This Project has received funding from European Commission by means of Horizon 2020,
the EU Framework Programme for Research and Innovation, under Grant Agreement no.727348

Grant Agreement No. 727348

Project Acronym: SOCRATCES

Project title: **SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage.**

DELIVERABLE D9.8

Technological Brochure

Funding scheme:	Research and Innovation Action (RIA)		
Project Coordinator:	USE		
Start date of the project:	01.01.2018	Duration of the project:	36 months
Contractual delivery date:	Month 24		
Actual delivery date:	29.12.2019		
Contributing WP:	WP9		
Dissemination level:	Public		
Authors:	Ricardo Chacartegui (USE), Carlos Ortiz (USE), Andrés Carro (USE)		
Contributors:	CLS,TTZ,CERTH, VM, CSIC, AUTH, BIO, ISI		
Version:	V1		
Document name	SOCRATCES Deliverable 9.8		

SOCRATCES

Solar Calcium looping integRAtion for Thermo-Chemical Energy Storage SOCRATCES

H2020 Grant Agreement No. 727348

Foreword by Ricardo Chacartegui (USE), SOCRATCES Coordinator

Novel energy storage systems, based on abundant, cheap and environmental friendly materials, are required for the deployment of large scale solar renewable energy.

The Calcium-Looping process (CaL) as thermochemical energy storage system (TCES) could be a CSP game-changing technology in next years. It is based on calcium carbonate, one of the most abundant materials in Earth and the concept has an outstanding expected performance. For its successful development new knowledge about processes and components is required.

The project SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage (SOCRATCES)"is a research and innovation action (RIA) funded by the European Union's Horizon 2020 programme and coordinated by the University of Seville. SOCRATCES project aims to advance in the knowledge of this technology and to demonstrate its feasibility by erecting a pilot-scale plant by mid-2020.

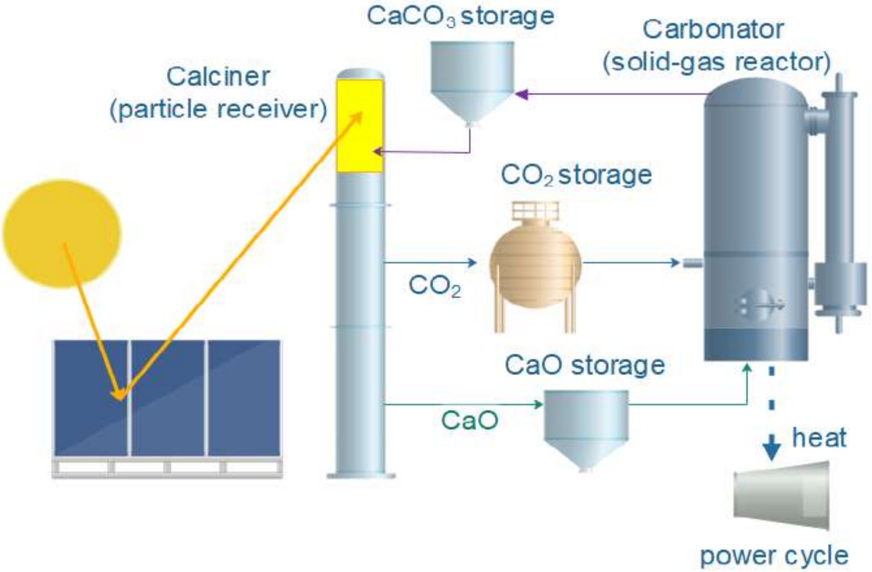
THE SOCRATCES PROJECT

The Ca-Looping (CaL) process based upon the reversible calcination/carbonation of Calcium Carbaonate ($CaCO_3$) is one of the most promising technologies for thermochemical energy storage (TCES) in Concentrating Solar Power (CSP) plants.

The **wide availability of natural limestone** (almost pure $CaCO_3$) and its low price (<10€/ton) are key factors for the feasibility of the CaL process.

RENEWABLE ENERGY STORAGE AT LARGE SCALE: A BIG CHALLENGE

Energy storage is one of the most important challenges for a short-term deeper penetration of renewable energy sources, which are usually characterized by the intermittency of power production.



