

Grant Agreement No. 727348

Project Acronym:

**SOCRATCES**

Project title:

**SOLar Calcium-looping integRation for Thermo-Chemical Energy Storage.**

**DELIVERABLE D9.5**

**Dissemination materials**

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<b>Project Coordinator:</b>	USE		
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## **1 INTRODUCTION**

This deliverable aims to show all the dissemination material developed for the SOCRATCES project and the dissemination efforts done during the 48 months of the project. These activities have been designed and carried out to show the objectives, challenges and purpose of the project.

Different dissemination material of SOCRATCES was developed during the project with the aim of sharing it with the main stakeholders. This material was formed by a project leaflet, a technical brochure and some posters that the partners created to boost the potential of the SOCRATCES thermochemical energy storage concept and related technological advances.

However, due to the COVID-19 crisis, we committed to a dissemination strategy focused on creating more digital content. This digital strategy consisted of developing different videos campaigns and banners for social media as well as network collaboration based on online events.

## 2 PRINTABLE DISSEMINATION MATERIAL

During the project, different dissemination material has been developed with the aim of making the concept of SOCRATCES known to different target groups. In this section, we have compiled the items that could be printed to be distributed at different events and activities.

### 2.1 LEAFLET

A **project leaflet** was designed at the beginning of the project in order to communicate the core objectives, challenges and purpose of the project. This leaflet content was explained in detail within deliverable 9.7.

Link: [https://socratces.eu/wp-content/uploads/SOCRATCES-flyer-pages\\_web\\_v2.pdf](https://socratces.eu/wp-content/uploads/SOCRATCES-flyer-pages_web_v2.pdf)

**PROJECT INFORMATION**

One of the great challenges for renewable energy widespread is the development of sustainable energy storage systems. Among the most promising energy storage technologies are the thermochemical energy storage systems (TCES). In them, thermal energy is used to break chemical bonds, energy that is recovered when the products are mixed. They can reach very high energy densities and allow seasonal storage.

The Ca Looping (CaL) process based upon the reversible carbonation/calcination of CaO is one of the most promising technologies for thermochemical energy storage (TCES). The wide availability of natural limestone (almost pure CaCO<sub>3</sub>), one of the most abundant materials in Earth, and its low price (~10€/ton) are key factors for the feasibility of the CaL process.

**SOCRATCES** is aimed at demonstrating the feasibility of this integration by erecting a pilot-scale plant that uses cheap, abundant and non-toxic materials as well as mature technologies used in the industry.

**SOCRATCES** global objective is to develop a prototype that will reduce the core risks of scaling up the technology and solve challenges: further understand and optimize the operating efficiencies that could be obtained with the longer term goal of enabling highly competitive and sustainable CSP plants.

**SOCRATCES TECHNICAL APPROACH**

The proposed system works as follows: solar irradiation is used to carry out the calcination of CaCO<sub>3</sub> (endothermic reaction) in a solar receiver reactor at high temperatures (725-950°C). Once calcination takes place, the product (CO<sub>2</sub> and solid CaO) are stored separately.

When power is needed the stored products are brought together into the carbonator reactor, where energy is released through the exothermic carbonation reaction at temperatures between 650-1000°C depending on the CO<sub>2</sub> partial pressure, which leads to a power cycle thermodynamic efficiency higher than in currently commercial CSP plants.

**EXPECTED RESULTS AND IMPACT**

Main expected results during the SOCRATCES project:

- Prototype demonstration of capacity for energy storage. System tested at TRL5. Solids and CO<sub>2</sub> storage.
- Successful calcination at prototype scale by means of flash calcination technology.
- Successful carbonator design with possibility for the scale-up. Integration of high temperature carbonator (~700°C) and Stirling engine for power production.
- Particles attrition, agglomeration and fouling analysis. Successful solids conveying and control system management.
- Study of CaC precursor and process conditions to allow high and stable multicycle activity.

**SOCRATCES CONSORTIUM**

**PROJECT INFORMATION**

Grant Agreement: 727348.  
 Funding programme: H2020.  
 Call: LCR-07-2016-2017  
 Duration: 01/01/2018 – 31/12/20 (36 months).  
 Total budget: 4.975.402,50€ (EC contribution: 4.973.402,50€).

**CONTACT DETAILS**

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**SOCRATCES**

[www.socratces.eu](http://www.socratces.eu)

CONTRACT N°: 727348  
 Starting date: 1st January, 2018  
 Duration: 36 months

Figure 1: SOCRATCES leaflet







Figure 5: Some posts from SOCRATCES profile on LinkedIn

**YOUTUBE**

It was also opened a YouTube channel in which we created different playlists, which includes the #SOCRATCESteam campaign and the content of the #SOCRATCESwebinars. The official video of the project and other short videos of the SOCRATCES technology also are uploaded here.

The channel currently has **20 subscribers and 27 videos**.



**Figure 6: YouTube Channel of SOCRATCES project**



**Figure 7: Playlists of SOCRATCES YouTube channel**

### 3.2 ONLINE EVENTS

The consortium has taken advantage of the boom in online events to organize different events with which to share project work and establish synergies and links with other projects, entities and organizations.

In order to achieve the greatest possible repercussion of these events and to combine the work of each one of them with the common objective of disseminating the project and its results, a corporate image was sought to bring them together, and a great effort was made in design and dissemination strategy specific to each of them. These strategies included the design of banners, a digital dissemination campaign on social networks, mailing campaigns with personal invitations to the target audience, and developing newsletters for the general public.



Figure 8: Banners of SOCRATCES webinars



Figure 9: Footers used in the e-mails of the partners.

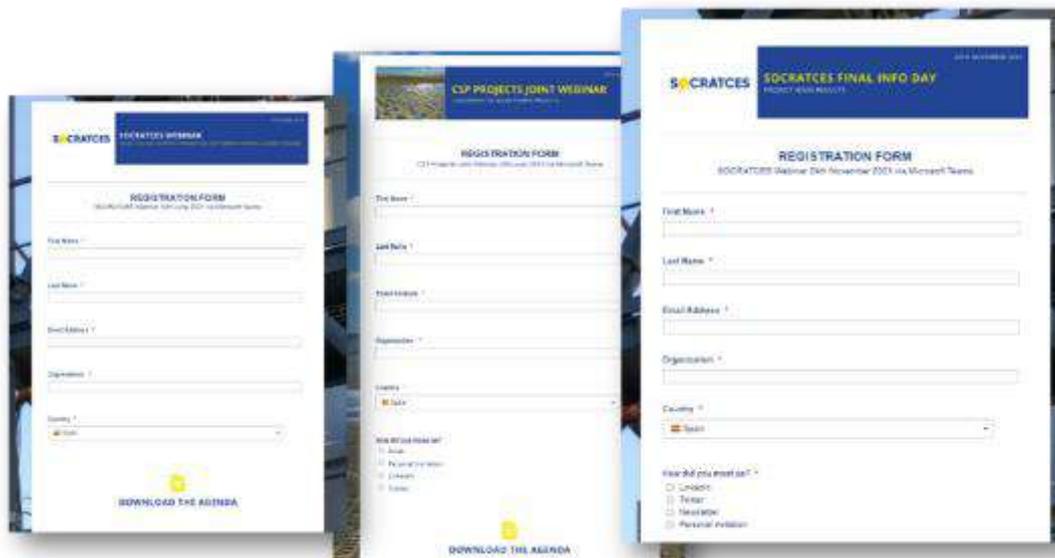


Figure 10: Invitation cards including registration links distributed by partners



Figure 11: Newsletters

Furthermore, registration forms were prepared to know the audience and establish future collaborations, in addition to complying with the data protection law regarding the recording of events and subsequent use of email addresses in other campaigns.



**Figure 12: Registration forms**

- **SOCRATCES Webinar on the 10<sup>th</sup> of June 2021.**

The consortium of the SOCRATCES organized the first webinar with the aim was to share the work developed in the project at the laboratory, generating new knowledge about the processes, developing novel models and with the design and construction of a novel CSP-CaL integration prototype to generate new knowledge and to reduce the core risks of scaling up the technology and solve challenges. It had a great acceptance, with around **100 participants** joining.



**Figure 13: Screenshots of SOCRATCES webinar June 10**

 <span style="float: right;">10<sup>TH</sup> JUNE 2021 Online seminar</span>	
<b>SOCRATCES WEBINAR</b> SOLAR CALCIUM-LOOPING INTEGRATION FOR THERMO-CHEMICAL ENERGY STORAGE	
9:00 H	<b>OPENING &amp; WELCOME</b>
9:05 H	<b>SOCRATCES PROJECT OVERVIEW: OBJECTIVES &amp; CHALLENGES</b> Ricardo Chacartegui, Professor of the Energy Engineering Department at the University of Seville
09:25 H	<b>COMPARISON OF DIFFERENT INTEGRATIONS OF CaL-CSP THROUGH MULTI-OBJECTIVE APPROACH</b> Umberto Tesio, PhD student at Energy Department of Politecnico di Torino
9:45 H	<b>OPERATIONAL PERFORMANCE OF CSP AND Ca-L</b> Luis M. Romo, Professor of the Mechanical Engineering Department at the University of Zaragoza
10:05 H	<b>CARBONATOR MODELING AND CONSTRUCTION</b> Kyriakos Fotiadis, Mechanical Engineer, MSc at Centre for Research and Technology Hellas
10:25 H	<b>COFFEE BREAK</b>
10:30 H	<b>OPTIONS FOR SCALING UP SOLAR CALCINATION</b> Thomas Hill, Research Engineer at Calix Europe Limited
10:50 H	<b>USE OF STEAM DURING CALCINATION IN THE CAL-CSP PROCESS: KINETICS AND CYCLABILITY</b> Juan Jesús Arcelegui, Postdoctoral researcher at Consejo Superior de Investigaciones Científicas
11:10 H	<b>INTEGRATION OF A POWER CYCLE WITH THE SOCRATCES TECHNOLOGY</b> Muhammad Eusha, Project Manager at TTZ Bremerhaven
11:30 H	<b>ROLE OF ACOUSTIC FIELDS ON THE FLUIDIZED BED CARBONATION FOR TCES IN CSP APPLICATIONS</b> Paola Ammendola, Researcher at Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibile
11:50 H	<b>REACTION KINETICS AND DEACTIVATION</b> Thanasis Scaltsoyionnes, PhD Candidate at Aristotle University of Thessaloniki
12:10 H	<b>HIGH-TEMPERATURE SOLAR-THERMAL TECHNOLOGY AND CALCINATION INTEGRATION. PROTOTYPE CONSTRUCTION AND INTEGRATION</b> Juan Valverde, Scientific Advisor at Virtualmechanics S.L.
12:30 H	<b>CLOUSURE</b>
Organized by: <span style="float: right;"><a href="#">Click to register</a></span>	
	
 <small>This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Grant Agreement 727348.</small>	

Figure 14: Agenda SOCRATCES webinar June 10

- **CSP Joint Webinar on the 25<sup>th</sup> of June 2021.**

The **SOCRATCES** consortium, together with [MUSTEC](#), [NEXTOWER](#) and [SFERA-III](#) H2020 projects, organized on June 25<sup>th</sup> a **CSP Projects Joint Webinar** with the aim of highlighting *Concentrated Solar Power Plants*, their potential and the future within the new Horizon Europe framework.

More than 100 participants registered for the webinar, which was moderated by **Ángela Magno**, project manager at [Bioazul](#) and dissemination leader of the SOCRATCES project.



Figure 15: Screenshots of the CSP Joint Webinar

CSP JOINT WEBINAR		25 <sup>TH</sup> JUNE 2021 <small>Online seminar</small>
<b>CSP PROJECTS JOINT WEBINAR</b> <small>CONCENTRATED SOLAR POWER PROJECTS</small>		
<b>10:00 H</b>	<b>OPENING &amp; WELCOME</b> Angela Magna, I+D Project manager and Director of Communication and Marketing at BIOAZUL.	
<b>PROJECTS PRESENTATION</b>		
	<b>MUSTEC</b> Market uptake of Solar Thermal Electricity through Cooperation Alexandra Papadopoulou, Senior Researcher at TEESLab, UPRC, MUSTEC Dissemination Leader.	
	<b>NEXTOWER</b> Advanced material solutions for next generation high efficiency concentrated solar power tower systems. Antonio Rinaldi, Senior researcher at the ENEC Sustainability Department of Productive and Territorial Systems explained. Coordinator of NEXTOWER.	
<b>10:05 H</b>	<b>SFERA-III</b> Solar Facilities for the European Research Area Ricardo Sanchez, EU Project Manager, Coordinator SFERA-III.	
	<b>SOCRATCES</b> Solar Calcium-looping integration for Thermo-Chemical Energy Storage Ricardo Chacartegui, Professor of the Energy Engineering Department of the University of Seville, Coordinator SOCRATCES	
	<b>CSP ERANET</b> Public-public partnership in the Concentrated Solar Power technology Julio Marchamelo, ERANET CoLead International project manager at the Spanish Foundation for Science and Technology, third party of the Spanish State Research Agency (AEI-TECYT).	
<b>11:00 H</b>	<b>COFFEE BREAK</b>	
	<b>OPEN SESSION</b> Round table to discuss the potential of Concentrated Solar Power Plants and its future within the Horizon Europe framework. Moderator: <b>Luis M. Romeo</b> , Professor of the Mechanical Engineering Department at the University of Zaragoza	
<b>11:15 H</b>	<ul style="list-style-type: none"> <li>Alexandra Papadopoulou, Senior Researcher at TEESLab, UPRC, MUSTEC Dissemination Leader.</li> <li>Antonio Rinaldi, Senior researcher at the ENEC Sustainability Department of Productive and Territorial Systems explained. Coordinator of NEXTOWER.</li> <li>Eduardo Zarza (Head of the Lina-Fortis Solar Thermal Technologies Unit at the Plataforma Solar de Almería)</li> <li>Ricardo Chacartegui, Professor of the Energy Engineering Department of the University of Seville, Coordinator SOCRATCES</li> </ul>	
<b>11:45 H</b>	<b>CLOSURE</b>	<a href="#">Click to register</a>
Organized by:		
    		
 <small>These projects have received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Grant Agreements No 727348, 8716426, 8721345, 8821881.</small>		

Figure 16: Agenda of the CSP Joint Webinar

• **CSP Technology day on the 21<sup>st</sup> of October 2021.**

The CSP Technology Day was a webinar organized by CSP ERANET and H2020-SOCRATCES as a side event within the **EU Sustainable Energy Week (EUSEW)**. The event was attended by more than 60 people, which aimed to present the achievements and further challenges of CSP, and present upcoming funding opportunities on the sector to keep feeding the development of this promising sustainable technology.



Figure 17: Screenshots of the CSP Technology day



Figure 18: Agenda of the CSP Technology day

• **SOCRATCES Final Info Day on 24<sup>th</sup> of November 2021.**

Last November 24th, the consortium of SOCRATCES organized the **Final Info Day** to celebrate the end of the project and present the main results achieved. More than 90 people attended this final event.

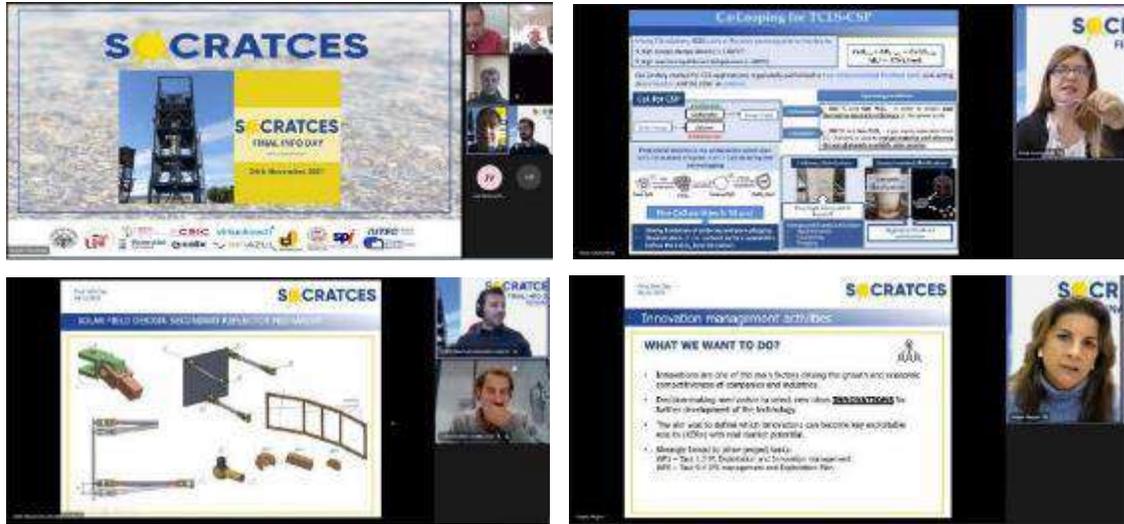


Figure 19: Screenshots of SOCRATCES webinar June 10

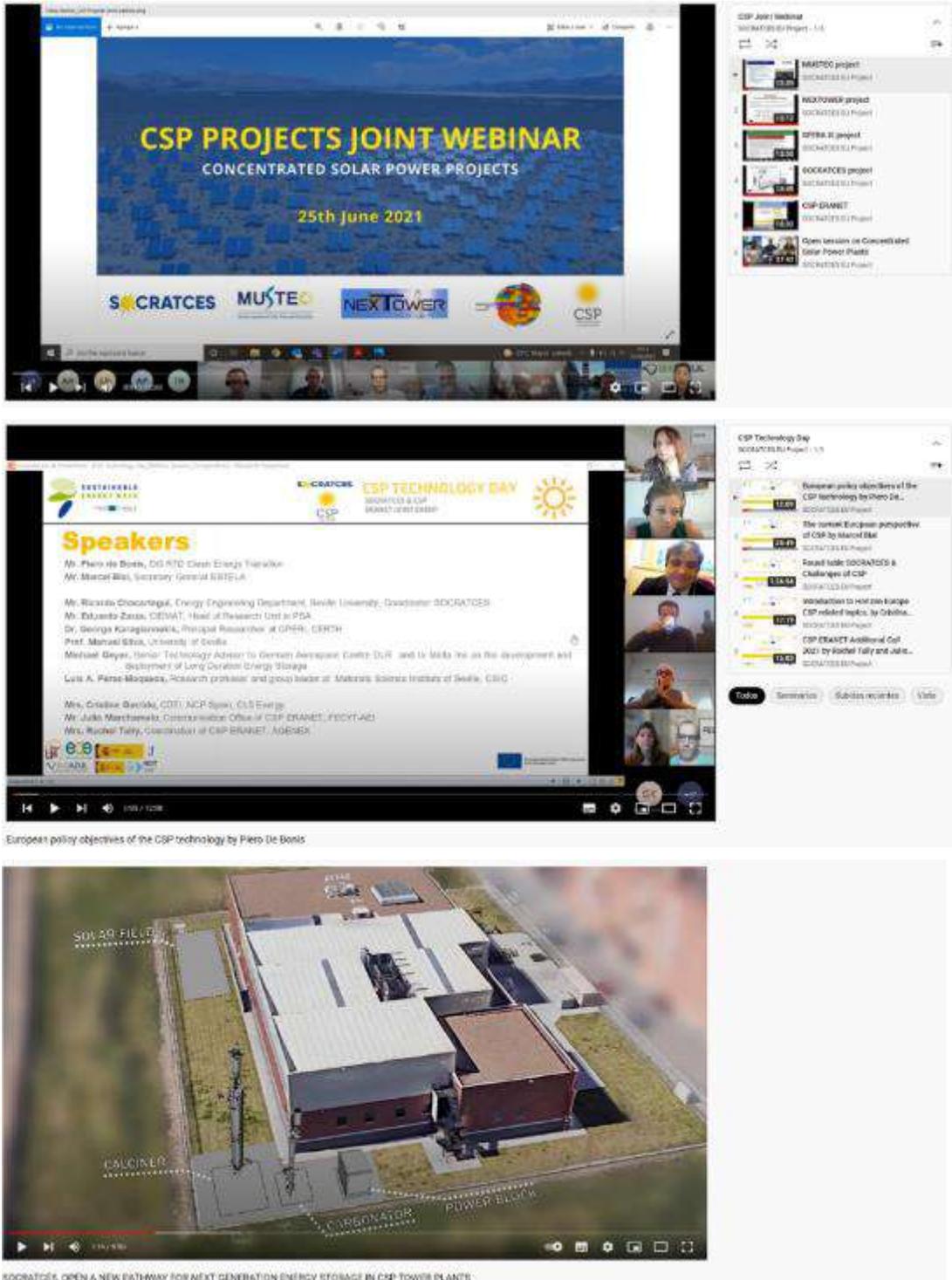
SOCRATCES		24 <sup>th</sup> NOVEMBER 2021 Online seminar
<b>SOCRATCES FINAL INFO DAY</b> SOLAR CALCIUM-LOOPING INTEGRATION FOR THERMO-CHEMICAL ENERGY STORAGE		
9:30 H	<b>OPENING &amp; WELCOME: SOCRATCES PROJECT OVERVIEW: CHALLENGES &amp; RESULTS</b> Ricardo Charataguí, Professor of the Energy Engineering Department at the University of Seville	
09:50 H	<b>COMPARISON OF DIFFERENT INTEGRATIONS OF CAL-CSP THROUGH MULTI-OBJECTIVE APPROACH</b> Umberto Tesei, PhD student at Energy Department of Politecnico di Torino	
10:00 H	<b>OPTIMIZATION OF INTEGRATION OF A STIRLING ENGINE WITH THE SOCRATCES TECHNOLOGY</b> Muhammad Easha, Project Manager at TTTZ Bremen/Haven	
10:10 H	<b>CARBONATION ON FINE LIMESTONE PARTICLES FOR TCES-CSP AS AFFECTED BY ACOUSTIC PERTURBATION</b> Paula Ammendola, Researcher at the Institute of Sciences and Technologies for Sustainable Energy and Mobility - CNR	
10:20 H	<b>KINETICS OF CALCIUM LOOPING REACTIONS AND DEACTIVATION OF MATERIALS</b> Theodoros Sotiriou-Lentres, PhD Candidate at Aristotle University of Thessaloniki	
10:30 H	<b>USE OF STEAM DURING CALCINATION IN THE CAL-CSP PROCESS: KINETICS AND CYCLABILITY</b> Juan Jesús Arcepegui, Postdoctoral researcher at Consejo Superior de Investigaciones Científicas	
10:40 H	<b>CARBONATOR MODELING AND CONSTRUCTION / NEXT STEPS</b> Kyriakos Patselis, Mechanical Engineer, MSc at Centre for Research and Technology Hellas	
10:50 H	<b>COFFEE BREAK</b>	
11:10 H	<b>SCALING UP AND SOCRATCES TECHNOLOGIES OPPORTUNITIES</b> Luis M. Romeo, Professor of the Mechanical Engineering Department at the University of Zaragoza Thomas Hill, Research engineer at calix Europe Limited	
11:30 H	<b>LESSONS LEARNED FROM SOCRATCES CONSTRUCTION AND OPERATION</b> Juan Valverde, Scientific Advisor at VirtualMechatronics, S.L. Carlos Ortiz, Professor at Loyola University and Researcher at University of Seville	
11:40 H	<b>INNOVATION MANAGEMENT &amp; SOCRATCES DISSEMINATION</b> Angela Magno, R&D&I project manager and Director of marketing and communication at Bionair	
11:50 H	<b>SOCRATCES Business Plan and Exploitation Strategy</b> Daniel Hirtaux, Consultant at SPI	
12:00 H	<b>ROUND TABLE</b> Moderator: Ricardo Charataguí Vittorio Verda (POLITEC), Spyros Vouziatis (CERTH), Luis Pérez Maguado (CSIC), Oskar Schreck (TTZ), Luis M. Romeo (ZNR), Angelita Llamas-Gómez (ALITH), Juan Valverde (VM)	
12:30 H	<b>CLOSURE</b>	

Figure 20: Agenda SOCRATCES webinar June 10<sup>th</sup>



**#SOCRATCESwebinars**

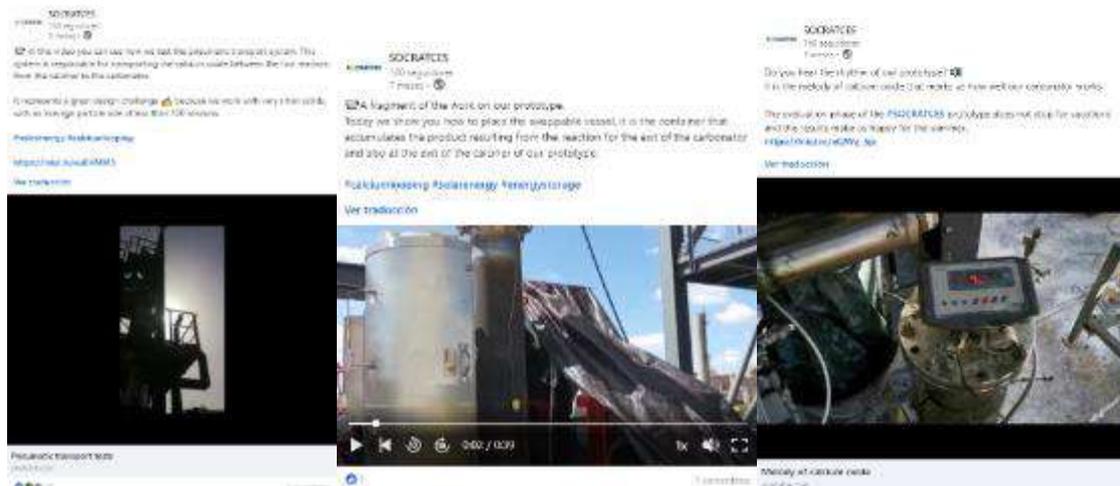
Another of the main actions of the dissemination strategy has been the organization of different webinars by the SOCRATCES consortium. These webinars have been the SOCRATCES Webinar (10-06-21), the CSP Joint Webinar (25-06-21), CSP Technology day (21-10-21) and the SOCRATCES Final Info Day (24-11-12). The recordings of all these webinars were also uploaded to youtube and published on LinkedIn.



