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Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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Coordinated by: Julian Blanco Gálvez
Marta Ruiz McEwan

Edited and Published:
Editorial CIEMAT
Avda. Complutense, 40 28040-MADRID
e-mail: editorial@ciemat.es
Edtorial news

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2 General Presentation

The Plataforma Solar de Almería (PSA), a department of the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), is the largest concentrating solar technology research, development, and test centre in Europe. PSA activities are integrated in the CIEMAT organization as an R&D division of the Department of Energy.

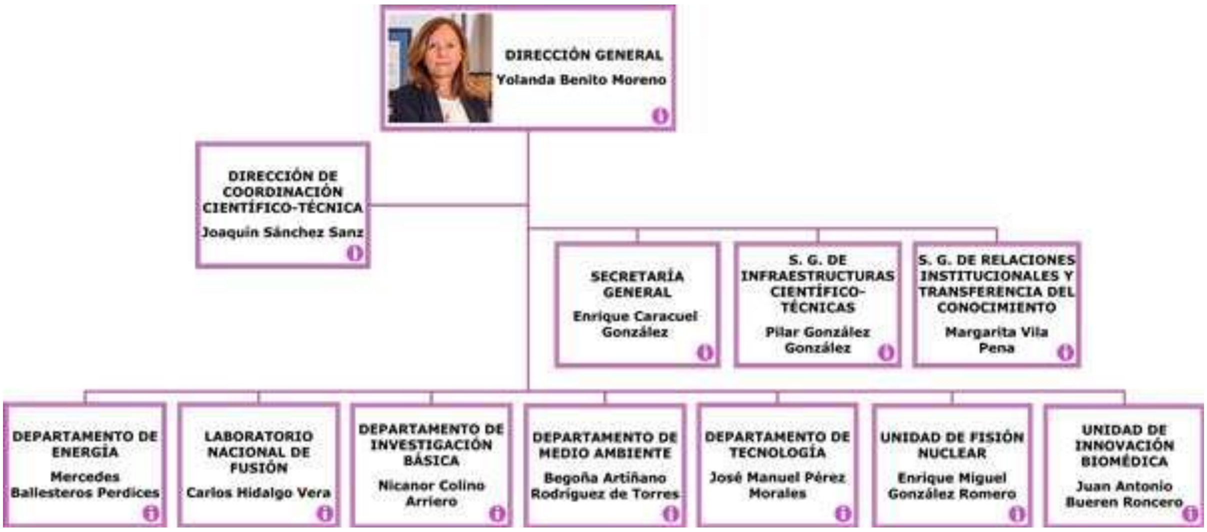


Figure 1. Integration of the PSA in the CIEMAT organization

The following goals inspire its research activities:

- Contribute to establishing a sustainable clean world energy supply.
- Contribute to the conservation of European energy resources and protection of its climate and environment.
- Promote the market introduction of solar thermal technologies and those derived from solar chemical processes.
- Contribute to the development of a competitive Spanish solar thermal export industry.
- Reinforce cooperation between business and scientific institutions in the field of research, development, demonstration, and marketing of solar thermal and solar photochemical technologies.
- Strengthen cost-reducing techno-logical innovations contributing to increased market acceptance of solar thermal technologies.
- Promote North-South technological cooperation, especially in the Mediterranean Area and Latin-American Community.
- Assist industry in identifying solar thermal and solar photochemical market opportunities.

Since 2021, research activity at the Plataforma Solar de Almería has been structured around seven R&D Units under a Technical Coordinator, plus a strong unit to manage and coordinate all facilities and laboratories, namely the PSA Management Unit. In addition to the different horizontal services (IT services, Instrumentation, Maintenance, Civil Engineering Operation, etc.), two additional facilities (METAS and LECE), physically allocated within PSA but with associated personnel formally outside PSA structure, are also included in this PSA Management unit.

Figure 2. Aerial view of the PSA

The seven R&D Units are as follows:

a. *Line-Focus Concentrating Solar Thermal Technologies*. Devoted to testing, evaluating and developing components and applications for linear focusing solar concentrators, its scientific and technological objectives are:
   - Advanced heat transfer fluids with lower environmental footprint for working temperatures higher than 400 °C.
   - Cheaper collector designs and innovative plant configurations achieving better use of solar energy resource and technologies.
   - More efficient, cost-effective and reliable components (e.g. receiver tubes, mirrors and flexible connections.
   - Integration of solar thermal power plants with other technologies.
   - New applications for linear focusing concentrating technologies.

b. *Point-Focus Concentrating Solar Thermal Technologies*. Target focused on providing technical assessment to the industry stakeholders together with the research and innovation related to power tower technologies such as the measurement of concentrated solar flux, R&D of new fluids and receivers, optical and numerical analysis, its scientific and technological objectives are:
   - Development of receivers for mean solar fluxes >1MW/m^2 and thermal efficiencies higher than 85 % for temperatures above 600 °C.
   - New innovative working fluids with operating temperatures above 600 °C for Rankine cycles, and above 750 °C for unfired Brayton cycles.
   - Self-calibrating and cheaper heliostats, below 90 EUR/m2 (installed).
   - High precision heliostat field and automated control for long focal distance and/or high temperature applications up to 1,200°C.
   - Innovative plant configurations achieving better use of solar energy resource and technologies.

- High degree of automation of condition monitoring of all relevant plant parameters to optimize O&M, including virtualization of plants, augmented reality and remote supervision.
- Provide solutions for onsite measurements to characterize the total solar receiver's surface in terms of temperature and concentrated solar irradiance, and solar radiation extinction within the solar field.
- New applications for point-focus solar thermal technologies.

c. *Thermal Energy Storage for Concentrating Solar Thermal Technologies.* Addressing the design, testing and optimization of thermal storage systems for temperatures above 120°C up to 800°C, its scientific and technological objectives are:
   - Feasibility of materials for thermal storage systems.
   - Testing and characterization of prototypes, components and equipment for thermal storage systems.
   - Design and optimization of thermal storage systems following a holistic approach.
   - Integration of thermal storage systems in different applications.

d. *Materials for Concentrating Solar Thermal Technologies*. Addressing the development and testing of new or improved materials for CST solar technologies or their applications, as well as thermal treatment, aging or modification of materials, its scientific and technological objectives are:
   - Development and testing of advanced materials and coatings for CST technologies (primary and secondary reflectors, absorbers, receiver covers, receiver particles, etc.) for increased robustness, efficiency and long-term durability under operating conditions in harsh climates or environments.
   - Development and standardization of suitable methodologies for the optical characterization and lifetime prediction of materials for CST technologies.
   - Development and testing of cost-effective cleaning methods to reduce the water consumption in the O&M activities.
   - Usage of CST technologies for materials' treatment, including thermal treatment, synthesis, characterization, aging and processing of materials at high temperature, by surface or volume treatment (with solar receivers or reactors).
   - Development and testing of nanostructured materials to enhance thermal conductivity.
   - Development of catalysers for electrochemical and solar thermal applications to produce fuels (hydrogen, ethanol, methanol…).

e. *Solar Thermochemical Processes and Technologies*. This includes high temperature processes based on concentrated solar energy to hydrogen and other valuable and energy intensive raw materials production, its scientific and technological objectives are:
   - Solar-to-fuel conversion efficiencies ≥ 15 %, with the integration of heat recovery.
   - Proof-of-concept operation of solar fuels production reactors, comparable to "traditional" chemical industrial plant operation.
   - Development of components for high solar concentration, especially those with a significant impact on the performance of the technology (solar receivers, secondary concentrators, windows, etc.).
   - Use of materials that do not exhibit toxicity and/or corrosion issues, especially under the extreme conditions that many thermochemical cycles require.
   - 1 MW (H_2 production) scale demonstrator with at least 1,000 hours of operation time.

- Explore custom-made solar field options capable of achieving the high temperatures required on high-efficiency receivers/reactors.
- Integration of receiver/reactor concepts to the requirements of industrial processes, such as lime, aluminium, etc.

f. *Solar Thermal Applications.* Devoted to the development and evaluation of solar thermal technology applications in industrial processes, including desalination and brine concentration, its scientific and technological objectives are:
   - Development and evaluation of advanced solutions to reduce energy and water consumption, operation and maintenance costs of solar thermal applications.
   - Development of design, simulation and optimization tools for solar thermal application systems.
   - Integration of solar thermal energy in hybrid process heat applications.
   - Optimization of solar fields to improve the efficiency of low temperature heat applications.
   - Design and implementation of solar thermal separation solutions for desalination, water treatment, brine concentration and product recovery.
   - Integration of desalination technologies in concentrated solar power plants for water and power cogeneration and water saving.

g. *Solar Treatment of Water*. Focused on exploring the chemical possibilities of solar energy, especially the potential for water decontamination and disinfection and the production of solar fuels by means of photochemical processes, its scientific and technological objectives are:
   - Design, improvement and optimization of solar photo-reactors.
   - Technologies at the edge of the knowledge based on a combination of reductive and oxidative photochemical processes for the elimination of particularly complex and persistent contaminants.
   - Combination of advanced solar photo-oxidation processes with other innovative technologies for decontamination and disinfection of all kinds of wastewater for reusing purposes (own industrial processes or crops irrigation).
   - Production of fuels and artificial photosynthesis by solar photocatalysis.
   - Residues valorisation. Combination of separation technologies and solar processes to achieve the recovery of nutrients from wastewaters for their subsequent use in agricultural activities.
   - Comprehensive systems analysis. Techno-economic assessment and Life cycle analysis for new developed technologies and/or applications.

Supporting these R&D Units are the Direction and Technical Services Units mentioned above. These units are largely self-sufficient in the execution of their budget, planning, scientific goals, and technical resource management. Nevertheless, the seven R&D units share many PSA resources, services, and infrastructures, so they stay in fluid communication with the Direction and Services Units, which coordinate technical and administrative support services. For its part, the Director's Office must ensure that the supporting capacities, infrastructures, and human resources are efficiently distributed. In addition, the Director's Office channels demands to the different general support units located at CIEMAT's main offices in Madrid.

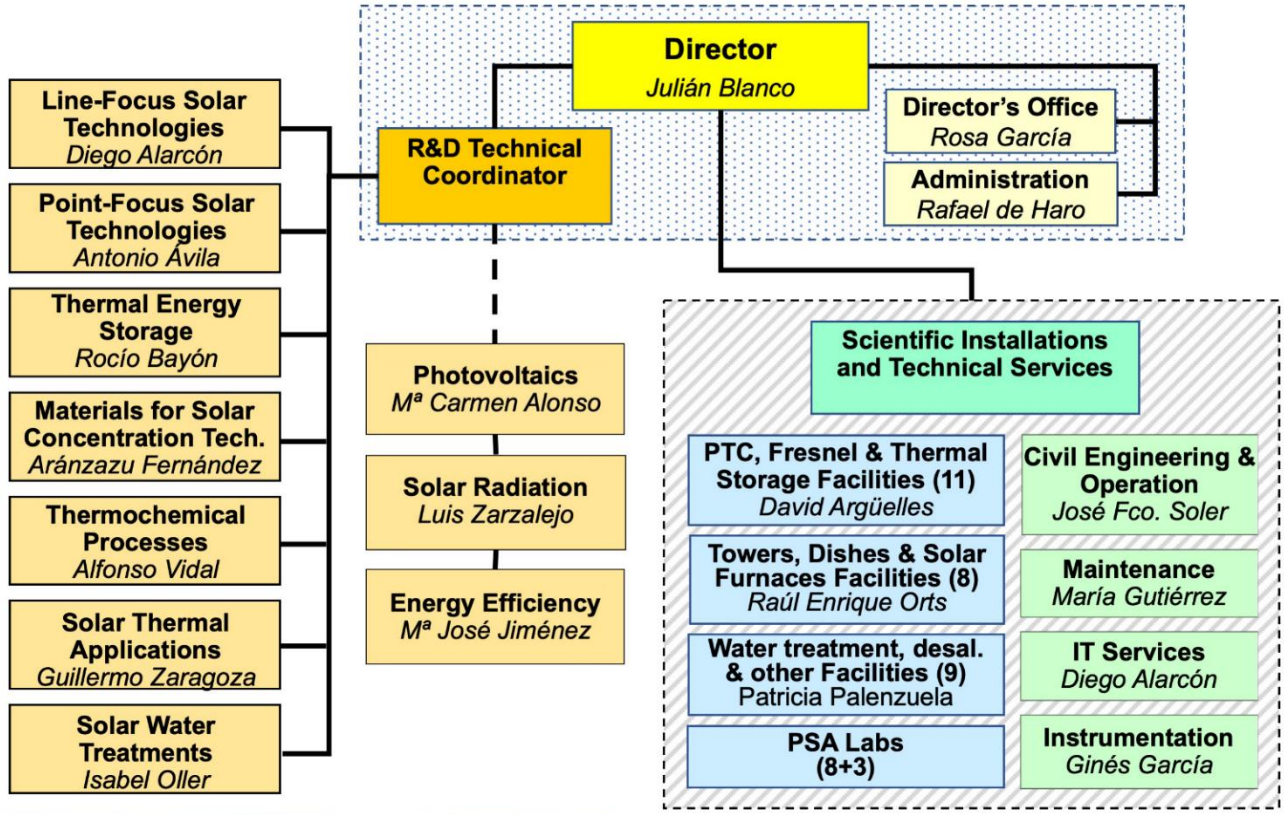


Figure 3. Internal organizational structure of PSA in 2023

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 139 people that as of December 2023 made up the permanent staff lending its services to the Plataforma Solar de Almería. In addition to this staff, there is a significant flow of personnel in the form of visiting researchers, fellowships and grants handled by the Director's Office. Out of the 121 people who work daily for the PSA, 70 are CIEMAT personnel, 15 of whom are located in the main offices in Madrid.

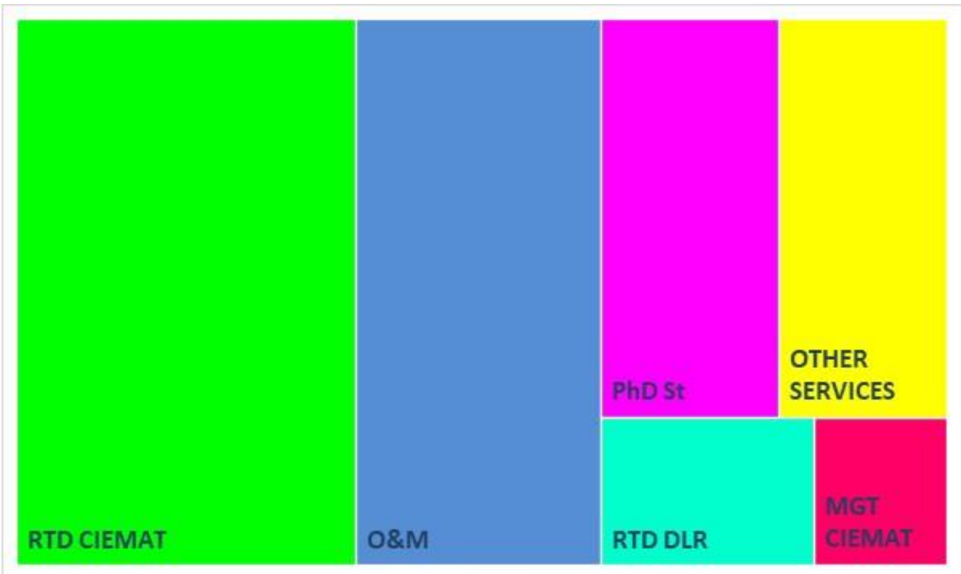


Figure 4. Distribution of permanent personnel at the PSA as of December 2023

In addition, the 8 people who make up the DLR permanent delegation as a consequence of its current commitments to the Spanish-German Agreement also make an important contribution.

The rest of the personnel is made up of a no less important group given the centre’s characteristics. They are the personnel working for service contractors in operation, maintenance and cleaning in the different facilities. Out of these 34 people, 17 work in operation, 13 in maintenance and 4 in cleaning. The auxiliary services contract is made up of 5 administrative personnel and secretaries, 7 IT technicians for user services, and another 5 people from the security contract, which makes a total of 17 people.

The effort CIEMAT has made during the last several years to provide the PSA with the necessary human resources should be emphasized. This continued effort is allowing us to undertake our task with greater assurance of success.

The PSA operating budget in 2023 totals 5,4M Euros (not including R&D personnel or new infrastructure).

Figure 5. Personnel at the PSA as of December 2023

3 Line-focus Concentrating Solar Thermal Technologies Unit

Introduction

The objective of this R&D Unit is to promote and contribute to the increase in the use of concentrated solar radiation employing line-focus solar thermal technologies. For this purpose, the current working lines are related to the analysis and development of (a) optical systems to concentrate solar radiation (parabolic trough collectors, linear Fresnel systems); (b) solar receiver technologies, where the absorption and transformation of concentrated radiation into thermal energy is performed using different transfer media (water/steam, synthetic oils or pressurised gases); (c) integration of line-focus solar thermal systems into electricity generation cycles and into industrial processes that demand thermal energy in the temperature range from 150°C to 500°C; and (d) provision of scientific-technical support to companies in the solar thermal sector.

In addition to the techno-scientific activities carried out within specific R&D projects, this PSA unit also devotes a great deal of effort to dissemination activities, participating (in person or virtually) in international conferences, workshops, seminars and master's courses to promote knowledge of line-focus solar thermal technologies and their applications.

During 2023, this PSA R&D unit has continued its activities in the field of developing, testing, and evaluating components for line-focus solar collectors (Si-CO, PhoToHy, NEOSOLAR & DETECTIVE Projects), developing new techniques, measuring capabilities and test facilities (SFERA-III Project), testing a new silicone fluid for parabolic troughs (SING & Si-CO Projects), modelling and simulating power plants with parabolic-troughs in order to analyse their integration with other renewable energy sources for power generation (POSYTYF & INTECSOL Projects) and contributing to the development of standards and guidelines for the testing and evaluation of components for solar thermal power plants (participation in the development of new standards in the IEC TC117 and AEN/CTN 206 SC117 committees, and also through FlexPipe-REPA Guide and Si-HTF Standard projects financed by SolarPACES). The collaboration with the industry and other research centres related to system simulations or experimental tests continued within the framework of partnership agreements or technical services in 2023. Special mention should be made of the licensing agreement reached with the company Meteo for Energy for the incorporation of the simulation tool for parabolic trough solar thermal power plants, developed by this Unit in the meteorological forecasting tool of this company, extending its capacity to the prediction of electricity generation. By the end of 2023, this tool was already in operation in six commercial solar thermal power plants, and work was underway to incorporate the simulation tool in seven more plants during 2024.

List of projects this PSA Unit has been involved in

- Solar Facilities for the European Research Area (SFERA-III)
- Silicone Fluid Next Generation (SING)
- Powering System Flexibility in the Future through Renewable Energy Sources (POSYTYF)
- Silicone Based HTF in Parabolic Trough Applications - Preparation of an International Standard (Si-HTF)
- High Performance Parabolic Trough Collector and Innovative Silicone Fluid for CSP Power Plants (Si-CO)

- Developing the Guideline for Testing of Flexible Pipe Connectors for Trough Collector Fields (FlexPipe-REPA Guide)
- Photocatalytic Generation of White Hydrogen (PhoToHy)
- Development of an Innovative Concept of a Solar Thermal Plant with a Fixed-Tube Parabolic Trough Collector and Salt Circuit with Thermal Storage by Means of a Thermocline Coupled to a Green Hydrogen Generation System (NEOSOLAR)
- Development of a Novel Tube-Bundle-Cavity Linear Receiver for CSP Applications (DETECTIVE)
- Technological Innovations for Improving the Viability of Concentrating Solar Thermal Plants (INTECSOL)

The Head of this unit has also participated in the European projects: "Implementation of the Initiative for Global Leadership in Solar Thermal Electricity' (HORIZON-STE) and "Solar Twinning to Create Solar Research Twins' (Solartwins).

(a)

(b)

Figure 6. Unit staff at Plataforma Solar de Almería in Tabernas (a) and CIEMAT Headquarters in Madrid (b).

4 Point-Focus Solar Thermal Technologies Unit

Introduction

The objective of the unit is to promote and contribute to the development of Point Focus technologies, mainly Central Receiver Systems, for the utilisation of concentrated solar radiation for both electricity and process heat generation for applications demanding temperatures above 400 – 500 °C.

In particular, during 2023 the unit has been working in our main research lines:

(1) The simulation and development of advanced ceramic and metallic volumetric receivers (ASTERIx-CAESar project, SUNFLOWER project and INTECSOL project);
(2) The automation of heliostat characterization and calibration method (LEIA project);
(3) The development of innovative and cost-effective heliostats (INTECSOL project);
(4) The analysis and comparison of the existing heliostat characterization methodologies (SolarPACES project);
(5) The improvement in the measurement of variables of control in real time for power tower plants (SFERA-III project, LEIA project, HELIOSUN project, AdaptedHelio project);
(6) The application of artificial intelligence to improve the heliostat tracking control system to reduce the CAPEX and OPEX of central receiver systems (ASTERIx-CAESar project, HELIOSUN project);
(7) The assistance to industrial stakeholders to achieve an effective development of the technology (SOLARBLUE, BCB).

List of projects the group has been involved in

- Solar facilities for the European Research Area – SFERA-III.
- Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage – ASTERIx-CAESar.
- Solar field measurements to Increase performance – LEIA.
- Sustainable Near-net-shape Fabrication of Low Environmental impact Receiver materials – SUNFLOWER.
- More efficient Heliostat Fields for Solar Towers – HELIOSUN.
- Innovaciones tecnológicas para la mejora de la viabilidad de las plantas termosolares de concentración – INTECSOL.
- Analyze Heliostat Field – SolarPACES Task III.
- Wind adapted heliostat, based on field measurements in the heliostat field and validation of wind tunnel measurements – AdaptedHelio.
- PV Plant with Thermal Cogeneration - SOLARBLUE.
- Solar extinction measurement system commercialization – Ref. 8510/2018.