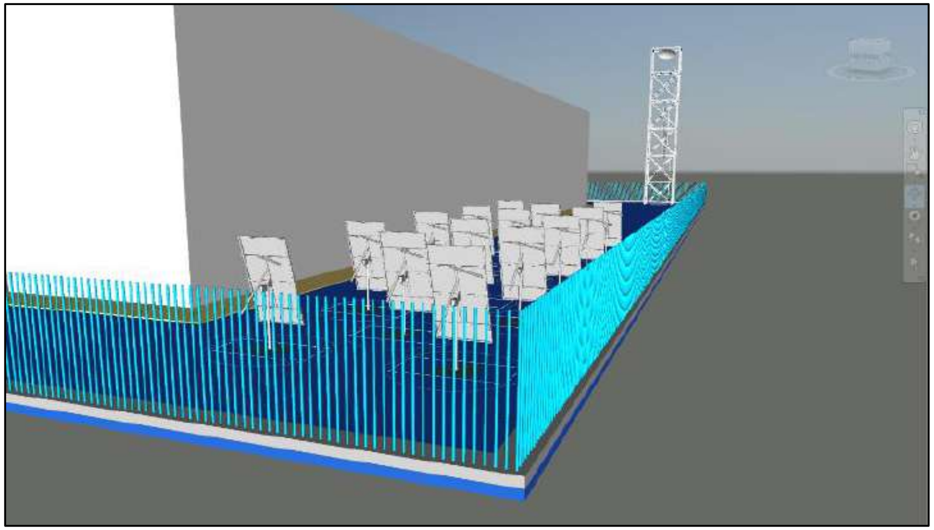
SOCRATCES conceptual scheme

THE SOCRATCES PROJECT

The global objective of the project SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage (SOCRATCES) is to advance in the knowledge of the Calcium Looping (CaL) for Energy Storage (TCES), processes and components, in order to reduce the core risks for scaling up the technology. It includes design and integration of its main components as well as the control and optimization of the operation under different CSP operation conditions. All them oriented to support scaling up designs with the longer-term goal of enabling its integration in highly competitive and sustainable CSP plants.

SOCRATCES is aimed at demonstrating the feasibility of this integration by erecting a pilot-scale plant where processes and components will be tested.

SOCRATCES technology is based on the use of cheap, abundant and non-toxic materials, and at commercial scale is conceived to integrate as mature technologies used in the industry, such as gas-solid reactors, pneumatic conveying or gas storage vessels.



SOCRATCES solar field

THE SOCRATCES PROJECT

SOCRATCES is an integral and multidisciplinary approach where different knowledge areas are involved. Associations and stakeholders offer the opportunity to widely disseminate the project and will link consortia with relevant industries in Europe.

Consortium:

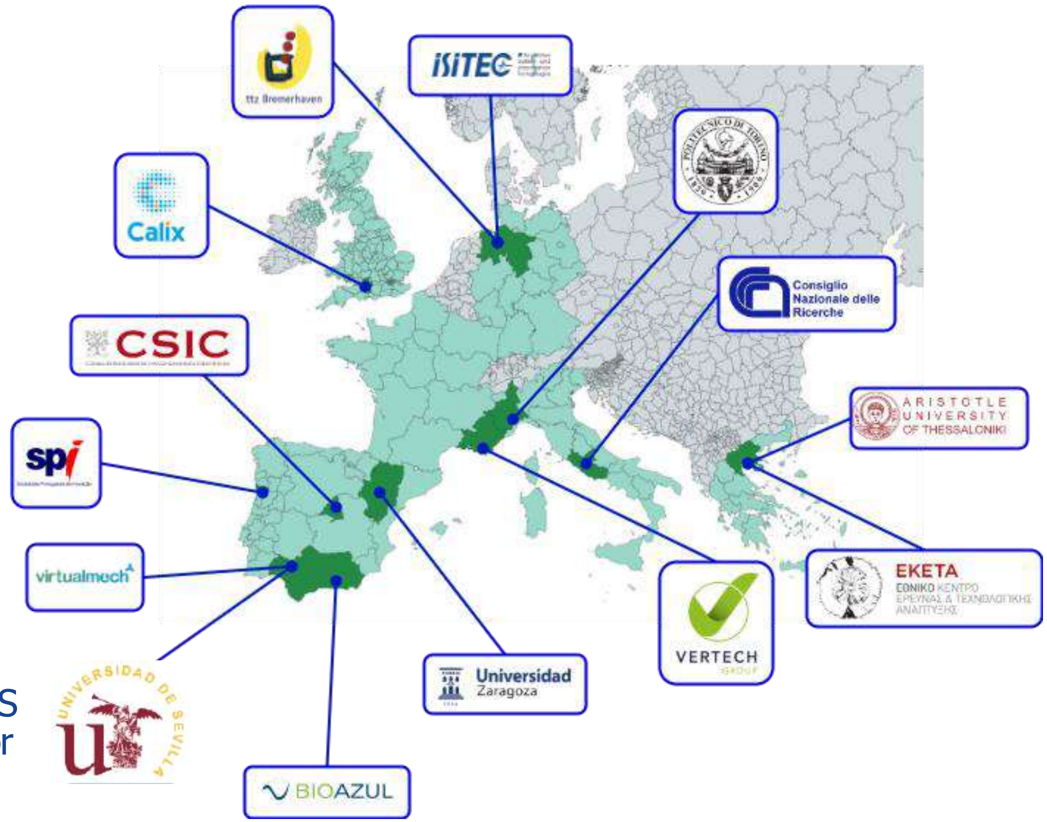
- 14 Partners
- 7 Countries

Multidisciplinary R&D groups

SMEs

Companies

SOCRATCES Coordinator



THE PROCESS

The Ca-Looping (CaL) process based upon the reversible calcination/carbonation of $CaCO_3$ is one of the most promising technologies for thermochemical energy storage (TCES). It is a potential game changing technology for CSP deployment.

SOLAR CALCINATION AND ENERGY STORAGE

The CaL process starts by using the heat available in the solar receiver to drive the calcination reaction (endothermic). Once calcination takes places in the solids particle receiver, the reaction products (CO_2 and solid CaO) are stored separately.

$$CaCO_{3\,(s)} \longrightarrow CaO_{(s)} + CO_{2\,(g)} \quad \Delta H_r = +178\ \text{kJ/mol}$$

calcination

CARBONATION AND POWER PRODUCTION

When energy is needed, the stored products are brought together at the required conditions for the reverse exothermic reaction (carbonation) to occur, which releases the previously stored energy.

$$CaO_{(s)} + CO_{2\,(g)} \longrightarrow CaCO_{3\,(s)}$$

carbonation

ADVANTAGES

- High energy storage density
- Products can be stored at ambient temperature
- Very abundant, cheap and environmentally friendly raw materials
- Energy release at high temperature

CHALLENGES

- Particles solar receiver
- High-temperature solids/gas handling

TECHNOLOGY

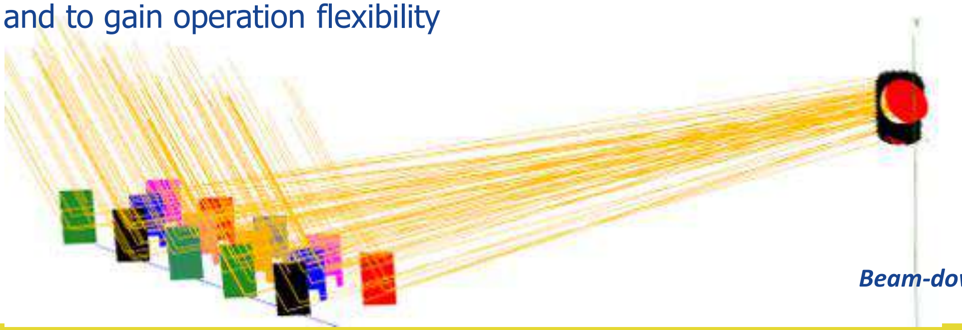
While particle solar receiver and high-temperature solids conveying represent a design challenge for the development of the CSP-CaL integration, other equipment of the plant are currently mature on an industrial scale, mainly from the cement and lime industry. This is the case of the gas-solid heat exchangers, reactors or cyclones.