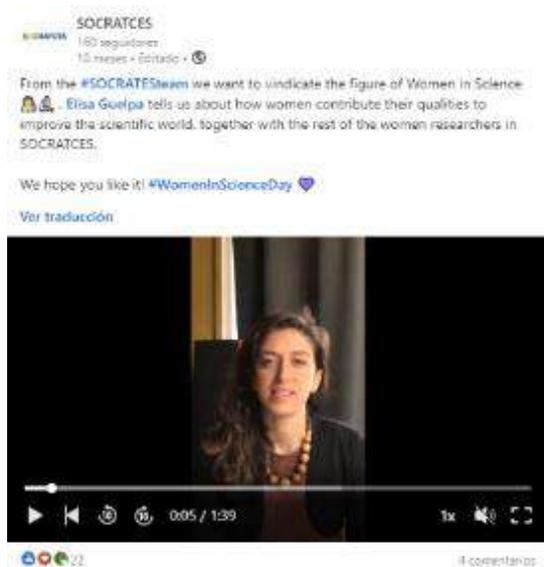
**Figure 23: Different videos of SOCRATCES webinars**

**OTHER VIDEOS**

Apart from this campaign, different videos have been published related to the different phases of the construction of the project. Another important video was the one made for Women in Science Day, where all the consortium women appear to support this initiative. The last video made has been the office of the project where all the work done and the prototype developed are explained.



**Figure 24: Videos of the construction and tests of the prototype**



**Figure 26: Women in Science Day video**



**Figure 25: SOCRATCES official video**



Figure 27: RTVE interview



Figure 28: CSIC videos



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Figure 29: Video interview by the Deutsche Welle magazine

### 3.4 PARTNER'S DIGITAL DISSEMINATION ACTIVITIES

The partners that made up the SOCRATCES consortium had disseminated the main activities of the project on their webs and social media profiles.

**Table 1 – List of dissemination activities by SOCRATCES consortium**

Partner	Type of media	Type of channel	Weblink	Date	Publication Topic	Info about the publication
USE	Press Release	Partner website	<a href="https://www.us.es/actualidad-de-la-us/la-us-acoge-el-lanzamiento-del-proyecto-socratces">https://www.us.es/actualidad-de-la-us/la-us-acoge-el-lanzamiento-del-proyecto-socratces</a>	17/01/2018	Project Dissemination	Project launched
BIOAZUL	Press Release	Partner website	<a href="https://www.bioazul.com/comienza-el-proyecto-socratces/">https://www.bioazul.com/comienza-el-proyecto-socratces/</a>	19/01/2018	Project Dissemination	Project launched
BIOAZUL	Other	Partner website	<a href="https://www.bioazul.com/en/portfolio/socratces/">https://www.bioazul.com/en/portfolio/socratces/</a>	19/01/2018	Project Dissemination	SOCRATCES portfolio description
ZAR	Press Release	Partner website	<a href="https://www.unizar.es/noticias/la-universidad-de-zaragoza-participa-en-un-proyecto-europeo-de-almacenamiento-de-energia">https://www.unizar.es/noticias/la-universidad-de-zaragoza-participa-en-un-proyecto-europeo-de-almacenamiento-de-energia</a>	30/01/2018	Project Dissemination	Project launched
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/socratces-covered-at-the-local-bremerhaven-newspaper/">https://socratces.eu/socratces-covered-at-the-local-bremerhaven-newspaper/</a>	11/02/2020	Project Dissemination	SOCRATCES covered at the local Bremerhaven newspaper
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/bremerhaven-university-student-workshop-on-socratces/">https://socratces.eu/bremerhaven-university-student-workshop-on-socratces/</a>	13/02/2020	Workshops	Bremerhaven University Student Workshop on SOCRATCES
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://twitter.com/bioazul_spain/status/1228274275787968512?s=20">https://twitter.com/bioazul_spain/status/1228274275787968512?s=20</a>	14/02/2020	Events	Publication related to the World Energy Day, promoting the project and the event with SCARABEUS
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/posts/bioazul-spain_daedamundialde-la-energaeda-socratces-activity-6634041088300597248-D9FI/">https://www.linkedin.com/posts/bioazul-spain_daedamundialde-la-energaeda-socratces-activity-6634041088300597248-D9FI/</a>	14/02/2020	Events	Publication related to the World Energy Day, promoting the project and the event with SCARABEUS
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/scarabeus-dissemination-day/">https://socratces.eu/scarabeus-dissemination-day/</a>	25/02/2020	Events	SOCRATCES participates at the SCARABEUS Dissemination Day

BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/scienceies-youth-with-researchers/">https://socratces.eu/scienceies-youth-with-researchers/</a>	26/02/2020	Workshops	SOCRATCES collaborates with the project 'Youth with Researchers SCIENCEIES Sevilla' 2020
BIOAZUL	Blog post	Project website	<a href="https://socratces.eu/solar-energy-as-the-basis-for-obtaining-the-exclusive-use-of-renewables/">https://socratces.eu/solar-energy-as-the-basis-for-obtaining-the-exclusive-use-of-renewables/</a>	22/04/2020	General News	SolarPower Europe and LUT University have released a new report that models a 100% renewable scenario
BIOAZUL	Blog post	Project website	<a href="https://socratces.eu/coronavirus-global-response/">https://socratces.eu/coronavirus-global-response/</a>	14/05/2020	General News	The Commission launches several specific Research and Innovation (R&I) actions through H2020 since COVID-19
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6668130802901102592/">https://www.linkedin.com/feed/update/urn:li:activity:6668130802901102592/</a>	15/05/2020	Project Dissemination	Dissemination of the work developed by Carlos Ortiz as researcher of SOCRATCES
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6686943975275868160">https://www.linkedin.com/feed/update/urn:li:activity:6686943975275868160</a>	09/07/2020	Events	6th General Assembly of the SOCRATCES project
BIOAZUL	Media Briefing	Social network-Twitter	<a href="https://twitter.com/bioazul_spain/status/1281152357263462401?s=20">https://twitter.com/bioazul_spain/status/1281152357263462401?s=20</a>	09/07/2020	Events	6th General Assembly of the SOCRATCES project
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/6th-socratces-general-assembly/">https://socratces.eu/6th-socratces-general-assembly/</a>	14/07/2020	Events	6th General Assembly of the SOCRATCES project
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6688772816785043456">https://www.linkedin.com/feed/update/urn:li:activity:6688772816785043456</a>	14/07/2020	Others	Launch of the SOCRATCES Linkedin page
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6691652952966393856">https://www.linkedin.com/feed/update/urn:li:activity:6691652952966393856</a>	22/07/2020	Events	6th General Assembly of the SOCRATCES project
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/update-carbonator-construction/">https://socratces.eu/update-carbonator-construction/</a>	05/08/2020	Project Dissemination	Update about the SOCRATCES' Carbonator construction
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6697078803128233984">https://www.linkedin.com/feed/update/urn:li:activity:6697078803128233984</a>	05/08/2020	Project Dissemination	Update about the SOCRATCES' Carbonator construction
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6701752196817584128">https://www.linkedin.com/feed/update/urn:li:activity:6701752196817584128</a>	19/08/2020	Workshops	Bremerhaven University Student Workshop on SOCRATCES
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6712261835476803584">https://www.linkedin.com/feed/update/urn:li:activity:6712261835476803584</a>	17/09/2020	Project Dissemination	Rendered images of the SOCRATCES prototype
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/youth-with-researchers-scienceies/">https://socratces.eu/youth-with-researchers-scienceies/</a>	28/09/2020	Project Dissemination	Honourable Mention for SOCRATCES within the "Youth with Researchers SCIENCEIES"

BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6716289480094998528">https://www.linkedin.com/feed/update/urn:li:activity:6716289480094998528</a>	28/09/2020	Project Dissemination	Honourable Mention for SOCRATCES within the “Youth with Researchers SCIENCEIES”
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6719202241905012736">https://www.linkedin.com/feed/update/urn:li:activity:6719202241905012736</a>	06/10/2020	Project Dissemination	Images of the Solar Tower construction
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6724208354538905600">https://www.linkedin.com/feed/update/urn:li:activity:6724208354538905600</a>	20/10/2020	Project Dissemination	Power block testing in Bremerhaven
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6730384562024714240">https://www.linkedin.com/feed/update/urn:li:activity:6730384562024714240</a>	06/11/2020	Project Dissemination	Calciner on the site
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6740210265993867265">https://www.linkedin.com/feed/update/urn:li:activity:6740210265993867265</a>	03/12/2020	Project Dissemination	Calciner installation
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6746740992365400064">https://www.linkedin.com/feed/update/urn:li:activity:6746740992365400064</a>	21/12/2020	Project Dissemination	Paper on the integration of Thermochemical Energy Storages (TCES)
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6747420603587837953">https://www.linkedin.com/feed/update/urn:li:activity:6747420603587837953</a>	23/12/2020	Project Dissemination	Christmas card
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6752841320768827392">https://www.linkedin.com/feed/update/urn:li:activity:6752841320768827392</a>	07/01/2021	Project Dissemination	New website section: projects related to the Concentrated Solar Power
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6755744511147720704">https://www.linkedin.com/feed/update/urn:li:activity:6755744511147720704</a>	15/01/2021	Project Dissemination	Opportunity to publish about Thermochemical Energy Storage (TCES)
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/sfera-iii-solar-facilities-for-the-european-research-area/">https://socratces.eu/sfera-iii-solar-facilities-for-the-european-research-area/</a>	20/01/2021	General News	SFERA III: Solar Facilities for the European Research Area
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6757552389126971392">https://www.linkedin.com/feed/update/urn:li:activity:6757552389126971392</a>	20/01/2021	General News	SFERA III: Solar Facilities for the European Research Area
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6762296988995256320">https://www.linkedin.com/feed/update/urn:li:activity:6762296988995256320</a>	02/02/2021	Project Dissemination	Calciner and carbonator structures built
BIOAZUL	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=dR-CYe57YYA&amp;ab_channel=SOCRATCESEUProject">https://www.youtube.com/watch?v=dR-CYe57YYA&amp;ab_channel=SOCRATCESEUProject</a>	02/02/2021	Project Dissemination	POLITO presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6762625730456252416">https://www.linkedin.com/feed/update/urn:li:activity:6762625730456252416</a>	02/02/2021	Project Dissemination	POLITO presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6765887269661405185">https://www.linkedin.com/feed/update/urn:li:activity:6765887269661405185</a>	12/02/2021	Others	Women in Science Video

BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6769535156626755584">https://www.linkedin.com/feed/update/urn:li:activity:6769535156626755584</a>	22/02/2021	Project Dissemination	Visit of Radio Television Española
BIOAZUL	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=pz3rTvOerWA&amp;ab_channel=SOCRATCESEUProject">https://www.youtube.com/watch?v=pz3rTvOerWA&amp;ab_channel=SOCRATCESEUProject</a>	23/02/2021	Others	CNR presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6770251714860732416">https://www.linkedin.com/feed/update/urn:li:activity:6770251714860732416</a>	23/02/2021	Others	CNR presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6772789307817119744">https://www.linkedin.com/feed/update/urn:li:activity:6772789307817119744</a>	03/03/2021	Events	Final Conference of MUSTEC project
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6774982576118472704">https://www.linkedin.com/feed/update/urn:li:activity:6774982576118472704</a>	09/03/2021	Others	CINEA shares our Women in Science Video
BIOAZUL	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=ZVccwHblFQ8&amp;ab_channel=SOCRATCESEUProject">https://www.youtube.com/watch?v=ZVccwHblFQ8&amp;ab_channel=SOCRATCESEUProject</a>	09/03/2021	Others	SPI presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6775309310000959488">https://www.linkedin.com/feed/update/urn:li:activity:6775309310000959488</a>	10/03/2021	Others	SPI presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6777846061131173888">https://www.linkedin.com/feed/update/urn:li:activity:6777846061131173888</a>	17/03/2021	Project Dissemination	Updated timeline of SOCRATCES
BIOAZUL	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=j-LyDiVknuM&amp;ab_channel=SOCRATCESEUProject">https://www.youtube.com/watch?v=j-LyDiVknuM&amp;ab_channel=SOCRATCESEUProject</a>	24/03/2021	Others	UNIZAR presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6780397007715500032">https://www.linkedin.com/feed/update/urn:li:activity:6780397007715500032</a>	24/03/2021	Others	UNIZAR presentation video
BIOAZUL	Press Release	Project website	<a href="https://socratces.eu/youth-with-researchers-2021/">https://socratces.eu/youth-with-researchers-2021/</a>	25/03/2021	Events	Youth with Researchers – 2021
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6782904414857383936">https://www.linkedin.com/feed/update/urn:li:activity:6782904414857383936</a>	31/03/2021	Events	Youth with Researchers – 2021
BIOAZUL	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=obHAMYAOGSY&amp;ab_channel=SOCRATCESEUProject">https://www.youtube.com/watch?v=obHAMYAOGSY&amp;ab_channel=SOCRATCESEUProject</a>	25/03/2021	Others	CALIX presentation video
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6785441248615378944">https://www.linkedin.com/feed/update/urn:li:activity:6785441248615378944</a>	07/04/2021	Others	CALIX presentation video

BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6787977795533340672">https://www.linkedin.com/feed/update/urn:li:activity:6787977795533340672</a>	14/04/2021	Events	SOCRATCES presentation at the virtual conference "Regional experience in the management of industrial thermal efficiency."
BIOAZUL	Media Briefing	Social network-Linkedin	<a href="https://www.linkedin.com/feed/update/urn:li:activity:6790514567391932417">https://www.linkedin.com/feed/update/urn:li:activity:6790514567391932417</a>	21/04/2021	Others	Video of the heliostats
CSIC	Other	Social network-Youtube	<a href="https://www.youtube.com/watch?v=-AWs6BP8ikY&amp;list=PLpXlg-AvzIEKIWUFefSsfboavv-BA6wg0&amp;index=15">https://www.youtube.com/watch?v=-AWs6BP8ikY&amp;list=PLpXlg-AvzIEKIWUFefSsfboavv-BA6wg0&amp;index=15</a>	30/04/2021	Project Dissemination	Video about the project. Participation in the local (Seville) outreach activities: "Feria de la ciencia y salón del estudiante 2021"
CLX	Press Release	Partner web	<a href="https://www.calix.global/news/news-issue-april-2021/">https://www.calix.global/news/news-issue-april-2021/</a>	19/04/2021	Project Dissemination	Feature within Calix general newsletter, April 2021.
AUTH	Media Briefing	Social network-Youtube	<a href="https://www.youtube.com/watch?v=wE8H_7Z0I6U">https://www.youtube.com/watch?v=wE8H_7Z0I6U</a>	01/06/2021	Project Dissemination	AUTH presentation video
BIOAZUL	Other	Partner web	<a href="https://www.bioazul.com/en/event/socrates-webinar-on-solar-energy-storage/">https://www.bioazul.com/en/event/socrates-webinar-on-solar-energy-storage/</a>	01/06/2021	Events	SOCRATCES webinar promotion
USE	Press Release	Third-party web	<a href="https://theconversation.com/como-podemos-capturar-co-para-mitigar-el-cambio-climatico-162280">https://theconversation.com/como-podemos-capturar-co-para-mitigar-el-cambio-climatico-162280</a>	22/06/2021	Project Dissemination	Potential for CaL technology
CSIC	Other	Social network-Youtube	<a href="https://www.youtube.com/watch?v=0ryl4W89Ruw">https://www.youtube.com/watch?v=0ryl4W89Ruw</a>	07/06/2021	Project Dissemination	Video where we described our participation in SOCRATCES
BIOAZUL	Other	Partner web	<a href="https://www.bioazul.com/en/event/csp-projects-joint-webinar/">https://www.bioazul.com/en/event/csp-projects-joint-webinar/</a>	11/06/2021	Events	CSP projects joint webinar day promotion
BIOAZUL	Other	Partner web	<a href="https://www.bioazul.com/en/event/csp-technology-day-eusew-2021/">https://www.bioazul.com/en/event/csp-technology-day-eusew-2021/</a>	01/10/2021	Events	CSP Technology day promotion
CLX	Press Release	Partner web	<a href="https://www.calix.global/co2-mitigation-focus-area/using-lime-to-store-energy-project-socrates/">https://www.calix.global/co2-mitigation-focus-area/using-lime-to-store-energy-project-socrates/</a>	28/10/2021	Project Dissemination	SOCRATCES general information
BIOAZUL	Other	Partner web	<a href="https://www.bioazul.com/en/event/socrates-final-info-day/">https://www.bioazul.com/en/event/socrates-final-info-day/</a>	01/11/2021	Events	Final info day promotion
BIOAZUL	Press Release	Partner web	<a href="https://www.bioazul.com/en/events-september-november-2021/">https://www.bioazul.com/en/events-september-november-2021/</a>	30/11/2021	Events	Summary CSP Technology day

TTZ	Interview	Social network- Youtube	<a href="https://www.dw.com/en/a-quest-to-store-the-power-of-the-sun/av-60148086">https://www.dw.com/en/a-quest-to-store-the-power-of-the-sun/av-60148086</a>	16/12/2021	Project Dissemination	Interview in Deutsche Welle
ZAR	Event's promotion	Social network- Youtube	<a href="https://www.youtube.com/watch?v=KtEgajHOjeU">https://www.youtube.com/watch?v=KtEgajHOjeU</a>	20/05/2021	Events	Cambio climático y oportunidades de negocio: Descarbonización industrial y tecnologías de captura, almacenamiento y usos del CO2.