5 Thermal Energy Storage Unit

Introduction

During 2023, the researchers of this Unit have been actively working in international, national and regional funded projects. Apart from those, some technical services have been provided to companies, mainly dealing with testing and characterization of components and equipment for molten salt loops. The R&D activities of this Unit deal with different aspects related to the development, verification and optimization of efficient Thermal Energy Storage Systems and they can be divided in four general lines:

1. Optimization and improvement of the reliability of current commercial systems. Large Installations and power to heat (P2H-Carnot batteries) technologies
2. Storage prototype testing: both sensible and latent even under real solar conditions
3. Modelling and integration of thermal storage systems
4. Viability of materials as thermal storage media

Also, the staff of Thermal Energy Storage Unit carries out transversal activities such as teaching, mentoring, dissemination and networking so they actively participate as experts in several scientific networks (Energy Storage JP of EERA and IEA TCPs: Task III of SolarPACES and Task 67/40 SHC/ECES).

List of funded projects the unit has been involved in

- Red española de almacenamiento de energía térmica. RedTES.
- Towards the standardization of molten salt loops': instrumentation and components. MOSAIC
- Integrated European research, calibration and testing infrastructure for fibre-optic thermometry, INFOTHERM
- Smart Thermal Storage for Decarbonisation of Energy Sector, STES4D
- Storage Research Infrastructure Eco-System, StoRIES
- Solar facilities for the European Research Area - Third Phase, SFERA-III
- Concentrated solar power in the transport sector and in heat and power production, ACES2030

Figure 7. Researchers of Thermal Energy Storage Unit in 2023

6 Materials for Concentrating Solar Thermal Technologies Unit

Introduction

The research activities performed in this PSA Unit are focused on the development, characterization and testing of advanced materials and coatings for CST technologies (primary and secondary reflectors, absorbers, receiver covers, receiver particles, etc.). The aim is to increase robustness, efficiency and long-term durability under operating conditions in harsh climates or environments, as well as the usage of CST technologies for materials' treatment and processing. This usage includes thermal treatment, synthesis, characterization, aging and processing of materials at high temperatures, by surface or volume treatment (with solar receivers or reactors). In particular, during 2023, we have worked on the development and testing of selective and non-selective absorber coatings (INTECSOL project), the development of a non-selective high-temperature solar absorber coating for receiver particles (COMPASSCO2 project), the development of antisoiling coatings both for solar reflectors and glass solar tubes (INTECSOL project), the testing of solar reflectors under several outdoor environments as well as accelerated aging conditions (SOLARTWINS and GREENCOAT projects), the accelerated aging of materials for CST technologies under high radiation fluxes in solar furnaces (SFERA-III, HiPIMSOLAR, HIDROFERR, ASTERIX-CAESar and SUNFLOWER projects), the development of a proper methodology to characterized soiled reflectors (SFERA-III) and standardization of the methodology to measure optical properties of components for CST technologies (reflectors and receiver particles) (participation in the development of new standards in the IEC TC117 and AEN/CTN 206 SC117 committees and also through the SP-SOILING-II project financed by SolarPACES).

In addition to the work related to the funded projects previously mentioned, we have worked on four PhD thesis projects. Within the first one, a procedure is being developed for the measurement of degradation of primary reflectors within the solar field in commercial plants. The investigation addresses the evaluation of commercial reflectometers, in-field microscopic analysis for the early detection of degradation and optical systems for the determination of the degraded area of reflectors. Within the second PhD thesis project, a design of new optical coating materials that guarantee a high absorption efficiency (absorptance > 95 %), low emission losses and good durability in extreme temperature and weather conditions is under study with a view to their future application in high temperature solar thermal plants. A third PhD thesis project is focused on developing antisoiling coatings that might be applied on both solar reflectors and glass solar tubes, durable enough to maintain the optical properties of such components under real operating conditions. Finally, a fourth PhD thesis project began at the end of 2022, with the main goal of studying the degradation suffered by the solar reflectors due to the interaction of the solar radiation and ambient temperature and humidity.

List of projects the unit has been involved in

- Components and materials' performance for advanced solar supercritical CO_2 power plants, COMPASsCO2.
- Solar facilities for the European Research Area, SFERA-III
- Solar Twinning to Create Solar Research Twins, SOLARTWINS

- Impulso a tecnología de producción H2 por vía termosolar mediante desarrollo y validación de nuevos materiales para receptores cerámicos de durabilidad extendida, HIDROFERR
- Nuevos recubrimientos nanoestructurados para absorción eficiente de la radiación solar en dispositivos de concentración, HIPIMSOLAR
- Soiling measurement of solar reflectors, SOILING-SPII
- Innovaciones tecnológicas para la mejora de la viabilidad de las plantas termosolares de concentración, INTECSOL
- Desarrollo y análisis de la vida útil de recubrimientos protectores sin plomo para espejos en plantas de energía solar térmica), GREENCOAT
- Sustainable Near-net-shape Fabrication of Low Environmental impact Receiver materials, SUNFLOWER
- Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage, ASTERIx-CAESar

(a)

(b)

Figure 8. Unit Staff at CIEMAT Headquarters in Madrid (a) and at Plataforma Solar de Almería in Tabernas (Almería) (b)

7 Thermochemical Processes for Hydrogen and Feedstock Production Unit

Introduction

The strategic task of the Group of Solar Hydrogen and solarisation of industrial processes addresses the demonstration, scale-up, of solar-driven thermochemical processes for the production of fuels (e.g., hydrogen, syngas) and industrial processes (e.g., cement, metallurgy, etc), by exploiting their know-how to develop suitable solar reactors and components and to qualify reactor materials to transfer the results to larger scales close to industrial size.

During 2023, our researchers have been actively working in international, national and regional funded projects, listed in the following paragraph. Through its experts, the Solar Fuels Unit participates actively in several scientific networks: Task II of SolarPACES TCP of the IEA and Spanish association for Hydrogen -AeH2-. The Unit has been recently invited to participate in the development of a new task on renewable hydrogen production, within the IEA Hydrogen TCP framework (Tasks in definition - IEA Hydrogen).

A recent approach is to use thermochemical processes on the Moon and Mars to produce vital resources in space.

The lines of activity are concentrated in the following fields:

- Development of hybrid solar/fossil endothermic and thermochemical cycles processes for hydrogen production with concentrated solar energy.
- Technological feasibility of the use of solar thermal energy as the energy supply in high temperature industrial processes.
- Characterization of materials and components for solar reactors under extreme conditions.
- A recent approach on track is to use thermochemical processes on the Moon and Mars to produce vital resources in space.

List of projects the unit has been involved in

- A Concentrated Solar energy storage at Ultra-high temperatures aNd Solid-state cONversion (SUNSON).
- Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond, HYDROSOL-BEYOND
- Promoting solar thermal hydrogen production technology through the development and validation of new materials for ceramic solar receivers with improved durability and added ferrites (HIDROFERR).
- Concentrated solar power in the transport sector and in heat and power production, ACES2030
- Solar facilities for the European Research Area - Third Phase, SFERA-III

8 Solar Thermal Applications Unit

Introduction

The Solar Thermal Applications Unit (STA) is devoted to the development and evaluation of solar thermal technology applications in industrial processes, including desalination and brine concentration. The main objective is to generate new scientific and technological knowledge in the field of thermal applications of solar energy, seeking approaches that take into account circular economy and the water-energy-food nexus.

Main current research lines are the following:

- Application of solar thermal energy to large capacity distillation processes, with special emphasis on multi-effect distillation (LT-MED, TVC-MED, ABS-MED).
- Application of solar thermal energy to small capacity distillation processes, with special emphasis on membrane distillation (MD) and forward osmosis (FO).
- Evaluation of technologies to reduce water demand in solar thermoelectric plants and facilitate cogeneration of water and electricity (CSP+D).
- Evaluation of innovative technologies for cooling on solar thermal plants for electricity production and inland thermal desalination.
- Application of solar thermal energy to separation processes for brine concentration and treatment of industrial effluents.
- Dynamic modelling, process optimization and advanced control strategies in solar thermal applications.
- Application of heat pumps to solar thermal processes.

During 2023, the Unit has continued approaching Open Innovation procedures by strengthening the Sustainable Desalination Living Lab and incorporating our activities as much as possible in its framework. We have reinforced our co-creation, knowledge sharing and transfer activities with its Community of Practice, constituted by relevant stakeholders in the water-energy-food nexus, including industry, public administration and society in general. We have significantly strengthened our outreach activities to society, mainly by participating in activities with educational centres (7 more than last year) with the aim of promoting scientific vocations, explaining the importance of our research and giving visibility to the role of women in science. We have participated in collaborative training actions at University of Tarapacá (Chile), in several reach out activities at workshops (i.e., Open Living Lab Days) and other events (at Parque de las Ciencias of Granada), and especially in two events with the Regional Ministry for Sustainability, Environment and Blue Economy to help defining the Andalusian Strategy for Sustainable Blue Economy in Andalusia. Our influence in that draft document is one of the most relevant milestones of 2023, culminated with the PROA Prize on Blue Knowledge awarded to the Unit by the Maritime Marine Cluster of Andalusia.

In addition, we have been active as PI in 5 EU and 2 National projects, and participated in another 3 EU and 1 National project.

The international relevance of the activities carried out in the Unit is supported by the participation in EU projects and the following positions currently held:

- Coordination of the Renewable Energy and Desalination Working Group of the EU Platform Water Europe.
- Chair of the Scientific Committee of the European Desalination Society.
- CIEMAT's representative in the EERA Joint Digitalization Program for Energy.
- Spain's ExCo delegate at the IEA Technology Collaboration Programme on Heat Pumping Technologies.

List of projects the unit has been involved in

- Bio-Mimetic and Phyto-Technologies designed for low-cost purification and recycling of water, INDIA-H2O
- Next generation water-smart management systems: large scale demonstrations for a circular economy and society, WATER-MINING
- Intelligent water treatment technologies for water preservation combined with simultaneous energy production and material recovery in energy intensive industries, INTELWATT
- European Twinning for research in Solar energy to (2) water (H_2O) production and treatment technologies, SOL2H2O
- Sustainable membrane distillation for industrial water reuse and decentralised desalination approaching zero waste, MELODIZER
- Hybrid cooling solutions for water saving in solar thermal applications, SOLHYCOOL
- SOL-préndete: Didáctica y divulgación de la energía solar térmica de concentración con nuevas tecnologías de realidad aumentada y virtual
- More efficient Heliostat Fields for Solar Tower Plants, HELIOSUN
- Solar facilities for the European Research Area - Third Phase, SFERA-III
- Solar Twining to Create Solar Research Twins, SOLARTWINS
- Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage (ASTERIX - CAESAR)

Figure 9. Solar Thermal Applications Unit staff in 2023.

9 Solar Treatment of Water Unit

Introduction

The main objective of the Solar Treatment of Water Research Unit is the use of solar energy for promoting photochemical processes, mainly in water, for treatment and purification applications but also for chemical synthesis and production of photo-fuels. Our knowledge about solar photochemical systems and processes at pilot and pre-industrial scale is backed by 30 years of research activity. The Unit was pioneer in Spain and maintains a consolidated national leadership. The Unit has participated in more than 28 EU projects since 1997 mainly focused on the development of solar technologies for water treatment. The facilities are extremely well equipped and are among the best in the world in the field of advanced oxidation processes (AOPs). We are also pioneers in the use of advanced analytical and microbiological techniques for the evaluation of such processes. Formal collaborations in the academic sector include dozens of public institutions in the EU, South America, Australia and Africa. Industrial collaborations on recent projects include companies from Austria, Italy, Denmark, India, and many others in Spain.

In order to promote the higher education of young researchers in the environmental applications of AOPs, as well as to overcome national boundaries and bureaucratic barriers, a group of European scientists founded the “European PhD School on Advanced Oxidation Processes” in June 2014. Subsequently (October 18, 2018), with the aim to make the school international, Institutions from Latin America have joined it. Currently, the School includes 52 Scientific Committee members from 17 different Countries. The PSA is one of the members of this school since its creation and the Solar Treatment of Water Unit coordinates the European Branch. The Summer School is among the initiatives organized for the AOP School PhD candidates but other PhD students, MSc students, post-doctoral researchers and professionals are also welcome.

The high international relevance of the activities carried out by the Solar Treatment of Water Unit is demonstrated by its active collaboration with a high number of international institutions and companies as well as their participation in different specialized forums and committees: Leader of subtask B Solar water decontamination and disinfection systems in task 62 ”Solar Energy in industrial water and wastewater management” from the International Energy Agency; members of the core-group of the Zero Pollution and Water security action groups in the Water Europe Platform, etc.

The research activities already consolidated by this unit are the following, cross-linked with the projects and networks summarised below:

- Solar photocatalytic and photochemical processes as tertiary treatment for the removal of pollutants of emerging concern and microorganisms, related with AQUACYCLE (CBC ENI MED), PANIWATER (H2020-India), SOL2H_2O, NAVIA, DIGIT4WATER and MODITRAGUA projects and IN2AQUASMarie Skłodowska-Curie Action.
- Solar photochemical processes for the remediation of industrial wastewaters, related with REFINE project, SMALLOPS and SYNGENTA service contracts.
- Integration of Advanced Oxidation Processes with other water treatment technologies (NF/UF; Ozone, Bioprocesses, etc.), related with IN2AQUAS Marie Skłodowska-Curie Action, PANI-WATER, AQUAENGRI projects.
- Evaluating photocatalytic efficiency of new materials under solar light in pilot reactors, related with NAVIA and ANDROMEDA projects, and SMALLOPS service contract.

- Photocatalytic and photochemical processes for water disinfection in different scenarios related with ENERGICA project (Green Deal).
- Pilot solar photo-reactors for production of hydrogen and other photo-fuels, related with SolarFuture, SOLCHEM5.0, REFINE and CONFETI projects.

List of projects the unit has been involved in

- Photo-irradiation and Adsorption based Novel Innovations for Water-treatment, PANIWATER
- Towards increasing the sustainable treatment and reuse of wastewater in the Mediterranean Region, AQUACYCLE
- Urban wastewater reclamation by Novel mAterials and adVanced solar technologies: assessment of new treatment quAlity Indicators, NAVIA
- Solar catalysis for a renewable energy future, SOLFUTURE
- ENERGy access and green transition collaboratively demonstrated in urban and rural areas in AfrICA, ENERGICA.
- Solar facilities for the European Research Area - Third Phase, SFERA-III
- Solar Twining to Create Solar Research Twins, SOLARTWIN
- Revalorización de diferentes aguas residuales mediante tecnologías que permitan mejorar el nexo agua-energía renovable-alimentos, AQUAENGRI.
- Hacia la mejora de la Resiliencia del Ciclo Urbano del Agua: Evaluación de tecnologías solares de regeneración de aguas con especial énfasis en la eliminación de subproductos de desinfección, bacterias y genes resistentes a antibióticos, DIGIT4WATER.
- Towards Digital Transition in Solar Chemistry, SolChem5.0.
- Monitorización y diagnóstico de la potabilización, depuración y regeneración de aguas urbanas en comarcas con estrés hídrico y desarrollo de tratamientos sostenibles alternativos a la cloración, MODITRAGUA.
- Advanced tertiary treatments based on combined reduction/oxidation processes and novel photocatalytic materials applied to the simultaneous disinfection and removal of persistent and mobile compounds in urban wastewater, ANDROMEDA
- Green valorization of CO2 and Nitrogen compounds for making fertilizers, CONFETI
- From solar energy to fuel: A holistic artificial photosynthesis platform for the production of viable solar fuels, REFINE
- Human footprint on water from remote cold areas to the tropical belt. INtegrated Approach TO secure water QUAlity by exploiting Sustainable processes, IN2AQUAS
- European Twinning for research in Solar energy to water (H2O) production and treatment technologies, Sol2H2O

Figure 10. Solar Treatment of Water Unit staff in 2022.

10 Projects

Standardisation activities at national and international level

Participants: Members of IEC/TC 117 (Solar thermal electric plants) national committees and CTN-UNE 224 (Centrales termosolares) committee.

Contact: Diego-César Alarcón-Padilla, diego.alarcon@psa.es

Funding agency: CIEMAT

Background: Since Concentrating Solar Thermal (CST) systems are a relatively young technology, the CST sector is still experiencing a lack of standards. This lack of standards is a barrier to developing the technology and the evaluation and qualification of components. Despite the several standards developed during the last few years, there is still a significant lack of them. The development of international standards for the CST sector has been undertaken by the technical committee IEC/TC-117.

Objectives: The scope of the international committee IEC/TC-117 implemented within the umbrella of the International Electrotechnical Commission and the Spanish committee CTN-UNE 224 implemented within the UNE standardisation body is the development of standards for the Concentrating Solar Thermal (CST) sector by putting together the experience of R+D centres, industries, engineering companies, components manufacturers and promoters.

Achievements in 2023: PSA R&D units of Line-focus Concentrating Solar Thermal (UFL) Technologies, Point-focus Concentrating Solar Thermal (UFP) Technologies and Materials for Concentrating Solar Thermal Technologies (UMAT) have kept on participating in standardisation activities at both international and national levels in 2023. This contribution has been made under the umbrella of the international standardisation committee IEC/TC-117 and the Spanish UNE committee CTN-UNE 224.

Along 2023, UFP has participated in the final version of the IEC 62862-4-2 (Heliostat field control system), continued working in the IEC 62862-2-2 group (Thermal energy storage systems - Technical requirements for molten salt used as heat storage and heat transfer medium) and began its participation in the new working group IEC PT 62862-4-3, devoted to the technical requirements and design qualification of heliostats for solar power tower plants. At the national level, the participation of UFP was focused on the working group of high-temperature storage (CTN 224).

At a Spanish level, within CTN 224, UFL has coordinated and participated in the publication of the new UNE standard (224001:2023) *Centrales termosolares. Criterios de diseño, instalación y verificación de las prestaciones de las uniones cinemáticas en las centrales termosolares con tecnología de captadores cilindroparabólicos (Solar thermal electric plants. Criteria for design, installation and performance verification of flexible pipe connectors in parabolic trough collector technology)*.

At an international level, a member of UFL (Mrs. Lourdes González) has continued to serve as the secretary of the international technical committee IEC/TC-117 “Solar thermal electric plants” and as coordinator of the Working Group MT1 “Terminology” within such technical committee.

During 2023, PSA R&D units (UFL, UFP and UMAT) have also continued their work in the following IEC/TC117 project teams:

- MT1 – *Terminology*
- PT 62862-1-4 ED1 Solar thermal electric plants – Part 1-4: *Thermal insulation for solar thermal electric plants.*
- PT 62862-1-5 ED1 Solar thermal electric plants - Part 1-5: *Performance code test for solar thermal electric plants.*
- PT 62862-1-6 ED1 Solar thermal electric plants - Part 1-6: *Silicone-based heat transfer fluids for the use in line focusing CSP applications.*
- PT 62862-3-4 ED1 Solar thermal electric plants - Part 3-4*: Code of solar field performance test for parabolic trough solar thermal power plant.*
- PT 62862-3-5 ED1 Solar thermal electric plants – Part 3-5: *Laboratory reflectance measurement of solar reflectors.* (Project leader: Aránzazu Fernandez García, UMAT)
- PT 62862-3-6 ED1 Solar thermal electric plants – Part 3-6: *Durability of silvered-glass reflectors - Laboratory test methods and assessment.*
- PT 62862-4-2 ED1 Solar thermal electric plants – Part 4-2: *Heliostat field control system*
- PNW 117-194 ED1 Solar thermal electric plants - Part 3-7: *Criteria for design, installation and performance verification of flexible pipe connectors in parabolic trough collector technology. Status: New work item proposal for voting during 2023* (Project leader: Loreto Valenzuela, UFL)

Support to the Activities of the Concentrated Solar Thermal Technology Area of the Set PLAN, CST4ALL

Participants: DLR, ESTELA, CIEMAT, ENEA, METU.

Contacts: Julian Blanco, julian.blanco@psa.es

Ricardo Sánchez, ricardo.sanchez@psa.es

Funding agency: European Commission, HE-CL5-D3-02-15_ETIPs

Background: This project is a coordination and support action to provide support to the realisation of the Implementation Plan of the Set-PLAN for CST. This project is a continuation of previous project HORIZON-STE, having a very similar objectives and with the same partners forming the consortium, but with the additional objective of intensify the cooperation with other Implementation Working Groups (IWGs) of the Set-PLAN with common interest and clear existing synergies. CST4ALL project started on October 2022 with finalization scheduled on September 2025.

Objectives: Main project objectives are: a) to monitor the Implementation Plan and to provide support to the CSP Implementation Working Group; b) To enable cooperation across sectors covered by SET Plan/ETIPs from an industrial/market perspective; c) To enable cooperation across sectors covered by SET Plan/ETIPs from an R&D perspective; d) To use dissemination, exploitation and communication activities to maximise the project outcomes and impacts, including to address Green Deal Key Challenges.

Achievements in 2023: PSA activities in 2023 were mainly devoted to the Work Package (WP) 1, to provide support to the chair of CST IWG in all interactions and needed contributions related to the European Commission and Member States initiatives affecting CST and how the strategies of the CST IWG reflect the evolving European heat and power transition landscape. Among the most relevant achievements and contributions in 2023 we have the following:

a) CST Implementation Plan (SET Plan) full review and updating (from its first initial version of November 2017), achieving the approval of the SET Plan Steering Group in 2023.
b) SET Plan contribution and reporting. Reporting exercises related to the CST-IWG and the Clean Energy Technology Observatory (CETO). This also include the participation in several SET Plan Workshop organized within 2023.
c) Collaboration in the process of Solar Heat Europe (SHE) integration into CST IWG.
d) Contribution with inputs from R&I stakeholders to the SRIA Solar, the Clean Energy Transition Partnership (CETP calls) and Horizon Europe (HE) programmes.
e) SET Plan Conference 2023 organized in Barcelona, being Spain the host of the event.