SOLAR PARTICLE RECEIVER AS CALCINER

The calciner operates at 900-950ºC under atmospheric pressure and 100% CO_2 atmosphere. $CaCO_3$ particles are calcined under flash calcination concept while they fall along the reactor.

A novel entrained flow reactor (downer reactor) has been designed to carry out the calcination. The reactor is externally heated by concentrated solar power to provide the heat required to calcine the particles falling inside. A beam-down system has been designed for prototype.

At prototype level, to emulate CSP tower cavity receiver scale up conditions, a long tube external diameter electrically heated is developed and installed in series to support calcination processes in order to extract maximum information for scaling up and to gain operation flexibility



Beam-down system and solar calciner designed in SOCRATCES

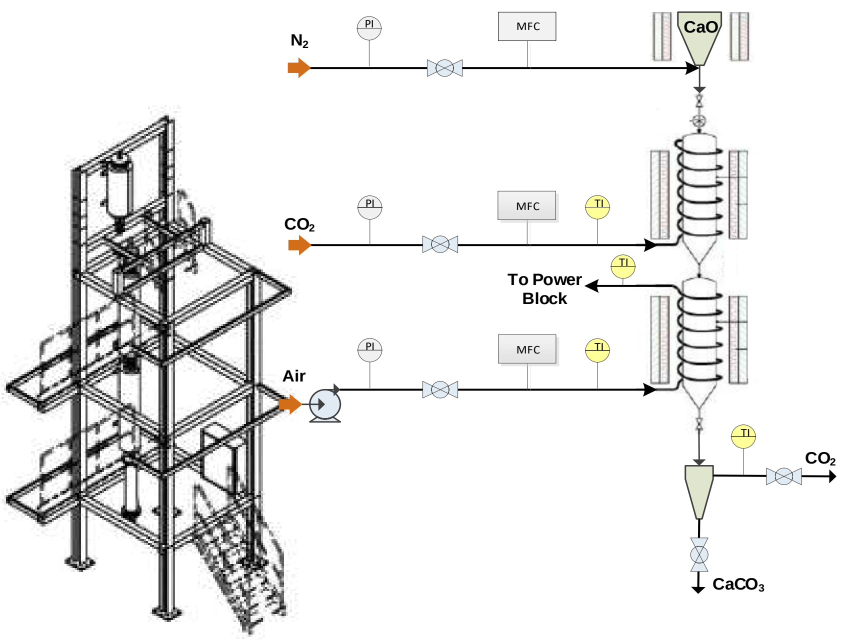
TECHNOLOGY (II)

ENTRAINED FLOW REACTOR (DOWNER REACTOR) AS CARBONATOR

As for the calcination, a novel entrained flow reactor (downer) has been designed to carry out the carbonation. This configuration allows using fine particles, which is a key point within the project scope.

The carbonator operates at ~ 800ºC under atmospheric pressure and pure CO2 atmosphere. CaO particles reacts with CO2 while they fall along the reactor.

The carbonator reactor is designed as a drop tube divided into two sections of two meters length each, comprising a four meters long reactor. Each carbonator section will be encircled by helical coils in order to remove the produced heat during the exothermic reaction. The first one is used to preheat the CO2 entering the reactor while the second is used to heat air (HTF) which is conveyed to provide heat to a power block.



SOCRATCES carbonator drawings

TECHNOLOGY (III)

SOLIDS CONVEYING SYSTEM

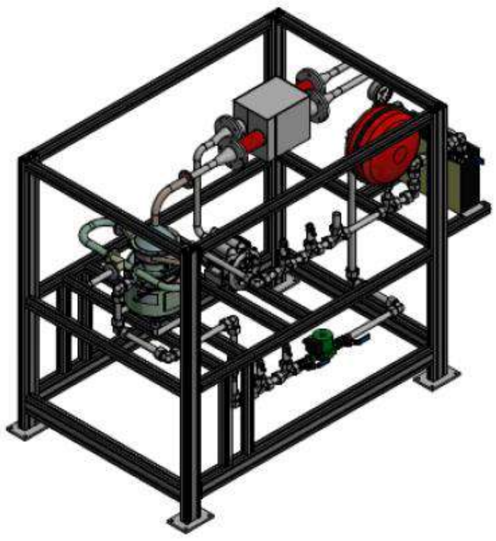
A pneumatic system is used to convey the $CaCO_3$ particles between reactor while CaO particles are transported within a swappable vessel.