**Table 2: Some examples of SOCRATCES Digital coverage**

Weblink
<a href="https://reneweconomy.com.au/salt-based-energy-storage-trial-taps-first-class-australian-technology/">https://reneweconomy.com.au/salt-based-energy-storage-trial-taps-first-class-australian-technology/</a>
<a href="https://reneweconomy.com.au/salt-based-energy-storage-trial-taps-first-class-australian-technology/">https://reneweconomy.com.au/salt-based-energy-storage-trial-taps-first-class-australian-technology/</a>
<a href="https://sfera3.sollab.eu/2021/07/08/replay_csp_projects_joint_webinar/">https://sfera3.sollab.eu/2021/07/08/replay_csp_projects_joint_webinar/</a>
<a href="https://prod5.assets-cdn.io/event/6530/assets/8378735303-57b0ab0b5a.pdf">https://prod5.assets-cdn.io/event/6530/assets/8378735303-57b0ab0b5a.pdf</a>
<a href="https://www.msloopproject.eu/wp-content/uploads/2019/07/Workshop_MSLOOP_SOCRATCES.pdf">https://www.msloopproject.eu/wp-content/uploads/2019/07/Workshop_MSLOOP_SOCRATCES.pdf</a>
<a href="https://www.daily-sun.com/printversion/details/575090/SOCRATCES-Green-Energy-Technology-and-Bangladesh-Scenario">https://www.daily-sun.com/printversion/details/575090/SOCRATCES-Green-Energy-Technology-and-Bangladesh-Scenario</a>
<a href="https://us15.campaign-archive.com/?u=be5a9e502ccb8c519b107bae4&amp;id=afe41fa009">https://us15.campaign-archive.com/?u=be5a9e502ccb8c519b107bae4&amp;id=afe41fa009</a>
<a href="https://www.power-technology.com/projects/seville-solar-tower/">https://www.power-technology.com/projects/seville-solar-tower/</a>
<a href="https://hotcopper.com.au/documentdownload?id=uOMxKkzFkiWRTLKhOROKAxjvSDYL4A20yRH0v%2FRh87FiGug%3D">https://hotcopper.com.au/documentdownload?id=uOMxKkzFkiWRTLKhOROKAxjvSDYL4A20yRH0v%2FRh87FiGug%3D</a>
<a href="https://jovenesconinvestigadores.wordpress.com/proyectos-de-investigacion-2020-2021/">https://jovenesconinvestigadores.wordpress.com/proyectos-de-investigacion-2020-2021/</a>
<a href="https://csp-eranet.eu/news-and-events">https://csp-eranet.eu/news-and-events</a>

#### 4 DISSEMINATION & COMMUNICATION ACTIVITIES

With the objective of a continuous follow-up of the communication and dissemination strategy, a monitoring document was created for these activities, which was reviewed periodically. For periodic monitoring of the execution of the communication and dissemination activities foreseen in the project and for a deeper analysis of the involvement and engagement of partners, a monitoring document was made available, in which each partner had to fill in the activities they were carrying out. This document was divided into three distinct sheets. Each sheet had a different purpose for filling in, as the name suggests:

1. Diss. & Comm. Activities
2. Scientific publications
3. Media Activity

In sheet 1, "Diss. & Comm. Activities", each partner was required to fill in the following fields:

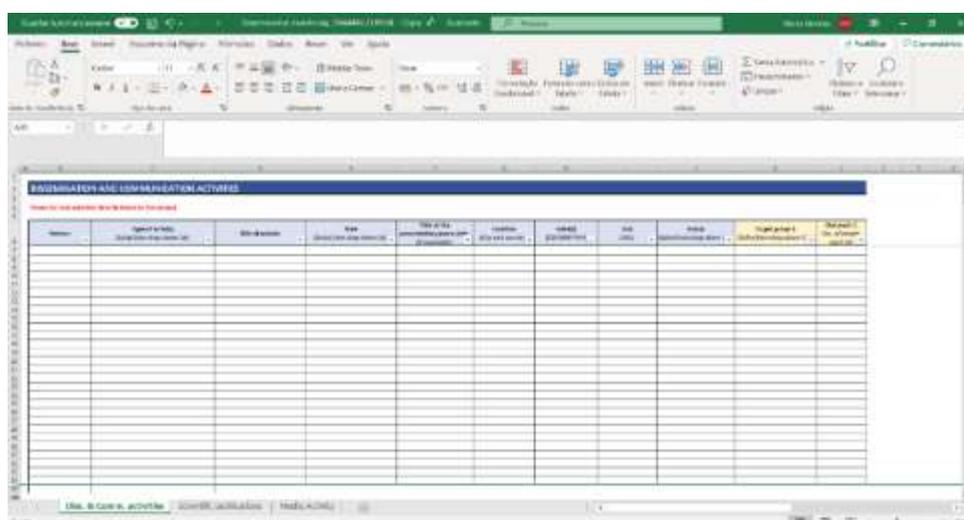
- Partner
- Type of activity
- Title of activity
- Role
- Title of the presentation/poster/etc.
- Location
- Date
- URL Link
- Status
- Target group
- Outreach

The following table describes the options for each field to be filled in.

**Table 3 - Fields to fill in sheet 1 "Diss. & Comm. Activities" and respective lists**

Partner	<ul style="list-style-type: none"> <li>• P01_USE</li> <li>• P02_POLITO</li> <li>• P03_ZAR</li> <li>• P04_CERTH</li> <li>• P05_CLX</li> <li>• P06_CSIC</li> <li>• P08_TTZ</li> <li>• P09_BIOAZUL</li> <li>• P10_CNR</li> <li>• P11_VERTECH</li> <li>• P12_SPI</li> <li>• P13_ISITEC</li> <li>• P14_AUTH</li> <li>• P15_VM</li> </ul>
Type of activity	<ul style="list-style-type: none"> <li>• Organisation of a conference</li> <li>• Organisation of a workshop</li> <li>• Exhibition</li> <li>• Training (specific training workshops)</li> <li>• Participation in a conference</li> <li>• Participation in a workshop</li> <li>• Participation in an event other than conference or workshop</li> <li>• Brokerage event</li> <li>• Pitch event</li> <li>• Trade fair</li> <li>• Participation in activities organised jointly with another H2020 project (s)</li> <li>• Press release (including newsletters)</li> <li>• Non-scientific and non-peer reviewed publications (popularized publications)</li> <li>• Flyers</li> <li>• Communication campaign (e.g. radio, TV)</li> <li>• Video/film</li> </ul>

Role	<ul style="list-style-type: none"> <li>• Social Media</li> <li>• Website</li> <li>• Other</li> </ul>
	<ul style="list-style-type: none"> <li>• Stand</li> <li>• Oral presentation</li> <li>• Poster presentation</li> <li>• Paper presentation</li> <li>• Distribution of dissemination material</li> <li>• Attendance</li> <li>• Other</li> </ul>
Status	<ul style="list-style-type: none"> <li>• Performed</li> <li>• To be performed</li> </ul>
Target group	<ul style="list-style-type: none"> <li>• Civil Society</li> <li>• Customers</li> <li>• General Public</li> <li>• Industry</li> <li>• Investors</li> <li>• Media</li> <li>• Policy makers</li> <li>• Scientific Community</li> <li>• Other</li> </ul>



**Figure 30 - Example of the monitoring document for "Diss. & Comm. activities"**

In sheet 2, "Scientific publications", each partner had to fill in the type of scientific publication in which was published the results of the project, identifying the following fields:

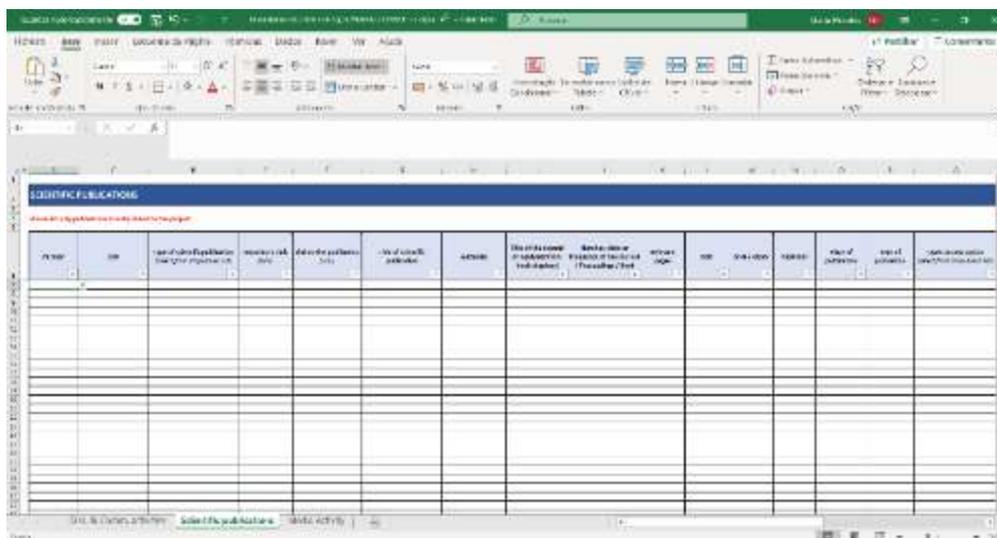
- DOI
- Type of scientific publication
- Repository URL Links
- Link to the publication (if the publication did not have a DOI)
- Title of scientific publication
- Author(s)
- Title of the Journal or equivalent (for book chapters)
- Number, date, or frequency of the Journal / Proceedings / Book
- Relevant pages
- ISBN
- ISSN / E-ISSN (only required if the scientific publication was an article in a journal)
- Publisher
- Place of publication
- Year of publication

- Open Access option
  - Length of the Embargo (*mandatory if Green OA*)
  - Amount of processing charges (*mandatory if Gold OA*)
- Peer-review
- Public & private publication
- Outreach
- Status

As for sheet 1, each field had specific lists to standardize and make easier and faster the filling in of each field. The lists defined are shown in the following table.

**Table 4 - Fields to fill in sheet 2 "Scientific publications" and respective lists**

Partner	<ul style="list-style-type: none"> <li>• P01_USE</li> <li>• P02_POLITO</li> <li>• P03_ZAR</li> <li>• P04_CERTH</li> <li>• P05_CLX</li> <li>• P06_CSIC</li> <li>• P08_TTZ</li> <li>• P09_BIOAZUL</li> <li>• P10_CNR</li> <li>• P11_VERTECH</li> <li>• P12_SPI</li> <li>• P13_ISITEC</li> <li>• P14_AUTH</li> <li>• P15_VM</li> </ul>
Type of scientific publication	<ul style="list-style-type: none"> <li>• Article in Journal</li> <li>• Book/Monograph</li> <li>• Chapter(s) in Book</li> <li>• Publication in Conference proceedings/Workshop</li> <li>• Thesis/Dissertation</li> <li>• Other</li> </ul>
Open Access option	<ul style="list-style-type: none"> <li>• Yes, available in Green OA</li> <li>• Yes, available in Gold OA</li> <li>• No</li> </ul>
Peer-review	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>
Public & private publication	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>
Status	<ul style="list-style-type: none"> <li>• Published</li> <li>• To be published</li> </ul>



**Figure 31 - Example of the monitoring document for "Scientific publications"**

In sheet 3, "Media Activity", each partner had to fill in the various communication and dissemination actions carried out in media channels, namely websites and social networks. The aim of this media activity was, in the first place, the widespread dissemination of the project results, but also the communication of news and initiatives of interest for each target region related to the theme. In this regard, the following fields had to be filled in:

- Planning stage
- Type of media
- Type of channel
- Weblink
- Date
- Publication Topic
- Comments

To facilitate the filling in of each field and to create a common language for all partners, it was necessary to create lists for certain fields of the sheet, as defined in the following table.

**Table 5 - Fields to fill in sheet3 "Media Activity" and respective lists**

Partner	<ul style="list-style-type: none"> <li>• P01_USE</li> <li>• P02_POLITO</li> <li>• P03_ZAR</li> <li>• P04_CERTH</li> <li>• P05_CLX</li> <li>• P06_CSIC</li> <li>• P08_TTZ</li> <li>• P09_BIOAZUL</li> <li>• P10_CNR</li> <li>• P11_VERTECH</li> <li>• P12_SPI</li> <li>• P13_ISITEC</li> <li>• P14_AUTH</li> <li>• P15_VM</li> </ul>
Planning stage	<ul style="list-style-type: none"> <li>• Future: planned</li> <li>• Future: confirmed</li> <li>• Past: broadcast</li> <li>• Past: published</li> </ul>
Type of media	<ul style="list-style-type: none"> <li>• Articles published in the popular press</li> <li>• Film</li> <li>• Flyer</li> <li>• Interview</li> <li>• Media Briefing</li> <li>• Newsletter</li> <li>• Post</li> <li>• Press Release</li> <li>• Other</li> </ul>
Type of channel	<ul style="list-style-type: none"> <li>• Partner web</li> <li>• Third party web</li> <li>• Social network-Facebook</li> <li>• Social network-Instagram</li> <li>• Social network-LinkedIn</li> <li>• Social network-Twitter</li> <li>• Social network-YouTube</li> </ul>
Publication Topic	<ul style="list-style-type: none"> <li>• General News</li> <li>• Events</li> <li>• Project Dissemination</li> <li>• Regional News</li> <li>• Workshops</li> <li>• Others</li> </ul>

Partner	Planning stage	Type of needs	Type of channel	Website	Date	Publication Topic	Comments

**Figure 32 - Example of the monitoring document for "Media Activity "**

Below we include the information collected thanks to this work of monitoring communication and dissemination activities.

*Note: the information regarding "Media Activity" has been previously included in section 3.4 Partner’s digital dissemination activities.*

**Table 6 – List of Dissemination & communication activities carried out by SOCRATCES consortium.**

Dissemination & communication activities					Estimated number of persons reached	
Name of the activity / URL	Date	Location	Role	Partner	Target group	Outreach
<a href="#">16ª FERIA DE LA CIENCIA</a>	3-5/05/2018	Seville (Spain)	Stand	USE	Civil Society & Scientific Community	7000
<a href="#">ISCRE 25 2018—The 25th International Symposium on Chemical Reaction Engineering</a>	20-23/05/2018	Florence (Italy)	Poster presentation	AUTH	Scientific Community & Industry	500
<a href="#">CIES 18</a>	22/06/2018	Madrid (Spain)	Oral presentation	USE	Scientific Community & Industry	100
<a href="#">PRES 2018</a>	25-29/08/2018	Prague (Czech Republic)	Oral presentation	CERTH	Scientific Community & Industry	300
<a href="#">PRES 2018</a>	29/08/2018	Prague (Czech Republic)	Oral presentation	USE	Scientific Community & Industry	300
<a href="#">ESTAC12</a>	27-30/08/18	Brasov (Rumania)	Oral presentation	CSIC	Scientific Community	400
<a href="#">GRIDSOL</a>	25/09/2018	Athens (Greece)	Poster presentation	CERTH	Industry & Scientific Community	300
<a href="#">THE EUROPEAN RESEARCHERS' NIGHT</a>	28/09/2018	Seville (Spain)	Oral presentation	USE	General Public & Civil Society	5000
<a href="#">SOLARPACES 2018</a>	04/10/2018	Casablanca (Morocco)	Oral presentation	USE	Scientific Community & Industry	200
<a href="#">Workshop on Thermochemical Solar conversion</a>	18/10/2018	Seville (Spain)	Oral presentation	USE	Scientific Community	30
<a href="#">Youth with Researchers - SCIENCEIES</a>	16-28/01, 13/02, 04/04/2020	Seville (Spain)	Other	USE	General Public	50
<a href="#">Youth with Researchers - SCIENCEIES</a>	16-28/01, 13/02, 04/04/2020	Seville (Spain)	Other	CSIC	General Public	50
<a href="#">11th Annual MENA New Energy 2019</a>	26-27/03/2019	Dubai (UAE)	Oral presentation	VM	Industry & Scientific Community	400
CATCAR28 & MoldTAC2	9-10/05/19	Timisoara (Romania)	Oral presentation	CSIC	Scientific Community	N.A

Dissemination & communication activities					Estimated number of persons reached	
Name of the activity / URL	Date	Location	Role	Partner	Target group	Outreach
<a href="#">17ª FERIA DE LA CIENCIA</a>	16-18/05/2019	Seville (Spain)	Stand	USE	Civil Society & Scientific Community	7000
<a href="#">ICheaP 14</a>	26-29/05/19	Bologna (Italy)	Oral presentation	CNR	Scientific Community & Industry	300
<a href="#">12th Panhellenic Scientific Conference of Chemical Engineering</a>	29-31/05/2019	Athens (Greece)	Oral presentation	AUTH	Scientific Community & Industry	500
<a href="#">Water Innovation Europe 2019</a>	11-12/06/19	Brussels (Belgium)	Attendance	BIOAZUL	Industry & Investors	N.A
<a href="#">11th Mediterranean Combustion Symposium - MCS11</a>	16-20/06/2019	Tenerife (Spain)	Oral presentation	CNR	Scientific Community & Industry	200
<a href="#">ECOS 19</a>	23-28/06/2019	Wroclaw (Poland)	Oral presentation	USE	Scientific Community & Industry	200
<a href="#">ECOS 19</a>	23-28/06/2019	Wroclaw (Poland)	Oral presentation	POLITO	Scientific Community & Industry	200
<a href="#">ECOS 19</a>	23-28/06/2019	Wroclaw (Poland)	Oral presentation	ZAR	Scientific Community & Industry	200
<a href="#">ECOS 19</a>	23-28/06/2019	Wroclaw (Poland)	Oral presentation	CERTH	Scientific Community & Industry	200
<a href="#">ECOS 19</a>	23-28/06/2019	Wroclaw (Poland)	Oral presentation	CNR	Scientific Community & Industry	200
<a href="#">Workshop MSLOOP 2.0</a>	09/07/2019	Madrid (Spain)	Oral presentation	USE	Scientific Community & Industry	50
<a href="#">CEEC-TAC5 &amp; Medicta2019</a>	27-30/08/19	Rome (Italy)	Poster presentation	CSIC	Scientific Community	300
<a href="#">The 12th European Congress of Chemical Engineering</a>	15-19/09/2019	Florence (Italy)	Oral presentation	AUTH	Scientific Community & Industry	150
<a href="#">Aportando valor al CO2</a>	02-03/10/2019	Madrid (Spain)	Poster presentation		Scientific Community & Industry	90
<a href="#">PRES 2019</a>	20-23/10/2019	Agios Nikolas, Crete (Greece)	Oral presentation	POLITO	Scientific Community & Industry	200

Dissemination & communication activities					Estimated number of persons reached	
Name of the activity / URL	Date	Location	Role	Partner	Target group	Outreach
<a href="#">PRES 2019</a>	20-23/10/2019	Agios Nikolas, Crete (Greece)	Oral presentation	CERTH	Scientific Community & Industry	200
<a href="#">CAPTure WORKSHOP AT THE EUROPEAN UTILITY WEEK</a>	12/11/2019	Paris (France)	Oral presentation	CALIX	Industry & General Public	33
<a href="#">13th Annual CSP MADRID 2019</a>	19-20/11/2019	Madrid (Spain)	Attendance	VM	Industry & Scientific Community	600
<a href="#">IX International Workshop for the efficient use of sustainable energy</a>	19-21/2019	Arequipa (Perú)	Oral presentation	USE	Scientific Community	50
Publication in the newspaper Nordseezeitung	04/02/2020	Bremerhaven (Germany)	Other	TTZ	Civil Society	N.A
Introduction to the SOCRATCES project	06/02/2020	Bremerhaven (Germany)	Oral presentation	TTZ	Scientific Community	12
<a href="#">Annual meeting of the ProcessNet specialist group for energy process engineering</a>	04-05/03/20	Frankfurt (Germany)	Poster presentation	TTZ	Scientific Community	N.A
<a href="#">ICSREE 2020</a>	5/05/2020	Online	Oral presentation	POLITO	Scientific Community	30
<a href="#">ECOS 20</a>	29/06/2020-3/07/2020	Osaka (Japan) ONLINE	Oral presentation	POLITO	Scientific Community & Industry	200
<a href="#">ECOS 20</a>	29/06/2020-3/07/2020	Osaka (Japan) ONLINE	Paper presentation	ZAR	Scientific Community & Industry	200
<a href="#">SOLARPACES2020</a>	1-5/09/2020	Albuquerque (New Mexico)	Oral presentation	USE	Scientific Community & Industry	200
<a href="#">SDEWES congress 2020</a>	1-5/9/2020	Cologne (Germany)	Paper presentation	VM	Industry	570
<a href="#">SDEWES congress 2020</a>	1-5/9/2020	Cologne (Germany)	Paper presentation	USE	Industry	570
<a href="#">SDEWES congress 2020</a>	1-5/9/2020	Cologne (Germany)	Oral presentation	POLITO	Industry	570
<a href="#">SDEWES congress 2020</a>	1-5/9/2020	Cologne (Germany)	Oral presentation	AUTH	Industry	570

Dissemination & communication activities					Estimated number of persons reached	
Name of the activity / URL	Date	Location	Role	Partner	Target group	Outreach
<a href="#">SDEWES congress 2020</a>	1-5/9/2020	Cologne (Germany)	Paper presentation	CERTH	Industry	570
<a href="#">ATI 20</a>	15-16/09/20-	Roma (Italy) ONLINE	Oral presentation	POLITO	Scientific Community & Industry	70
<a href="#">Feature within Calix general newsletter, April 2021.</a>	19/04/2021	Online	Other	CALIX	Industry & General Public	1237
<a href="#">Youth with Researchers - SCIENCIES</a>	13/02, 04/04/2021	Seville (Spain)	Other	USE	General Public	50
Workshop on Thermochemical Solar conversion	18/05/2021	Seville (Spain)	Oral presentation	USE	Scientific Community	30
<a href="#">ISCRE 2021</a>	7/05/2021	Online	Oral presentation	POLITO	Scientific Community	30
<a href="#">Cambio climático y oportunidades de negocio</a>	20/05/2021	Online	Oral presentation	ZAR	Scientific Community	100
<a href="#">ICheaP 15</a>	23-26/05/2021	Napoli (Italy)	Oral presentation	CNR	Scientific Community & Industry	300
<a href="#">Workshop GECAT. Young researchers</a>	04/06/2021	Spain. ONLINE	Oral presentation	CSIC	Scientific Community	N.A
<a href="#">International Summer School for PhD students</a>	5-9/07/21-	Gliwice (Poland)	Oral presentation	USE	International PhD students from 15 countries	40
Speed-Networking für Wissenschaftler*innen aus Bremerhaven	07/08/2021	Online (Bremerhaven)	Oral presentation	TTZ	Scientific Community	15
<a href="#">International Conference on Chemical Reactors</a>	12-17/09/2021	Online	Oral presentation	AUTH	Scientific Community	500
<a href="#">AIChE Annual Meeting 2021</a>	15-19/11/2021	Online	Oral presentation	AUTH	Scientific Community	1000

#### 4.1 ORAL PRESENTATIONS

The partners of the SOCRATCES consortium attended different conferences and events where they made oral presentations and also introduced some posters about the project. This is the list of the oral presentations of the partners:

- **XVI Congreso Ibérico y XII Congreso Iberoamericano de Energía Solar (CIES). 20-22 June 2018 MADRID, ESPAÑA.**

The CIES conference is one of the most important events of solar energy in the Iberian Peninsula and Latin America and is aimed at scientists, educators, engineers, architects, economists, entrepreneurs, technologists, administration and end-users, united by the objective of promoting solar energy in Latin America in areas as diverse as building, transport, power generation or heat of the industrial process. The conference topic in this edition was "Clean and manageable energy for everyone. From the University of Seville, Carlos Ortiz was in charge of presenting the SOCRATCES project, which addressed the main opportunities and challenges of the CSP-CaL system.

##### **Almacenamiento termoquímico en plantas CSP basado en calcium-looping: retos y oportunidades.**

Thermochemical energy storage has been gaining attention in the last years to be integrated into CSP plants. Among the various possibilities, the Calcium-looping (CaL) process, based on the multicyclic calcination/carbonation of  $\text{CaCO}_3$ , is considered one of the most promising systems. However, for the commercial deployment of CSP, several challenges must be solved. This work presents a critical analysis of the status of the technology with the aim of evaluating the main challenges and opportunities of the CSP-CaL integration. The SOCRATCES project, founded from the European Union's Horizon 2020 research and innovation programme, aims to develop a CSP-CaL prototype at a pilot scale in Seville (Spain).