Figure 11. CST4ALL Kick-off meeting organized in Brussels

In addition to WP1 activities, in November 2023 the project organized an online workshop on Cross-Cutting Materials Challenges of Renewable Energy Technologies, which raised significant interest from various sectors of renewable energy technologies, with stakeholders from industry, research institutions, and universities, totalling over 150 participants. Also, the planning of all industrial and R&I related workshops to be organized during the project was defined, as follows:

Workshops on CST cross-cutting related topics within ETIPs, targeting R&I Actors:

- Materials Challenges of Renewable Energy Technologies (Nov. 2023)
- R&I challenges for the hybridization of CST with other renewable energy technologies (May 2024)
- Meteorology (Sept/Oct 2024)
- Future Energy Mix with 100 % Decarbonisation Level (Jan 2025)

Workshops addressing the hybridisation of CST with other Renewable Energy Technologies:

- CST-Photovoltaics (Feb. 2024)
- CST-Bioenergy (May 2024)
- CST-Wind (t.b.d.)
- CST-Heat (t.b.d.)
- CST-Geothermal (t.b.d.)

Full information about these workshops and project activities can be found at project website.

Solar Twining to Create Solar Research Twins, SolarTwins

Participants: METU, CIEMAT, DLR

Contact: Julián Blanco, julian.blanco@psa.es

Funding agency: European Commission, HORIZON-2020 WIDESPREAD-03-2018 TWINNING

Background: Europe is a global leader in CST technologies but this leading position is increasingly being challenged by large investments in other countries. SolarTwins is designed to respond to this challenge to European Technological Leadership by Twinning PSA and DLR's Institute for Solar Research to the CST research laboratory at the Center for Solar Energy Research and Applications (METU-GÜNAM-ODAK) of the Middle East Technical University (METU) at Ankara (Turkey). SOLAR TWINS started in January 2020 and will have a final duration of 42 months.

Objectives: 1) Build-on and strengthen METU-GÜNAM's synergistic integration into existing EU CST and solar water treatment and desalination R&I networks containing PSA and DLR; 2) Strengthen the scientific profiles of METU-GÜNAM and its researchers; 3) Train a large, diverse and promising pool of METU Early Stage Researchers; 4) Formulate joint research lines (JRL) and look for opportunities to increase research funds to all partners; and 5) Disseminate and promote CST, water treatment and desalination technologies in Turkey. The project name *SolarTwins* reflects the formulation and execution of Individual Twinning in which an expert from PSA or DLR is Twinned to a researcher at METU-GÜNAM.

Achievements in 2023: The project successfully ended in December 2023. During this last year, the consortium has successfully elaborated 8 joint Research lines on topics relevant to the CST sectors. These should be better framed incorporating the industrial vision for Turkey, therefore capitalizing on the interaction with relevant Turkish industries, and identifying possible funding opportunities and potential partners or end users. Among the conclusions of the project it was considered important to explore additional networking opportunities (like IEA initiatives) and an increased participation in building jointly funding applications participating in funding schemes would mitigate the non-participation of Turkey in the EU-SOLARIS initiative, initially targeted but not possible due to administrative and political difficulties to achieve it from the Turkey side. Contribution from PSA has been focused on the areas of Solar Desalination, Solar Water Treatment and Materials for CST Technologies, with the active involvement of all scientific personnel of this PSA Research Units.

Solar Facilities for the European Research Area - Third Phase, SFERA-III

Participants: CIEMAT (Spain), CNRS (France), ENEA (Italy), DLR (Germany), CEA (France), UEVORA (Portugal), ETHZ (Switzerland), IMDEA (Spain), CYI (Cyprus), Fraunhofer (Germany), LNEG (Portugal), METU (Turkey), UAL (Spain), EURO (France), ESTELA (Belgium).

Contacts: Ricardo Sánchez, ricardo.sanchez@psa.es

Funding agency: European Commission, H2020-INFRAIA-2018-1.

Background: Research infrastructures (RIs) are facilities, resources and services that are used by the research communities to conduct research and foster innovation in their fields. They play an increasing role in the advancement of knowledge and technology and their exploitation. By offering high quality research services to users from different countries, by attracting young people to science and by networking facilities, RIs help to structure the scientific community and play a key role in the construction of an efficient research and innovative environment. Because of their ability to assemble a ‘critical mass’ of people, knowledge and investment, they contribute to national, regional and European economic development. RIs are also key in helping Europe lead a global movement towards open, interconnected, data-driven and computer-intensive science and engineering.

Objectives: The SFERA-III project aims to engage all major European Solar Research Institutes with relevant and recognized activities in the Concentrating Solar Thermal (CST) technology field, into an integrated structure, operating a unique set of Concentrating Solar Thermal (CST) RIs to promote innovative research, to improve services offered by CST research infrastructures and to train researchers and engineers on the CST technologies. In this project, both academia and industry users are targeted.

Achievements in 2023: During this year, CIEMAT successfully organised and coordinated several General Assembly, Management Board and Access Manager meetings in order to favourably implement the project. Also this year, CIEMAT has organised a project review meeting where the assessment of all the activities was carried out. Finally, CIEMAT coordinated the evaluation of the proposals received in the fifth call, including the organisation of the fifth User Selection Panel meeting to discuss the scores.

In WP1, CIEMAT participated in the Summer School organised by DLR in Cologne from 11 to 15 September 2023, giving a talk on “A meteorological forecast and simulation pipeline tool for a more efficient management of Solar Thermal Electricity (STE) Plants”. A member of CIEMAT was also co-chair of the Doctoral Colloquium held back-to-back with the Summer School.

In WP2, CIEMAT organised two short-term trainings, one on solar photo-reactors using Compound Parabolic Collectors (CPC) combined or not with other conventional and advanced technologies for wastewater treatment/disinfection and reuse in different applications, from 25 to 27 April 2023, and another on hydrogen production by solar photocatalysis in presence of organic electrons donors, from 28 to 29 March 2023. CIMEAT also participated in the workshop (WS5) related to WP9 on intercomparison of flux measurement systems, organized by CNRS at Odeillo from September 2022 to February 2023.

In WP3, CIEMAT, as leader of the task for the promotion of long-term sustainability but also as responsible of the EU-SOLARIS ERIC, led the work to organise the formal constitutive meeting held in Madrid in January 2023, and the general assembly in November 2023.

In the framework of the transnational access activity, CIEMAT has offered a total of 19 weeks of access to 6 users to the DESAL installation.

Thermal Energy Storage Unit coordinates WP6, entitled Development of Test Procedures for Materials and Components of Thermal Storage Systems. In the last year of the project, it has coordinated the elaboration of the deliverables and technical reports committed in the project. Also, some of the results have been disseminated with an oral presentation in a conference and by writing two scientific papers which are currently under review.

In WP7, and particularly within Task 7.2, CIEMAT has collaborated with the University of Évora in the testing of a new CPC solar reactor. Experimental tests of degradation by photolysis and heterogeneous photocatalysis with titanium dioxide of four pharmaceutical compounds and phenol were carried out to test the performance of this prototype under real climatic conditions. As part of Task 7.3, multivariable controller has been completed and validated at the nanofiltration pilot plant (see Figure 12), demonstrating the simplicity of integration. CIEMAT has also developed and validated a new guideline to evaluate the performance of MED processes in real environments. The assessment for the performance evaluation have been implemented at the MED pilot plant in a control and data acquisition system developed by CIEMAT using open tools and standards with a web-based dashboard for visualization of real-time data and plant performance analytics. Within Task 7.4, CIEMAT has collaborated with CEA to benchmark their software developments for RO+PV and MED.

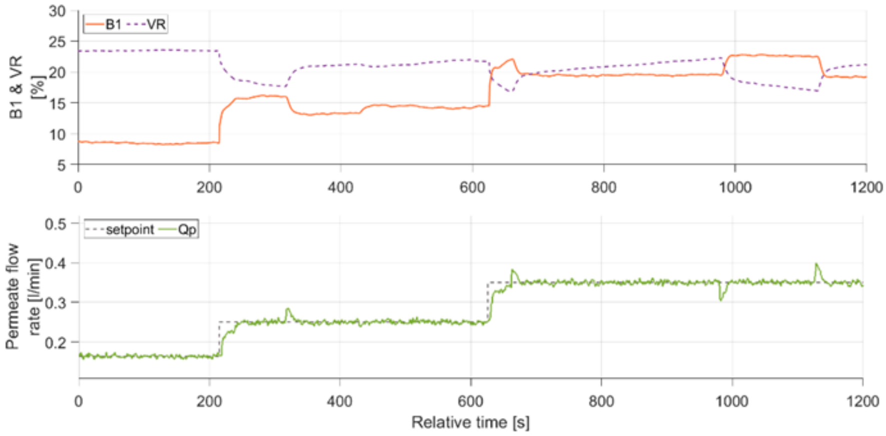


Figure 12. Experimental results obtained with the multivariable controller to control the permeate flow rate at the NF pilot plant.

In WP8, CIEMAT is involved in in tasks 8.2 and 8.3. During 2023, CIEMAT has participated in drafting the following deliverables:

- D8.4 Report on testing of optimisation strategies and benchmarking techniques in ongoing experimental campaigns within the consortium
- D8.5 Report on implementation of reactor and system control tools

In Deliverable 8.4, the performance indicators developed in task 8.2 for solar thermochemical reactors and processes were applied to the results obtained during the testing vamping carried out with Hydrosol Beyond. In deliverable 8.5., our efforts on dynamic control and automation of solar fuel reactors applied to the SolH2 reactor operated during a short experimental campaign were outlined. The goal has been to provide detailed examples of the performance of control strategies to track set point changes in a proposed water-splitting reactor alternating between two temperatures. The proposed control strategy has been tested in simulation. A temperature constraint has been considered to avoid thermal stress in the reactor. Figure 13 shows the results obtained in simulation. As can be observed, the temperature follows the setpoint (Figure 13 (a)) with an error lower than 30 °C at the start-up. This error can be reduced by lowering the sample time of the optimization algorithm. Nevertheless, at steady-state conditions, when the reactor temperature reaches 1400 ℃, the steady-state error is almost cero. Work developed in task 8.3 has been performed in collaboration with the Solar Thermal Unit in PSA.

In WP9, within task 9.2 “Improving the infrared temperature measurements thanks to better assessment of the emittance and its evolution”, CIEMAT has participated in the round robin comparison of emissivity measurements of receiver materials for CST, together with CNRS, DLR, CEA and LNEG. The task was completed in 2023 and two scientific papers have been published.

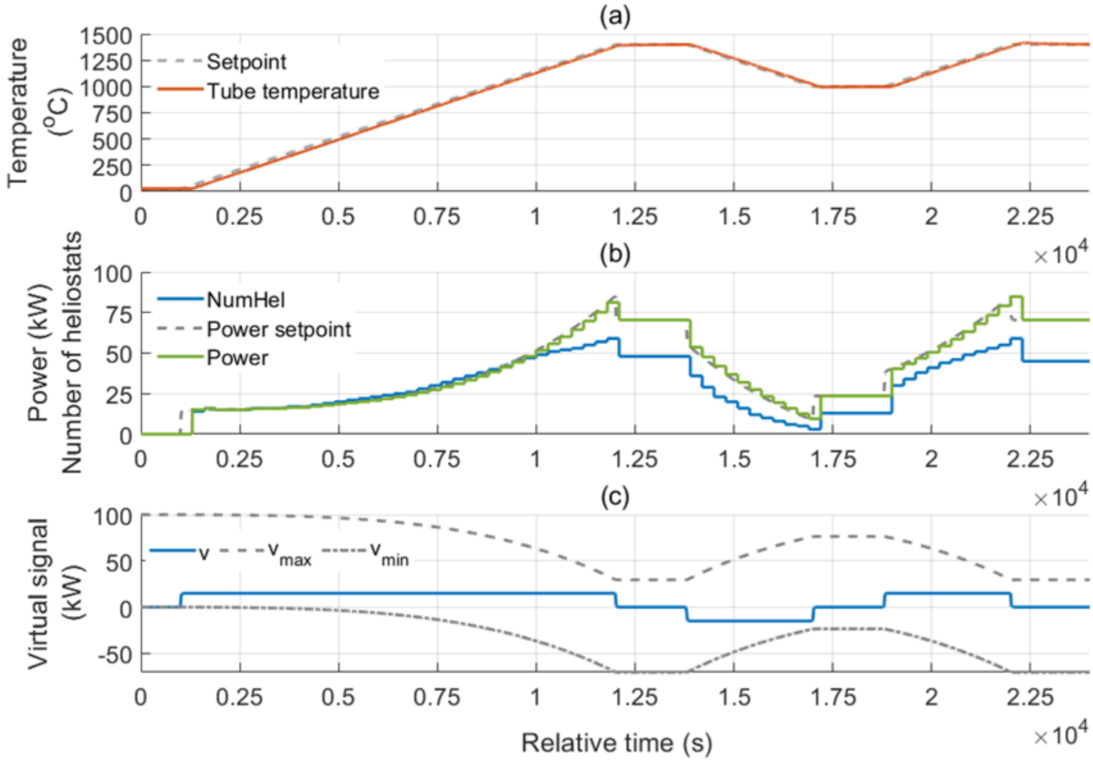


Figure 13. Simulation results obtained with the FLC strategy. (a) Setpoint and simulated temperature in the reactor, (b) number of heliostats focused on the reactor, setpoint and simulated power, (c) PID control signal (virtual signal), maximum and minimum values allowed for the virtual signal.

In WP10, specifically in Task 10.1 "Improved sensor monitoring/calibration and measurement accuracy of IR laboratory test beds", the Materials for Concentrating Solar Thermal Technologies Unit has participated during 2023 in Task 10.1.A activities. The round robin tests for artificially soiled solar mirrors conducted in previous years was further evaluated and discussed within the partners of this task. The linear transfer functions for the handheld reflectometers as well as the participating TRaCs Device were identified for two types of sand (Almeria and Negev) and for the soiling coupons, dedicated for calibration and reproducible intercomparison of the devices. The focus was given to an improved understanding of transfer functions and influence of soiling on application and measurement. The behaviour of the soiling coupons (developed by DLR and CIEMAT) was further analysed with respect to spectrally resolved hemispherical and specular reflectance. It was agreed that the sand blasted samples showed the most robust results in the round robin tests, and showed generally a more similar behaviour to solar mirrors subject to soiling. In task 10.3 “Increase the quality of services for optical characterization of line- and point-focussing concentrators”, the point-focus CST technology unit has completed an intercomparison campaign of methodologies for measuring heliostat shape (Milestone MS33), which took place at the PSA in June-July 2023 (Month 51-52). The objectives of the campaign were to ensure that all the developed methodologies for measuring the shape of reflecting surfaces, in particular heliostats, are comparable and offer similar results for the same measured specimen. Techniques used on the comparison were photogrammetry (CIEMAT), deflectometry (DLR), inverse reconstruction (CYL) and laser scanner measurement (DLR). A whole description of these measurement techniques can be found in deliverable 10.6 (Techniques for shape measurement of heliostat units). The heliostat selected was a 12-facets, 39.4m^2 heliostat. The facets are spherical with a focal distance of 220 m and the whole heliostat is spherically canted with a focal distance of 209.29 m. Figure 14 shows the heliostat in the measured position.

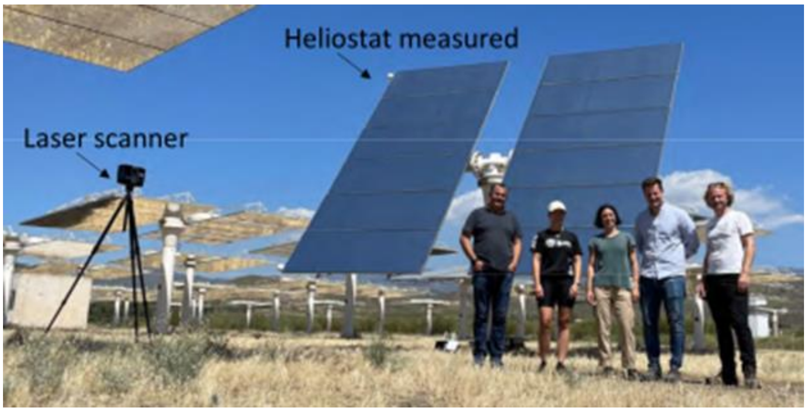


Figure 14. CESA I Heliostat selected for the intercomparison.

It is also worth mentioning the coordination of WP11, which is devoted to the detailed design of the e-infrastructure that will connect the main European R+D centres involved in concentrating solar technologies. During this year, CIEMAT has been working with the company TECNATOM on the detailed design and specifications of the e-infrastructure as well as on the budget required to implement it in the future.

Powering System flexibility in the future through renewable energy sources, POSYTYF

Participants: ENEDIS, CIEMAT, IBERDROLA, Dowel, RTE, ETHZ, UPC, ECN, Comillas-IIT, HTW, Bachmann.

Contacts: Lourdes González Martínez. lourdes.gonzalez@ciemat.es

Funding agency: European Commission, EU - H2020 - LC-SC3-RES-16-2019 (Jun 2020 – May 2024)

Background: The Energy Union framework strategy aims to make the EU "the world leader in renewable energy". A high share of variable renewable generation will pose new challenges for the integration of the energy produced in an efficient and cost-effective way, for the operation of EU power systems. A key question is whether there will be enough flexibility in the power system.

Objectives: The POSYTYF project intends to support the further integration of Renewable Energy Sources (RES) into the power system by developing the Dynamic Virtual Power Plant concept (DVPP). This DVPP aims to aggregate in a portfolio some renewable sources of both dispatchable and non-dispatchable natures, thus enabling an optimal internal redispatch of resources.

Achievements in 2022: This project started in June 2020 and CIEMAT is contributing to work packages WP1, WP2 and WP5. In WP2, CIEMAT was involved in developing simulation models for grid integration studies of concentrating solar thermal power plants. A simplified model of Solar Thermal Electricity (STE) plants that can be easily integrated with power generation models was built and tested in MATLAB®, including its validation with real data from commercial STE plants.

In WP5, CIEMAT collaborated on generating renewable production data sets of STE plants for the operation and management of VPPs (Virtual Power Plants). In addition, CIEMAT participated in the improvement of simulation models of STE plants for the economic optimization of DVPPs (Dynamic Virtual Power Plants), sharing information on operation parameters, response times and typical features of STE plants. Besides, a novel and simple method to generate random solar radiation profiles oriented to the uncertainty assessment of STE production forecasting was also developed within WP5. All this activity was completed during 2023, with advisory work for the rest of the project partners in relation to solar thermal power plants for the configuration of the VPPs.

Silicone Based HTF in Parabolic Trough Applications – Preparation of an international standard, Si-HTF Standard

Participants: DLR, CIEMAT, MASEN, IEECAS, NREL, Industrial partners.

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agency: SolarPACES (International Energy Agency) (Mar 2021 - Oct 2022)

Background: Recent improvements in silicone-based heat transfer fluids, in terms of increasing maximum operation temperatures and reducing cost, have originated the development of new projects that are demonstrating the applicability of said fluids and the economic viability in parabolic trough collectors (PTC) applications.

Objectives: After the formation of an international expert work group that prepared a SolarPACES guideline document about the use of silicone based HTF in parabolic trough applications, which is available at the SolarPACES website, this new project aims to compile an international standard to be submitted to the IEC TC 117 that records the results of the guideline work. The project has a duration of 18 months and has the following objectives:

- Continuation of the international expert work group that successfully elaborated the guideline for the admission of SHTF in parabolic trough collector applications.
- Incorporation of international feedback concerning the guideline document published through SolarPACES.
- Compilation of an international standard including test methods for the qualification and use of silicone based thermal oils.

Achievements in 2023: The project started in March 2021 with the preparation meetings to launch the project proposal of the standard draft to be submitted to the International Standardization Committee IEC TC 117:Solar Thermal Power Plants. The structure of the standard is similar to the one already published in Spain for HTFs currently used in Spanish solar power plants with parabolic troughs (UNE 206015), in which preparation CIEMAT was also involved. The draft of the standard IEC 62862-1-6 for SHTFs has been circulated by IEC during 2023 to collect comments from the different worlwide national standardisation committees. At the end of 2023, the final version was closed, and during 2024, it is expected to get the official publication. Status can be tracked in this link.

HELISOL®XLP evaluation under real solar conditions, SING

Participants: DLR (coordinator), CIEMAT, Wacker Chemie AG, TSK Flagsol Engineering GmbH, Senior Flexonics GmbH, TÜV NORD SysTec GmbH & Co. KG, STEAG Energy Services GmbH, Rioglass Solar, S.A. Flucon Fluid Control GmbH, Dickowpumpen GmbH, RWE Renewables GmbH, Heat 11 GmbH & Co. KG

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agencies: BMWi - Federal Ministry for Economic Affairs and Energy (Sept. 2020-August 2022).

Background: Silicone based heat transfer fluids (I-SHTF) have been used in the past as heat transfer fluids in medium scale installations such as PTC test loops e.g., at PSA (Spain), NREL (USA) and elsewhere (DOW, Syltherm 800®). Si-HTFs are pumpable below 0 °C, environmental-friendly, low in hydrogen formation, almost odourless and very low in acute toxicity. New silicone oils are being developed by other companies, as well as an international standard is being prepared to define the characterization procedure for this type of oils. The development, testing and demonstration of the reliability, performance and competitiveness of new Si-HTFs are of great interest of the CSP sector.

Objectives: The SING project is the continuation of the SIMON and SITEF projects (2016 and 2020) and has the objective to accelerate the market introduction of a new HELISOL® product: HELISOL® XLP with improved properties and associated parabolic troughs solar field's components (REPAs and receiver tubes) at temperatures up to 450°C. Such operation temperatures are beyond state of the art in PTC power plants and increase the overall power plant efficiency. This innovate project is based on a German-Spanish cooperation making use of the so called PROMETEO and REPA test facilities located at PSA.