POWER BLOCK

At prototype level, a Stirling engine is indirectly integrated with the carbonator to produce electricity from the heat released in the carbonator. It is used to identify the effect of laod integration in carbonator. At large scale, closed CO_2 Brayton or Rankine cycles could be integrated with high efficiencies due the high-temperature (>800 ºC) thermal power released in the carbonator

CO_2 STORAGE SYSTEM

A complete CO_2 compression and storage train has been designed to demonstrate the high dispatchability of the CSP-CaL plant.

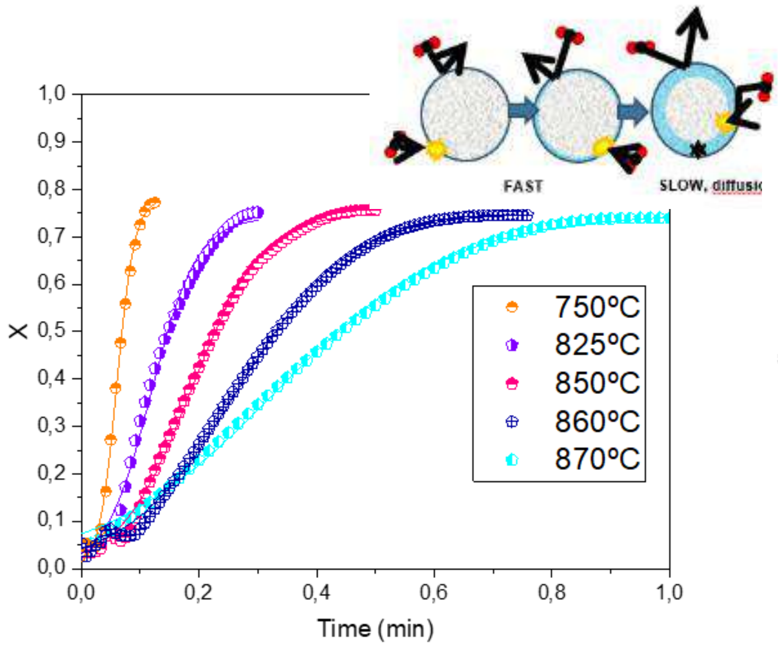


SOCRATCES power block

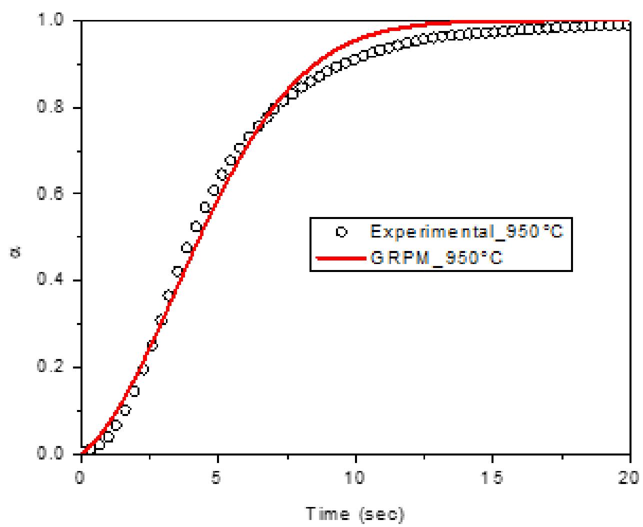
SOCRATCES MAIN OUTCOMES

CARBONATION AND CALCINATION TAKE PLACE FAST UNDER SOCRATCES CONDITIONS

An intense laboratory campaign of carbonation tests under different conditions has been carried out to assess the kinetics of the reaction. Under the specific conditions applied in the SOCRATCES concept (rich CO_2 atmosphere , small particles, carbonation in the range of 700-800ºC, calcination in the range of 925-950ºC), lab-scale tests predict a fast carbonation and calcination processes under SOCRATCES design operation. A novel kinetic model has been developed and validated at lab-scale.