*Figure 33: Oral presentation Carlos Ortiz, CIES 2018*

- **3<sup>rd</sup> SEE SDEWES, Novi Sad, Serbia, 30 June-4 July 2018.**

##### **Role of particle size on the multicycle Calcium Looping activity of limestone for Thermochemical Energy Storage of Concentrated Solar Power**

Pedro E SANCHEZ-JIMENEZ, Antonio PEREJON, Pablo GARCÍA TRIÑANES, Luis A. PEREZ-MAQUEDA, José M. VALVERDE, Jonatan DURAN

The Calcium Looping process (CaL), based upon the reversible carbonation/calcination of  $\text{CaO}/\text{CaCO}_3$ , stands as a promising technology for thermochemical energy storage in

Concentrated Solar Power (CSP) plants [1]. The high enthalpy of this reaction (178 kJ/mol) together with the low cost and abundance of natural limestone would help develop the technology at the necessarily large scale required for commercial expansion. The main obstacle to overcome though is the progressive loss of CaO activity as the number of carbonation/calcination cycles progresses. In a recently proposed CaL-CSP integration scheme, carbonation would be carried out under pure CO<sub>2</sub> at high temperature while calcination would be performed at a lower temperature under Helium, which enhances quick decomposition at reduced temperatures [2]. Under such reaction conditions, CaO deactivation is mainly driven by surface pore plugging during the very rapid carbonation stage, which prevents the percolation of CO<sub>2</sub> into the inner pores of the CaO particle. This phenomenon is quite marked for larger particles since a large fraction of the surface remains inaccessible for carbonation. On the other hand, the use of small particles (particle size below about 40 microns) is not possible due to losses by elutriation and excessive cohesiveness of the fine powder, which hinders its flowability. Thus, choosing an optimum limestone particle size becomes critical for the effective large scale implementation of the CaL-CSP integration. In this work, multicycle carbonation and calcination tests were performed employing natural limestone samples with a narrow particle size distribution and average particle sizes ranging from 2 to 700 microns. Our goal was to assess the optimum particle size to be employed in practice. Influence of size on sample microstructure along the carbonation and calcinations cycles by SEM and porosimetry.

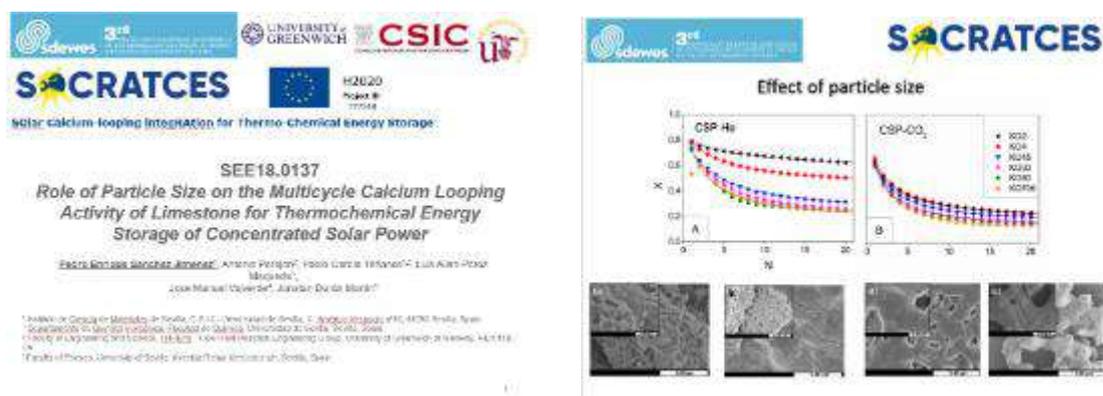


Figure 34: slides 1 and 8 of the presentation at 3rd SEE SDEWES

- ESTAC12 Conference, Brasov, August 27 – 30, 2018.

#### Reversible carbonation-decarbonation reactions for CO<sub>2</sub> capture and thermal energy storage

Luis A PEREZ-MAQUEDA, Beatriz SARRIÓN, Antonio PEREJON, Pedro E. SANCHEZ-JIMENEZ, Mónica BENITEZ, José M. VALVERDE, Ricardo CHACARTEGUI, Carlos ORTIZ

The calcium looping process (Ca-L) is based on the multicycle carbonation/calcination of CaO. This process has been demonstrated for CO<sub>2</sub> capture at low cost in fossil fuel power plants as a technology to help mitigate climate disruption. In CaL, the CO<sub>2</sub> released with the flue gas stream from the power plant (in a concentration of about 15%v) reacts with CaO particles in a carbonator reactor at temperatures of about 650°C.

CaL has also been recently proposed for thermal energy storage, in particular in concentrated solar power plants that face the limitation of their intermittent nature. In this case, the endothermic calcination process could be performed at the high temperature achieved in the power plant, while the energy could be recovered from the exothermic carbonation reaction. Thus, in this application, limestone would be calcined by solar irradiation during the daytime,

and both CO<sub>2</sub> and CaO would be stored. When energy is required, they will be mixed together, and the released thermal energy will be used to produce electricity.

This work was supported by the H2020 project SOCRATCES, Grant Agreement no.727348



Figure 35: slides 1 and 3 of the presentation at ESTAC12

- **13<sup>th</sup> SDEWES Conference, Palermo 30<sup>th</sup> August-5 September 2018.**

#### **Thermochemical Energy Storage of Solar PV to enhance dispatchability and large scale commercial expansion.**

Solar photovoltaics (PV) plants are today a competitive alternative to power plants based on fossil fuels. Cost reduction in PV modules, scalability (from kW to MW) and ease of installation of PV plants enable a rapid expansion of the technology throughout the world. Nevertheless, PV dispatchability still remains the major challenge to overcome due to the intrinsic variability of solar energy. Most of the current PV facilities lack energy storage, while those with storage systems rely on expensive batteries. Batteries are based on nickel, lithium or cadmium, whose scarcity hinders the sustainability of batteries for storing energy on a large scale. This manuscript presents a novel concept to integrate thermochemical energy storage in PV plants. Furthermore, the concept is also directly adaptable to wind power plants in order to store surplus energy. In particular, this paper analyses the suitability of the Calcium-Looping (CaL) process as a thermochemical energy storage system applied to large scale PV facilities. The PV-CaL integration works as follows: a part of power produced in the PV plant provides electricity to the grid while the rest is used to supply heat to carry out the calcination of CaCO<sub>3</sub>. After calcination, the products of the reaction (CaO and CO<sub>2</sub>) are stored separately. When power production is required, the stored products are brought together in a carbonation reactor wherein the exothermic reaction releases energy for power production. The overall system is simulated in order to estimate the process behaviour, and results show that storage efficiencies of ~40% can be achieved. Moreover, an economic analysis is developed to compare the proposed system with batteries. Due to the low price of natural CaO precursors such as limestone and the longer lifetime of equipment than batteries, the CaL process can be considered as a promising alternative to increase dispatchability in PV plants. Moreover, limestone is abundant and non-toxic, which is an essential requirement for the storage of energy in massive amounts.

- **24<sup>th</sup> SolarPaces Conference 2018. October 2-5, 2018. Casablanca (Morocco)**

#### **Off-design model of concentrating solar power plant with thermochemical energy storage based on Calcium-Looping.**

For a massive deployment of CSP facilities, significant efforts should be made in order to reduce investment costs and/or increase conversion efficiency. The present work focuses on integrating the Calcium-Looping (CaL) process, based on the cyclic calcination/carbonation of  $\text{CaCO}_3/\text{CaO}$ , as Thermochemical Energy Storage (TCES) system in CSP plants. The advantages of  $\text{CaCO}_3/\text{CaO}$  TCES are related to its high energy density and to the low cost, wide availability and non-toxicity of natural CaO precursors (i.e. limestone or dolomite). Solar irradiance is used to carry out the endothermic calcination reaction, which produces CaO and  $\text{CO}_2$  that are stored separately. When energy is needed, CaO and  $\text{CO}_2$  are brought together to release the stored energy through the carbonation (exothermic) reaction. Because the carbonation reaction can occur at temperatures as high as  $\sim 890^\circ\text{C}$  in pure  $\text{CO}_2$  atmosphere at ambient pressure (and even higher temperatures at increased reactor pressure), a high heat temperature is introduced in the thermodynamic cycle, which leads to a cycle efficiency superior to that of molten salt-based plants.

### Solar Calcium-Looping Integration for Thermochemical Energy Storage: SOCRATCES Project.

The Calcium-Looping (CaL) process, based on the multicyclic calcination/carbonation reaction of  $\text{CaCO}_3$ , is a promising technology for thermochemical energy storage in concentrating solar power plants (CaL-CSP). The basic idea behind the CaL-CSP integration is using concentrated solar energy to carry out the endothermic calcination reaction. The products of the reaction (CaO and  $\text{CO}_2$ ) are separately stored and, when energy is needed, brought together to release the energy stored by means of the exothermic carbonation reaction. The application of this process to store CSP could improve both dispatchability and efficiency. However, several challenges are yet to be solved for a large-scale deployment of the CaL technology, such as mitigating the multicycle CaO deactivation, achieving proper hot solids management and designing competitive particle solar receivers to carry out the calcination. This manuscript analyses the work currently carried out within the SOCRATCES project that aims to analyse the feasibility of the CaL process for the storage of CSP by erecting a pilot-scale facility.



Figure 36: Presentation at SolarPACES 2018

- CATCAR28 & MoldTAC2, Timisoara, Romania, 9-10 May 2019.

### Reversible carbonation and decarbonation reactions for large scale $\text{CO}_2$ capture and thermal energy storage

Pedro E SANCHEZ-JIMENEZ, Antonio PEREJON, José M. VALVERDE, Ricardo CHACARTEGUI, Jonatan DURAN, Carlos ORTIZ, Luis A. PEREZ-MAQUEDA

The multicycle carbonation/calcination of CaO, also known as calcium looping (CaL) has been demonstrated as a feasible technology for reducing CO<sub>2</sub> emissions in fossil fuel power plants at low cost. Recently, CaL has also been proposed as a thermochemical energy storage system in concentrated solar power plants (CSP-CaL). In this way, solar radiation is employed to drive the endothermic decarbonation reaction at high temperatures. The chemical energy stored in the reaction products, CO<sub>2</sub> and CaO can be recovered by inducing the exothermic carbonation reaction, thereby producing electricity on demand even after sunset. In this way, the intermittent nature of solar energy can be overcome.

The reliable estimation of the kinetics driving both carbonation and calcination reactions is of fundamental importance for modelling the process and designing the plant. For instance, the minimum required residence times for significant carbonation are quite relevant as short residence times are a must for CaL to be efficient. An important drawback of this technology is related with the sintering-induced deactivation of CaO with the number of cycles that requires of frequent make up of fresh sorbent. Such deactivation is a consequence of significant reduction in the active surface available for fast carbonation but also due to the formation of a blocking calcium carbonate layer on the particles surface when the carbonation reaction is carried out at high temperatures. The working conditions for carbonation and calcination are constrained by the application and by the composition of the flue gas stream. Thus, to improve the performance of the sorbents, some strategies have been proposed, such as the use of thermal or mechanical pretreatments or the employment of inert additives such as nanosilica, alumina or zirconia to act as a hindering agent for sintering. Alternatively, the use of dolomite instead of limestone shows great promise as the nanometric grains of MgO produced after dolomite appear homogeneously dispersed and are able to maintain the sorbent stability during a much larger number of cycles.

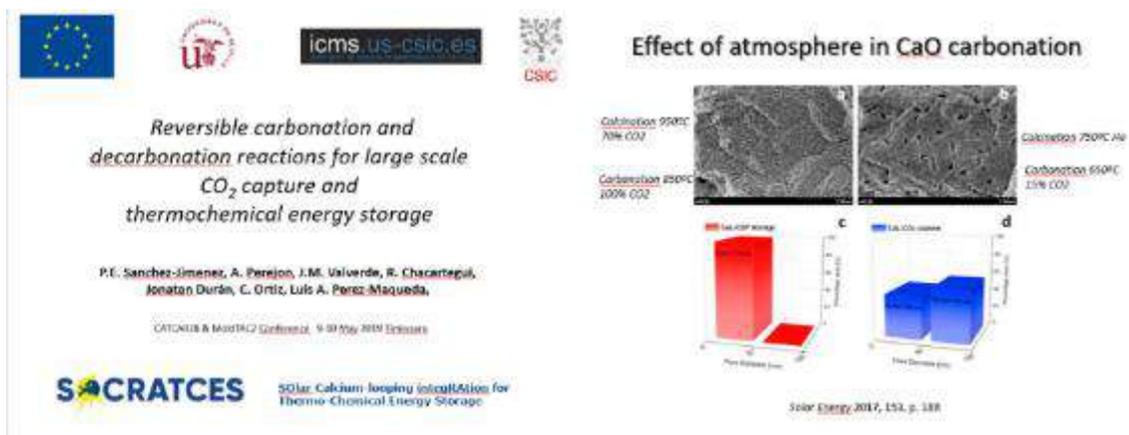


Figure 37: slides 1 and 9 of the presentation at ESTAC12

- ECOS 2019 Conference, Wroclaw 23<sup>th</sup> -28<sup>th</sup> June 2019.

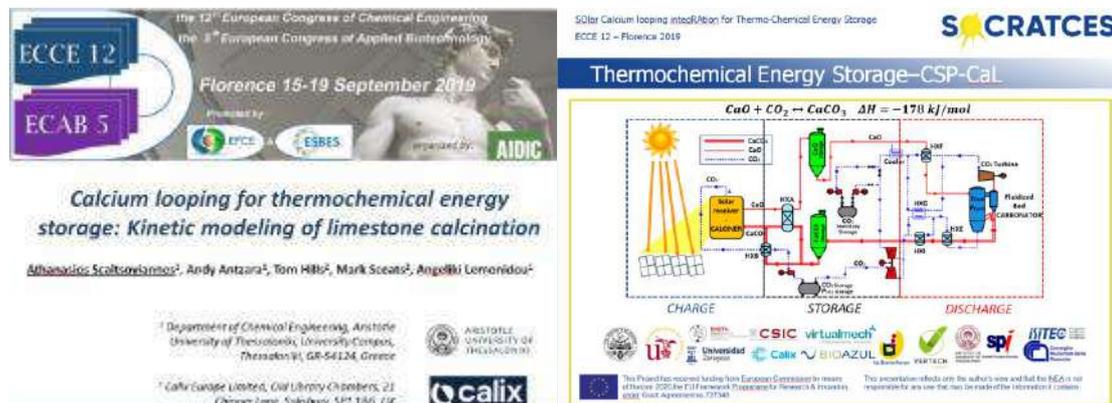
#### Effect of radiant properties and heat transfer mechanisms on the thermal performance of a Calcium Looping carbonator reactor

The promising Calcium-Looping technology can be integrated as thermochemical energy storage (TCES) in Concentrating Solar Power plants, having the potential to compete with the molten salt thermal storage system, the most cost-effective solution nowadays. In the Calcium-Looping process, the previously stored solar energy is released in the carbonator reactor, which is a key component of the system. The complexity of this gas-solid reactor requires the use of simulation tools to achieve a better understanding of the main parameters affecting its thermal performance. The heat transfer mechanisms inside a gas-solid reactor are complex processes to

be analyzed. The aim of this work is to model the heat transfer involved in the carbonator, which in this work is considered as a downer reactor. The present investigations systematically approach every heat transfer mechanism, from lower to higher complexity, starting from the parameters representing the extreme cases and progressively refining the solution of the physical system. One dimensional carbonator reactor model is described and implemented, evaluating the effect of the evolution of the size-dependent radiant properties of the particle-CO<sub>2</sub> stream. The variation of particle size over time due to agglomeration is considered, and its impact on the performance of the system is evaluated. The model includes the kinetics of the carbonator reaction and gas-particle wall convection and radiation heat transfer in the downer reactor. The carbonator thermal performance is evaluated under different load scenarios. The ability to operate efficiently under partial-load conditions could give this technology an advantage to better release the stored energy coupling the demand requirements.

- **12<sup>th</sup> European Congress of Chemical Engineering, 15-19 Sep.2019, Florence.**

Thermochemical energy storage (TCES) is of growing interest, especially for concentrated solar power plants (CSP). The current technology is based on the storage of sensible thermal energy using molten salts, which “suffer” from short period storage, crystallization at temperatures lower than 200°C and degradation at temperatures higher than 550°C. A promising alternative is the calcium looping (CaL) due to the highly exothermic carbonation reaction and the higher operating temperatures (~850°C). This work focuses on the kinetic measurements and modelling of the calcination reaction as well as on the deactivation evolution of limestone through the cycles. A fixed bed reactor flow unit was used for the experiments in order to achieve efficient gas-solid contact and eliminate the control by external transfer phenomena. A two-stage mechanism was adopted for the kinetic modelling. For comparison, two different models were used, namely a Prout Tompkins equation and a Generalized Random Pore Model (GRPM), which is a modified version of the RPM. The evolution of the deactivation through cycling was described with existing models. Calcination under the studied conditions is completed in a few seconds, rendering limestone appropriate as a solid heat carrier for CSP-TCES applications.



**Figure 38: SOCRATCES slides 1 and 5 of the presentation at ECCE 2019**

- **ECOS 2019 - THE 32<sup>ND</sup> INTERNATIONAL CONFERENCE ON EFFICIENCY, COST, OPTIMIZATION, SIMULATION AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS JUNE 23-28, 2019, WROCLAW, POLAND**

**Energy consumption minimization for a solar lime calciner operating in a concentrated solar power plant for thermal energy storage**

Calcium-looping systems can be coupled with concentrated solar power plants as an alternative for thermal energy storage. This storage concept is based on the high temperature reversible

calcination-carbonation reactions, in which limestone and lime are alternatively converted. These reactions produce or consume a specific amount of CO<sub>2</sub> and consume or release important quantities of thermal energy. Energy from CSP can be stored by limestone calcination (endothermic reaction) at high temperatures producing pure streams of CaO and CO<sub>2</sub>. This energy can be later released when demand increases by means of carbonation reaction (exothermic) at relatively high temperatures. In order to produce power, the energy released in the carbonation reaction has to be transferred to a Rankine cycle. Calciner reactor is a complex system where heterogeneous chemical reactions take place while absorbing heat from a solar concentrating equipment. It is a key element of the process. Depending on the design and distribution of heat along the calciner, the amount of heat required in this reactor to store the same amount of chemical energy in the form of lime varies, and the temperature of the solids strongly varies. Optimal design and operating conditions will minimize average temperature in the calciner for a given flow of produced lime. In this work, the modelling of a multi-stage solar calciner is described in the frame of a new solar-based CSP plant. The reactor will consist of a number of downward entrained flow design reactors, and the model encompasses fluid dynamics, chemical kinetics and energy balance. The results, provided along a 1-D discretization, comprise conversion rates, gas temperatures and flow rates, and heat transfer rates.



Figure 39: SOCRATCES slides 1 and 13 presentation at ECOS 2019

**On the modelling of a lime carbonator operating in a concentrated solar power plant for energy storage**

Calcium-looping systems can be integrated in concentrated solar power plants serving as an energy storage alternative. This concept is based in the reversible calcination-carbonation reaction, in which limestone and lime are alternatively converted, generating and using CO<sub>2</sub> and introducing (storing) or releasing important quantities of energy. Energy from concentrated solar power (CSP) can be stored by limestone calcination (endothermic reaction) at high temperatures producing pure streams of CaO and CO<sub>2</sub>. This energy can be used when demand increases by means of carbonation reaction (exothermic) at relatively high temperatures suitable for Rankine cycles. Carbonator reactor is a complex system where heterogeneous chemical reactions take place together with heat release and heat transfer to the production of steam for the Rankine cycle. It is a key element of the process. In this work the modelling of a future commercial-scale carbonator is described, in the frame of a new solar-based plant. The reactor has been considered with a downward entrained flow design, and the model encompasses fluid dynamics, chemical kinetics and energy balance. The results, provided along a 1-D discretization, comprise conversion rates, gas temperatures and flow rates, and heat transfer rates to the external cooling fluid. The round trip efficiency of the energy storage technology is assessed for different carbonator dimensions.

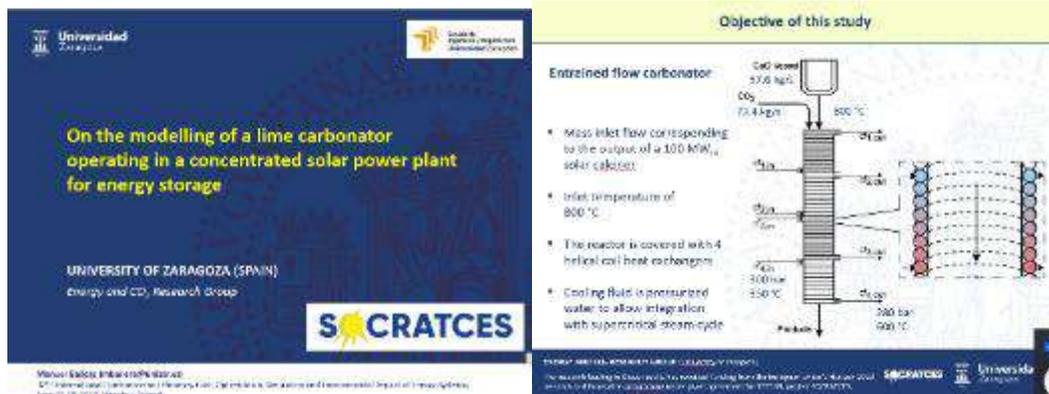


Figure 40: SOCRATCES slides 1 and 9 presentation at ECOS 2019

**Description:** Concentrated solar power (CSP) is becoming a widespread technology because of its potential for efficient exploitation of the solar source in large capacity plants. This technology is usually combined with thermal energy storage (TES) in order to cover the discrepancy in time between the energy production and energy demand, that is mainly due to the intermittent nature of the solar source. In this work, a concentrated solar plants with thermochemical energy storage based on Ca-looping for power production is considered. The goal of this work is to analyze the system with the aim of evaluating the best configuration of the power cycle. In particular, exergoeconomic analysis is applied a-posteriori to four optimized configurations of Brayton cycles using supercritical CO<sub>2</sub> as the working fluid. The analysis is conducted with the goal of highlighting the advantages of exergoeconomic analysis while suggesting changes in a system which might refer not only to the design parameters, but also to the system configuration.

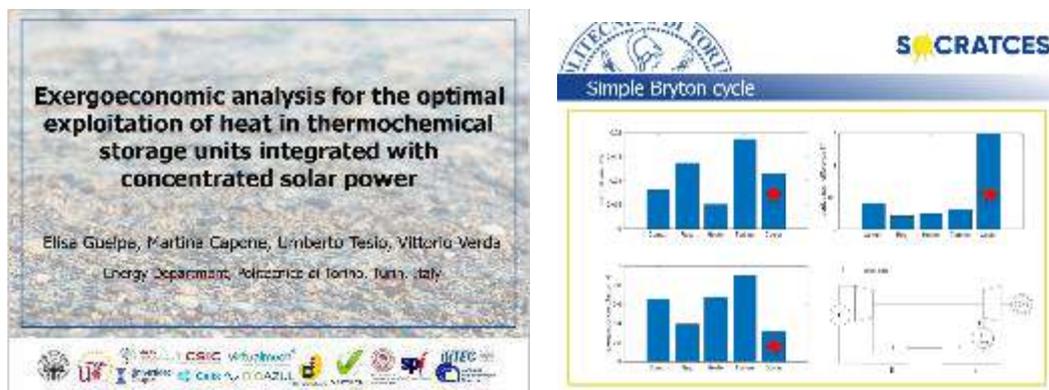


Figure 41 - Slides 1 and 6 of presentation at ECOS 2019

**Description:** Concentrated Solar Power (CSP) is attracting large interest because of the potential integration in industrial sites and off-grid applications. Among the most important technologies connected to the solar receiver of a typical concentrated solar plant are the storage the power cycle. Concerning energy storage, thermochemical storage is particularly interesting for the possibility of increasing the energy density. Concerning power cycle various options are possible. Increasing of the operating temperature enable the use of CO<sub>2</sub> supercritical Brayton cycles. This paper aims at presenting a comparison between various types of CO<sub>2</sub> supercritical Brayton cycles. A compact model has been built for each system configuration that can be used to investigate the system performances varying the design variables. The study includes various steps: 1) An investigation of the heat exchanged at the regenerator 2) a parametric analysis 3) an optimization. Results show that this type of cycle guarantees performances over 45%.