Achievements in 2023: Activities performed by CIEMAT in the SING Project were split into two main areas: a) providing technical support to DLR (project coordinator) and the partners in the preparation for the sensor bypass installation at the collector field outlet, and b) conducting PROMETEO plant operation and maintenance, civil work and piping loop modification activities. This involved supervising the installation of the old existing magnetic-drive pump in parallel with the new one already installed in 2022. In terms of the HELISOL®XLP proof of concept, at the end of 2023, the accumulated operating hours were 300 hours at 435 °C.

Figure 15. PROMETEO test facility used at PSA for HELISOL®XLP proof of concept.

High performance parabolic trough collector and innovative silicone fluid for CSP power plants, Si-CO

Participants: Acciona Industrial (coordinator), DLR, CIEMAT, Wacker Chemie AG, Rioglass Solar Systems LTD., Thermal Power Engineering S.L., Rioglass Solar SCH S.L., Senior Flexonics GmbH

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agencies: CSP ERANET Co-fund Call – T3. Parabolic Trough with Silicon Oil. Transnational Call CSP 4.3 2016; MICINN Proyectos I+D+i Programación Conjunta Internacional, Convocatoria 2020-2. Referencia PCI2020-120704-2 (Apr 2021-Oct 2024)

Background: Silicone based heat transfer fluids (Si-HTF) have been used in the past as heat transfer fluids in medium scale installations such as PTC test loops e.g., at PSA (Spain), NREL (USA) and elsewhere (DOW, Syltherm 800®). SHTFs are pumpable below 0 °C, environmental-friendly, low in hydrogen formation, almost odourless and low in toxicity. Until now, such fluids are not used in large-scale commercial CSP power plants because available SHTFs have been far more expensive than the widely used eutectic mixture of diphenyl oxide and biphenyl (DPO/BP). However, the development of new formulations of SHTFs open the door to their wide application in parabolic trough applications. Such new application e.g., in future power plants, to make them more competitive, will also require new designs of parabolic troughs optimized to work with the new operating conditions allowed for new SHTFs.

Objectives: The Si-CO project aims to techno-economically demonstrate a new optimized and large-scale parabolic trough collector (Si-PTC) design that operates using HELISOL®XLP at 430 °C, a Si-HTF. The demonstration will take place at Plataforma Solar de Almería, mainly at the so-called PTTL test facility.

Achievements in 2023: In 2023, once the final design of the collector had been defined, work was carried out on the development of a model to study the optical behaviour by ray tracing and obtain incidence angle modifier (IAM) curves, which will have to be validated once the first prototype collector is installed in the PTTL pilot plant. In the laboratory, a new campaign was carried out to measure the thermal losses of H2-doped receiver pipes before providing them to the KONTAS facility, where tests began at the end of 2023. In relation to the preparation of the PTTL plant and integration activities, the company has collaborated with Acciona and TEWER on the engineering to make the necessary changes to the pilot plant for the integration of the prototype. Delays in supplies and obtaining permits to start the civil works and also the construction of the prototype in the assembly workshop have caused some delays in the execution of the project. In 2024, the construction of the prototype collector, its assembly and installation at PTTL and the mechanical and optical qualification, which is carried out by CIEMAT, will be realised.

(a)

(b)

Figure 16. Aerial views of the PTTL pilot plant at the Plataforma Solar de Almería: (a) in red the area where the new large aperture parabolic trough prototype will be installed and (b) the BOP where equipment upgrades and the new Si-HTF (HELISOL® XLP) conditioning have already been carried out (Latitude 37°05′45″N, Longitude 2°21′12″W).

Development of Innovative Concept for a Thermo Solar Parabolic-Through Power Plant with Molten Salts in Fixed Tube and Thermocline-Type Heat Storage Coupled with Green Hydrogen Generation System, NEOSOLAR

Participants: Intecsa Ingenieria Industrial S.A. (Coordinator), Esasolar Energy System S.L., Tewer Engineering S.L., CIEMAT, CENER

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agencies: CDTI (Programa Misiones, Ciencia e Innovación, 2021). Ref. MIG-20211012 (Oct. 2021-Dec. 2024)

Background: The achievement of the objective defined by the European Commission for the reduction of greenhouse gases emissions (55 % with regard to the emissions in 1990) demands a huge effort from all the member countries in order to decarbonize their energy sector by means of a massive use of renewable energy sources in the domestic, transport and industrial sectors. The use of cost-effective energy storage systems becomes more and more important as the implementation of non-dispatchable renewable energies technologies increases. At the same time, the production of green hydrogen is considered a very suitable way to couple the electricity sector and the gas sector with a twofold use: to provide a flexible energy storage option and to use the curtailments of renewable electricity plants. Therefore, developing plants to produce renewable hydrogen and at the same time supply electricity at a competitive cost, is of high interest nowadays.

Objectives: NEOSOLAR is aimed at developing an innovative renewable energy system based on a solar thermal power plant with cheaper and more efficient parabolic-trough collectors using molten salts as working fluid and an electrolyser plant that altogether will reduce the curtailments that would otherwise be wasted and are affecting negatively to the profitability of renewable electricity plants. The innovative plant concept pursued in NEOSOLAR will deliver cheaper solar thermal electricity and competitive green hydrogen that could be used as both energy storage medium and energy vector.

Achievements in 2022: During the year 2023, CIEMAT collaborated with the companies in the engineering of the final prototype collector, defining the test plan for the geometric qualification, and engineering the integration of the system in the HTF Loop. For the optical and geometrical qualification, PSA has prepared ray-tracing and 3D models for IAM and interception factor determination, as well as set-ups for the large facets to be characterised in the laboratory before their installation in the prototype in 2024.

Figure 17. Aerial view of the PSA HTF Test Loop and planned location for NEOSOLAR

Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage – ASTERIx-CAESar

Participants: CENER (coordinator), CIEMAT, Universidad de Sevilla, Bluebox, Doosan Skoda Power Sro, Universidad de Roma, Fraunhofer-IKTS, Clancy Haussler Rita, Aalborg CSP, Europena Turbine Network, IMDEA-Energía, Softinway, Innovation Therm Technologies, Walter Pritzkow, Hellenic Electricity Distribution Network, Engionic, Apria.

Contacts: Antonio Avila-Marin, antonio.avila@ciemat.es

Jesús Fernández-Reche, jesus.fernandez@psa.es

Patricia Palenzuela Ardila, patricia.palenzuela@psa.es

Inmaculada Cañadas Martínez, i.canadas@psa.es

Funding agency: European Commission. HORIZON-CL5-2022-D3-03-01. Grant Agreement number: 101122231.

Background: Highly efficient energy conversion of solar power and storage will play a vital role in a future sustainable energy system. Thus, this project focuses on the development of a novel high-efficiency solar thermal power plant concept with an integrated electricity storage solution. The project combines air-based central receiver Concentrated Solar Power (CSP) and Compressed Air Energy Storage (CAES) to maximize conversion efficiency and power grid energy management, enabling a new operation strategy and business models. The hybrid concept initiates a futuristic era with adaptive renewable power plants, producing both electrical and thermal energy, including process heat supply and reverse osmosis desalination. Since cheap off-peak electricity is used to provide the air compression work of the topping Brayton cycle, the overall peak solar-to-electric energy conversion efficiency of the proposed power plant may reach up to 40 % efficiency, which roughly doubles the peak efficiency with respect to state-of-the-art CSP technology.

Objectives: ASTERIx-CAESar project's main development will cover: (a) an advanced high-efficiency solar volumetric receiver, (b) optical sensors and AI-based control, (c) optimized CAES with heat exchangers and compressor/expander detailed designs and (d) innovative integration of desalination. The project's activity will cover the techno-economic-environmental optimisation of the innovative CSP-CAES plant using representative boundary conditions, provided by grid operators and specialised partners, as well as the development and extensive testing of key components needed for its implementation.

Achievements in 2023: The project started in October 2023 and the kick-of meeting took place in November 2023 at the CENER facilities in Pamplona. PSA has started with the dismantling of the CAPTURE prototype in order to check those components that will be reused in the ASTERIx-CAESar project, and with the definition of the best location for the CAES and desalination unit. In addition, numerical simulations of the volumetric receiver have already started using commercial CFD software.

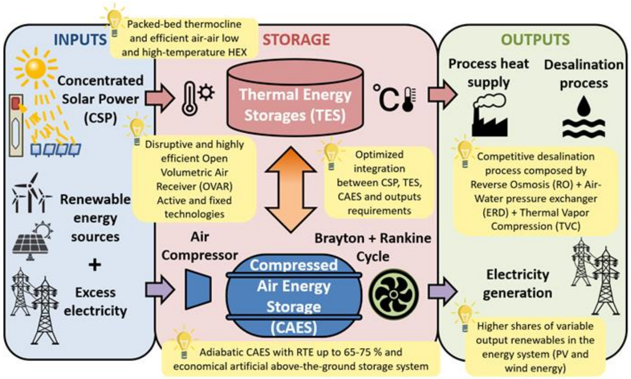


Figure 18. ASTERIx-CAESar concept overview

Solar field measurements to increase performance – LEIA

Participants: CIEMAT (coordinator), Acciona Industrial, CSP Services, DLR, TEWER Engineering, CENER, Siemens Energy, Grupo Cerro.

Contact: Antonio Avila-Marin, antonio.avila@ciemat.es

Jesús Ballestrín, jballestrin@psa.es

Rafael Monterreal, rafael.monterreal@psa.es

Jesús Fernández-Reche, jesus.fernandez@psa.es

Funding agency: CSP ERA-Net Additional Call. T5 - Improved central receiver molten salt technology. Transnational Call CSP ERA-Net COFUND 2021. MICINN Proyectos I+D+I “Programación Conjunta Internacional”, Convocatoria 2022-2. Reference PCI2022-135015-2 (Dec 2022 - Nov 2025).

Background: Central receiver systems using molten nitrate salts as heat transfer fluid are the preferred choice when the power tower technology is the CSP solution. Current commercial plants with this technology envisaged for a reduction in both operation and maintenance costs as well as the great deal of labour that some processes, such as heliostat calibration, receiver operation, solar field and whole plant control strategies, etc.

Objectives: The aim of the project is to contribute to the market deployment of the next generation of innovative, reliable, and smart Concentrated Solar Power (CSP) plants focusing on new control and Operation and Maintenance (O&M) solutions for the central receiver technology using molten salts, as the most promising cost-effective solution with the highest market potential. To achieve it, the LEIA project will develop and test at PSA, CENER, and the Cerro Dominador CSP plant the following innovations:

- Smart heliostat field control solutions to automate and improve calibration and characterization.
- Smart Receiver Control solutions to measure receiver temperature, emittance and high solar irradiance distribution.
- Solar Field O&M control strategies such as Automated Soiling Inspection and a Smart Energy Management system.

Achievements in 2023: Besides the project management and coordination, CIEMAT-PSA participated in two main activities. a) Task 2.1 which deals with an online heliostat field characterization system, and the work done so far has been basically the description of a CESA-1 scale model of image acquisition and information organization, which could be exportable to Cerro, simply by carrying out the necessary changes in order to adapt it to any specificity or local requirement of the plant's nomenclature. We are currently in the step prior to the optical characterization campaign. B) Task 3.2 that proposes the development of a high irradiance hybrid measurement method. To do so, a high-performance digital camera with a suitable lens and attenuating filter will be used to take images of the irradiated receiver. A radiometer will be used in the vicinity of the receiver that allows digital images to be translated into flux maps. Two options are considered for the installation of this radiometer: (i) calibration unit and/or (ii) cold finger. The flux measurements carried out will be validated with those carried out with the standard methodology with the help of a Lambertian target. It is expected that the tests will be performed during 2024.

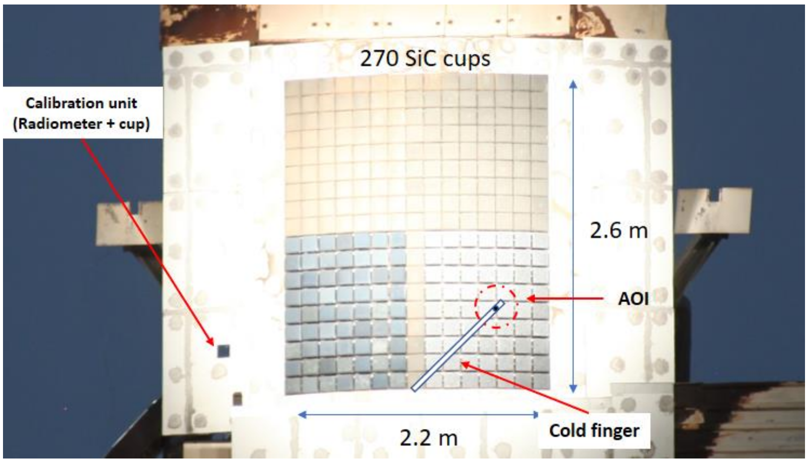


Figure 19. CESA I tower facility – Level 82 m

More Efficient Heliostat Fields for Solar Tower Plants - HELIOSUN

Participants: CIEMAT, Universidad de las Islas Baleares.

Contacts: Jesús Ballestrín, jballestrin@psa.es

Loreto Valenzuela, lvalenzuela@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Proyectos de Generación de Conocimiento 2021.

Background: Among the existing concentrating solar technologies, central receiver tower technology has the greatest potential for improvement. Amid all the components of the technology (solar field, receiver, energy storage system and power block), the cost reduction in the solar field, formed by thousands of heliostats, would have the greatest impact on the cost reduction of a central receiver plant.

Objectives: The present project approaches cost reduction on heliostat fields from three different but complementary points of view (control, extinction model, software). These three approaches will allow improving the operation of solar tower plants as a whole, optimizing in particular the operation of the solar receiver and the solar field, increasing the annual electricity generation and therefore the technical and economic efficiency of these systems.

Achievements in 2023: An artificial vision system with object recognition based on neural networks is proposed, which allows the closed-loop tracking control of the heliostats in the solar field. This system, consisting on the installation of a low-cost camera and processor in each one of the heliostats in the solar field, will eliminate the positioning sensors and therefore upgrading the heliostat tracking accuracy, improving the concentrated solar radiation distribution on the solar receiver surface. During this year, images have been taken with two of these low-cost cameras installed in two separate heliostats to train an intelligent ANN system.

Solar extinction in PSA is being measured daily with the aim of obtaining a typical year for this variable that allows reliable models to be incorporated into tower plant designs. During this year, the typical year of solar extinction for PSA has been obtained from the measurements carried out since June 2017. Work has also begun to develop and validate extinction models by comparison with this typical year.

A ray-tracing simulation software, based on OTSun, is being developed, including a more accurate prediction of the behaviour of a solar tower plant with central receiver considering spectral analysis, as well as including all the experimental results presented above. A simple solar extinction model has been implemented in OTSun once the extinction coefficient at PSA had been known.

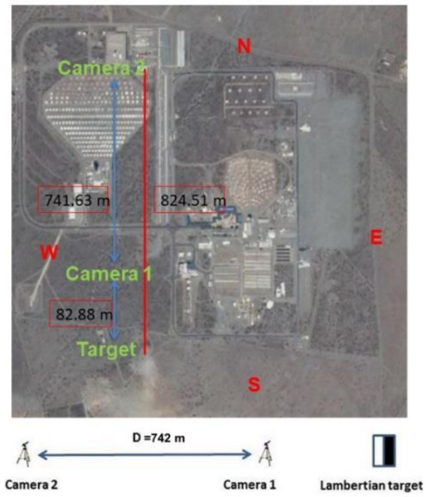


Figure 20. Extinction measurement system layout at PSA.

Analyze Heliostat Field – SolarPACES Task III

Participants: CENER (coordinator), CIEMAT, DLR, CSIRO, CyL, ANU, NREL, TEKNIKER, IMDEA, SANDIA.

Contacts: Jesús Fernández-Reche, jesus.fernandez@psa.es

Rafael Monterreal, rafael.monterreal@psa.es

Antonio Ávila-Marín, antonio.avila@ciemat.es

Funding agency: SolarPACES Task III project (International Energy Agency).

Background: During the last years, great efforts have been made to assembly a consensus on heliostat testing and a specific SolarPACES task was launched to provide a Heliostat Testing Guideline, which, being designed for a single heliostat evaluation - focused on prototype validation and qualification - is not applicable for the evaluation of heliostat in currently operating heliostat fields. The focus of this proposal is to set the basis towards a SolarPACES guideline for Heliostat Field Performance testing by means of a review, comparison, discussion and validation under a common framework of existing methodologies, some of them recently developed, involving, as key role, the knowledge and thoughts of industrial stakeholders.

Objectives: The project addresses to review, compare, and discuss the advantages and disadvantages of heliostat evaluation methodologies, which are either currently developed or being developed, to be used in already operating heliostat fields to maximize their performance. Prior to that, the short-term objective of the proposal is to review, discuss and analyse existing problems and worries in current heliostat fields with the high involvement of the industrial stakeholders. In this sense, a common framework, parameters to measure and figure of merits will be proposed.

Achievements in 2023: A detailed Heliostat Performance testing guideline report has been developed that offers a comprehensive review of current optical metrology tools and techniques and provides the current consensus among experts on the topic. This review specifically distinguishes between heliostat metrology guidelines, characterization, flux measurement and tracking calibration. This document also reports on an initial survey to industrial stakeholders on the topic of heliostat metrology, highlighting several key aspects hindering CSP technologies development.

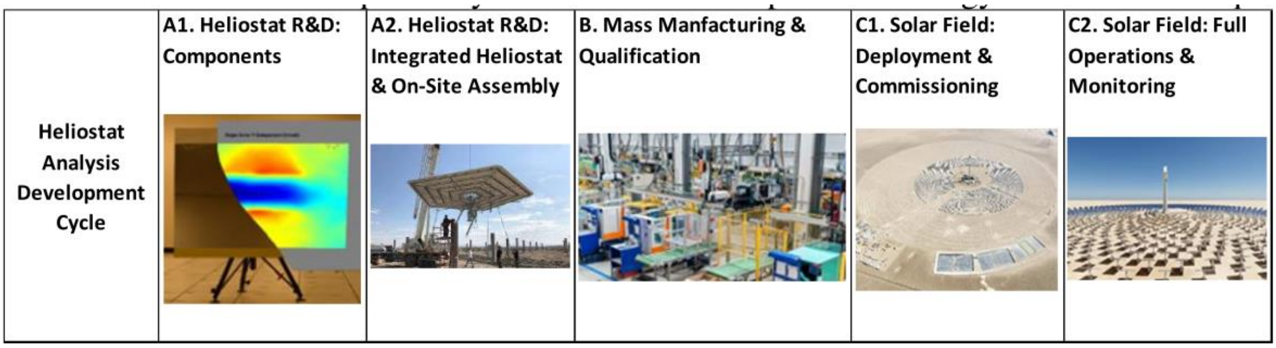


Figure 21. Heliostat development cycle breakdown for optical metrology tools and techniques.

Wind adapted heliostat, based on field measurements in the heliostat field and validation of wind tunnel measurements – AdaptedHelio.

Participants: DLR, FRAUNHOFER, CIEMAT-PSA.

Contacts: Raúl Enrique, raul.enrique@psa.es

Jesús Fernández-Reche, jesus.fernandez@psa.es

Funding agency: German Federal Ministry for Economic Affairs and Energy (BMWi, contract number 03EE5056).

Background: The cost of installing heliostat fields accounts for approximately 50 % of the total cost of a central tower solar power plant, which allows for a large margin of cost reduction. Knowing the wind intensity and direction profile in the heliostat field can help to relax the technical requirements of the heliostats installed in the heliostat field. In this way, more economical heliostats can be installed in those areas where the wind intensity allows it.

Objectives: The objective of the AdaptedHelio collaboration between DLR, Fraunhofer and CIEMAT is to determine the space-time wind profile on a semi-commercial heliostat field and to develop procedures to extend these results to heliostat fields of different types: larger and with heliostats of different sizes.

Achievements in 2023: During 2023 a whole testing campaign has been performed with all the instruments installed on the CESA-I solar field. The local measurements of the four anemometers located in different positions of the solar field are complemented with the wind speed distribution map over the heliostat field generated by the two lidars. All these measurements, combined with the orientation (azimuth and elevation) of each of the 300 heliostats of the solar field, have allowed modelling both, the distribution of wind speeds in the heliostat field, as well as the behaviour of the heliostats under this wind speed distribution.

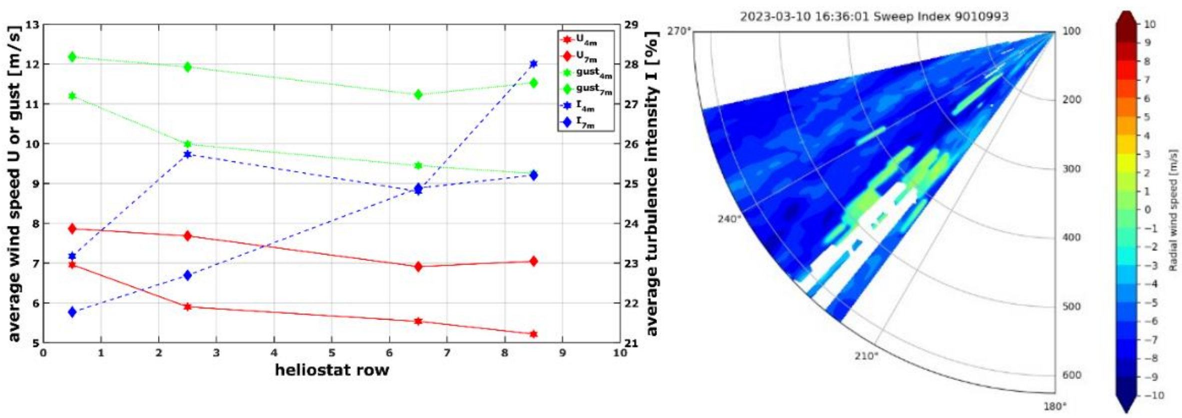


Figure 22. Mean wind velocity, wind gust and turbulence intensity per heliostat row (left), and wind velocity maps over the heliostat field (right).

