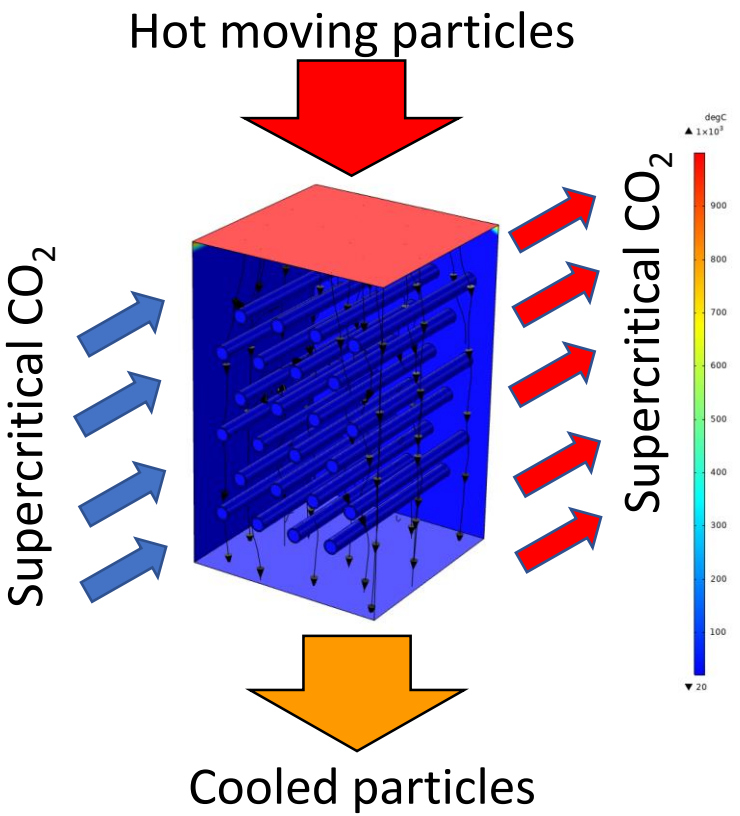
Activities and Progress: Plant Operation Conditions

Solar receiver & field optimization

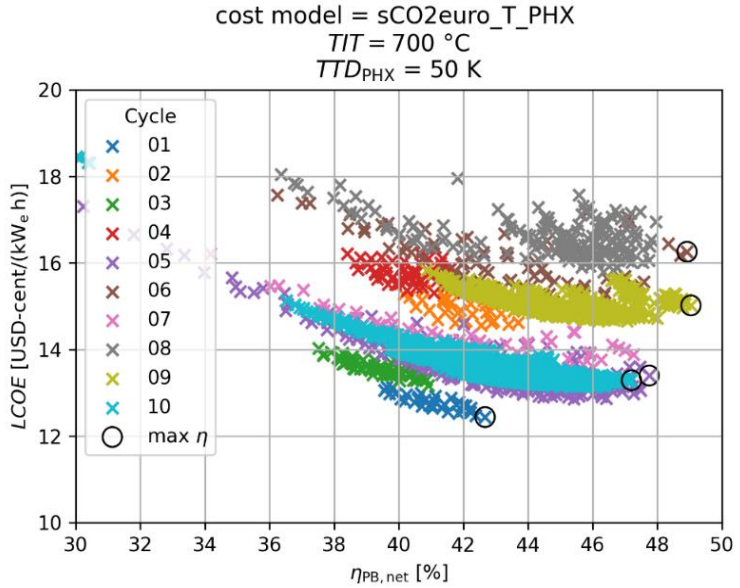




Heat Exchanger conceptual design



sCO2 Brayton power block investgation



Cycle	*LCOE* [USD-cent/kWeh]	$\eta_{PB,net}$ [%]	$T_{PHX,sCO2,in}$ [°C]	$T_{PHX,sCO2,in,RH}$ [°C]
09	15.0	49.0	533	583

Activities and Progress: Particles

Light weight proppants

Intermediate strength

High strength

State of the art proppants

Al_2O_3 rich

Price: ~1 – 1.2 €/kg

SaintGobain stopped proppant production → alternatives are needed!

3 generations developed

Raw material : recycled iron oxide from steel industry (~1 €/kg possible)

Very good thermal stability

2 generations developed

Raw materials : >70wt. % of recycled products (today)

Very high absorptance

Electrofusion process is expensive (~3 €/kg)

New particles

Tailored for CSP/CST application

Activities and Progress: Particles

Measurement of:

- Microstrucutural analysis and surface properties
- Heat capacity & density
- Softening temperature
- Breaking force
- Solar absorptance
- Thermal emittance
- Circularity and roundness

Activities and Progress: Particles

- Coating development
- Aging at constant temperature of 1000°C
- Ambient temperature abrasion experiments (impact test and planetary mill)
- High temperature attrition experiment (set-up)
- Modelling and micromechanical simulations

Activities and Progress: Metals for HX tubes

- State-of-the-art steels and Ni-based alloys selection
  - P92, IN740, Haynes 282, Sanicro 25, IN617
- Characterization (hardness, microstruture, precipitates, grain size, etc.)
- Development and production of novel Cr-NiAl alloys
  - Paper in preparation, ageing behavior > 1000 °C, corrosion test, simulations, mechanistic studies
- Development of Cr-based with silicides intermetallics alloys and coatings for conventional Fe-, Ni-base materials
  - Slurry coating, diffusion coatings with increase hardness.
- Modelling (precipitates, diffusion bonding, microstructure, etc.)

Activities and Progress: Particles + Metal + sCO2 interation

- Creep tests in air
- Creep tests in CO2
- Corrosion tests in air and CO2 at 700 and 900 °C
- Cyclic oxidation testing in air and CO2
- Isothermal oxidation tests in CO2 at 700 °C
- Preparation of corrosion tests under supercritical CO2
- High temperature erosion in air
- Simulation of corrosion and erosion

Activities and Progress: Heat Exchanger pilot test

- Pneumatic particle transportation system tests
- Electric particle heater design
- Air filter design
- Cold test to assess particle flow field
- Hot long-term abrasion test design
- Heat exchanger design
- Final demonstrator design

Project's contribution to the Processes4Planet objectives

- Selection of optimal sCO2 Brayton cycles for solar power plants
- Development of particles as heat carriers for high temperature (1000°C), thus supporting the decarbonization of industrial processes
- Development of structural materials for heat exchanger or other applications under harsh conditions regarding temperature, pressure, erosion, oxidation, corrosion, thermal cycling, etc.
- Testing and modelling of material degradation

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Thank you for your attention!