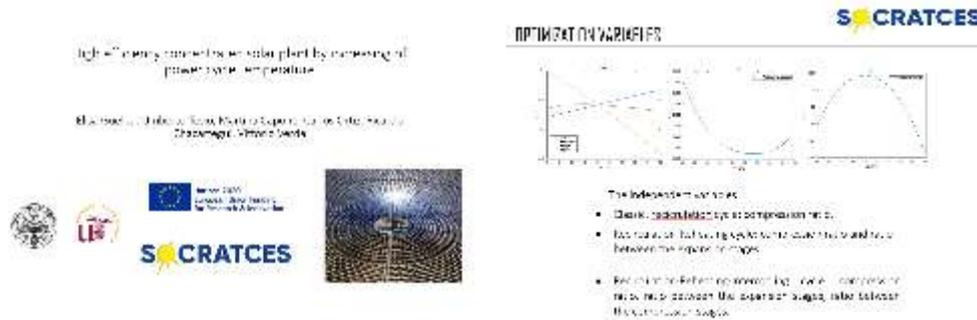


Figure 42 - Slides 1 and 15 of presentation at ECOS 2019

- 14th International Conference on Chemical and Process Engineering – IcheaP 14, Bologna (Italy), May 26-29, 2019 -. Title of the presentation: “Preliminary study on sound assisted calcium looping for TCES in CSP applications”

**Description:** Thermochemical energy storage (TCES) is considered as a promising technology to accomplish high energy storage efficiency in concentrating solar power (CSP) plants. Among all the alternatives, the calcium-looping (CaL) process, based on the reversible calcination–carbonation of CaCO<sub>3</sub>, is one of the most promising solution due to the high energy density achievable and the extremely low price, nontoxicity, and wide availability of natural CaO precursors such as limestone. In this work, sound-assisted fluidization has been used to improve the carbonation of fine CaO particles (< 10 μm) at CSP conditions. In particular, CaL tests have been performed under ordinary and sound-assisted fluidization conditions in order to study the influence of the application of high-intensity acoustic fields on the agglomeration of fine CaO particles. Tests have been carried out in a lab-scale experimental apparatus at CSP-CaL conditions. The effect of sound parameters (SPL and frequency) have been also highlighted.

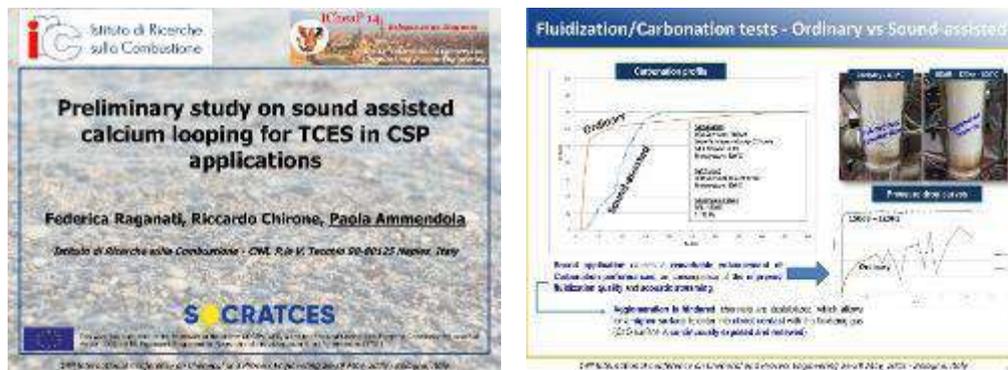


Figure 43. slides 1 and 10 of the presentation at IChEaP 14

- 11th Mediterranean Combustion Symposium – MCS11, Tenerife (Spain), June 16-20, 2019. Title of the presentation: “Role of acoustic fields on the fluidized bed carbonation for TCES in CSP applications”

**Description:** Thermochemical energy storage (TCES) is considered as a promising technology to accomplish high energy storage efficiency in concentrating solar power (CSP) plants. Among all the alternatives, the calcium-looping (CaL) process, based on the reversible calcination–carbonation of CaCO<sub>3</sub>, is one of the most promising solution due to the high energy density achievable and the extremely low price, nontoxicity, and wide availability of natural CaO precursors such as limestone. In this work, sound-assisted fluidization has been

used to improve the carbonation of fine CaO particles ( $< 10 \mu\text{m}$ ) at CSP conditions. In particular, CaL tests have been performed under ordinary and sound-assisted fluidization conditions in order to study the influence of the application of high intensity acoustic fields on the agglomeration of fine CaO particles. Tests have been carried out in a lab-scale experimental apparatus at CSP-CaL conditions. The effect of sound parameters (SPL and frequency) have been also highlighted.

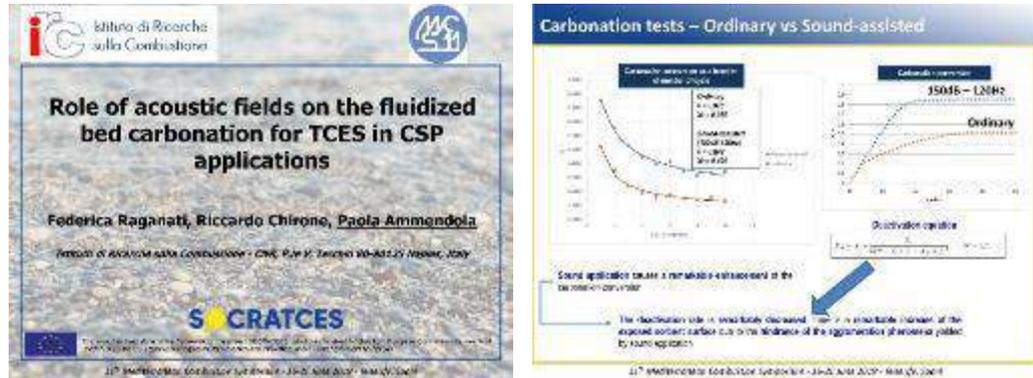


Figure 44: slides 1 and 10 of the presentation at MCS11

- 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems - ECOS 2019”, Wroclaw (Poland), June 23-28. Title of the presentation: “Role of acoustic fields on the fluidized bed carbonation for TCES in CSP applications”

**Description:** Thermochemical energy storage (TCES) is considered as a promising technology to accomplish high-energy storage efficiency in concentrating solar power (CSP) plants. The high temperatures achievable by CSP are used to drive an endothermic chemical reaction, whose products are stored separately to be employed when needed for carrying out the exothermic reverse reaction, which releases the heat previously used. Among all the alternatives, the calcium-looping (CaL) process, based on the reversible calcination–carbonation of  $\text{CaCO}_3$ , is one of the most promising solution due to the high energy density achievable and the extremely low price, nontoxicity, and wide availability of natural CaO precursors such as limestone. It is typically performed in two interconnected fluidized beds, one acting as carbonator and the other as calcinator. In particular, aiming at achieving high overall efficiency for TCES and electricity generation in CSP plants, carbonation would be carried out at high  $\text{CO}_2$  partial pressure and high temperature (around or above  $800 \text{ }^\circ\text{C}$ ), whereas, calcination could be performed at relatively low temperature ( $\sim 700 \text{ }^\circ\text{C}$ ). As regards the fast phase of the carbonation reaction, the use of fine particles ( $< 100$  microns) can be beneficial in terms of reduction of the intraparticle diffusion resistance on the reaction rate. However, the use of fine particles arises agglomeration issues caused by their intrinsic cohesiveness, which in turns would remarkably hinder the reaction efficiency due to poor and heterogeneous gas/solid contact and mass/heat transfer.

In this work, sound-assisted fluidization has been used to improve the carbonation of fine CaO particles ( $< 10$  microns) at CSP conditions. In particular, CaL tests have been performed under ordinary and sound-assisted fluidization conditions in order to study the influence of the application of high intensity acoustic fields on the agglomeration of fine CaO particles. The effect of sound parameters (intensity and frequency) have been also highlighted.

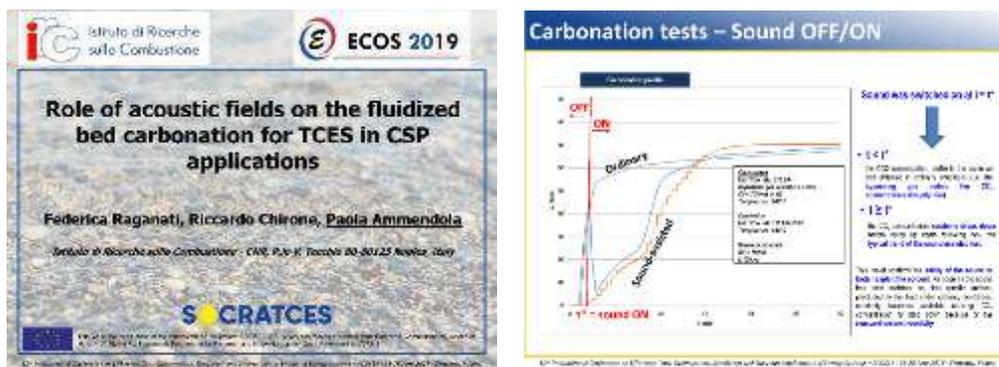


Figure 45: slides 1 and 11 of the presentation at ECOS 2019

- 25<sup>th</sup> SolaPACES Conference. 1-4 October 2019. Daegu, South Korea.

Thermochemical Energy Storage (TCES) systems are gaining momentum as a feasible alternative to sensible heat storage by molten salt-based systems in CSP plants. Among TCES systems, the Calcium-Looping (CaL) process stands as a promising option due to the low price and wide availability of the raw materials to be employed (natural limestone or dolomite) as well as its high-efficiency integration in CSP tower-based plants. The ambitious European project SOCRATCES is currently developing a CSP-CaL prototype at the kW-scale. CSP provides the heat required for the endothermic calcination of CaCO<sub>3</sub>, which yields CO<sub>2</sub> and CaO that are stored separately. When power production is demanded, CO<sub>2</sub> and CaO are combined to release energy through the reverse carbonation reaction.

Most of the equipment of the plant, such as reactors, conveying systems and heat exchangers, are well-known at a large scale since calcination is the basis of the cement industry, among many other applications. However, the solar calciner (receiver) remains as a major technological challenge. Several particle solar receivers have been proposed as calciners, based on either horizontal rotary or fluidized bed receivers. A novel solar-driven indirect calcination is proposed in the present work. This paper investigates the solar receiver geometry and the associated solar field to provide 100 MW of net thermal power at the receiver. An indirect calcination model is analyzed to assess heat transfer efficiency and the calcination degree.



Figure 46: Presentation at SolarPACES 2019

- 22<sup>nd</sup> PRES Conference, Agios Nikolaos, 20-23 October 2019

**Description:** Concentrated solar power (CSP) is a promising technology since it allows efficiently exploiting the solar source in medium-large capacity plants. Concentrated solar plants are usually combined with thermal energy storage to reduce the effects of the large variability of solar sources both in the short term (day/night) and in the long term (summer/winter). Thermochemical storage is a possible solution to this issue, as it allows storing heat with high

long-term efficiencies. In this work, a concentrated solar plants with a thermochemical energy storage based on Ca-looping for power production is considered. The aim of the present work is to find the optimal design of the heat recovery system in a CSP plant. Direct integration is considered. The optimal design is done to reach 100 % renewable and to improve system efficiency. This is done by combining a) an optimization tool b) the pinch analysis technique to evaluate the minimum external needs for each configuration. The analysis is performed for different values of CaO activity and carbonator temperatures. The maximum system efficiency under the constraint of 100 % renewable heat exploitation is assumed as the objective function in the optimization. The analysis is conducted using the software Aspen+®, which is integrated with a Matlab® software for the analysis of the configurations.

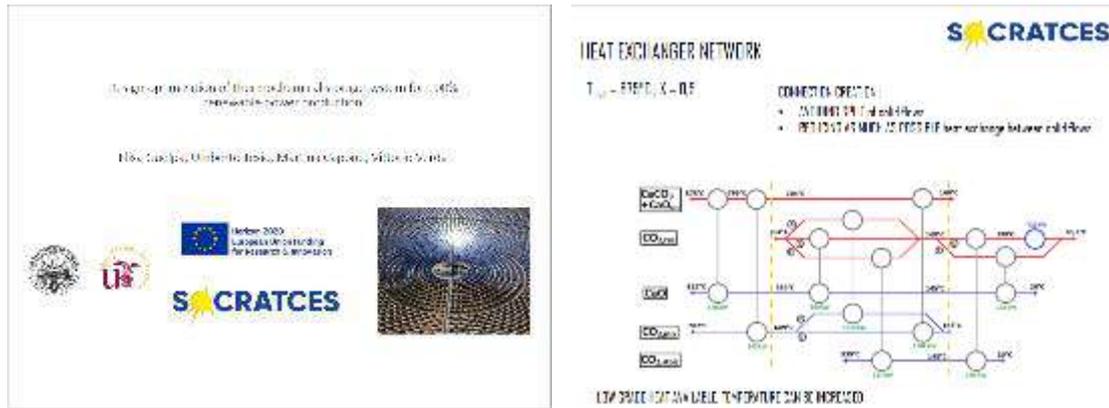


Figure 47: Slides 1 and 26 of presentation at PRES 2019

**Description:** Discrepancy of thermal demand and power production is one of the main issues that must be tackled while dealing with concentrated solar power (CSP). In this work, thermochemical energy storage (TCS) based on Ca-looping technology is considered as a possible way to store heat at ambient temperature and thus tackle the issue of long term operation. In TCS-CSP there are various components of the system where heat flux are available or requested at different temperature levels. Pinch analysis is a very suitable approach for optimally exploiting the available heat and thus obtaining optimal system configurations. This is particularly true in the considered application, where the temperatures in the thermochemical reactors are kept low, in order to reduce the issues related with sintering in the calcination. Various options for power cycles which can be directly and indirectly coupled with the discharging reactor (the carbonator) are considered. For each power cycle, the optimal system configuration is examined also varying the design parameters within an integrated optimization framework. Results show that, depending on the selected power cycle, efficiencies can vary between about 25 % to almost 50 %.

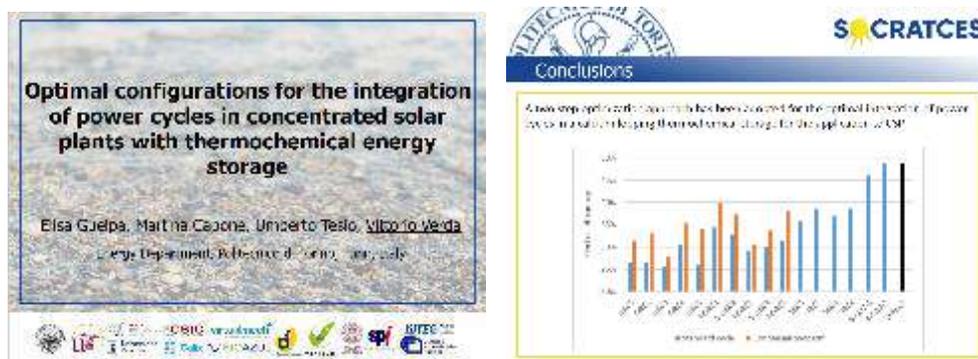
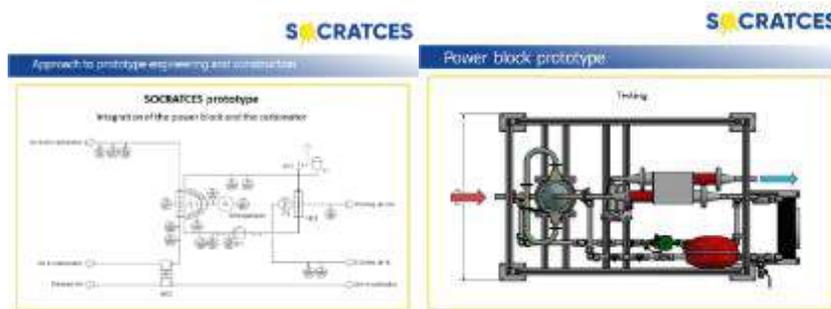


Figure 48 - Slides 1 and 14 of presentation at PRES 2019

- **Introduction to SOCRATCES at TTZ Bremerhaven for the students of PEET of the University of Applied Sciences, Bremerhaven on the 11<sup>th</sup> February 2020.**

**Description:** Students from the local university (Hochschule Bremerhaven) were invited and 11 students from different departments joined to learn about the SOCRATCES project on February 11th. After the head of process engineering department Mr. Faraz Rasheed Mir welcome the students and introduced the speaker, Mr. Muhammad Eusha commenced his talk with a brief overview of the project and what it is trying to accomplish. Different modules of the project, i.e. calciner, carbonator and power block were briefly discussed with the last receiving the most emphasis since that is the module TTZ is involved in. Stirling engines, their operation relevance and potential were presented as well. Afterwards the students were offered refreshment, following which a visit to the laboratory followed to conclude the presentation.



*Figure 49: Example slide from the presentation*

- **15<sup>th</sup> Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES) Online. September 1 – 5, 2020.**

#### **On the Design of the Solar Field and Receiver for CaL Thermo-chemical Energy Storage.**

This work presents the analyses developed for the design and development of solar calciner to be integrated within a prototype for demonstration of the calcium looping thermochemical energy storage concept. The necessity of high-temperature heat to feed the calcination reaction successfully required the use of a CSP point focusing system, in this case, heliostat field plus tower. The calcination occurs in a free-fall reactor. Due to the reduced size of the system, a beam down configuration is optimal, adding a secondary reflector to the optical system, see Figure below. The process integrates the solar field design, solar field design, secondary reflector design and control system, all based on MonteCarlo Raytracing. The prototype model has 14 heliostats positioned from 50 to 70 meters away from the tower, a paraboloid concentrator with a protection screen in front of it in order to protect the steel structure, and a cavity receiver.

With these simulations, radiation maps on the receiver cavity walls were obtained. Temperature and heat fluxes were developed from them, solving the fluid-thermal problem on the cavity/reactor by coupled CFD/FEM simulation. With heat fluxes and temperature field on the receiver, the mechanical design of this complex component, including material selection, has been performed, taking into account structural integrity and optimized energy transfer to the calcination reaction. Deformation and stress are monitored on the cavity receiver for that purpose.

One relevant question regarding the feasibility of a CSP TCES is the controllability under transient conditions of the solar resource. This paper presents the results of several control strategies of the solar field and their impact on the stability of the reactions. A hybrid open-loop (based on raytracing performance of the solar field) and closed-loop (based on actual DNI and thermocouple readings) model is developed. These results will be validated against a prototype currently under construction.

### Improving the performance of CSP plants by a novel Calcium-Looping Solar Combined Cycle (CaLSCC)

Dispatchability is one of the great challenges for the massive deployment of renewable energy systems. Among the promising Thermochemical Energy Storage (TCES) systems with the potential to improve currently commercial molten salt-based plants, the Calcium-Looping (CaL) process is gaining momentum due to its high energy density, low price and abundance of the raw material (limestone) and the high turning temperature. The stored energy can be released at temperatures above 1000°C, allowing CSP to integrate with highly efficient combined cycles. Solar power share in current Integrated Solar Combined Cycles (ISCC) is typically lower than 20%. Nevertheless, the Dispatchable Solar Combined Cycle (CaLSCC) based on the integration of a TCES system enhances notably the solar share with a high capacity factor of the plant. A model has been developed for simulating the proposed plant. Results show overall plant efficiencies higher than 45% (excluding solar side losses), which justifies the potential interest in this novel cycle.



Figure 50: Presentation at 15<sup>th</sup> SDEWES Conference

### Design of a 10 kWth carbonator pilot reactor for thermochemical energy storage applications with calcium looping

Nowadays, drop-tube reactors are well known in the chemical and petrochemical industry as they are applied in fast gas-solid reaction systems. Among others (i.e., FCC processes, cooper oxidation etc.), these kinds of reactors have been recently suggested for thermochemical energy storage applications (TCES). Calcium looping (CaL) has been proposed as a promising candidate for TCES as it stores high energy density in the form of chemical bonding through the calcination/carbonation reaction ( $\text{CaCO}_3 \leftrightarrow \text{CaO} + \text{CO}_2$ ). This study presents a novel drop-tube reactor design and configuration as the carbonator, in which exothermic carbonation reaction will occur in near-equilibrium conditions releasing 10 kW of thermal energy. Moreover, the manuscript provides information related to performance characteristics, expected results through process modelling and indicative plans and layouts for the whole reactor unit.

### MgO-Stabilized CaO for Thermochemical Energy Storage via Calcium Looping: Kinetics and Cyclic Stability

Calcium looping (CaL) has been proposed as thermochemical energy storage (TCES) system for concentrated solar power (CSP) plants. The solar energy drives the endothermic reaction in a calciner reactor, while the reverse carbonation reaction can produce electricity via a power cycle. Carbonation reaction is highly exothermic and can take place at temperatures  $>850^\circ\text{C}$ , increasing the power cycle efficiency (3<sup>rd</sup> Generation CSPs). Herein, dolomite and synthetic MgO-doped CaO sorbents are evaluated experimentally in terms of the reaction kinetics and the cyclic stability under TCES relevant conditions. The materials used were a natural dolomite and

different CaO/MgO sorbents derived by wet mixing (acetification) and subsequent calcination of natural precursors (limestone, dolomite and huntite). The cyclic stability was tested in a TGA apparatus. The material with 40% wt. MgO content exhibited stable CO<sub>2</sub> sorption capacity of 5 mol CO<sub>2</sub>/kg sorbent (more than 3 times higher compared to limestone) after 60 cycles and under severe conditions (carbonation: 850°C, pure CO<sub>2</sub>, calcination: 930°C, pure CO<sub>2</sub>). A fixed-bed reactor flow unit was used for the carbonation kinetic experiments in order to achieve efficient gas-solid contact and eliminate the control by transfer phenomena. The experiments were conducted under different CO<sub>2</sub> concentrations slightly above atmospheric pressure. A first order reaction with respect to CO<sub>2</sub> partial pressure was identified and a particle model was used to relate the available surface area with the reaction rate. All the materials exhibited high reaction rates (in the order of a few seconds) during carbonation showing the applicability of the process using commercial drop-down tube reactors.