PV Plant with Thermal Cogeneration - SOLARBLUE

Participants: MAGTEL, CAPSUN, CSIC, CIEMAT-PSA. GHENOVA.

Contacts: Rafael Monterreal, rafael.monterreal@psa.es

Raúl Enrique raul.enrique@psa.es

Jesús Fernández-Reche, jesus.fernandez@psa.es

Funding agency: CDTI. FEDER- INNTERCONECTA 2018.

Background: CAPSUN Technologies and GHENOVA Ingeniería have jointly developed a disruptive technology that integrates the best characteristics of Photovoltaic Plants (PV) and Concentrated Solar Plants (CSP). By means of a selective optical filter, the light spectrum is divided. The filter allows the efficient passage of radiation used by the photovoltaic panel (mainly visible light) while reflecting 40 % of the energy (mainly blue light and infrared). Selective filters were validated by CIEMAT-PSA in a former project (SPIRE).

Objectives: As a continuation of the SPIRE project, SOLARBLUE aims to demonstrate, among other aspects, the concept of hybrid heliostat, that generates electricity due to the PV panels installed and, at the same time, reflects part of the solar spectra (mainly Blue and Infrared wavelengths) to a solar receiver. The role of CIEMAT in the project is the optical and energetic characterization of a 40-square meter prototype that will be installed at PSA's CESA-I solar field.

Results in 2023: A whole heliostat prototype (40m^2) has been equipped with 1m^2 size PV SOLARBLUE panels (coated with the selective layer) in order to check the manufacturing process as well as concentrating and PV performances. These panel's performance have been compared with the performance of commercial mono and bifacial PV panels installed in both the heliostat structure (2 axis sun tracking system), and one axis tracking commercial system (south oriented, tilted at the placement latitude and with east-west sun tracking). Highlighting the best behaviour of the PV panels coated with the selective layer developed into the project.

Figure 23 Testing facilities installed on the PSA for the comparison pf the different PV technologies.

Solar extinction measurements system commercialization – Ref. 8510/2018.

Participants: BCB Informática y Control S.L., Plataforma Solar de Almeria (CIEMAT-PSA).

Contact: Jesús Ballestrín, jballestrin@psa.es

Background: CIEMAT has developed a solar extinction measurement system at PSA after years of research. This measurement system is now a reference and is demanded by companies in the concentrated solar sector.

Objectives: The main objective of the project is the commercialization of a system for measuring solar extinction developed by CIEMAT at PSA. This system allows quantifying the losses from the heliostats to the receiver placed at the top of the tower plant. In order to respond to the demand for this measurement system by companies in the concentrated solar sector, knowledge about this system have been transferred to BCB company with the consequent economic consideration to CIEMAT for each one of the installed systems.

Achievements in 2023: As a result of the technology transfer contract to the Spanish engineering company BCB, the second commercial atmospheric extinction measurement system has been fully implemented in a 100 MW commercial power tower plant that is using molten nitrate salts at the Mohammed bin Rashid Al Maktoum Solar Park in Dubai (United Arab Emirates).

Components' and Materials' Performance for Advanced Solar Supercritical CO2 Power Plants, COMPASsCO2

Participants: DLR (coordinator), CIEMAT (Plataforma Solar de Almería-PSA and Materials for Energy Interest Division-DMXE), CVR, Dechema, John Cockerill, Jülich, Ocas, Ome, Saing-Gobain, Sugimat, University of Birmingham, VTT.

Contacts: Gema San Vicente Domingo, gema.sanvicente@ciemat.es

Funding agency: EU-H2020- NMBP-ST-IND-2018-2020.

Background: The development of systems that can reach higher temperatures than those currently applied on commercial solar power plants (390 °C of thermo-oil and 560 °C of molten salt) allow the connection of solar energy into highly efficient and/or innovative systems. These systems could be high-temperature thermodynamic cycles (as Brayton cycles) and chemical or high-temperature processes as those related to solar fuels, materials processing and/or production or synthesis of chemicals. Among the media currently investigated to allow temperatures of 1,000 °C or more in high-temperature solar receivers, the use of solid particles have the advantage that they can also be directly used as the thermal energy storage medium.

Objective: The project is focused in the integration of two innovative processes: a CSP solid particles system coupled to a highly efficient s-CO_2 Brayton power cycle for electricity production. For this purpose, the project aims to research on tailored particles and alloy combinations that will be produced ant tested to withstand the extreme operating conditions in terms of temperature, pressure, and abrasion to validate a particle/s-CO_2 heat exchanger.

Achievements in 2023: During this year, a new composition of absorber black coatings was developed composed of CuMnCoOx with silica nanoparticles. The introduction of the nanoparticles in the composition produced rougher surfaces, which increased the solar absorptance. This new composition was applied on the novel particles developed in the project, particles giving place to black coated particles stable at 1,000 °C with solar absorptance values close to 0.98, with 4 consecutive layers. Thus, the solar absorptance was increased by 13.5 % compared to uncoated particles. Moreover, during this year, the coated particles developed in the project were tested to study their performance and durability. Static thermal tests, cyclic thermal tests and abrasion tests at both ambient and high temperature were done. CIEMAT-PSA's particles have passed the tests with good results. Moreover, CIEMAT made the optical characterization of all the particles before and after being tested.

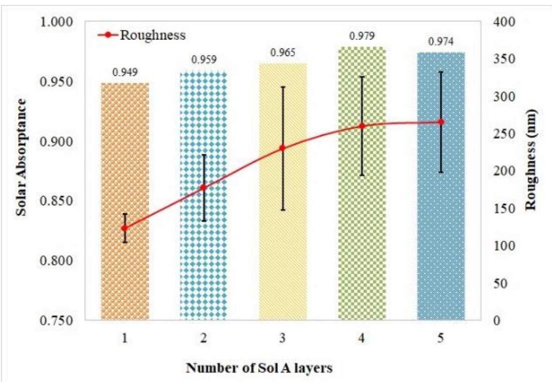


Figure 24. Solar absorptance and surface roughness values of a new spinel/silica coating on the novel Gen 3 particles

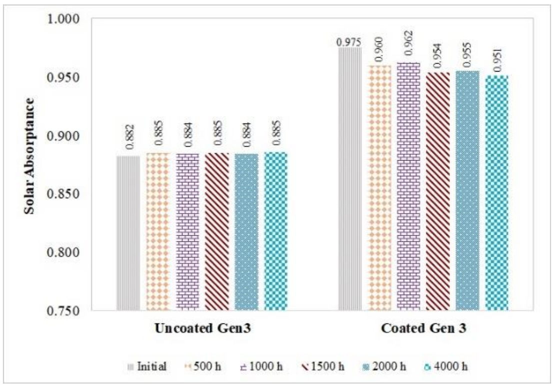


Figure 25. Evolution of the values of solar absorptance for uncoated and CIEMAT coated Gen 3 particles during the thermal stability test at 1,000 °C

Innovaciones tecnológicas para la mejora de la viabilidad de las plantas termosolares de concentración, INTECSOL

Participants: CIEMAT-PSA (Materials for CST Technologies Unit, Point Focus CST Technologies Unit, Line Focus CST Technologies Unit)

Contacts: Aránzazu Fernández García. arantxa.fernandez@psa.es

Gema San Vicente Domingo. gema.sanvicente@ciemat.es

Antonio Ávila Marín. antonio.avila@ciemat.es

Lourdes González Martínez. lourdes.gonzález@ciemat.es

Funding agency: Ministry of Science and Innovation. Call "Proyectos de Generación de Conocimiento 2021. (PID2021-126664OB-I00).

Background: The current market situation stablishes two dominant concentrated solar thermal (CST) technologies, the well-known and mature parabolic-trough collectors (PTC), and solar tower (ST) systems. However, the new generation of the CST plants requires technological innovations for improving its feasibility either reducing cost and/or increasing efficiencies.

Objective: The INTECsol project focuses its R&D activities in the main solar components of a CST plant, the solar reflector and the receiver (for both PTC and ST systems), with the analysis and development of new components, and the implementation of improved materials and updated component features. These activities are aimed at improving efficiency and reducing costs.

Achievements in 2023: During 2023, the following activities were performed, within the different project tasks:

Within the development of wire mesh for Open Volumetric Receivers (OVR), a deep analysis of the convective heat transfer coefficient and the hydrodynamic behaviour in dense wire mesh absorbers was accomplished and the final steps are being performed. The two extreme arrangements were analysed: the stagger arrangement results have already been published, whereas the inline arrangement results are under revision. In addition, the comparison of both arrangements is being underdevelopment. Finally, a multi-objective optimization of wire mesh OVR and the analysis of different working conditions were prepared and simulated, and the results will be analysed in the next year.

With respect to the development of parabolic-trough collector (PTC) envelopes with antisoiling (AS) coatings, the study of different fluorinated precursor solutions to produce anti-soiling coatings for both solar reflectors and glass covers was covered in this year. The coatings were prepared by dip coating and then a heat treatment was done in order to obtain hard and durable coatings. Two different compounds with two sizes of fluorinate chains were studied, obtaining more hydrophobic coatings with the longer ones. However, it was also observed that longer reaction times were required in these solutions. The heat treatment conditions of the coatings were studied in order to obtain the optimal conditions. Moreover, the condensation resistance of the coatings was studied by accelerated tests in climate chamber (see Figure 26).

Another task performed was focused on carrying out a simulation study of the effect of soiling on the parabolic mirrors and the receiver tube. So far, soiling studies were carried out only considering its effect on parabolic mirrors, through the measurement of reflectance. This parameter allowed including a constant cleaning factor in the energy balance considered in the simulation model of the solar collector and the solar field. In this project, the effect of soiling on the glass cover of the receiver tube will also be considered, allowing it to vary over time due to the effect of wind, suspended particles, meteorological processes (rain, suspended dust, etc.) and cleaning cycles. In 2023, as the first year of the project, the main activities were the development of the simulation model in Python of the PTC (as the main component of the solar field) and the rest of components of a concentrating solar power plant (thermal storage, power block, pumps, etc.). In addition, bibliographic references were reviewed related to the soiling of solar concentrators and especially PTC.

Within the activity related to the development of measurement equipment for solar reflectors, silvered-glass reflector samples were exposed in a corrosive environment (close to the sea) to monitor the appearance and possible growth of corrosion spots, using a portable microscope.

Finally, in relation to the study of the degradation of solar reflectors due to different environmental parameters, silvered-glass reflector samples with and without copper layer were initially characterized to expose them in several representative outdoor sites and to perform accelerated aging tests combining UV radiation, temperature and humidity.

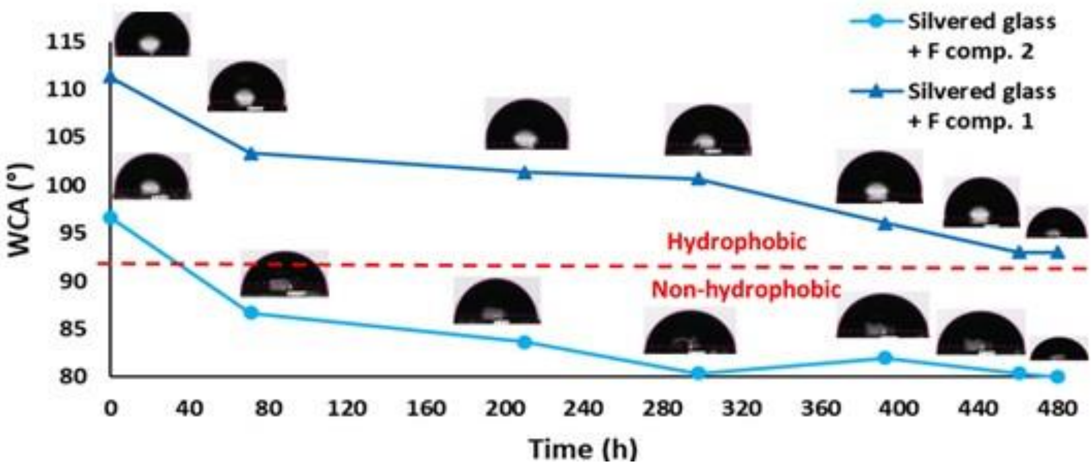


Figure 26. Evolution of the static water contact angle (°) with the condensation test at 40°C of anti-soiling coatings prepared from two fluorinated solutions.

Update of guideline "Recommendations for reflectance measurements on soiled solar mirrors", SP-SOILING-II

Participants: CIEMAT (coordinator), DLR, ENEA, Fraunhofer ISE, University of Zaragoza, NREL, QUT, National University of Australia, IMDEA Energy.

Contacts: Johannes Wette. johannes.wette@psa.es

Funding agency: SolarPACES (International Energy Agency).

Background: Although the SolarPACES Reflectance Guideline gives recommendations for the use of reflectance measurement instruments and their calibration, it is only focused on clean and new reflectors. It has been demonstrated that even using well calibrated reflectometers, the achieved results differ substantially for different instruments and measurement parameters when measuring soiled reflectors in the solar field.

Objectives: The main goal is to update the SolarPaces Guideline for soiled reflectors, to ensure the reliability of specular reflectance measurements on soiled mirrors. It is approached through outlining the proper features of the field reflectometers and obtaining correlations between the reflectance values given by different field reflectometers and the complete reflectance information determined with lab equipment.

Achievements in 2023: This project started in April 2023 and is being performed by CIEMAT in cooperation with DLR in the OPAC facility. During this first year, a set of key questions were identified to be asked to the plant operators in order to acquire enough knowledge of the reflectance measurement protocol currently followed in the commercial CST plants. These questions will be asked to the identified plant operators throughout several interviews. In addition, several reflector samples were outdoor exposed at the PSA to obtain different representative soiling level (see Figure 27). These samples are being measured with both portable reflectometers (see Figure 27) and advanced lab equipment to derive transfer functions among them. Another task performed was a deep revision of the available devices to identified soiling in the solar fields, different to portable reflectometers. Finally, a low cost measurement device is being developed in cooperation with ENEA.

Figure 27. Left: Reflector samples exposed at different inclinations to achieved several soiling levels. Right: portable reflectometers included in the study of the transfer functions.

GreenCoat

Participants: DLR, AGC, MIPA, CIEMAT

Contact: Ricardo Sánchez Moreno. ricardo.sanchez@psa.es

Funding agency: Ministry for Economic Affairs and Climate Action (BMWK)

Background: State-of-the-art solar reflectors consist of a silvered 4-mm low-iron glass protected by a copper layer and 2 or 3 protective paint layers. The protective paint base layer usually contains up to 10-wt % lead as corrosion inhibitor. However, lead pigments are toxic and carcinogenic. For these reasons, lead needs to be removed from solar mirrors.

Objectives: The main goal of the project is the development and testing of lead-free mirror coatings, finding alternative corrosion inhibitors to protect the metallic silver layer during its expected lifetime of more than 25 years in a harsh desert environment.

Achievements in 2023: During this second year of the project, the accelerated ageing tests have continued at the OPAC facilities in order to estimate the performance of a new lead-free mirror coating developed by MIPA, which include the following tests: Neutral salt spray test (NSS), Copper Accelerated Acetic Acid Salt Spray test (CASS), Condensation test (COND), Thermal Cycling / Humidity test (TCH), Damp Heat test (DH), and UV / Humidity test (UVH). According to the first results of the accelerated aging tests, although the lead-free mirror samples showed promising results, several improvements were identified in the protective paint layers and the company is producing a next generation of the these materials. In addition, the reflector samples exposed in the different sites (PSA, Almería, Erfoud, Missour, Zagora, Antofagasta, Sines and Abu Dhabi) were measured after 6 and 12 months of outdoor exposure.

New nanostructured coatings for efficient absorption of solar radiation in CSP systems, HIPIMSOLAR

Participants: ICMSevilla - CSIC (coordinator), CIEMAT and University of Seville.

Contacts: Inmaculada Cañadas Martínez, i.canadas@psa.es

Ángel Morales Sabio, angel.morales@ciemat.es

Funding agency: Andalusian Regional R&D Programme (2020-2022). FEDER Programme for R&D&I in Universities and Research Centres. P18-RT-2641.

Background: Recent studies focus on the development of new high-temperature selective solar coatings to improve the performance of concentrating solar power (CSP) plants. The aim is to maximise absorption in the visible and near-infrared regions, and minimise thermal emissivity in the far-infrared. Nowadays, solar towers do not use selective coatings but absorber coatings with high absorptance (α>0.95) as well as high emittance (ε>0.8). Their degradation at temperatures above 550 °C makes frequent renewal necessary.

This project is carried out through the collaboration of two research groups, one from the Materials Science Institute of Seville ICMS-CSIC (TEP-958) and the other from the Plataforma Solar de Almería CIEMAT-PSA (TEP-247).

Objective: Multilayer solar selective absorber coatings based on three chromium aluminium nitride (CrAlN) layers with different stoichiometries and Al2O3 were deposited on 316L steel and Inconel 625 (two of the most common metallic components used in concentrated solar collectors) by means of magnetron sputtering, evaporating the materials via high-energy impulses (HiPIMS - High Power Impulse Magnetron Sputtering).

Achievements in 2023: Two sets of nanostructured coatings developed by ICMS-CSIC have been tested to study their durability in concentrated solar conditions. Solar fluxes were controlled to limit the maximum working temperature at 650 °C and their optical performance was compared with commercial paint Pyromark©, deposited on similar substrates during 50 hours. Additionally, aging behaviour was evaluated by cycling the samples 15 times up to 650 °C. The optical properties have been measured using portable equipment typically used in the industry as well as reference spectrophotometers in laboratories OPAC, OCTLAB and MATERLAB.

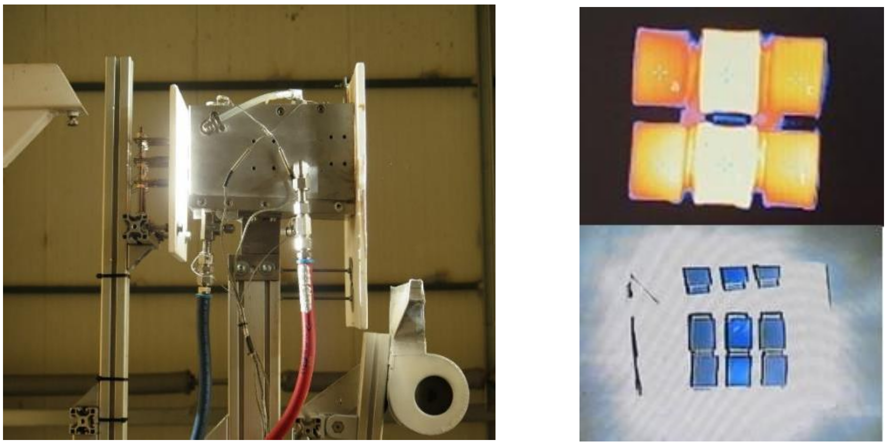


Figure 28. Left: Test bench for solar ageing of metallic specimens at solar furnace SF40. Right: New nanostructured coatings developed by ICMS-CSIC under CST conditions.

Sustainable Near-net-shape Fabrication of Low Environmental impact Receiver materials, SUNFLOWER

Participants: Fraunhofer-IKTS (coordinator), Fraunhofer-IFAM, CIEMAT (Materials for CST Technologies Unit and Point-Focus CST Technologies Unit), Aalborg CSP, AMAZEMET, ESK-SiC, CENER.

Contact: Inmaculada Cañadas, i.canadas@psa.es

Antonio Ávila-Marin, antonio.avila@ciemat.es

Funding agency: CET Partnership. Agencia Estatal de Investigación - Co-funded by the EU. Referencia PCI2023-145996-2.

Background: Concentrated Solar Power (CSP) is a very relevant renewable energy sector that can provide cheap energy storage in order to enable higher shares of non-dispatchable renewables, by stabilizing the electricity grid. Nevertheless, the recent decline in cost of photovoltaic power generation (0.02-0.03 €/kWh) has significantly lowered the competitiveness of CSP (0.07 - 0.12 €/kWh). Considering this immense price difference, the unique and very valuable advantage of CSP providing cheap thermal energy storage - TES - (thus providing dispatchable operation) is not sufficient to be competitive anymore, and a technology breakthrough is needed. First, the conversion efficiency of CSP must be improved, as well as the capital expenditure (CAPEX) has to be reduced and, secondly, massive, and efficient electricity storage must be provided by the CSP plant of the future. Recent research has shown that CSP plants using air as heat transfer fluid (HTF) can have high conversion efficiency, low cost of thermal energy storage as well as the potential of efficient electricity storage integration when combing a CSP power plant with compressed air energy storage (CAES).

Objectives: The strategic development line of this project is therefore the analysis and optimization of novel air-based hybrid CSP-CAES plants, focusing on the solar receiver, in particular the open volumetric receiver (OVAR). The interaction of the material properties, the structure itself and the requirements of the preparation technique determine the performance of absorbers for OVAR. Therefore, the SUNFLOWER project targets the following interconnected specific objectives:

- Optimization of raw material processing and absorber structure design.
- Absorber material and fabrication improvement.
- Testing and overall assessment.

Achievements in 2023: The project was officially launched in November 2023. CIEMAT-PSA participate in five of the eight work packages: WP3 - Modelling assisted absorber design, WP5 - Testing of developed materials and receiver structures, WP6 - Assessment process, WP7 - Reporting and Knowledge Standard Work Package, and WP8 - Project coordination, leading WP5. The main activities that CIEMAT-PSA will carry out are: a) Modelling solar absorber structures to identify optimal morphologies, and their integration in the solar receiver for highest thermal efficiency. Two types of potential receiver materials will be analyzed, together with two concepts, (i) the classical static absorber concept, and (ii) an innovative active rotary absorber concept; b) CIEMAT-PSA will conduct all the tests needed to thoroughly characterize the preselected metallic and ceramic materials compositions, the final absorber structures, and the innovative and novel active high-flux volumetric absorber.