SOCRATCES carbonation tests



SOCRATCES calcination tests

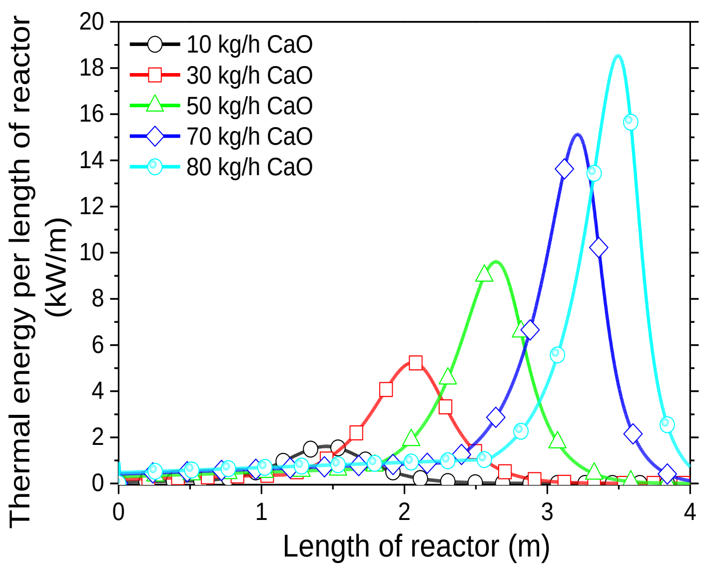
Calcination kinetics have been validated from different kinetics models such as the modified Prout-Tomkins and the Generalised Random Pore models.

SOCRATCES MAIN OUTCOMES (II)

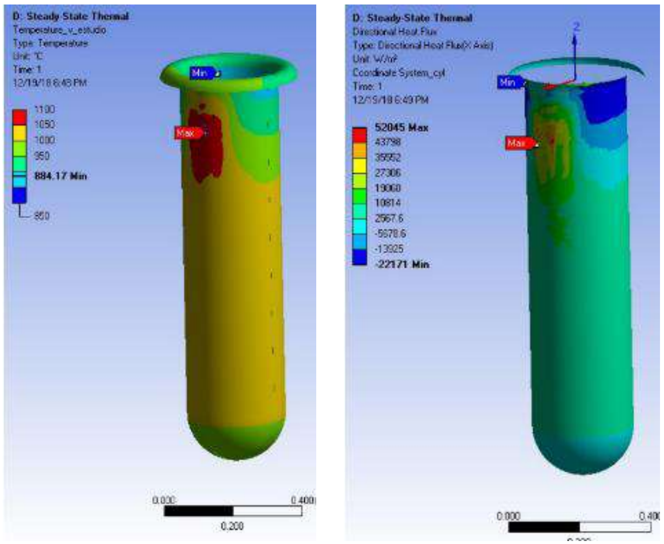
REACTORS MODELS AND DESIGN

Results from laboratory scale have been used for the design and modelling of the reactors (calciner and carbonator). Mathematical models for the reactors have been developed to understand the reactions as well as the physical and chemical transport phenomena taking place.

A proper understanding of the heat transfer mechanisms is needed to properly analyze the heat required/released in the reactor.



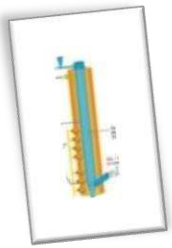
SOCRATCES carbonation model



SOCRATCES calciner design

SOCRATCES TIMELINE

The first year of the project has served to advance the knowledge of reactions and systems by modelling and test performance at laboratory scale. The important result reached have been the basis for the Front-End Engineering Design (FEED) and the Engineering Procurement and Construction (EPC) tasks. The construction is expected to start by the beginning of 2020 and the experimental campaigns (WP7) will be finished before the end of 2020.



INDIVIDUAL MODEL REPORTS

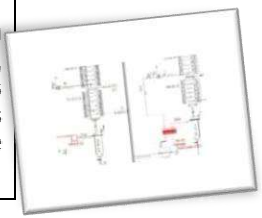
Delivery of carbonator reactor & integration model and calciner reactor & integration model.

INDIVIDUAL PROTOTYPES

Delivery of the individual prototypes for operation under Socratces operating conditions.

FINAL RESULTS

Final reports on protoype performance, characteristic curves and recommendations for scale-up the technology.