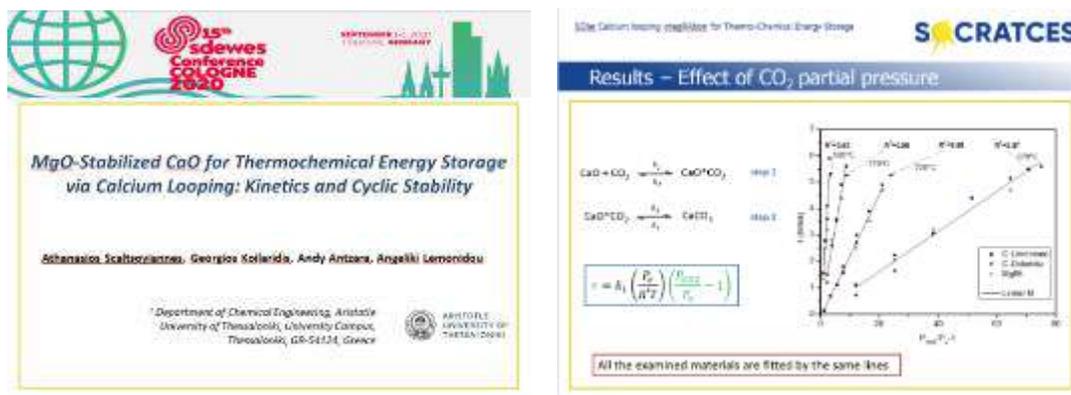


Figure 51: SOCRATCES slides 1 and 11 of the presentation at SDEWES 2020

- ECOS 2020 - THE 33<sup>RD</sup> INTERNATIONAL CONFERENCE ON EFFICIENCY, COST, OPTIMIZATION, SIMULATION AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS JUNE 29-JULY 3, 2020, OSAKA, JAPAN

#### Solar calcium looping energy storage: Preliminary comparison between pilot and large scale.

Calcium-looping process can be integrated into concentrated solar power plants serving as an energy storage alternative. Limestone calcination (endothermic reaction) allows storing thermal energy at high temperatures (950 °C), producing pure streams of CaO and CO<sub>2</sub>. This energy is released when required by means of a carbonation reaction (exothermic) at relatively high temperatures (600 – 800 °C). Then, power is produced through a Rankine cycle using the fluid heated in carbonation.

In this work, the solar calcium looping concept is analysed at pilot and large scale as a preliminary scale-up of the technology. The main problem arising from the scale-up of the carbonator is the heat removal. A single entrained flow reactor cooled by external coils results insufficient and reaction becomes inhibited, thus prolonging residence times and required lengths (up to 60 meters long for 4-meter diameter reactors, at scale of 100 MWth of solar power input). Some solutions to this issue are proposed and briefly assessed (e.g., multitube reactor, internal cooling). Moreover, the size of the storage tanks for the CaO and CO<sub>2</sub> may become unreasonable if aimed for a seasonal storage at large scale. A proper operation schedule has to be defined, stating the proper temporal framework for the storage.



Figure 52: SOCRATCES presentation at ECOS 2020.

- 75<sup>th</sup> ATI Congress, Rome, 15-16 September 2020

**Description:** Storing energy in thermo-chemical form is a promising alternative for renewable energy sources and one of the fields that could exploit its advantages is constituted by Concentrated Solar Power (CSP). High efficiencies, high energy densities, long-term storage and dispatchability in power generation could be tackled with the employment of a Calcium-Looping in a central tower CSP plant. Although Brayton cycles based on sCO<sub>2</sub> and He probably represent the most efficient option, it can be interesting to investigate the integration of Steam Rankine cycles because of the lower costs and the higher stage of development that characterize this technology. The present work has the purpose of studying this kind of integration and analyzing the system in both energy and economic terms. To perform a comprehensive investigation, the power block layout and its thermal feeding strategy are included in the analysis and optimized. In addition, a multi-objective optimization is performed to evaluate possible compromises between the two most important aspects related to the entire power plant.



Figure 53 - Slides 1 and 6 of presentation at ATI 2020

- 6<sup>th</sup> ICSREE Conference, Strasbourg, 5-7 May 2021

**Description:** The need for clean energy production in order to mitigate the climate changes is a mandatory task that present society has to fulfil. In this context, the dispatchable generation achievable with energy storage coupled to renewable power plants is an important research topic. In particular, the integration of a Calcium-Looping in a central tower Concentrated Solar

Power plant represents a promising application for Thermochemical Energy Storage. This technology would allow to exploit high-quality heat, achieving high energy density and long-term storage with near zero energy losses; in addition, most of the components needed are already developed on a commercial scale and the process could exploit limestone as natural CaO precursor. Regarding power generation, an indirect integration makes possible to choose between many different thermal cycles, but, on the other hand, it requires the development of a proper strategy to find both the optimal layout and the operating conditions. The aim of the present work is to compare the optimal integration of the most promising thermal cycle alternatives: Rankine cycle, CO<sub>2</sub> Brayton cycle and He Brayton cycle. The problem of synthesis, design and operation optimization is addressed with the aim to perform an analysis as comprehensive as possible. Several layouts with the scale of a pilot plant are considered and the study is performed both in terms of energy efficiency and investment cost. For the same optimization criteria, some similarities arise in the section devoted to the heat recovery from carbonation products, while the most important differences are stressed and explained. The total plant layouts are relatively structured, since composed by different processes, but the energy efficiency of the system results to be strictly bonded to the power cycle performance. This comparison is intended to provide some of the most important elements for the choice of a suitable power block integration according to the desired prerequisites and to underline both advantages and criticalities of the alternatives investigated.

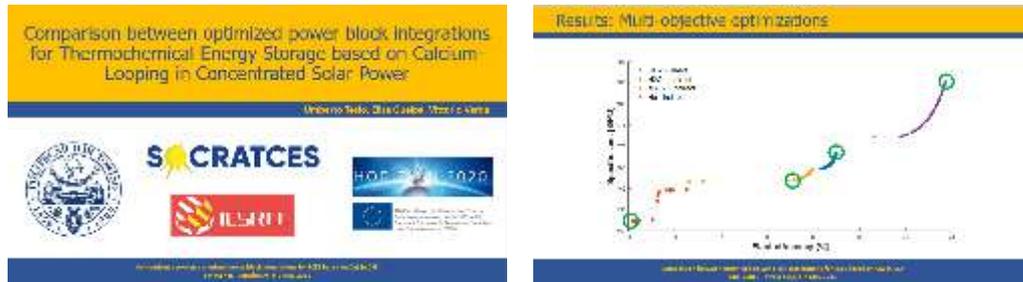


Figure 54 - Slides 1 and 8 of presentation at ICSREE 2021

- **Foro tecnológico. Cambio climático y oportunidades de negocio: Descarbonización industrial y tecnologías de captura, almacenamiento y usos del CO<sub>2</sub>. May 20, 2021, Zaragoza, Spain**

**Description:** Descarbonización de procesos industriales mediante oxidación, hidrógeno y producción de metano sintético. Almacenamiento energía. Usos químicos CO<sub>2</sub>: Proyecto SOCRATCES.



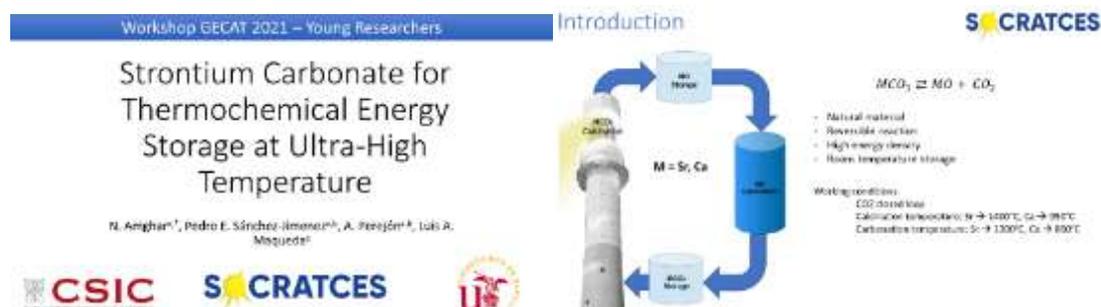
Figure 55: SOCRATCES slides 1 and 3 presentation at Foro Tecnológico 2021

- **Workshop GECAT 2021 – Young Researchers, Spain 4 June 2021**

### Strontium Carbonate for Thermochemical Energy Storage at Ultra-High Temperature

Nabil AMGHAR, Pedro E. SANCHEZ-JIMENEZ, Antonio PEREJON, Luis A. PEREZ-MAQUEDA.

Ca-Looping process has attracted ample attention for its potential as a thermochemical energy storage system (TCES) at temperatures as high as 850°C. However, as the maximum attainable efficiency of heat-to-power conversion increases with operational temperatures, systems able to work at even higher temperatures are of great interest. Therefore, this study proposes SrCO<sub>3</sub> as a viable alternative to CaCO<sub>3</sub> for TCES at ultra-high temperatures. The system is analogue to the CaCO<sub>3</sub>/CaO pair; highly reversible, non-toxic and with high energy density. The reaction was performed in pure CO<sub>2</sub> atmosphere to avoid the need of costly and complicated gas separation systems. The starting SrCO<sub>3</sub> was subjected to calcination temperatures of 1400°C and 1300°C while carbonation temperature was varied from 1200°C to 950°C. As its calcium counterpart, SrCO<sub>3</sub> shows a decay in the multicycle activity with repeated cycling. The harsh conditions involved in this study are responsible for the deactivation of SrCO<sub>3</sub>, which is mainly related to surface area suppression by extensive sintering. Higher effective conversions are achieved at the lower tested carbonation temperatures. Furthermore, for identical carbonation temperature, the higher the prior calcination temperature the lower the conversion. In any case, residual conversion obtained are similar to those reported for the CaCO<sub>3</sub>/CaO pair at much lower temperatures. Consequently, the SrCO<sub>3</sub>/SrO system, distinguished by a notable reaction enthalpy, constitutes a very high energy density TCES. Moreover, for a thermal cycle, working at higher temperature would allow to enhance the exergy of the process, which turns out into a greater net energy input.



**Figure 56: Slides 1 and 2 presentation at GECAT 2021**

- **CEEC-TAC6 & MEDICTA2021 Conference, SPLIT July 20 - 24, 2021.**

### High-temperature thermochemical energy storage (TES) for concentrated solar power plants (CSP)

Luis A PEREZ-MAQUEDA, Pedro E. SANCHEZ-JIMENEZ, Antonio PEREJON, Nabil AMGHAR, Virginia MORENO, Juan ARCENEGUI-TROYA, José M. VALVERDE, Carlos ORTIZ, Ricardo CHACARTEGUI

Concentrated solar power plants (CSP) concentrate the solar irradiation using mirrors to drive an engine that produces electricity. Thus, in principle, electricity can be produced only when there is solar irradiation. Modern CSP plants have an energy storage system that allows producing energy even at night. The state-of-the-art technology for energy storage in commercial CSP plants is based on molten salts. This technology has several limitations, namely limited power cycle efficiency because of the maximum working temperature of the salt, a relevant energy consumption to maintain the salt in the molten state to avoid solidification and corrosion and high price issues. A new alternative to such molten salts is the use of

thermochemical energy storage. It is of the most interest to the system based on the calcination-carbonation reaction of  $\text{CaCO}_3/\text{CaO}$ , known as Calcium Looping (CaL process). This CaL uses limestone, which is an abundant and cheap mineral, as raw material. Concentrated solar energy is used to promote the endothermic calcination of the limestone, producing  $\text{CO}_2$  and  $\text{CaO}$  that are stored in different containers. When energy is required, the stored reactants are mixed to perform the exothermic carbonation reaction that produces  $\text{CaCO}_3$  and releases the stored energy.

In the frame of the SOCRATCES project, funded by the European Union’s Horizon 2020 research and innovation programme under grant agreement No 727348 this technology is being demonstrated in a pilot plant scale.



Figure 57: SOCRATCES slides 26 and 27 of the presentation at CEEC-TAC6 & MEDICTA2021

- **International Conference on Chemical Reactors, Online September 12-17, 2021.**

The reaction of  $\text{CO}_2$  with  $\text{CaO}$ -based solid sorbents in cyclic mode, also known as calcium looping (CaL), has great potential for capturing  $\text{CO}_2$  at stationary sources, storing/releasing energy in concentrated solar power plants, or even enhancing thermodynamically limited reactions such as reforming and water-gas-shift. Lime (pure  $\text{CaO}$ ) suffers from severe deactivation mainly due to enhanced sintering phenomena at high temperatures. Many efforts are being put on preventing the loss of capacity of  $\text{CaO}$  through sorption/desorption cycles, by introducing an inert stabilizing phase in the  $\text{CaO}$  lattice. Herein, we investigate the carbonation reaction kinetics of materials with different stabilizing agents aiming at developing a robust reaction kinetic model. Carbonation reaction of  $\text{CO}_2$  with  $\text{CaO}$ -based sorbents exhibits fast kinetics (in the order of a few seconds), which is of great importance for real applications. Carbonation is a first order reaction with respect to  $\text{CO}_2$  with a low activation energy of  $22.1 \pm 5.9$  kJ/mol. A kinetic model was developed applicable for  $\text{CaO}$ -based sorbents with different type and content of stabilizing phase.

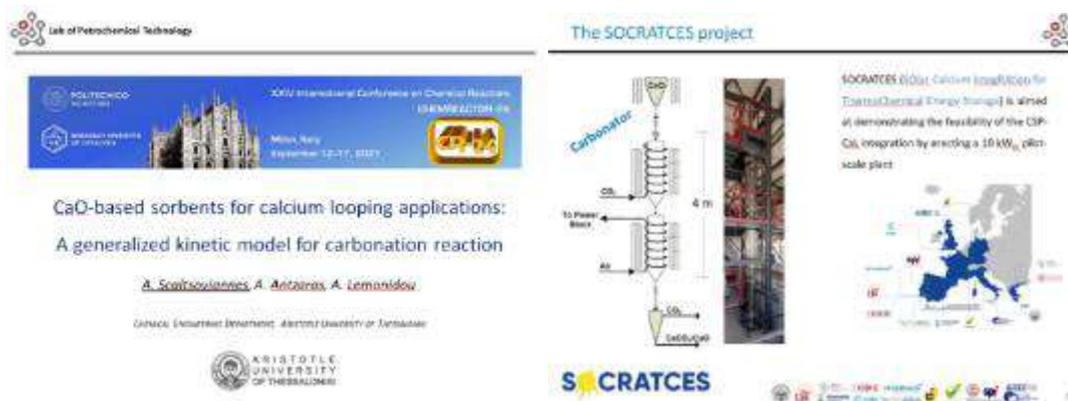
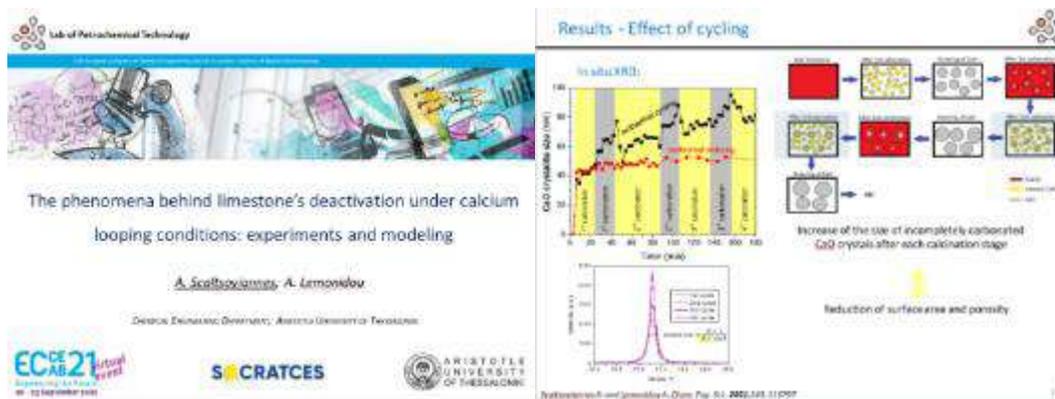


Figure 58: SOCRATCES slides 1 and 21 of the presentation at CR24 2021

- **13<sup>th</sup> European Congress of Chemical Engineering, Online September 20-23, 2021.**

The reversible reaction of CO<sub>2</sub> with lime, the basis of calcium looping, is a promising process for post-combustion CO<sub>2</sub> capture and energy storage applications. The precursors of CaO can be minerals with high availability and low cost. The major sorbent candidate for calcium looping applications is limestone, a non-toxic, abundant natural material with a low cost of around 10 \$/tn. The cyclic behaviour of limestone under calcium looping conditions has shown a fast decay of reactivity after a few cycles and this is considered as its main disadvantage. High make-up flows of fresh material and/or regeneration treatments of spent sorbents (e.g. hydration) have been proposed as competitive strategies for limestone usage in large scale applications. Herein, the phenomena governing the activity loss of limestone under calcium looping conditions are investigated. Sintering of CaO and structural changes during each calcination reaction were identified as the main factors leading to the deactivation of limestone under calcium looping conditions. Based on the experimental observations, a robust model for the prediction of the sorption capacity of limestone in calcium looping applications is proposed.



**Figure 59: SOCRATCES slides 1 and 14 of the presentation at ECCE 2021**

- **27<sup>th</sup> SolarPACES Conference. September 27 – October 1, 2021. Online**

**Solar-Driven Indirect Calcination for Thermochemical Energy Storage.**

Thermochemical Energy Storage (TCES) systems are gaining momentum as a feasible alternative to sensible heat storage by molten salt-based systems in CSP plants. Among TCES systems, the Calcium-Looping (CaL) process stands as a promising option due the low price and wide availability of the raw materials to be employed (natural limestone or dolomite) as well as its high-efficiency integration in CSP tower-based plants [1]. The ambitious European project SOCRATCES is currently developing a CSP-CaL prototype at the kW-scale. CSP provides the heat required for the endothermic calcination of CaCO<sub>3</sub>, which yields CO<sub>2</sub> and CaO that are stored separately. When power production is demanded, CO<sub>2</sub> and CaO are combined to release energy through the reverse carbonation reaction.

Most of the equipment of the plant, such as reactors, conveying systems and heat exchangers are well-known at a large scale since calcination is the basis of the cement industry among many other applications. However, the solar calciner (receiver) remains as a major technological challenge [2]. Several particle solar receivers have been proposed as calciners, based on either horizontal rotary or fluidized bed receivers. A novel solar-driven indirect calcination is proposed in the present work. This paper investigates the solar receiver geometry and the associated solar field to provide 100 MW of net thermal power at the receiver. An indirect calcination model is analyzed to assess heat transfer efficiency and the calcination degree.



Figure 60: Presentation at SolarPACES 2021

- **16<sup>th</sup> SDEWES Conference, Dubrovnik 10-15 October 2021**

**Description:** The Calcium-Looping (CaL) process based on the multicyclic calcination-carbonation of CaCO<sub>3</sub>/CaO is a promising Thermochemical Energy Storage (TCES) technique to be integrated into solar thermal plants. As a novelty, this work proposes a CaL integration that considers low-pressure calcination under pure CO<sub>2</sub> at reduced temperature. Low-pressure calcination (0.01 bar) provides a suitable solution to reduce CaO sintering and its consequent loss of reactivity in the carbonation stage. Since calcination temperature is reduced (from 950°C at ambient pressure to 765°C), energy losses at the receiver are lowered. In addition, a reduced calcination temperature allows using metallic receivers already tested at the MW scale, which notably increases the CSP-CaL integration reliability. Moreover, the multicycle CaO reactivity in short residence times is promoted, requiring a simpler reactor design. The proposed plant proposes a smooth integration of the CaL process in CSP plants, with a moderate storage level and supported by a natural gas back-up system (solar share higher than 50%). Results show that solar thermal-to electric efficiency is above 30%, which shows potential integration potential.



Figure 61 SOCRATCES slides 1 and 6 presentation at SDEWES 2021

- **AIChE Annual Meeting, Online November 15-19, 2021.**

Calcium looping (CaL), which relies on the cyclic reaction of CaO with CO<sub>2</sub>, is potentially a means for storing solar energy in a chemical substance by driving the endothermic CaCO<sub>3</sub> decomposition. The reverse carbonation reaction can then produce heat ( $\Delta H^\circ = -178$  kJ/mol) at high temperatures (~850°C under pure CO<sub>2</sub> atmosphere), increasing the power cycle's efficiency, while the regeneration of CaCO<sub>3</sub> is feasible within the operational temperature range of CSP towers. These features, along with materials' abundance, high energy density and lack of toxicity render CaL a promising route for storing solar energy in the long term. CaCO<sub>3</sub> decomposition reaction has been studied for many years, but consensus has not been achieved regarding the rate expression and the effect of CO<sub>2</sub> partial pressure. The existence of a robust kinetic model is

of high importance for the reactor design. Additionally, the design of a calciner that efficiently converts solar to chemical energy through  $\text{CaCO}_3$  decomposition is probably the greatest challenge of this concept. Herein, a lab-scale experimental kinetic study of limestone decomposition was carried out targeting to the development of a reliable kinetic model that will explain the literature discrepancies. This kinetic model was then used for the design of a 1-D drop-down reactor that can be used for thermochemical storage of solar energy in CSP plants.

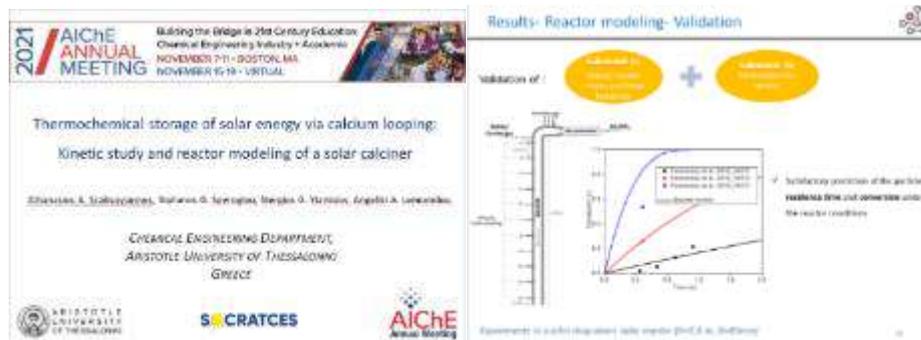


Figure 62: SOCRATCES slides 1 and 23 of the presentation at AIChE 2021

- QIES Biannual Meeting 2022, Seville 30<sup>th</sup> January – 2<sup>nd</sup> February 2022

**Ca-Looping for Thermochemical Energy Storage**

Nabil AMGHAR, Andres CARRO, Pedro E. SANCHEZ-JIMENEZ, Antonio PEREJON, Carlos ORTIZ, Ricardo CHACARTEGUI, Luis A. PEREZ-MAQUEDA

Ca-Looping process has aroused interest as a high temperature thermochemical energy storage (TCES) system. The process consists of the reversible reaction between  $\text{CaO}$  and  $\text{CaCO}_3$ . Within the framework of the H2020 European project SOCRATCES, a novel pilot plant has been built in Seville with the aim to demonstrate the viability of the integration of the Ca-Looping process in concentrated solar power to store solar energy (CSP). The plant is composed of two separate reactors: one for calcination in the air atmosphere at high temperatures ( $\sim 1000^\circ\text{C}$ ) and a carbonator that operates in  $\text{CO}_2$  at  $800^\circ\text{C}$ . The facility involves 12 heliostats which heat the reactor to drive the endothermic decomposition of  $\text{CaCO}_3$ . The resulting  $\text{CaO}$  is translated by means of a pneumatic system to the carbonator reactor where is placed in contact with a  $\text{CO}_2$  atmosphere to induce the reverse exothermic reaction and produce energy on-demand. Here, we discuss the feasibility of the process considering the preliminary results obtained from the tests carried out in the plant. Calcination degree achieved is over 70%. On the other hand, carbonation results show a decay in the performance related to the deactivation of the  $\text{CaO}$ . These results are encouraging about the feasibility of the scale-up. As the plant is operating, a series of adjustments will be made to improve calcination/carbonation cycles and generate additional information. Therefore, there is a positive trend towards as the system is adjusted and experience and knowledge in the technology are gained.