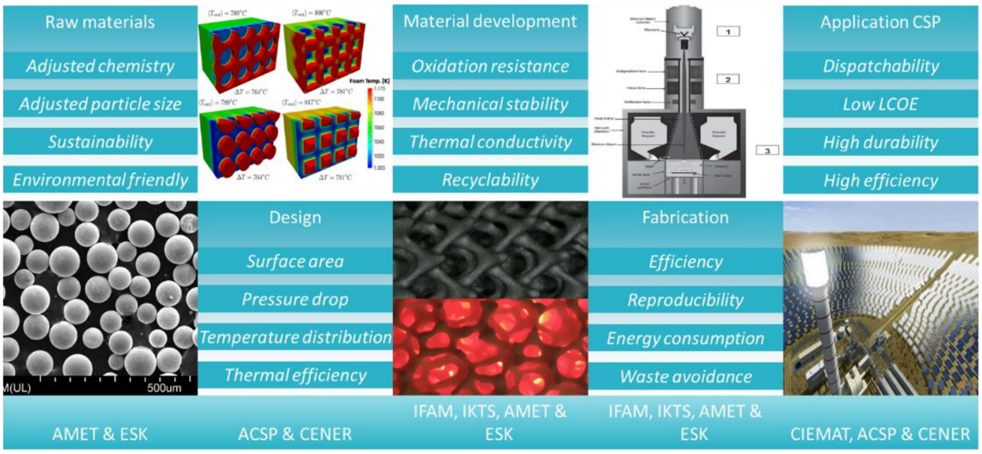


Figure 29. Main objectives of the SUNFLOWER project

Red española de almacenamiento de energía térmica. RedTES.

Participants: UdL (coordinator), UB, URV, UJI, UCLM, UC3M, UPC, UPV, UBU, VIRTUALMECH, US, UAH, CSIC-EHU, UNIOVI, CIEMAT, GREENDUR, B2Z, ANALYSIS-DSC, CIIEAE, CADE, UNED, CIC ENERGIGUNE, UPCT, UPV-EHAU, CYD, UNIGE, CENER.

Contact: Esther Rojas, esther.rojas@ciemat.es

Funding agency: Ministerio de Ciencia e Innovación (AEI).

Background: Already in 2011, CIEMAT participated in the creation and launching of this national Network. After several years of activity, we decided to leave given the low profit/effort ratio achieved. On this occasion, and after the insistence of the Network coordinator, we decided to re-join back.

Objectives: This network aims to carry out actions for eliminating the current technological, economic and social barriers for the deployment of thermal energy storage. Also it aims to consolidate collaboration between Spanish groups working on the issue and continue the Spanish leadership at international level.

Achievements in 2023: This project started in June 2023 and in November a hybrid workshop, entitled *Retos sociales e industriales en el almacenamiento de energía térmica* took place. In this workshop, Esther Rojas and the rest of the participants in the network presented the R&D activities on the Thermal Energy Storage carried out in their corresponding institutions.

Towards the standardization of molten salt loops': instrumentation and components. MOSAIC

Participants: DLR, CIEMAT, UEVORA, ENEA, FRA-ISE

Contact: Margarita Rodríguez, margarita.rodriguez@psa.es

Funding agency: SolarPACES

Background: The participants in SolarPACES Task III already have many experimental results from their experimental facilities related to components of molten salt circuits and thermal storage systems. Hence, they wanted to bring together the information obtained and present it a workshop/conference in order to give visibility to these facilities within the industrial sector related to the CSPT.

Objectives: This project is focused on dissemination with the aim of involving the industrial sector related to molten salt installations for CSPT by organizing/attending a workshop/conference focused on the industry and where the results already achieved by the different partners in Task III of SolarPACES are shown

Achievements in 2023: In October, the project partners organized a Workshop entitled "Characterization of components for CSP molten salt plants" in Evora (Portugal) focused on industrial participants. Margarita Rodríguez attended this workshop and gave various lectures reporting on the results obtained in both SFERA III project and SolarPACES working groups in relation to the characterization of components for molten salt circuits such us valves and pressure sensors.

Integrated European research, calibration and testing infrastructure for fibre-optic thermometry, INFOTHERM

Participants: PTB (coordinator), BAM, CEM, CMI, CNAM, DFM, DTI, JV, LNE, RISE, UL, CEA, CIEMAT, CITY, ELKEM, IEG, IPHT, NORCE, TUB, UM, APL, ENGIONIC, HYME, SCHOTT, STATNETT, VIANI

Contact: Margarita Rodríguez, margarita.rodriguez@psa.es

Funding agency: European Partnership on Metrology, JRP-s13

Background: Thermal energy storage systems for applications like electricity production or seasonal storage require accurate and reliable temperature measurements with high spatial resolution, revealing the true distribution of energy along a long trajectory. Also, it is necessary to control the temperature in a way that is not affected by variable electromagnetic fields and this can be achieved by using fiber optic thermometry.

Objectives: This project aims to develop a research, calibration and testing infrastructure for fiber-optic thermometry measurements by minimizing uncertainties in large-scale applications and harsh environments. Up to 7 case studies in key application areas for fiber optic thermometry will be conducted. At CIEMAT, fiberglass-based thermometry will be tested both in MOSA and ALTAYR facilities.

Achievements in 2023: The project started in September 2023 so, apart from an online kick-off meeting, year no activities have been developed yet.

Smart Thermal Storage for Decarbonisation of Energy Sector, STES4D

Participants: UNIZAR (coordinator), UPV-EHU, CIEMAT

Contact: Rocío Bayón, rocio.bayon@ciemat.es

Funding agency: Ministerio de Ciencia e Innovación, Proyectos Estratégicos Orientados a la Transición Ecológica y a la Transición Digital (TED2021)

Background: As gathered in the PNIEC 2021-2030, there is an imperative need to promote solutions for the development of thermal renewable energies. However, due to their inherent intermittent nature, this can only be achieved if efficient and technologically mature thermal energy storage (TES) systems are available.

Objectives: STES4D project aims to contribute to the deployment of TES systems to reduce CO_2 emissions related to the energy demand in buildings and industry and to enable the increase of renewable sources integration into energy production and management. In this context, the work of CIEMAT is focused in the selection, characterization and validation of the storage materials (mainly PCM) to be implemented in the different storage applications considered in the project.

Achievements in 2023: During the last year, CIEMAT has progressed in the degradation studies of low temperature PCM from the family of monocarboxylic acids (myristic and stearic) and the results have been presented at 13CNIT conference. Moreover, by taking into account the previous degradation results for adipic acid, other dicarboxylic acids have been selected as organic PCM (succinic, suberic and sebacic) to be studied because having melting temperatures in the range of 130 °C-180 °C makes them very attractive as latent storage media for industrial applications.

Storage Research Infrastructure Eco-System, StoRIES

Participants: KIT (coordinator), AIT, CIEMAT, CLERENS, CNR, CSIC, DTU, EASE, ECCSEL, ERIC, EDF, EERA, ENEA, ENI, FZJ, SINTEF

Contact: Rocío Bayón, rocio.bayon@ciemat.es

Funding agency: EU, H2020-LC-GD-2020

Background: According to the European Green Deal goals, new energy storage technologies will supply more flexibility and balance in the grid by providing a backup to intermittent renewable energy and contributing to seasonal energy storage challenges. However, above all, the main challenge for energy storage development is economic.

Objectives: The main objective of StoRIES project is to create an industrial research ecosystem at European level in the field of energy storage by providing access to high level research infrastructures and services and by developing specific services and tools with the aim of improving materials and optimizing the hybrid energy systems.

Achievements in 2023: During this year, Thermal Energy Storage Unit has actively participated in the preparation of the Roadmap for Hybridization of Energy Storage (D3.5). Also Rocío Bayón, who is the IP of this project from CIEMAT's side, has attended the project meeting number 5 that took place in Vienna and the different workshops organized by EERA along the same meeting.

Energía solar térmica de concentración en el sector del transporte y en la producción de calor y de electricidad, ACES2030.

Participants: IMDEA-Energy (coordinator), CIEMAT, CSIC, UC3M, UNED, UPM, URJC, PROTERMOSOLAR (associate partner), Empresarios Agrupados (associated partner), Abengoa Energía (associated partner), Grupo Cobra (associated partner), Rioglass Solar (associated partner), REPSOL (associated partner).

Contact: Esther Rojas, esther.rojas@ciemat.es

Funding agency: Programas de I+D En Tecnología 2018 de la CM

Background: Three main challenges covering aggressive penetration of CSP within end use energy mix by 2030: Renewable electricity where a new class of better CSP plants are required; Solar process heat where technologies and integration schemes are required; Solar fuels for transport, where materials, technologies and processes for the H2 production and storage are required.

Objectives: Challenges to improve CSP within end use energy mix by 2030 are approached through 4 R&D lines: (i) optical engineering; (ii) solar receivers and reactors together with the corresponding materials and thermal fluids; (iii) energy storage systems; and, finally, (iv) the analysis of integration of thermodynamic cycles and industrial processes.

Achievements in 2023: The project ended in April 2023 so the last activities were finished and the last milestone was achieved: [Hito O2.3.2.] Modelos analíticos de estimación de vida útil que permitan predecir el comportamiento de los PCM a largo plazo y diseñar ensayos acelerados y Validación de los modelos analíticos de almacenamiento termoclino a partir de resultados.

Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond (HYDROSOL-BEYOND)

Participants: APTL (Greece), DLR (Germany), Hygear (Netherlands), ENGICER SA (Switzerland), SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA (Switzerland), COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES (France), ABENGOA HIDROGENO SA (Spain) and CIEMAT-PSA (Spain).

Contacts: Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: European Commission, H2020-JTI-FCH-2018-1

Background: The HYDROSOL-Beyond project is a follow-up of the HYDROSOL projects: HYDROSOL II (2006-2009), HYDROSOL-3D (2010-2013) and HYDROSOL-Plant (2014-2018) which required an upscaling of the current solar reactor technology from 100 kW to 750 kW and the development of all aspects in the solar receiver plant such as heliostat field, monitoring and control or feedstock conditioning and hydrogen storage.

HYDROSOL-beyond is an ambitious scientific endeavour aiming to address the major challenges and bottlenecks identified during the previous projects and further boost the performance of the technology via innovative solutions that will increase the potential of the technology's future commercialization.

Objectives: The main objectives of the project are summarized above are: (1) Improvement of the stability, cyclability and performance of the redox materials (1,000 cycles or 5000 hours of operation). (2) Design novel solutions for high temperature solid-solid and solid-gas heat recovery (higher than 50 %). (3) Embed and validate smart solutions to minimize the consumption of auxiliaries like flushing gas. (4) Design and development of intelligent systems and a smart process of control and automation, including predictive and self-learning tools.

Achievements in 2023: As it was previously mentioned, one of the main tasks of the project was to evaluate new materials and porous structures that can form the absorber of the thermochemical reactor. In the framework of this project, a semi-cylindrical cavity tubular reactor (Figure 30 left) was used to test and evaluate nickel ferrite pellets (Figure 30 right). These pellets fill the ceramic tubes inside the reactor cavity where the thermochemical cycle is carried out. Two thermochemical testing campaigns were conducted in which H_2 was produced.

Another of the project's goals was the construction and evaluation of a metal-ceramic heat exchanger that can operate at very high temperatures in order to improve the efficiency of heat recovery from the facility's exhaust gases. During 2023, this heat exchanger has been installed and integrated into the main Hydrosol-Beyond facility.

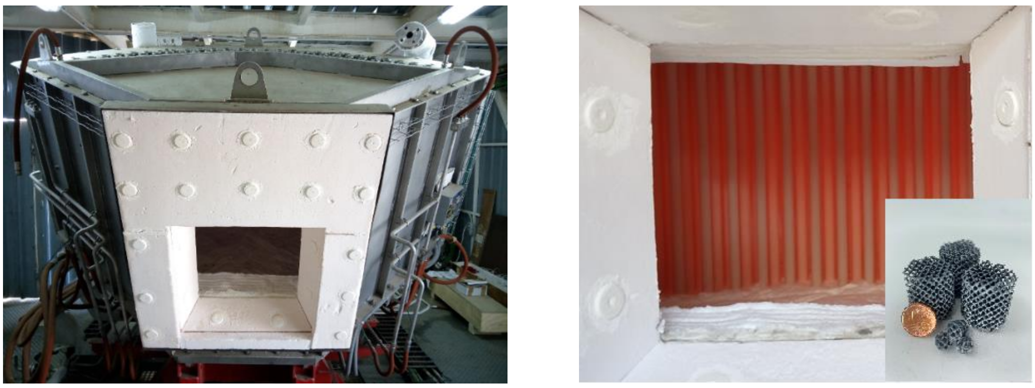


Figure 30. Left: Semi-cylindrical tubular reactor. Right: Ceramic tubes and Nickel ferrite pellets.

On the other hand, after a long campaign of both thermal and hydrogen production tests carried out over several years, the facility required the repair and fine-tuning of several of its components in order to initiate the final tests under optimum conditions. Among the plant's renovation carried out this year, the following improvements stand out: on one hand, the design and construction of a new secondary steel concentrator that withstands the high solar radiation fluxes coming from the solar field (Figure 31 left); on the other hand, the complete renovation and subsequent installation of a new ferrite foam absorber (Figure 31 right) where the thermochemical cycles and H2 generation take place.

With these improvements, the plant is now ready to start a new hydrogen production test campaign under optimal conditions.

Figure 31. Left: Secondary steel concentrator. Right: Nickel ferrite absorber.

Boost to the solar thermal H_2 production via the development and validation of new materials for ceramic solar receivers with improved durability (HIDROFERR)

Participants: CIEMAT-PSA and ITC-AICE (Institute of Ceramic Technology) in Castellón.

Contacts: Diego Martínez, dmartinez@psa.es
Inmaculada Cañadas, i.canadas@psa.es

Funding agency: Spanish State Research Agency

Background: The partners are pushing forward a joint activity in order to develop optimal materials and operating procedures for the characterisation of materials for volumetric receivers as well as improving the feasibility of hydrogen production via solar thermochemistry.

A first step in that direction is to achieve the goals of this project: characterisation of ceramic materials able to be tested at high temperature under very high concentrated solar radiation, and developing combinations of ceramic and metallic materials able to deliver high hydrogen yields under concentrated solar radiation. The secondary goals would be to develop permanent testing infrastructures and a multidisciplinary R&D team to keep this joint endeavour going.

Objectives: General Objectives: 1. Advance the knowledge in the hydrogen production process via solar thermochemical water splitting at very high temperature. 2. Development and characterisation of high temperature ceramic materials for use as volumetric receivers in CST. 3. Develop improved solar concentrating facilities for testing of materials for thermochemical applications. 4. Build up the necessary skills and training capacity in the partnering teams to continue working on this issue. 5. Promote a long-lasting inter-institute collaboration on this topic.

Specific Objectives: 1. Find out combinations of receiver materials (ceramic substrate plus metal oxide coating) that improve significantly currently reported reaction efficiencies and minimize operational issues. 2. Develop manufacturing and accelerated ageing characterisation paths for such combination of materials. 3. Determine the optimal operating conditions for their proper behaviour under high concentrated solar fluxes and a maximum yield of hydrogen, i.e. temperatures for reduction/oxidation steps, feed-in gases flowrates and pressures and cycle timing.

Achievements in 2023: The thermal exposure of most candidate materials to be used as ceramic substrates has been nearly concluded. A number of properties are being analysed by the ITC right now in order to select the most promising materials. Particularly important are the XRD and SEM techniques. Also, a number of experiments are on their way at the OCTLAB in CIEMAT-Madrid, in order to find out the optimal configuration to carry out the deposition of the ferrite coating on the ceramic substrate and its accelerated ageing in MATERLAB.

On the other hand, a new line of research has been open to study porous ceria as candidate material for the receiver, without any specific coating. The challenge with this material is the mechanical resistance as it tends to be weak and it is necessary to find additive to strengthen it.

Last but not least, a special reflecting device 'the butterfly mirror', has been developed and tested at the SF40 in order to obtain a homogeneous flux area of 5 cm diameter on a horizontal plane. This is a need of the project in order to attain thermal treatment as homogeneous as possible on the treated samples.

Energía solar térmica de concentración en el sector del transporte y en la producción de calor y de electricidad, ACES2030.

Participants: IMDEA Energia (Coordinator), CSIC-ECI (Instituto de Catálisis y Petroleoquímica), UC3 - MISE(Universidad Carlos III de Madrid / Escuela Politécnica Superior), UNED-STEM (Universidad Nacional de Educación a Distancia / Escuela Técnica Superior de Ingenieros Industriales), UPMGIT (Universidad Politécnica de Madrid / E.T.S.I. Industriales), URJC – SOLAR (Universidad Rey Juan Carlos / Escuela Superior de Ciencias Experimentales y Tecnología) , CIEMAT-PSA and ABENGOA Hidrógeno (company subsidiary of the ABENGOA group) acting as industrial companies with active collaboration and interest in the possible exploitation of the project results.

Contacts: Alfonso Vidal, alfonso.vidal@ciemat.es

Esther Rojas: esther.rojas@ciemat.es

Funding agency: Programas de I+D en Tecnología 2018 de la CAM

Background: The new challenges regarding emissions abatement in preparation for the National Integrated Plan on Energy and Climate imply a twofold increment of renewable energy penetration with the aim to reach 32 % contribution in the energy mix (end use energy) in the horizon of the year 2030. The R&D program ACES2030 on concentrating solar thermal power assumes the new priorities for CSP and relies on important outcomes obtained during the previous programmes SOLGEMAC, S2009/ENE1617 and ALCCONES, S2013MAE2985.

Objectives: ACES2030 focuses its R&D objectives on three main challenges covering aggressive penetration of CSP within and use energy mix by 2030: Objective 1 – Renewable electricity. Objective 2 – Solar process heat. This objective is aligned with the integrated EC project INSHIP (Integrating National Research Agendas on Solar Heat for Industrial Processes) with the ultimate goal to prepare an ECRIA (European Common Research and Innovation Agenda) on this subject. Objective 3 – Solar fuels for transport.

Achievements in 2023: The contribution of the CIEMAT Hydrogen Unit to the present project is focused on technologies and processes for the production of H_2 and other alternative solar fuels for transport. In particular, the development of new materials for thermochemical cycles that aimed at clean hydrogen production. These new materials should make it possible to reduce the high temperatures of the reduction stage of the material (1,400 -1,600 °C) as well as to improve the kinetics of O_2 and H_2 production.

A model perovskite material $La_{0,6}Sr_{0,4}Fe_{0,8}Co_{0,2}O_3$ (LSCF) was employed to study the effects of acid etching. Three different samples were analysed, the commercial LSCF and the other two obtained by acid treatment, named LSCF2h and LSCF6h, with different treatment times of 2 and 6 hours, respectively. Several cycling tests were carried out to study the effect of etching in activation and hydrolysis steps. No significant change was found during the reduction step being O2 production similar for the three materials; however, the hydrogen release is strongly affected by acid treatment and time.

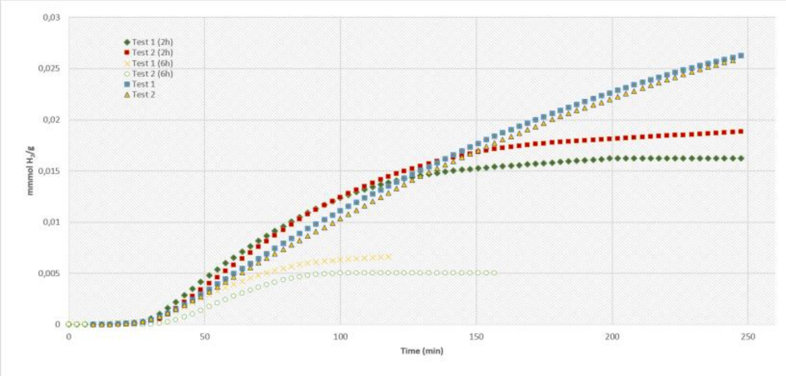


Figure 32. Profiles of H_2 evolution in the two-step water splitting tests for three samples LSCF (Test 1 and 2), LSCF2h (Test 12h and Test 22h) and LSCF6h (Test 1 6h and Test 26h)

Typical profiles in Fig. C show that the production of H_2 starts immediately after the injection of steam, reaches a peak and then decreases slowly, reaching a plateau. The data further revealed that the LSCF reduction reaches 90 % of completion after 250 min, whereas the etched samples, LSC 2h and LSCF 6h, reach the same extent of completion after 120 min and 75 min respectively.

Based on these observations, the estimated fuel productivity is calculated to be 320 µmol/g, 280 µmol/g and 240 µmol/g for $LSCF_{2h}$, LSCF and $LSCF_{6h}$, that is, the $LSCF_{2h}$ can exceed the fuel productivity achieved for commercial perovskite allowing more cycles per day and increasing by 30 % the H_2 produced.

Part of this work has been published in an Energy and Fuels journal.

Concentrated Solar energy storage at Ultra-high temperatures aNd Solid-state cONversion (SUNSON)

Participants: UPM (Spain), IDENER (Spain), NTNU (Norway), CIEMAT-PSA (Spain), IONVAC (Italy), HOLOSS (Portugal)

Contact: Thorsten Denk; tdenk@psa.es

Funding agency: European Commission, HORIZON-CL5-2021-D3-03.

Background: SUNSON proposes a breakthrough in the field of Solar to Heat to Power (S2H2P) generation. The SUNSON prototype will be designed, developed, and validated as a modular, ultra-compact and decentralised solution for dispatchable solar power generation with 10 times less volume than current concentration solar power (CSP) technologies that efficiently store solar energy as heat for electricity conversion on demand. It integrates, within a unique solution, novel approaches for solar radiation conversion technology (flux splitting optics for beam-down concentrator), ultra-high temperature thermal energy storage (TES) above 1200°C, and solid-state conversion technology based on thermophotovoltaic (TPV) generators.

Objectives: On the one hand, a flagship prototype of the proposed technology (SUNSON-Box) integrating optics for beam down CSP technology, high-temperature latent heat storage, and the TPV conversion will be demonstrated at TRL4. On the other hand, SUNSON entails the development of smart digital tools (SUNSON-Tool) for design, management and replicability purposes based on multidisciplinary optimisation. In addition, it will provide a set of features usable for dissemination, exploitation, and communication actions within and beyond the project.