2018 - January	2018 - June	2018 - December	2019 - June	2019 - December	2020 - June	2020 - December
Start	M6	M12	M18	M24	M30	M36

FIRST STEPS

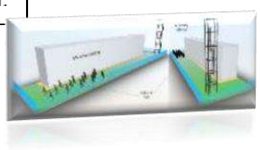
First dissemination and comunication & Research and management plan, SOCRATCES website, ...

INDIVIDUAL MODEL REPORTS

Final carbonator & calciner model, power cycles schemes, model, analysis & stirling engine integration.

FULL SYSTEM PROTOTYPE

Delivery of the integrated system.



NEXT

LONGER-TERM GOAL: ENABLING HIGHLY COMPETITIVE AND SUSTAINABLE TCES CSP PLANTS

SOCRATCES project will reach a TRL 5 at the end of the project in December of 2020.

Behind SOCRATCES the forecasted pathway to commercial level for technology is:

Step 1 SOCRATCES(2018-2020)->TRL 5

Step 2 NEXT PROJECT (2021-2025) → TRL7

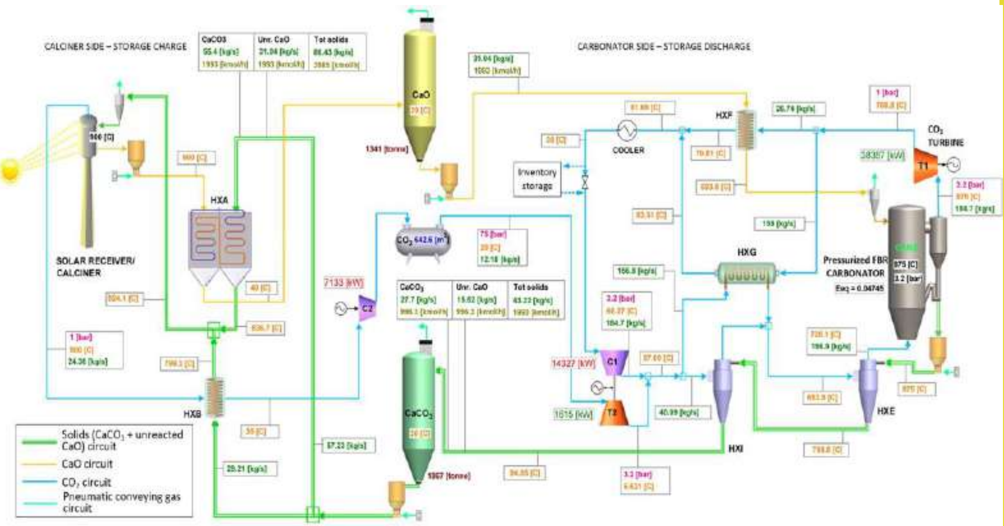
Step 3 NEXT PROJECT (2025-2029) → TRL10

Khi Solar One central tower configuration. Design with potential for scaling-up the SOCRATCES technology at next stages

IMPACT

SOCRATCES is intended to open a new pathway, with the development of an European game changing thermochemical energy storage technology, for next generation of CSP tower plants with high dispatchability based on a technology viable, profitable and sustainable. At commercial scale it is expected that the integration of this technology allows:

- A significant increase in the CSP plant **dispatchability and efficiency** by integrating the CaL process. Power cycle efficiencies higher than 45% are expected.
- **Industrial competitiveness:** optimization of the storage system are in line with a cost estimation at the end of the development roadmap at commercial level lower than 12€/kWhth.
- The closeness between the concept of SOCRATCES and components and processes in the cement industry could help for a **rapid penetration of the SOCRATCES TCES technology into the CSP market**.



R. Chacartegui, A. Alovisio, C. Ortiz, J.M. Valverde, V. Verda, J.A. Becerra, Thermochemical energy storage of concentrated solar power by integration of the calcium looping process and a CO2 power cycle, Applied Energy, Volume 173, 2016,

SOCRATCES

Contact

Ricardo Chacartegui

ricardoch@us.es

This Project has received funding from European Commission by means of Horizon 2020,
the EU Framework Programme for Research & Innovation, under Grant Agreement no.727348.