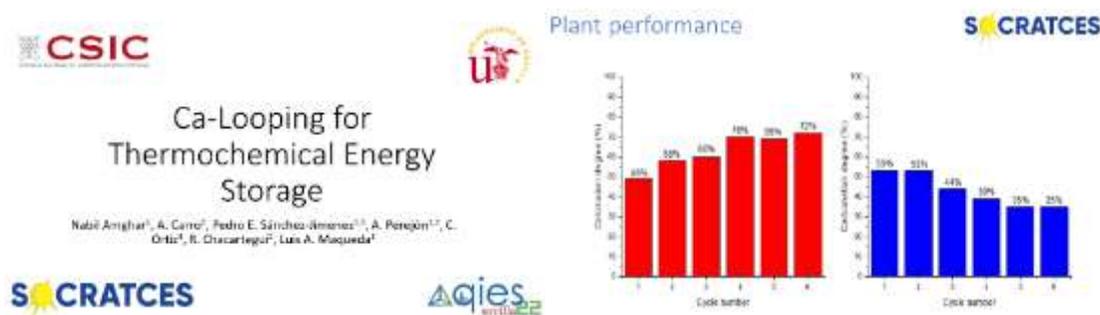


Figure 63: Slides 1 and 4 at QIES 2022

## 4.2 SCIENTIFIC POSTERS

The project partners have developed and presented scientific posters at conferences and events that we collect in this section:

- **25<sup>th</sup> International Symposium on Chemical Reaction Engineering – ISCRE25.**

**Description:** Carbonate looping is a promising ex-situ post-combustion CO<sub>2</sub> capture technology based on the reversible gas-solid reaction of CaO with CO<sub>2</sub>. CaO has been thoroughly studied as a CO<sub>2</sub> sorbent because of its high sorption ability. Flue gases at high temperatures are separated from CO<sub>2</sub>, which is captured in the sorbent bed in the carbonator. After the sorbent's saturation, the material is led to the calciner where it is regenerated at higher temperatures and CO<sub>2</sub> is removed as pure stream, ready for sequestration. However, the main challenge of this approach is the high temperature required for regeneration (up to 950°C), which leads to severe sintering of CaO and in rapid deactivation upon multiple cycles. The required heat for the endothermic calcination can be provided by utilizing concentrated solar radiation. At this direction, the carbonate looping scheme could be integrated into a solar power plant for energy storage. The solar energy can be thermochemically stored by utilizing it for the endothermic CaCO<sub>3</sub> decomposition, and released when needed in a second step, by means of the exothermic carbonation reaction.

The use of dual fluidized bed reactors is considered the most suitable configuration for such processes; however, the problems of attrition and mechanical strength loss are common, especially for natural sorbents. The key for successful commercialization is the development of stable materials that can undergo multiple cycles without deterioration in their performance. In this work, we report the development of a Zr-promoted CaO-based sorbent, prepared with an advanced technique and the evaluation of its performance in a fluidized bed reactor. The Zr-promoted CaO-based CO<sub>2</sub> sorbent was tested in a fluidized bed reactor unit to determine its performance in cyclic CO<sub>2</sub> capture under various operating conditions. The material exhibited very high carbonation conversion (60-85%) during pre-breakthrough under all investigated conditions, with more than 75% CO<sub>2</sub> removal. The addition of steam in both the carbonation and calcination steps resulted, not only in higher conversions but also in significantly enhanced cyclic stability with less than 16% deactivation after 20 cycles. Under realistic calcination conditions (920°C and 80% CO<sub>2</sub> concentration) the sorbent maintained more than 70% of its initial capacity, a value almost 6 times higher than natural limestone. Although the cost of the synthetic material would apparently be higher than that of a natural sorbent, the increased sorption capacity and stability, even under severe calcination conditions, are expected to lead to lower amount of material circulating in the fluidized bed reactor and lower sorbent make-up flow, balancing the increased cost.



- **22<sup>nd</sup> Conference on Process Integration, Modelling and Optimisation for energy Saving and Pollution Reduction – PRES'19.**

**Description** The calcium looping (CaL) process stands as a promising technology for high energy storage efficiency in concentrating solar power (CSP) plants through thermochemical energy storage (TCES). The high energy density of the reversible calcination-carbonation reaction system as well as the low price, nontoxicity and wide availability of natural CaO precursors have driven the interest towards this application. In this work, a model-based investigation of the carbonation reaction ( $\text{CaO}_{(s)} + \text{CO}_{2(g)} \rightarrow \text{CaCO}_{3(s)}$ ) is carried out under different conditions. Specifically, a 1D heterogeneous model for a drop-tube carbonator reactor at steady state conditions is developed. The model handles gas and solids as two distinct phases (gas and solid phase), with each phase characterized by individual physical properties. Consequently, the model is based on an Euler-Euler approach, which means a segregated manipulation of each phase with conservation of mass, energy and momentum being used to couple them. A plug flow assumption has been considered for both phases and the simplified and reduced Navier – Stokes equations are solved for both. The model includes the heterogeneous gas-solid carbonation reaction kinetics, derived by a modified Prout-Tompkins model. Heat is generated in solids surface and transferred by convection to the gas phase and eventually to the reactor's wall. Also, a detailed model of the radiative heat transfer has been developed considering interactions between the gas-solid mixture and internal carbonator wall. This paper investigates the model capabilities under different operating conditions and reaction kinetics regimes. A wide range of solids sizes from fine particles ( $\sim 5\mu\text{m}$ ) to coarse particles ( $\sim 200\mu\text{m}$ ) is examined in terms of the carbonator performance. This work presents several parametric studies that have been performed using the 1D steady-state carbonator model regarding crucial operating variables such as inlet reactants temperature, reactor's wall temperature and  $\text{CO}_2$  excess. The model is run for high diluted entrained flows but also for dense solids flows, giving important provisions for scale-up studies. In this way, it can be incorporated in CaL-CSP integration studies as well as in integrated cement plants due to fine particles of them. Results are presented as profiles of reactants conversions, carbonator pressure, gas and solid phase temperature and velocity, as well as heat transfer rates and fluxes from the inner to the outer of the reactor with respect to reactor's length.



**CERTH**  
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS



**22<sup>nd</sup> Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, PRES'19, 20-23 October 2019, Agios Nikolaos, Crete, Greece**

## Study of a Drop-Tube Carbonator Reactor for CSP-Calcium Looping Based on a Heterogeneous Reaction model

Evgenios Karasavvas<sup>a</sup>, Kyriakos D. Panopoulos<sup>a,\*</sup>, Simira Papadopoulou<sup>a,b</sup>,  
Spyros Voutetakis<sup>a</sup>

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<sup>b</sup>Department of Industrial Engineering and Management, International Hellenic University (IHU), Greece

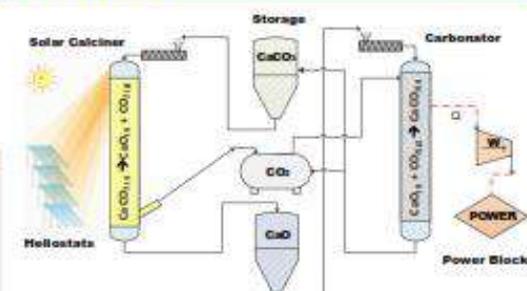
**CSP-Calcium Looping (CaL) concept in SOCRATCES**

- Concentrated Solar Power plants (CSP) along with Thermochemical Energy Storage (TCES) have been proposed as a sustainable solution for power production [1]
- Calcium-looping (CaL) stands among the most promising chemical systems for thermo-chemical energy storage
- This study focuses on a **carbonator** reactor model development

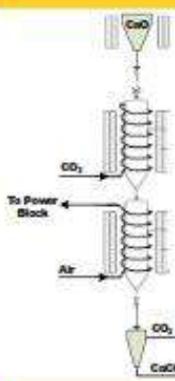


$$\text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g) \quad \Delta H_{T_{ref}}^0 = 178 \text{ kJ/mol}$$

- Solar driven calcination reaction
- High energy density of CaO/CaCO<sub>3</sub>
- Highly exothermic carbonation (T 600-1000 °C)
- Low price (<10 €/ton), Abundant, Harmless, Natural CaCO<sub>3</sub>



**Drop-tube carbonator reactor**



**Reactor description**

- Novel **drop-tube** carbonator reactor configuration
- ~0.15 m diameter, ~4 m length, 2 sections of 2 m each
- Initially calcined solids stored on top of the reactor in a heated tank
- Reactor encircled by a set of helical coils for cooling
- CO<sub>2</sub> provided by pressurized bottles
- Fresh air as a cheap source of heat sink
- Hot air pumped to the power block for power generation
- Electrical furnaces for preheating the reactor and solids

**Model assumptions**

- One-dimensional (1D) steady state plug flow** reaction model. Radial dispersions of mass, energy and momentum are neglected [3]
- Euler-Euler approach of both gas and solid phases
- The particle-wall and interparticle interactions are neglected [4]
- Solids assumed to be **spherical**, with **uniform size** and temperature
- Particle size remain unchanged during reaction [4]

**Continuity conservation equations for gas and solid phases**

$$\frac{d(\rho_g v_g a_g)}{dx} = - (1 - \epsilon_g(x)) \cdot \Gamma_{s-g}(x), \quad \frac{d(\rho_s v_s a_s)}{dx} = (1 - \epsilon_g(x)) \cdot \Gamma_{s-g}(x)$$

**Momentum conservation equations for gas and solid phases**

$$\frac{d(\rho_g v_g^2 a_g)}{dx} = F_D(x) - F_{ps}(x) + \tau_{s-g}(x) \rho_s(x) g + F_{wall}(x)$$

$$\frac{d(\rho_s v_s^2 a_s)}{dx} = - \frac{dP}{dx} - F_D(x) - F_{ps}(x) + \epsilon_g(x) \rho_g(x) g - F_{wall}(x)$$

**Energy conservation equations for gas and solid phases**

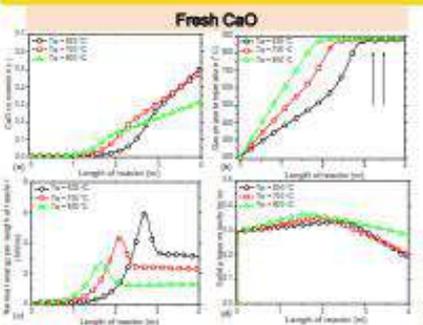
$$\frac{d(\rho_g v_g a_g T_g)}{dx} = \alpha_{sp}(x) h_{sp}(x) (T_g(x) - T_s(x)) + \Delta H_{rxn} R(x) (1 - \epsilon_g(x))$$

$$\frac{d(\rho_s v_s a_s T_s)}{dx} = \alpha_{ps}(x) h_{ps}(x) (T_s(x) - T_g(x)) + \alpha_{pm}(x) h_{pm}(x) (T_g(x) - T_s(x)) - \theta_{rad}(x)$$

**Species conservation and reaction rate**

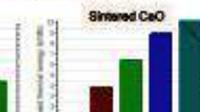
$$\frac{d(n_i)}{dx} = \frac{dN_{CaO}}{dx} - \frac{\rho_s(x)}{RT_g(x)} \cdot \frac{dN_{CaO}}{dx} = N_{CaO}(x) \left( 1 - \frac{N_{CaO}(x)}{N_{CaO,max}} \right) \cdot r(T, P) [2]$$

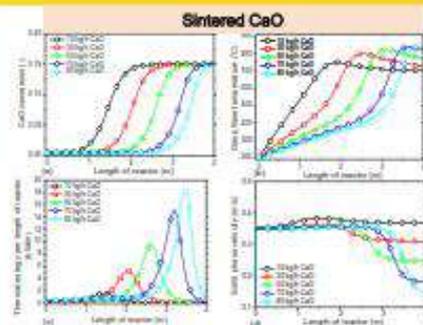
**Model results and discussion**



Carbonator variable/parameter	Fresh CaO	Sintered CaO
Inlet reactor temperature (°C)	200	200
Reactor pressure (kPa)	101.32	101.32
Initial CaO flow rate (kg/h)	10.2	10.9-30.0
Initial CO <sub>2</sub> flow rate (kg/h)	10.0	10.0
Solids average diameter (µm)	50	50
Reactor wall temperature (°C)	800-850	700
Maximum solvent conversion (-)	69.1	15.0

Severe inhibition of reaction rate occurs due to the equilibrium temperature approach



**Conclusions**

**References**

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[3] Torrado S., Antas B., Fernández J.R., Abanades J.C., 2018, Carbonator of Fine CaO Particles in a Drop Tube Reactor. *Ind. Eng. Chem. Res.*, 57, 13372-13380

[4] Schödl M.A., Schulenburg P., Tunk T., 2016, Oxidation of copper at high temperature as an example for gas-solid reactions in a downdraft reactor - experiments and model-based analysis. *Chem. Eng. Sci.*, 151, 110-120

**Acknowledgments**

This research has received funding from European Commission by means of HORIZON 2020, the EU Framework Programme for Research & Innovation, under Grant Agreement Number: 727348, SOCRATCES Project - All Rights Reserved. Duration: 01/01/2018 - 31/12/2025 (36 months). Total budget: 4,975,432 € (EC contribution: 4,975,432 €)



Figure 65 SOCRATCES poster presentation at PRES'19

- **5<sup>th</sup> Central and Eastern European Conference on Thermal Analysis and Calorimetry (CEEC-TAC5) and 14<sup>th</sup> Mediterranean Conference on Calorimetry and Thermal Analysis (Medicta2019).**

**Description: Thermal energy storage using low-cost natural compounds for concentrated solar power plants**

Jonatan DURAN, Carlos ORTIZ, Beatriz SARRIÓN, Antonio PEREJON, Pedro E SANCHEZ-JIMENEZ, José M. VALVERDE, Ricardo CHACARTEGUI, Luis A PEREZ-MAQUEDA

There is an enormous interest in increasing dispatchability in concentrated solar power plants (CSP). In fact, one of the main disadvantages of these power plants is its intermittency. Unlike conventional fuel power plants, that could be turn on and off when needed, solar power plants depend on the sun and it does not shine at all times. Therefore, there is a high need for energy storage. Available technology based on batteries is still an expensive solution, while storing thermal energy seems to be a more affordable option. The state of the art technology for storage in CSP plants is based on molten salts. Nevertheless, the high cost of this technology is a significant limitation. The use of thermochemical energy storage systems is a very promising technology for CSP. In particular, the system based on the calcination-carbonation reaction of CaCO<sub>3</sub>/CaO (also known as Calcium Looping (CaL process) have a great potential. This process is based on limestone, which is a low-cost, abundant and environmentally friendly material. The process is straightforward, the endothermic calcination reaction is induced by the concentrated solar power releasing CO<sub>2</sub> and CaO that are stored in separated containers (they could be stored for as long as needed). Then, when there is energy demand, CO<sub>2</sub> and CaO are mixed to promote the exothermic carbonation reaction that releases the thermal energy. This thermal energy is used to produce electrical power. This idea set the bases of the SOCRATCES project (grant agreement No 727348, Horizon 2020 research and innovation programme, European Union) that explores the feasibility of the CSP-CaL integration by constructing a pilot-scale plant to prove this technology and improve the understanding in the process integration

- **ProcessNet annual conference and 34<sup>th</sup> DECHEMA annual conference of biotechnologists 2020**

**Description:** The integration of an exothermic chemical reactor with a beta type 1 kW Stirling engine is investigated. In this scheme, solar energy is captured chemically through calcination of calcium carbonate in a calciner reactor, of central focus in this project, and calcium oxide and carbon dioxide are brought together in the carbonator reactor later to release the stored energy. The power-block module is designed to convert the liberated thermal energy in to electricity receiving an air stream heated to high temperatures by the carbonator through a spirally wound heat exchanger. A post-engine heat exchanger preheats the atmospheric air before sending to the carbonator as a cyclic integration was not contemplated to avoid expensiveness and complications for this prototype scale implementation of the scheme. Thermal performance is evaluated under different flowrate and temperature combinations. The experimental findings are then contrasted against the theoretical predictions. While the stand-alone thermodynamic efficiency of the engine is impressive, it exhibits poor overall conversion. The project (SOCRATCES) was authorized and funded by the European Commission under the Grant Agreement number 727348.

Link: <https://socratces.eu/wp-content/uploads/SOCRATCES-Stirling-PRESENTATION-DECHEMA.pdf>

# Feasibility Study of Combining the Stirling Cycle With the Solar Calcium-looping Integration for Thermochemical Energy Storage

M Eusha<sup>1,2</sup>, F Mir<sup>1</sup>, G Schories<sup>1</sup>  
<sup>1</sup>TTZ Bremerhaven, Germany

**Introduction**

The problem of storage is one of the most important challenges in contemporary renewable energy engineering. A chemical storage option is offered by the conversion of calcium carbonate in to calcium oxide and carbon dioxide which can be brought together in an exothermic reaction to power a thermodynamic cycle. The feasibility of integration depends virtually solely on the effectiveness of the heat transfer scheme from the exothermic reactor to the power cycle. This work studied the integration of a 1 kW beta type Stirling engine with the thermochemical energy storage scheme.

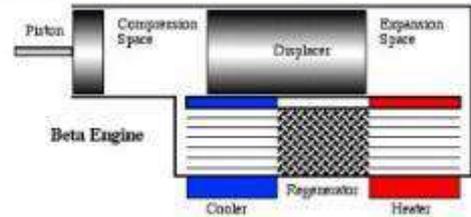


Fig 1: A Beta-type Stirling engine's schematic diagram [1]

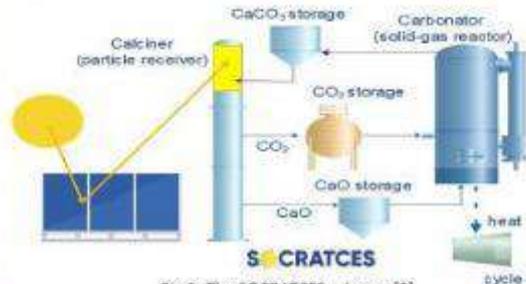


Fig 2: The SOCRATCES scheme [2]

**SOCRATCES PRINCIPLE**

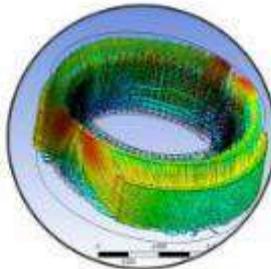
- a. A solar reactor (calciner) breaks  $\text{CaCO}_3$  in to constituents  $\text{CO}_2$  and  $\text{CaO}$ .
- b. The stored  $\text{CaO}$  and  $\text{CO}_2$  are brought together when solar power is no longer available to produce  $\text{CaCO}_3$  producing temperatures in excess of  $800^\circ\text{C}$  in a reactor called Carbonator.
- c. The heat liberated in the carbonator is delivered using a heat transfer fluid to the Stirling engine to produce electricity.

**Workflow**

CFD based mathematical modeling

Interface and module design

Building and testing





**Results and conclusion**

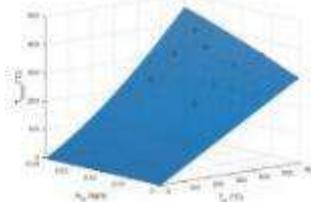


Fig 3: Engine's head temperature with respect to air mas. flowrate and incoming temperature

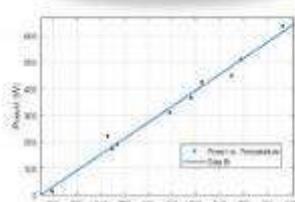


Fig 4: Power versus engine head temperature

- a. The engine was able to produce  $\sim 700\text{ W}$  at about 25% overall conversion efficiency with  $T_{in} = 556^\circ\text{C}$  at a flowrate of  $0.032\text{ kg/s}$ .
- b. The Stirling engine is not able to absorb enough heat without impractically large heat exchangers, thus having high thermodynamic efficiency at low temperatures is not very useful.
- c. The hot-side internal temperature of the engine is too low for it to be a feasible solution.
- d. The power/weight ratio is poor, with other cycles showing much better conversion efficiency

The theoretical model's prediction is in very good agreement with the experimental data with only slight deviations

**References**

1. I. Urieli, "Chapter 2b - Beta Type Stirling Engines," 2020. [Online]. Available: <https://www.ohio.edu/mechanical/stirling/engines/beta.html>.
2. C. Ortiz, "SOCRATCES," 2020. [Online]. Available: <https://socratces.eu/the-project/>



This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N° 727348. This dissemination material reflects only the author's view and that INEA is not responsible for any use that may be made of the information it contains.