Achievements in 2023: 2023 has been the first year of the project, therefore, mainly initial work was done. From CIEMAT-PSA's side, this included the definition of the requirements, determination of the interfaces, the design of the "solar-to-heat" component, and the simulation of the solar radiation. This included in particular the development of a beam-splitting device, needed to provide solar power to four separate absorber tubes, and the basic design of the system itself, whose design is crucially influenced by the geometry of the incoming solar beam. This included the assignment of basic dimensions for the three sub-components solar absorber, TES, and TPV.

The requirements include for all sub-components dimensions and volumes, modularity at large scale, and the protection of optically active cold parts from possible metal vapours. The contact surfaces between the solar absorbers and the TES on one side, and between the TES and the TPV on the other side, must be as large as possible to maximize heat transfer between the components. Furthermore, additional components like the insulation and the housing were defined.

The solar concentrator used for SUNSON will be the Solar Furnace SF-60 at the Plataforma Solar de Almería (Figure 33). The SF-60 has a 110 m², rectangular, parabolic concentrator with a focal length of 7.80 m.

Figure 33. The three PSA solar furnaces. The SF-60 is the one on the bottom right.

The simulation of the solar radiation was performed using ray tracing methods. About 85 % of the solar radiation from the concentrator will reach the focal plane. However, due to geometric restrictions of the receiver, only about half of this power will finally enter into the apertures (Figure 34). Nevertheless, this will provide still enough power for proper solar operation of the experiment.

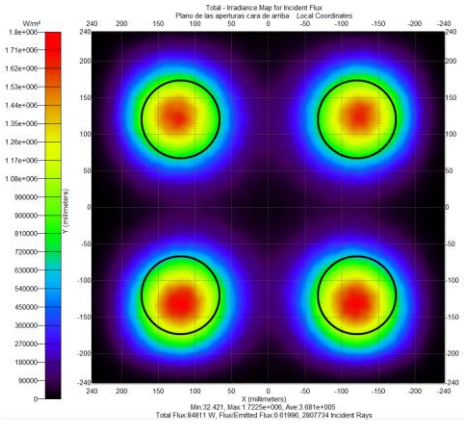


Figure 34. Solar flux distribution in the focal plane. The circles mark the apertures.

Bio-mimetic and phyto-technologies designad for low-cost purification and recycling of water, INDIA--H2O

Participants: UOB (coordinator), PDPU, CIEMAT, AQP, AQPA, IHE, LEITAT, GBP, MOD, BGU, DAV, ACWADAM, JU, OPC, CETIM, AU, CEERI

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, H2020-SC5-2018-2019-2020

Background: INDIA-H2O will develop, design, and demonstrate high-recovery, low-cost water treatment systems for saline groundwater and industrial wastewaters, focused on the arid state of Gujarat, with scarce surface water resources. Solutions will be demonstrated in small-scale rurally relevant low-cost systems, and a centre of excellence will be established in water treatment membrane technologies, design operation and monitoring.

Objectives: Develop novel batch-reverse osmosis technology for a 10-fold reduction in specific energy consumption with high water recovery (80 %) reducing operating costs. Develop forward osmosis at pilot scale for use in wastewater recovery applications including hybrid arrangements with reverse osmosis for further reduction in energy consumption. Develop business models, policy briefs and governance arrangements for adoption of the developed systems.

Achievements in 2023: CIEMAT's team coordinated the activities of WP4, focused on the development of ICT tools to enable remote monitoring, control and optimisation of the demonstration plants. CIEMAT also participated in the General Assembly and Consortium Meeting held in Gandhinagar in March, as well as in the Educational Workshop "Solar-powered high-recovery groundwater desalination with salt-tolerant crop cultivation for integrated brine management" that took place in Limassol (Cyprus) in May. Another project meeting was held online in September, with participation of the CIEMAT team.

Next generation water-smart management systems: large scale demonstrations far a circular economy and society, WATER-MINING

Participants: TU DELFT (coordinator), SEALEAU, KWR, EURECAT, NTUA, SELIS, CIEMAT, DECHEMA, BRUNEL, UNIABDN, WaterEurope, HEXION, UNIPA, WETSUS, UAB, JIN, ACSA, ICCS, RHDHV, KVT, LARNACA, NEMO, ACCIONA, USC, JIIS, ADA, REVOLVE, ENoLL, WEI,

LENNTECH, TITANSALT, ECSITE, SOFINTER, VSI, THERMOSSOL, NOURYON, FLOATING FARMS, MADISI

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, H2020-SC5-2019-2.

Background: The project aims to face the challenge of ensuring access to clean water and sanitation by developing innovative solutions for the sustainable use of alternative water sources, including urban and industrial wastewater and seawater desalination. Water is considered as a resource, a consumable and a durable good. To capture the full potential of the circular water economy, different strategies are proposed for each of these three water forms, involving six sector-specific case studies.

Objectives: CIEMAT is responsible of one of the two sea mining case studies, aiming to demonstrate that solar thermal desalination can improve the sustainability of current desalination technologies by reaching higher concentration towards zero liquid discharge, producing high quality salts and water suitable for agriculture. A living lab will also be created.

Achievements in 2023: Experimental campaigns were carried out at the NF pilot plant using real seawater, with the aim of comparing two different membranes (FILMTEC NF 270 and PRO XS3) in terms of performance indexes (recovery rate, specific electric consumption and rejection factor). Tests were also carried out at the MED unit using feed water without divalent ions at a wide range of operating conditions, covering high top brine temperatures to obtain new correlations of the heat transfer coefficients. A meeting of the Community of Practice was held in February to present the results obtained from the evaluation of different technical scenarios and the comparison of conventional desalination systems (RO) with thermal ones (MED) to achieve Zero Liquid Discharge. In addition, a newly developed Augmented Reality Tool was presented to the stakeholders, which allowed taking a tour through the facilities involved in Case Study 2 and discuss the results.

Intelligent water treatment technologies for water preservation combined with simultaneous energy production and material recovery in energy intensive industries, INTELWATT

Participants: NCSR (Coordinator), CNR, CNRS, PPC, WG, TH KOLN, UoB, POLITO, CUT, BIA Group, Fuelics, IHE DELFT, Studio Fieschi, TECHEDGE, ACSA, UJ, REDSTACK, CIEMAT, Nijhuis Water, NOKIA GREECE.

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, H2020-CE-SPIRE-01-07-09.

Background: The project will develop innovative, cost-efficient, smart separation technologies applied in energy- and water-intensive industries. Three case studies in electricity production, mining and electroplating facilities will demonstrate water preservation along with energy production and material recovery. The proposed solutions will also target zero liquid discharge while implementing maximum water reuse.

Objectives: CIEMAT participates in case study 2 (CS2) in Castellgali (Barcelona), where a pilot plant will be built. It will consist of an integrated reverse electrodialysis (RED) system and membrane distillation powered by solar energy to valorise a collector of brine from mining activities, with the aim of producing 3 MJ of electric energy per m^3 of treated brine (40 m^3/d) and 25 m^3/d of deionized water.

Achievements in 2023: A model of the solar-powered MD pilot plant has been evaluated at PSA prior to the final deployment in Castellgali. A complete DoE considering hot temperature, cold temperature and flow rate for a concentration of salts of the feed of 35 g/L was carried out. Efficiency, included thermal efficiency, permeate production and permeate quality, was studied. GOR (Gained Output Ratio), key performance indicator of thermal efficiency in thermal technologies, was in the range of 2.9 and 3.5, obtaining a maximum value of Recovery Ratio (RR) of 80 %. The permeate obtained was of an excellent quality with values lower than 10 μS/cm. Also, the efficiency was studied at a higher concentration of salts in feed solution, specifically 87.5 g/L and 115 g/L. The minimum GOR obtained was close to 2, although the RR was strongly affected with maximum values close to 30 % for 115 g/L. The quality of permeate was kept practically constant even at the highest salinity. The deliverable 3.12 ("Report on the operation of the lab scale MD/MCr process") was submitted in December, and subsequently approved by the Commission. One meeting of the Strategic Management Board was held online (2nd February) to monitor the progress of the project and two Consortium Meeting were held in May in Leverkusen (Germany) and in December in Turin (Italy).

Soluciones de refrigeración híbrida para ahorro de agua en aplicaciones solares térmicas (SOLHYCOOL)

Participants: CIEMAT

Contact: Patricia Palenzuela, patricia.palenzuela@psa.es

Lidia Roca, lidia.roca@psa.es

Funding agency: Agencia Estatal de Investigación-Proyectos de Generación del Conocimiento 2021 (Ref: PID2021-126452OA-I00)

Background: The need to reduce the water consumption in Solar Thermal Applications is increasing, especially because these applications have a larger market niche in areas with significant water shortages. This fact, together with the high water price, puts into question the cost-effectiveness of such applications and the sustainability of their implementation.

Objectives: The goal of this project is to advance in the hybrid cooling technology for its use in solar thermal applications at commercial scale, like Concentrating Solar Power plants and multi-effect distillation plants driven by solar energy and located inland, to subsequently achieve a reduction in water consumption in such applications. By using automatic control methods, an optimum management of the operation of the hybrid cooling systems in terms of water consumption should be achieved avoiding the penalty in the efficiency of the solar thermal applications in which the cooling systems are integrated thus, making the technology feasible from a technical and economical point of view.

Achievements in 2023: During this year, progress has been made with the modelling of the pilot hybrid cooler plant components. Specifically, models based on physical equations have been developed for the surface condenser (SC) and the Air Cooled Heat Exchanger (ACHE) (the latter in collaboration with University Miguel Hernández, Elche). In addition, the researcher Faisal Asfand (University of Huddersfield, UK) participated in a stay at PSA to carry out an experimental campaign with the Air Cooled Condenser (ACC) with the aim of modelling this component and making comparisons between conventional hybrid cooling systems (ACC and Wet Cooling Tower, WCT), only WCT and combined cooling (WCT and ACHE). In the case of the ACHE, the neural network-based model was also completed and validated. Based on all the pilot plant models obtained, the operation optimization strategy was designed for efficient resource management (water and electricity). The simulation results of this strategy were presented at the XLIV Jornadas de Automática 2023. Finally, at the end of the year, the first experimental tests of the hierarchical control system were carried out at the pilot plant. The preliminary results showed the potential of the technology to adapt to weather and operational changes.

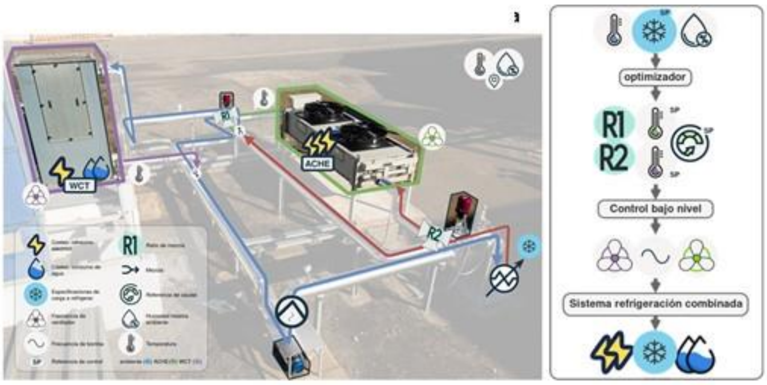


Figure 35. Visual example of optimal operation of the combined refrigeration pilot plant.

SOL-préndete: Didáctica y divulgación de la energía solar térmica de concentración con nuevas tecnologías de realidad aumentada y virtual

Participants: CIEMAT

Contact: Lidia Roca, lidia.roca@psa.es

Funding agency: Ministerio de Ciencia e Innovación, FECYT

Background: One of the aspects that the Spanish Strategy for Science, Technology and Innovation 2021-2027 (EECTI) considers as fundamental is the strengthening of the ICTS, being some of the objectives to communicate and disseminate to society the benefits derived from the ICTS.

Although PSA actively participates in several outreach activities and there is an external company (the *Centro de Visitantes*, CAV) in charge of managing the visits the facility receives (mainly from educational centres), it has been detected that a more active participation involving researchers is needed in order to make society aware of both the unique facilities and the research activities carried out at PSA.

Objectives: 1) Enrich education and outreach with digital tools, such as virtual and augmented reality; 2) bringing science closer to educational centres located in vulnerable neighbourhoods; 3) bringing research closer to pre-university students.

Achievements in 2022: During this year, the activities carried out by CIEMAT have been:

- Solar energy workshops in elementary schools including assembly on climate change and solar energy, experimentation with concentrating solar power, PSA virtual tour 360° with VR glasses.
- Outreach activities in secondary and high schools. Researchers, pre-doctoral and laboratory personnel from different research units have collaborated in developing workshops for high school students.

- In collaboration with the Institute of Communications and Computer Systems (ICCS) of Athens, an augmented reality application was tested at PSA facilities to explain in a fun and didactic way the circular use of water with solar thermal energy.
- Thanks to project funding, students from schools located in neighbourhoods defined as vulnerable were able to visit the PSA facilities and attend workshops on concentrating solar power.

European Twinning for research in Solar energy to (2) water (H2O) production and treatment technologies, SOL2H2O

Participants: UEVORA (Coordinator), CIEMAT, ITC, UNIPA.

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, HORIZON-WIDERA-2021-ACCESS-03.

Background: Gathering the experience of three first class partners (Universidad de Palermo, Instituto Tecnológico de Canarias and CIEMAT) with some of the most outstanding background and research infrastructure, at European level, in the development of Solar-driven water production and wastewater treatment technologies, Sol2H2O aims at supporting University of Évora in the development and establishment of high-level research in this field. Sol2H2O seeks to develop and implement a common scientific strategy, with a strong focus on an enhanced capacity building of researchers, going beyond purely scientific capacities and strengthening their research management and administration skills. With the goal of developing Solar-driven Water-Energy Nexus solutions, Sol2H2O aims at creating a reference European facility for the development and testing of Circular Solar-driven Water Production & Treatment technologies, enabling the development of renewable gas or agricultural economic activities upon exploitation of sustainable water resources.

Objectives: Engaging three top-class leading partners around a scientific strategy for stepping up and stimulating scientific excellence and innovation capacity on Solar-driven Water-Energy Nexus solutions, Sol2H2O aims at enhancing network with the Coordinator Widening partner, raising its research profile through the exploitation of their staff and infrastructural synergies in the establishment of a reference European facility for the development and testing of Circular Solar-driven Water Production & Treatment technologies. Specifically, a solar desalination system with zero liquid waste will be developed, and CIEMAT will contribute with membrane distillation technology.

Achievements in 2023: CIEMAT organized the second project meeting in Almería in July. The participation of the Unit was mostly on the definition of the Joint Research Activities related to zero liquid discharge desalination, namely the set-up of the pilot plant in Évora, which will consist of a PV-powered RO unit, a reactive crystallization unit for the recovery of magnesium and calcium hydroxides from RO brine, a solar-thermal powered membrane distillation unit for brine concentration and a solar evaporator for sodium chloride production. CIEMAT also participated in the definition of the first fast-track school to be held in 2024.

Sustainable membrane distillation for industrial water reuse and decentralised desalination approaching zero waste, MELODIZER

Participants: POLITO (Coordinator), CNR-ITM, Amapex, SolarSpring Gmbh, Inotex Spol. s.r.o., Deltamem AG, Athinaiiki Zythopiia Anonymos Etairia, Wings ITC, Aquabiotech, IRES, BlueTech Research Ltd, CIEMAT, Aalborg University, Warrang Hub S.p.A., Polymem, EnGits GmbH, Fraunhofer ISE, Municipality of Eilat (IL).

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, HORIZON-CL4-2022-RESILIENCE-01.

Background: MEloDIZER's overarching goal is to provide the needed step to transform membrane distillation (MD) and especially its core components, namely, membranes and membrane modules, into products for the benefit of industry and society. MEloDIZER implements high-performance membranes and modules in strategic applications of membrane distillation (MD), hence providing the decisive step for the success of MD.

Objectives: (i) creation of next-generation membranes and modules obtained with green and readily scalable approaches; (ii) rationally integrate the core innovative membrane and module components with energy and control systems that maximise their performance and enable the smart utilisation of renewable energy; (iii) demonstrate the performance of the next-gen membrane components in the overall system for the reduction of industrial waste streams, the reuse of water, the extraction of resources, and for the production of drinking water by decentralised and diffuse human-scale MD units; (iv) demonstrate the economic and environmental benefits associated with the implementation of the innovative membrane components and the resulting improved MD technology, also providing sustainable end-of-life management of membranes components and systems.

Achievements in 2023: CIEMAT's scheduled participation during the first year of the project is minimal. The Unit has participated in the first project meeting in Turin (January), together with the Steering Committee meeting and the second project meeting online (June). Also, in the collection of boundary conditions in preparation of Demos 2 and 3, the latter to be deployed at Plataforma Solar de Almería.

Photo-irradiation and Adsorption based Novel Innovations for Water-treatment, PANIWATER

Participants: Royal College of Surgeons in Ireland, National Environmental Engineering Research Institute, Universidad Rey Juan Carlos, Birla Institute of Technology & Science society-bits, National University of Ireland Maynooth, Society for Development Alternatives, INNOVA SRL, Kwality Photonics P Ltd, CIEMAT, Auroville Foundation/ASSA/Affordable Water Solutions, University of Cyprus, University of Ulster, Institute of Technology SLIGO-ITS, AGUASOIL, SRL, Universita de Salento, Buckinghamshire new University, Universidad de Santiago de Compostela, Society for Technology & Action for Rural Advancement.

Contact: Isabel Oller, isabel.oller@psa.es

Funding agency: European Commission, H2020-SC5-2018-1 (GA 820718)

Background: About 2.1 Billion people live without access to safe water sources. Contaminants of Emerging Concern (CECs) such as pharmaceuticals, personal care products, pesticides and nanoparticles are increasingly being detected in wastewater and in drinking water around the world, in addition to geogenic pollutants, pathogens, antibiotic resistant bacteria and antibiotic resistance genes. Water treatment systems that remove CECs and common contaminants from wastewater and drinking water are, therefore, urgently needed.

Objectives: PANIWATER will develop, deploy and validate in the field six prototypes for the removal of contaminants, including CECs, from wastewater and drinking water. The prototypes for wastewater treatment will consist of (i) a 20,000 L/day multifunctional oxidation reactor, (ii) a 10 L/day photoelectrochemical system, and (iii) a 100 L/day solar photolytic plant. The prototypes for drinking water treatment will consist of (iv) a 300 L/hour filtration, adsorption, and UVC LED system (v) a 20 L transparent jerry can for solar water disinfection, and (vi) a 2,000 L/day electrocoagulation, oxidation, and disinfection t system.

Achievements in 2023: The PANIWATER Steering Committee took place on the 17^{th}–18^{th} May, 2023 in Larnaca (Cyprus), conducted in hybrid mode. Preliminary results of disinfection byproducts (DBPs) generation in urban wastewater during ozonation treatment were presented. In September 2023, two members of Solar Treatment of Water Research Unit, Ilaria Berruti (post-doctoral researcher) and Kelly Castañeda Retavizca (pre-doctoral researcher), carried out a research stay at CSIR-National Environmental Engineering Research Institute (CSIR-NEERI) at Nagpur (India), under the supervision of Dr. Rita Dhodapkar. Experiments were conducted at the Bhandewadi Sewage Reuse Plant (Figure 36 (a)), in which the solar powered UV-C photolytic plant (SPP) has been installed. H_2O_2/UV-C process under continuous flow was evaluated for the simultaneous disinfection and decontamination of urban wastewater in the SPP plant. An optimal H_2O_2 concentration of 25 mg/L was selected for the satisfactory results on microcontaminant (MC) and pathogen removal in simulated wastewater (SWWTP) effluent, previously obtained at pilot plant scale at PSA. Samples were collected, extracted through solid phase extraction (SPE) and shipped to Spain for MCs analysis, performed by the research group of “Environmental Analysis” at the research centre CIESOL in the University of Almería.

Figure 36. (Left) Bhandewadi Sewage Treatment Plant (STP) used as demonstration site for the installation of the solar powered UV-C photolytic plant (SPP) (Right) picture of the SPP plant and the researchers involved in the experiment.

Moreover, multifunctional reactor (Figure 37) was also evaluated for the simultaneous disinfection and decontamination of urban wastewater. However, no significant difference was obtained for the total MCs between the inlet and the outlet. During the stay, the workshop on “Fostering Water Resilience through Community-led interventions ", organised by Development Alternatives (DA) (26th September 2023), was attended in TARAgram, Orcha, Bundelkhand (India).

On 13th December 2023, the workshop "Risk in Water Management" was celebrated in Rome (Italy), organized by INNOVA and Tecnopolo Tiburtino and the attendance was online.

The final general assembly meeting took place at CSIR-NEERI (Nagpur, India) and Kelly Castañeda Retavizca presented remotely the last results of the evaluation of the ozonation process for pathogens and microcontaminants removal in urban wastewater, assessing DBPs formation and the toxicity of the final effluent. For more details, visit the website.

Figure 37. (Left) Diagram and (Right) picture of the Multifunctional Reactor (MFR) installed at MES GE Air Force Sewage Treatment Plant (STP).

Towards increasing the sustainable treatment and reuse of wastewater in the Mediterranean Region, AQUACYCLE

Participants: CERTH, CIEMAT, IRM, HCWW, CERTE INGREF.

Contacts: Isabel Oller, isabel.oller@psa.es

Funding agency: European Commission, ENI CBC Mediterranean Sea Basin Programme 2014-2020. Thematic objective B.4, Priority G.4.1 (A_B.4.1_0027)

Background: Reclaimed municipal wastewater is considered a valuable non-conventional water resource. Especially in water scarce regions of the Mediterranean, the use of non-conventional water resources to complement or replace the use of fresh water resources provides multiple benefits in terms of supporting the local economy (e.g. in irrigated agriculture), improving the living standards of societies, reducing the pressures on natural resources and addressing climate change challenges.