<sup>2</sup>Corresponding author: [meusha@ttz-bremerhaven.de](mailto:meusha@ttz-bremerhaven.de)



**Figure 66 SOCRATCES poster presentation at DECHEMA Conference**

- **Annual Meeting of the ProcessNet professional group PAAT 2021.**

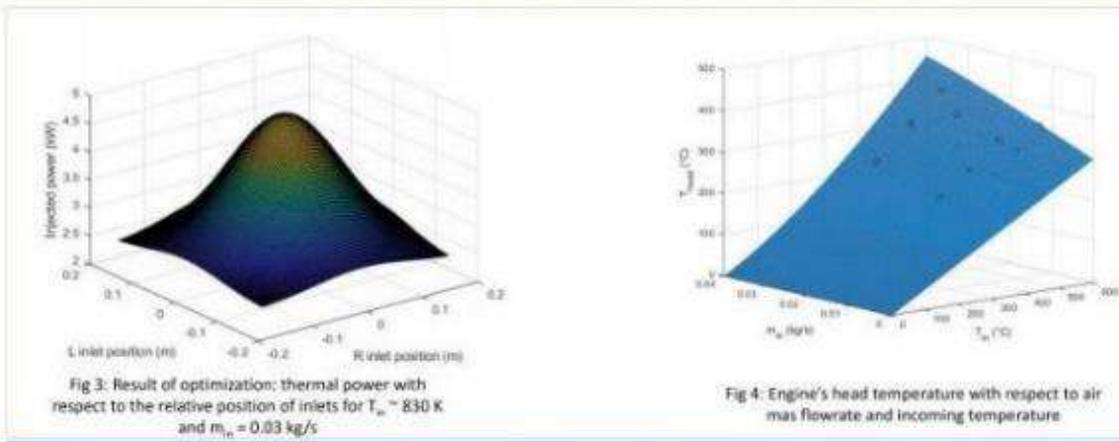
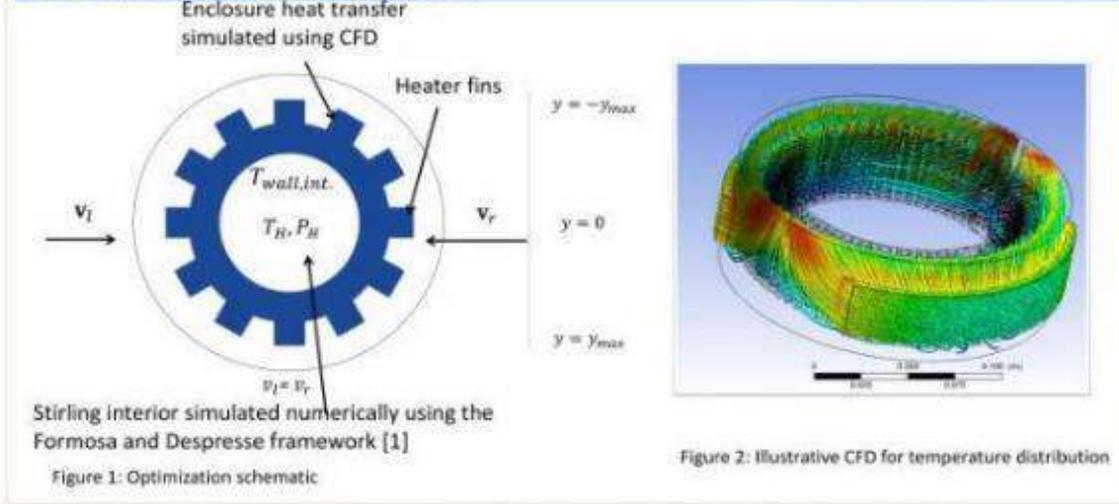
**Description:** A 1 kW Stirling engine's heater's integration with a heat source was investigated in different configurations. The objective was to maximize the heat extraction from the thermal energy-conveying stream of heated air. Due to the geometric and spatial constraints, the heater is ideally not able to cause a substantial temperature difference. In this work, we explored different ways of improving the heat transfer for non-combustion deployment scenarios for these small Stirling engines. The most effective approach was found to involve an opposed-blast arrangement with a hood to enhance the residence time of the stream in contact with the heater surface ensuring escape is not immediate, as it is with some other configurations. The design, based on the application of state of the art simulation computational fluid dynamics simulation software, was constructed and tested to check the consistency of the predicted results and the actual findings. It was found that the simulations had produced reliable prediction, with the engine able to extract more power and generate more electricity as compared to other configurations.

Link: [https://socratces.eu/wp-content/uploads/p\\_34648\\_1637027334.pdf](https://socratces.eu/wp-content/uploads/p_34648_1637027334.pdf)

# CFD-based optimization of thermal integration of a Stirling engine's heater

M Eusha<sup>1,\*</sup>, F Mir<sup>1</sup>, G Schories<sup>1</sup>  
<sup>1</sup>TTZ Bremerhaven, Germany

**Introduction**  
 A  $\beta$ -type 1 kW Stirling engine with a cylindrical and finned heater was integrated with an exothermic reactor. The integration was optimized, in terms of the incoming velocity vector, using CFD analysis, maximizing the penetration of thermal power into the engine core. A secondary indicator was the  $\Delta T$  across the enclosure. It was found that the greatest thermal power penetration is achieved when the velocity vector is split in a counter-blast arrangement. This project was financed by the European Commission (GA 727348).



**Discussion and Conclusion**

The optimized design was manufactured and was found to be in close agreement with the numerically predicted results. In non-combustion deployment scenarios of Stirling engines, it is important to pay attention to the geometric and orientational configurations as they significantly impact heat transfer efficiencies.

**References**  
 1. Formosa, F., G. Despresse, "Analytical model for Stirling cycle machine design," 2010. [Online]. Available: <https://www.semanticscholar.org/paper/Analytical-model-for-Stirling-cycle-machine-design-Formosa-Despresse/7b556228c295f13b027106c4ee5c02ca9f96469f5>

Figure 67 SOCRATCES poster presentation at PAAT 2021

4.3 SCIENTIFIC PUBLICATIONS**Table 7 – List of scientific publications published by SOCRATCES consortium**

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P14_AUTH	Article in Journal	CaCO <sub>3</sub> decomposition for calcium-looping applications: Kinetic modeling in a fixed-bed reactor	Athanasios Scaltsoyiannes, Angeliki Lemonidou	Chemical Engineering Science: X
P03_ZAR	Article in Journal	Calcium looping as chemical energy storage in concentrated solar power plants: Carbonator modelling and configuration assessment	Manuel Bailera, Pilar Lisbona, Luis M.Romeo, Luis I.Díez	Applied Thermal Engineering
P10_CNR	Article in Journal	Calcium-looping for thermochemical energy storage in concentrating solar power applications: Evaluation of the effect of acoustic perturbation on the fluidized bed carbonation	Federica Raganati, Riccardo Chirone, Paola Ammendola	Chemical Engineering Journal
P06_CSIC	Article in Journal	Calcium-Looping Performance of Biomineralized CaCO <sub>3</sub> for CO <sub>2</sub> Capture and Thermochemical Energy Storage	Juan Jesús Arcenegui, Pedro Enrique Sánchez-Jiménez, Antonio Perejón, José Manuel Valverde, Ricardo Chacartegui, Luis Pérez Maqueda	Industrial and engineering chemistry research
P10_CNR	Article in Journal	Carbonation Kinetics of Fine CaO Particles in a Sound-Assisted Fluidized Bed for Thermochemical Energy Storage	Federica Raganati, Paola Ammendola	KONA Powder and particle Journal
P01_USE P06_CSIC	Article in Journal	Carbonation of Limestone Derived CaO for Thermochemical Energy Storage: From Kinetics to Process Integration in Concentrating Solar Plants	C. Ortiz, J. M. Valverde, R. Chacartegui, L. A. Perez-Maqueda	ACS Sustainable Chemistry & Engineering
P02_POLITO	Article in Journal	Comparison of sCO <sub>2</sub> and He Brayton cycles integration in a Calcium-Looping for Concentrated Solar Power	Umberto Tesio, Elisa Guelpa and Vittorio Verda.	Energy
P03_ZAR	Article in Journal	Design and operational performance maps of calcium looping thermochemical energy storage for concentrating solar power plants	S. Pascual, P. Lisbona, M. Bailera, LM. Romeo	Energy
P04_CERTH	Article in Journal	Design of an Integrated CSP-Calcium Looping for Uninterrupted Power Production Through Energy Storage	Evgenios Karasavvas, Kyriakos D. Panopoulos, Simira Papadopoulou, Spyros Voutetakis	CHEMICAL ENGINEERING TRANSACTIONS

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P01_USE	Article in Journal	Dispatchability of solar photovoltaics from thermochemical energy storage	R. Fernández, C. Ortiz, R. Chacartegui, J.M. Valverde, J.A. Becerra	Energy Conversion and Management
P04_CERTH	Article in Journal	Energy and exergy analysis of the integration of concentrated solar power with calcium looping for power production and thermochemical energy storage,	Karasavvas Evgenios, Panopoulos Kiriakos, Papadopoulou Simira, Voutetakis Spyros	Renewable Energy
P03_ZAR	Article in Journal	Energy consumption minimization for a solar lime calciner operating in a concentrated solar power plant for thermal energy storage	Pilar Lisbona, Manuel Bailera, Thomas Hills, MarkSceats, Luis I.Díez, Luis M.Romeo	Renewable Energy
P01_USE	Article in Journal	Hybrid solar power plant with thermochemical energy storage: A multi- objective operational optimisation	Bravo, Ruben Ortiz, C. Chacartegui, Ricardo Friedrich, Daniel	Energy Conversion and Management
P02_POLITO	Article in Journal	Integration of ThermoChemical Energy Storage in Concentrated Solar Power. Part 1: energy and economic analysis/optimization	Umberto Tesio, Elisa Guelpa, Vittorio Verda,	Energy Conversion and Management: X,
P02_POLITO	Article in Journal	Integration of ThermoChemical Energy Storage in Concentrated Solar Power. Part 2: comprehensive optimization of supercritical CO2 power block.	Umberto Tesio, Elisa Guelpa, Vittorio Verda,	Energy Conversion and Management: X,
P06_CSIC	Article in Journal	Kinetics and cyclability of limestone (CaCO <sub>3</sub> ) in presence of steam during calcination in the CaL scheme for thermochemical energy storage	Juan Arcenegui-Troya, Pedro Enrique Sánchez Jiménez, Antonio Perejón Pazo, Virginia Moreno, José Manuel Valverde and Luis A. Pérez-Maqueda	Chemical Engineering Journal
P03_ZAR	Article in Journal	Modelling calcium looping at industrial scale for energy storage in concentrating solar power plants	M. Bailera, S. Pascual, P. Lisbona, LM. Romeo	Energy
P02_POLITO	Article in Journal	Multi-objective optimization of Helium power cycle for Thermo-Chemical Energy Storage in Concentrated Solar Power	Umberto Tesio, Elisa Guelpa and Vittorio Verda.	Energy Conversion and Management: X,12
P14_AUTH	Article in Journal	On the factors affecting the deactivation of limestone under calcium looping conditions: A new comprehensive model	Athanasios Scaltsoyiannes, Angeliki Lemonidou	Chemical Engineering Science

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P04_CERTH	Article in Journal	One-Dimensional Heterogeneous Reaction Model of a Drop-Tube Carbonator Reactor for Thermochemical Energy Storage Applications	Evgenios Karasavvas, Athanasios Scaltsoyiannes, Andy Antzaras, Kyriakos Fotiadis, Kyriakos D. Panopoulos, Angeliki Lemonidou, Spyros Voutetakis, Simira Papadopoulou	Energies 2020,13 (22), Special Issue Energy Management Strategies (EMSs) Based on Energy Storage Systems (ESSs))
P02_POLITO P01_USE	Article in Journal	Optimized synthesis/design of the carbonator side for direct integration of thermochemical energy storage in small size Concentrated Solar Power.	Umberto Tesio, Elisa Guelpa, Carlos Ortiz, Ricardo Chacartegui and Vittorio Verda.	Energy Conversion and Management: X, 4,
P10_CNR	Article in Journal	Preliminary Study on Sound Assisted Calcium Looping for TCES in CSP Applications	Federica Raganati, Riccardo Chirone, Paola Ammendola,	CHEMICAL ENGINEERING TRANSACTIONS
P06_CSIC	Article in Journal	Role of particle size on the multicycle calcium looping activity of limestone for thermochemical energy storage	Jonatan D. Durán-Martín, Pedro E. Sánchez Jimenez, José M. Valverde, Antonio Perejón, Juan Arcenegui-Troya, Pablo García Triñanes, Luis A. Pérez Maqueda	Journal of Advanced Research
P01_USE P06_CSIC	Article in Journal	Scaling-up the Calcium-Looping Process for CO <sub>2</sub> Capture and Energy Storage	Carlos Ortiz, José Manuel Valverde, Ricardo Chacartegui, Luis A. Pérez-Maqueda and Pau Gimenez-Gavarrell	KONA Powder and Particle Journal
P04_CERTH	Article in Journal	Study of a Drop-Tube Carbonator Reactor for CSP-Calcium Looping Based on a Heterogeneous Reaction Model	Evgenios Karasavvas, Kyriakos D. Panopoulos, Simira Papadopoulou, Spyros Voutetakis	CHEMICAL ENGINEERING TRANSACTIONS
P01_USE P06_CSIC	Article in Journal	The Calcium-Looping (CaCO <sub>3</sub> /CaO) process for thermochemical energy storage in Concentrating Solar Power plants	Ortiz, C. Valverde, J.M. Chacartegui, R. Perez-Maqueda, L.A. Giménez, P.	Renewable and Sustainable Energy Reviews
P01_USE P06_CSIC	Article in Journal	The mOxy-CaL Process: Integration of Membrane Separation, Partial Oxy-combustion and Calcium Looping for CO <sub>2</sub> Capture	C. Ortiz, J. M. Valverde, R. Chacartegui, and L. A. Perez-Maqueda	CHEMICAL ENGINEERING TRANSACTIONS
P01_USE	Article in Journal	Thermochemical Energy Storage Based on Carbonates: A Brief Overview	Carlos Ortiz	Energies

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P14_AUTH	Article in Journal	Towards a generalized carbonation kinetic model of CaO-based materials using a modified random pore model	Athanasios Scaltsoyiannes, Georgios Koilaridis, Andy Antzaras and Angeliki Lemonidou	Chemical Engineering Journal
P01_USE	Publication in Conference proceedings/Workshop	Almacenamiento termoquímico en plantas CSP basado en Calcium-looping: retos y oportunidades	Ortiz C., Fernández R., Chacartegui R., Valverde J.M., Becerra J.A.	Proceedings of CIES Conference
P02_POLITO	Publication in Conference proceedings/Workshop	Configurations for the Integration of Power Cycles in Concentrated Solar Plants with Thermochemical Energy Storage	Elisa Guelpa, Martina Capone, Umberto Tesio, Vittorio Verda	PRES19
P01_USE	Publication in Conference proceedings/Workshop	Effect of radiant properties and heat transfer mechanisms on the thermal performance of a Calcium Looping carbonator reactor	Pau Gimenez, Carlos Ortiz, Ricardo Chacartegui, José Manuel Valverde	Proceedings of ECOS 2019
P03_ZAR	Publication in Conference proceedings/Workshop	Energy consumption minimization for a solar lime calciner operating in a concentrated solar power plant for thermal energy storage	Pilar Lisbona, Manuel Bailera, Thomas Hills, Mark Sceats, Luis I. Díez and Luis M. Romeo	Proceedings of ECOS 2019
P02_POLITO	Publication in Conference proceedings/Workshop	Exergoeconomic analysis for the optimal exploitation of heat in thermochemical storage units integrated with concentrated solar power	Elisa Guelpa, Martina Capone, Umberto Tesio, Vittorio Verda	Proceedings of ECOS 2019
P04_CERTH	Publication in Conference proceedings/Workshop	Exergy analysis of the integration of a concentrated solar power plant with calcium	Evgenios Karasavvas, Kyriakos D. Panopoulos, Simira Papadopoulou, Spyros Voutetakis	Proceedings of ECOS 2019
P08_TTZ	Publication in Conference proceedings/Workshop	Feasibility study of combining the Stirling cycle with a solar thermochemical energy storage scheme	M. Eusha, F. Mir, Prof. Dr.-Ing. G. Schories	Chemie Ingenieur Technik
P02_POLITO	Publication in Conference proceedings/Workshop	High efficiency concentrated solar plant by increasing of power cycle temperature	Elisa Guelpa, Martina Capone, Umberto Tesio, Carlos Ortiz, Ricardo Chacartegui, Vittorio Verda	Proceedings of ECOS 2019
P02_POLITO	Publication in Conference proceedings/Workshop	Iterative design improvement of CSP integrated with thermochemical storage using exergoeconomics	Elisa Guelpa, Vittorio Verda	Proceedings of SDEWES 20

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P02_POLITO	Publication in Conference proceedings/Workshop	Multi-objective optimization of Helium power cycles for Thermo-Chemical Energy Storage in Concentrated Solar Power	Umberto Tesio, Elisa Guelpa, Vittorio Verda	Proceedings of ECOS 2020
P01_USE	Publication in Conference proceedings/Workshop	Off-design model of concentrating solar powerplant with thermochemical energy storage based on calcium-looping	Carlos Ortiz, Marco Binotti, Matteo C. Romano, José Manuel Valverde, Ricardo Chacartegui	AIP Publishing
P03_ZAR	Publication in Conference proceedings/Workshop	On the modelling of a lime carbonator operating in a concentrated solar power plant	Manuel Bailera, Pilar Lisbona, Luis I. Díez and Luis M. Romeo	Proceedings of ECOS 2019
P02_POLITO	Publication in Conference proceedings/Workshop	Optimal Indirect Integration of Steam Rankine Cycles in Concentrated Solar Power Coupled with Thermochemical Storage	Umberto Tesio, Elisa Guelpa, Vittorio Verda	E3S Web of Conferences
P02_POLITO	Publication in Conference proceedings/Workshop	Optimization of Thermochemical Storage System for 100% Renewable Power Production	Elisa Guelpa, Martina Capone, Umberto Tesio, Vittorio Verda	PRES19
P10_CNR	Publication in Conference proceedings/Workshop	Role of acoustic fields on the fluidized bed carbonation for TCES in CSP applications	Federica Raganati, Riccardo Chirone, Paola Ammendola	Proceedings of MCS-11
P10_CNR	Publication in Conference proceedings/Workshop	Role of acoustic fields on the fluidized bed carbonation for TCES in CSP applications	Federica Raganati, Riccardo Chirone, Paola Ammendola	Proceedings of ECOS 2019
P03_ZAR	Publication in Conference proceedings/Workshop	Solar calcium looping energy storage: Preliminary comparison between pilot and large scale	S. Pascual, M. Bailera, P. Lisbona, L. Díez, L.M. Romeo	Proceedings of ECOS 2020
P01_USE	Publication in Conference proceedings/Workshop	Thermochemical energy storage of solar PV to enhance dispatchability and large-scale commercial expansion	Reyes Fernandez, Carlos Ortiz, Ricardo Chacartegui, Jose Manuel Valverde, Jose Antonio Becerra	Proceedings of SDEWES 18
P08_TTZ	Publication in Conference proceedings/Workshop	CFD based Stirling engine optimization poster	M. Eusha, F. Mir, G. Schories	Chemie Ingenieur Technik

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P14_AUTH	Publication in Conference proceedings/Workshop	CaO-based sorbents for calcium looping applications: A generalized kinetic model for carbonation reaction.	Athanasios A. Scaltsoyiannes, Andy Antzaras and Angeliki A. Lemonidou	Proceedings of ChemReactor24
P14_AUTH	Publication in Conference proceedings/Workshop	The phenomena behind limestone's deactivation under calcium looping conditions: experiments and modelling	Athanasios A. Scaltsoyiannes, Angeliki A. Lemonidou	Proceedings of ECCE13
P14_AUTH	Publication in Conference proceedings/Workshop	Calcium looping for thermochemical energy storage: Kinetic modelling of limestone calcination	Athanasios A. Scaltsoyiannes, Andy Antzaras, Tom Hills, Mark Sceats and Angeliki A. Lemonidou	Proceedings ECCE12
P14_AUTH	Publication in Conference proceedings/Workshop	MgO-Stabilized CaO for Thermochemical Energy Storage via Calcium Looping: Kinetics and Cyclic Stability	Athanasios Scaltsoyiannes, Geogios Koilaridis, Andy Antzaras, Angeliki Lemonidou	Proceedings of SDEWES 2020
P14_AUTH	Publication in Conference proceedings/Workshop	Thermochemical storage of solar energy via calcium looping: Kinetic study and reactor modelling of a solar calciner	Athanasios A. Scaltsoyiannes, Stylianos G. Spyroglou, Stergios G. Yiantios and Angeliki A. Lemonidou	Proceedings of AIChE Annual Meeting 2021
P02_POLITO	Thesis/Dissertation	Analysis and optimization of supercritical CO <sub>2</sub> cycles integrated with solar concentrated power	Simone Beneduce	
P02_POLITO	Thesis/Dissertation	Application of pinch-analysis to the charging and discharging processes of Thermo-Chemical Energy Storage for Concentrated Solar Power plants	Giulia Novero	
P02_POLITO	Thesis/Dissertation	Calcium Looping Process as Thermochemical Energy Storage in CSP Plant: Integration Strategies and Preliminary Analysis	Gabriele Colelli	
P02_POLITO	Thesis/Dissertation	CFD analysis of a Stirling engine heat exchanger for CaL-CPS application	Giulia Mancò	
P02_POLITO	Thesis/Dissertation	Exergoeconomic analysis of supercritical CO <sub>2</sub> cycles for concentrated solar power	Paolo Borlengo	
P02_POLITO	Thesis/Dissertation	Numerical model of a carbonator reactor for thermochemical energy storage based on Calcium looping	Gianfranco Caforio	

Partner	Type of scientific publication	Title of scientific publication	Author(s)	Title of the Journal/ Proceedings/ Book
P02_POLITO	Thesis/Dissertation	Simulation and analysis of a Stirling engine for the application to solar power	Emanuele Vinco	
P02_POLITO	Thesis/Dissertation	Techno-economic analysis and improvement of the carbonator side heat exchanger network for the Calcium-Looping indirect integration with a supercritical Organic Rankine Cycle in a Concentrated Solar Power plant	Fabrizio Viti	
P02_POLITO	Thesis/Dissertation	Thermochemical energy storage for concentrated solar power	Fabio Scaiola	
P02_POLITO	Thesis/Dissertation	Thermochemical energy storage system for solar applications	Giuseppe Masci	
P06_CSIC	Thesis/Dissertation	Estudio de la influencia del tamaño de partículas en la descomposición del carbonato de calcio. Aplicaciones en la tecnología de almacenamiento termoquímico integrado en plantas de energía solar	Ángela Hortigón Alcaide	
P06_CSIC	Thesis/Dissertation	Búsqueda de nuevos materiales y optimización de los tiempos de residencia en la tecnología "Calcium-Looping" aplicada al almacenamiento termoquímico de energía	Mónica Salazar Lago	
P01_USE	Thesis/Dissertation	The calcium-looping process for advancing in the development of both CO2 capture and thermochemical energy storage systems	Carlos Ortiz Domínguez	

## **CONCLUSIONS**

This deliverable collects all the dissemination material developed in the project, which allows publicizing the development carried out in SOCRATCES as well as to place the target public and stakeholders in the current situation of the CSP and the innovation that our project raises in easy storage and solar energy efficient.

Throughout the execution of the project, the dissemination and communication strategy has evolved, adapting to the difficult conditions of the COVID-19 pandemic, readjusting to a more digital strategy and taking advantage of the opportunities available to the consortium.

A great effort has been made to reach both scientists and researchers in the sector as well as a more general public who can assess the potential of solar energy and its storage with innovative technologies, taking advantage of the synergies established with European projects and lobbying activities that may end up in future collaborations to continue our work.