Objectives: AQUACYCLE aspires to change the paradigm of viewing wastewater as an unsafe effluent, to that of an abundant all-year-round resource that has multiple uses. Our eco-innovative APOC technology, which combines anaerobic digestion (above, left), Photocatalytic Oxidation and a Constructed wetland, is set to capture the imagination of professionals and the public alike. Our hybrid set up not only augments water supply all year round but also produces biogas and fertilizer, setting a good example for the circular economy. It will create new, thriving biodiversity habitats as a visible climate change mitigation measure. In addition, but not least, it operates on solar energy, ensuring a low cost of operation.

Achievements in 2023: This project has officially ended the 31st of October, 2023 and the final meeting was held in Lebanon (Trípoli), from the 22nd to the 24th of June, 2023. The final meeting took place at the same time the final conference was organized by the partners from the University of Lebanon. Different municipalities were visited by all the partners of the projects onsite to spread the beneficial results obtained by the APOC system at DEMO scale in the municipal wastewater treatment plant of Blanca in Murcia (Spain). Along 2023 experiments at pilot plant scale in the facilities of the Solar Treatment of Wastewater Research Unit at PSA has been carried looking for the best operating conditions to be up-scaled in the DEMO site. In Figure 38 (a), it is shown a picture of the raceway pond reactor solar pilot plant used for tests and in Figure 38 (b), successful inactivation of *E. coli* contained in the actual effluent from the wetlands of the DEMO plant are shown when comparing solar light with the addition of H_2O_2 or PMS as oxidants. Successful results have been obtained in the simultaneous elimination of pathogens and microcontaminants mentioned in the Swiss law. For more details, visit the website.

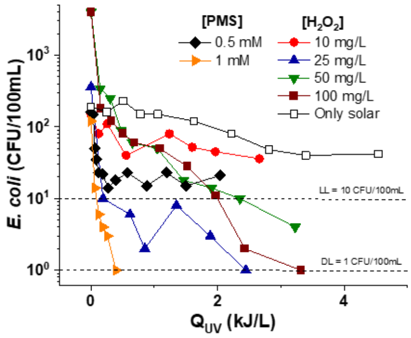



Figure 38. (Left) Solar raceway pond reactor pilot plant at PSA. (Right) *E. coli* inactivation through solar/H_2O_2 or solar/PMS photochemical processes at pilot plant scale.

ENERGy access and green transition collaboratively demonstrated in urban and rural areas in AfrICA (ENERGICA)

Participants: Technische Universitat Berlin, United Nations Environment Programme, Universite Abdou Moumouni de Niamey, Norges Teknisk-Naturvitenskapelige Universitet, Trialog, Finergreen Africa, Hudara GGMBH, Association Energy Generation, Ecowas Centre for Renewable Energy and Energy Efficiency, Fundacion Tekniker, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas, RISE Research Institutes of Sweden, The Waste Transformers Nederland, Freetown Waste Transformers, Ecosun innovations, Arenys Inox, Nanoe Madagascar, SADC Centre for Renewable Energy and Energy Efficiency, Association Africaine pour l electrification rurale (cluber), East African Centre of Excellence for Renewable Energy and Efficiency, The Kenya Power and Lighting Company, Odit-e, Hive Power, Opibus, Stima sas, Untapped Water Limited, Jokosun, Euroquality.

Contact: M. Inmaculada Polo, inmaculada.polo@psa.es

Isabel Oller, isabel.oller@psa.es

Funding agency: Horizon 2020 - Research and Innovation Framework Programme (H2020-LC-GD-2020-1)

Background: Green transition is at the forefront of political and societal ambitions for more sustainable economies, industries, and societies. The means to reach green transition usually consider

Renewable Energy Technologies as the key towards CO2 emission reduction and decarbonisation of the electricity grid. However, sustainable uptake of RETs can only be ensured through the effective implication of stakeholders all along the value chain and throughout the development of tailored technologies. In this context, the ENERGICA project focuses on a wider scope of activities than strictly technical, providing sustainable technologies.

Objectives: The main objective of ENERGICA is to demonstrate the efficient implementation of renewable energy technologies to match local contexts' needs. To do so, three different demonstration sites will rely upon local Energy Transition Boards, which will manage community-scale Integrated Community Energy Systems. Based on these methodologies and respective innovative technologies, ENERGICA will demonstrate positive social, environmental, technical, and economic impacts from the high-energy efficiency and low carbon emission renewable energy technologies. The main role of CIEMAT in this project is related to the implementation of water treatment solar-based solutions in two different countries: Madagascar and Sierra Leona.

Achievements in 2023: During this year, the TiO_2 photocatalytic material immobilized on a stainless steel substrate was selected as the most promising approach for implementation in pilot systems. The substrate was prepared accordingly and tested at pilot scale in a multi-step cascade reactor of 5 L total capacity and 0.5 m^2 of surface (Figure 39 left). The assessment of the water disinfection and decontamination of the photocatalytic reactor showed a good performance for the treatment of different water sources (demineralized water, well water and actual secondary effluent from an urban wastewater treatment plant. The targets monitored were Escherichia coli (at 106 CFU/mL initial concentration) as a model of bacterial indicator and sulfamethoxazole (SMX, Antibiotic), Trimethoprim (TMP, Antibiotic) and imidacloprid (IMD, Insecticide) as models of contaminants of emerging concern (at 100 µg/L of initial concentration). Besides, based on this type of flat reactor a pilot plant of 50 L total capacity and 4 m^2 of surface was developed and built by ARENYS (a partner of the project) incorporating the stainless-steel substrate coated with TiO_2 developed by TEKNIKER (a partner of the project) and tested at CIEMAT facilities for corroborating the water treatment performance (Figure 39 right). This pilot plant will be shipped to Sierra Leone (Waterloo) to be tested in the field for validation purposes and, in addition, the supply of electricity for running will be brought thanks to its coupling with a biodigester plant.

Figure 39. Multistep cascade reactors developed and tested in ENERGICA project for water treatment: (left) pilot plant of 5 L capacity and (right) pilot plant of 50 L containing TiO_2 immobilized in stainless steel stairs.

Urban wastewater reclamation by Novel mAterials and adVanced solar technologies: assessment of new treatment quAlity Indicators, NAVIA

Participants: Universidad de Almería, CIEMAT (Plataforma Solar de Almería), Universidad Politécnica de Valencia.

Contact: Isabel Oller, isabel.oller@psa.es

M. Inmaculada Polo, inmaculada.polo@psa.es

Funding agency: Ministerio de Ciencia e Innovación. Proyectos de I+D+I «Retos Colaboración» 2019 Reference: PID2019-110441RB)

Background: Wastewater reclamation is currently a reality with many advantages for the environment and human well-being. Nevertheless, it´s still requiring investigating practical aspects to enhance the correct management and implementation of the different novel technologies currently available (such as those using renewable sources of energy, like solar energy), with the purpose of selecting the best treatment technologies based on high efficiency, low energy, low cost and low or null chemical and microbiological risks.

Objectives: The NAVIA project aims to develop new technologies based on solar advanced oxidation processes for urban wastewater (UWW) reclamation. The following research areas will be covered along the project execution: synthesis of novel photocatalysts active under natural solar radiation, kinetics studies (modelling mechanistic degradation pathways) of new microbial pathogens (coliphages and antibiotic-resistant bacteria and genes (ARB and ARG)) and organic microcontaminants (OMCs) as treatment quality indicators at laboratory and pilot scale, the assessment of solar AOPs at pilot plant scale in batch and continuous flow mode and the development of a making-tool system based on water quality monitoring for UWW reclamation.

Achievements in 2023: In December 2023, the project was successfully finalised, completing all the project's technical objectives and promoting the visualisation of our activities in several national and international events. Regarding scientific outputs, the capability of different solar photocatalytic and photochemical treatments, including the novel photocatalytic material developed in this project, photo-Fenton with EDDHA as an iron chelate, H_2O_2 alone, peroxymonosulfate (PMS) and persulfate (PS) alone, for actual secondary effluents reclamation was assessed at laboratory and pilot plant scale (in batch) using a solar Compound Parabolic Collector (CPC) and a new reactor based on low-cost manufactured mirrors, so-called U-trough mirror reactor (Figure 40). Many water emerging targets have been monitored, including contaminants of emerging concern (trimethoprim, Sulfamethoxazole and pyrimethanil spiked), pathogens indicators (E. coli, coliforms and coliphages), and antibiotic-resistant genes (ARGs) (16S RNA, *Sul1, intl1, qnrS Tet(E), blaTEM*), allow us to identify key targets in water treatments and degradation mechanisms and interactions during the treatments investigated.

Regarding dissemination activities outputs, 18 scientific papers in indexed journals, 2 papers in technical/divulgation journals, 3 papers in conference proceedings and 21 contributions to national and international conferences have been obtained during the entire execution of the project.

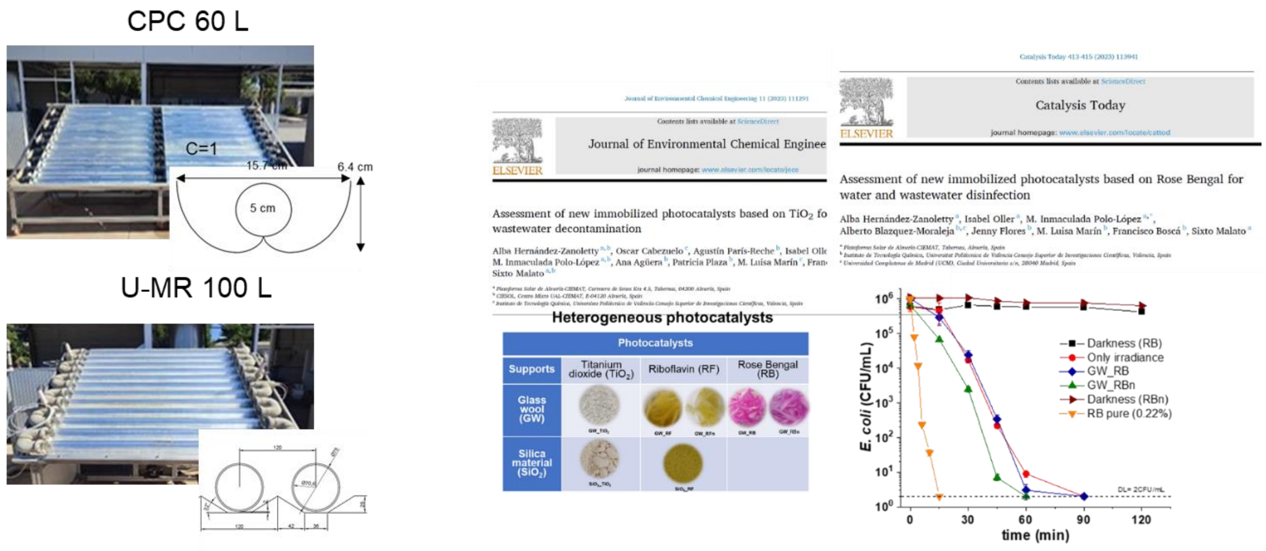


Figure 40. Left: Images of the solar CPC photo-reactor and U-trough mirror reactor used for UWW reclamation by solar photochemical treatment at pilot plant scale located at CIEMAT facilities. Right: examples of dissemination papers.

Solar catalysis for a renewable energy future, SOLFUTURE

Participants: Fundación IMDEA Energia, Instituto de Ciencia de Materiales de Madrid-CSIC, Fundacio institut catala D'investigacio quimica (ICIQ), PSA-CIEMAT, APRIA Systems, S.L., Compañia española de petroleos S.A. (CEPSA).

Contact: Sixto Malato, sixto.malato@psa.es

Funding agency: Proyectos de I+D+i en líneas estratégicas, en colaboración público-privada, del programa estatal de I+D+i orientada a los retos de la sociedad (Ref. PLEC2021- 007906).

Background: The implementation of new systems to produce sustainable fuels and chemicals by the integration of renewable energy sources is one of the major challenges for our society. SOLFuture proposes two new concepts of photoreactor prototypes for the generation of value-added products and fuels (H_2, CH_4, C_2+, NH_3 and chemical platforms).

Objectives: A combined strategy based on two complementary approaches has been designed: (i) the development of photocatalytic technologies based on the production of H_2 from waste water and biomass as reductant in liquid and gas phase using hybrid organic/inorganic heterojunctions based on metal oxides and conjugated porous polymers; (ii) a photo(electro)chemical cell formed by organic/inorganic heterojunctions in their thin-film form, and a PV-EC photoanode, made by the coupling of an organic solar cell and a highly active porous anode decorated with co-catalyst nanoparticles.

Achievements in 2023: The main goal of PSA was to explore pilot-scale combination of H_2 generation with simultaneous water disinfection or decontamination. Cu and Ni oxides are two of the most efficient low-cost transition metal oxide catalysts. Ternary photocatalyst studies based on CuO-NiO-TiO_2 for photocatalytic applications is not unusual but solar pilot plant scale results are still necessary.

The results of 2023 present novel insights in determining what proportions of the different oxides in the ternary mixture can give better results, as well as a detailed study of the metals leaching into water. All this carried out in a solar pilot plant, handling relevant volume of water in anoxic conditions, which can help better understanding the possible application of this technology to the production of hydrogen. The best hydrogen production was attained with a proportion of 10:1 of TiO_2:MeO, that corresponds to a total metal concentration of 7.2 wt %, being Cu and Ni in the same proportion.

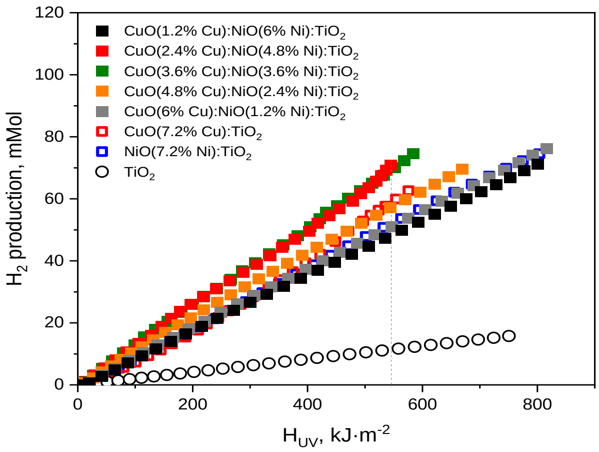


Figure 41. Photocatalytic H_2 generation using CuO-NiO-TiO_2 (single TiO_2, binary and ternary) systems with total metal of 7.2 wt %. Reaction conditions: photocatalyst concentration 100 mg L^{-1}, glycerol = 0.075 M.

Revalorisation of wastewater through technologies that improve the water-renewable energy-food nexus, AQUAENAGRI

Participants: Universitat Politècnica de Valencia, Universidad Rey Juan Carlos, Plataforma Solar de Almería

Contact: Sixto Malato, sixto.malato@psa.es

Isabel Oller, isabel.oller@psa.es

Funding agency: Proyectos de Generación de Conocimiento en el marco del Programa Estatal para Impulsar la Investigación Científico-Técnica y su Transferencia, del Plan Estatal de Investigación Científica, Técnica y de Innovación, 2021-2023 (Ref. PID2021- 126400OB-C33)

Background: Improve the quality of the effluents involved in aquaponics, as well as regenerated water to be used as an influent. For this purpose, it is necessary to monitor micropollutants, heavy metals, microplastics, antibiotics and pesticides removal, the inactivation of antibiotic-resistant bacteria (ARB) and the effect on the antibiotic-resistant genes (ARG).

Objectives: Investigating the advanced oxidation process for polishing regenerated water from MWWTP to be used in aquaculture, solar photocatalytic hydrogen production using the organic content of WWTP, aquaculture and hydroponic effluents as a sacrificial agent, evaluation of the applied processes for pathogens elimination in aquaculture and hydroponic inlets, development of materials with high photocatalytic performance under solar radiation.

Achievements in 2023: The first coordination meeting of AQUAENAGRI project was organized by The Solar Treatment of Water Research Unit and took place in Cartagena (Murcia) on March 23th-24th 2023. The main tasks considered in this meeting were related to establishing the main composition of the water matrices intended to be treated (aquaculture and hydroponic effluents) and performing a preselection of the microbiological and chemical contaminants of each water matrix according to literature data. To progress in this task, the members of the research unit visited two fish farms located in the province of Granada in the following months to obtain data about the water composition and contaminants through the analysis of real aquaculture effluents. With the real data obtained, a synthetic recipe for an aquaculture effluent was proposed in the second coordination meeting which took place in Toledo on September 6th-7th 2023. The proposal also includes the chemical and microbiological contaminants, as well as the techniques for their monitoring. From this meeting to the end of the year, the solar treatment of water research unit at PSA, worked to establish the quantification method for chemical contaminants monitoring as well as in the assessment of two photochemical treatments proposed: solar photo-Fenton-like process at neutral pH using a commercial micronutrient as iron source as well as in solar photocatalytic hydrogen production using wastewater organic content as a sacrificial agent.

Towards Digital Transition in Solar Chemistry: Photoreactors, SOLARCHEM 5.0

Participants: IMDEA Energy, ALBA-CELLS, Instituto de Ciencia de Materiales de Madrid -CSIC, Institute of Computational Chemistry and Catalysis - Univesity of Girona, Instituto de Química Física "Rocasolano"- CSIC, PSA-CIEMAT, Instituto de Ciencia de Materiales de Sevilla -CSIC, Universidad Politécnica de Madrid, Universidad Rey Juan Carlos

Contact: Sixto Malato, sixto.malato@psa.es

Diego Alarcón, diego.alarcon@psa.es

Funding agency: Proyectos orientados a la transición ecológica y a la transición digital, programa estatal para impulsar la investigación científico-técnica y su transferencia, del plan estatal de investigación científica, técnica y de innovación 2021-2023 (Ref. TED2021-130173B-C43)

Background: EU is immersed in an unprecedented ecological transition based on the increase of efforts to develop sustainable technologies aiming to achieve a climate neutrality towards a low-carbon economy. The development of technologies, Earth-abundant resources and wastes as raw materials, entail a breakthrough in the chemistry, energy production and storage industries. Moreover, the EU is also embarking on a transition towards digital leadership being a priority to place the research and innovation in Artificial Intelligence at the service of a sustainable industry.

Objectives: SolarChem 5.0 aims to develop Artificial Intelligence powered Solar photoelectrochemical technologies based on hybrid bio-based materials and efficient reactors that use Earth-abundant resources and waste as raw materials. R&D efforts are focused on: (1) Development of novel chemically stable hybrid photoelectrodes; (2) Highly active, selective, and long duration bio-based catalysts; (3) Optimized reactor design and upscaling; (4) Diversification of the considered feedstock; (5) Implementation of AI and Machine learning tools to achieve the development of autonomous Solar chemistry technologies; and (6) To advance on an appropriate standardized methodology and Adoption of Open Science practices

Achievements in 2023: Photocatalytic performance of the TiO_2-CuO mixture, for solar to hydrogen conversion at pilot plant scale under different irradiation conditions focusing on high-temperature pretreatment of the catalyst mixture to try to improve TiO_2 doping with copper. P25-TiO_2 and commercial CuO were used with different amounts of Cu (2 wt % or 7 wt % Cu) calcined at 200-400 °C during several hours. The photocatalyst prepared after heating at 200°C for 3 hours and with 7 wt % Cu, resulted in higher hydrogen production than under the other heating conditions and results were better (5-10 %)

than the untreated catalysts. CO_2 production and formation of formate and glycolate clearly demonstrated glycerol photoreforming, with an important fraction of lixiviated copper and copper deposition on the reactor walls. This critical drawback must be considered for large-scale applications.

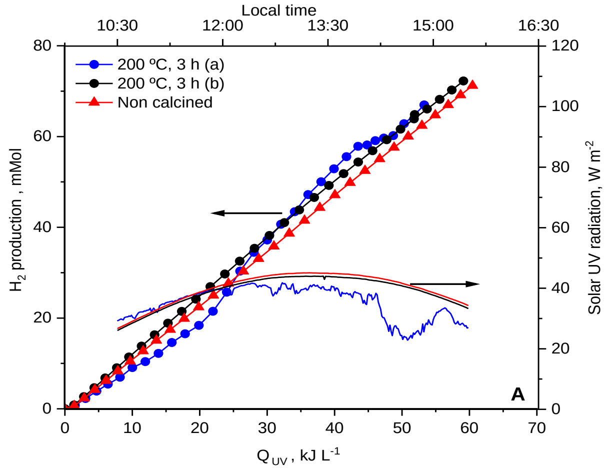


Figure 42. Photocatalytic H_2 generation with conventional and heated photocatalyst (7 wt % Cu), during different 5 h tests: (a) a partially cloudy day, (b) a mostly sunny day. Reaction conditions: CuO-TiO_2 = 0.1 g L-1, Glycerol = 0.075 M.

Towards the improvement of the Urban Water Cycle Resilience: Assessment of Solar Water Reclamation Technologies focused on Disinfection by-products, Antibiotic Resistant bacteria and Genes elimination, DIGIT4WATER

Participants: CIEMAT-PSA (coordinators), UPM and CIMNE

Contact: Isabel Oller Alberola, isabel.oller@psa.es

M Inmaculada Polo López, mpolo@psa.es

Funding agency: Proyectos orientados a la transición ecológica y a la transición digital, programa estatal para impulsar la investigación científico-técnica y su transferencia, del plan estatal de investigación científica, técnica y de innovación 2021-2023 (Ref. TED2021-129969B-C31)

Background: Treated wastewater reuse can be considered a reliable water supply, quite independent from seasonal drought and weather variability and able to cover peaks of water demand, especially in water-scarce areas. Wastewater reuse for irrigation in agriculture is by far the most established end-use for reclaimed water in low-income countries as well as in arid and semi-arid ones. In countries of higher income level, concerns tend to shift from microbial risk to organic microcontaminants (OMCs) such as pesticides, pharmaceuticals, illicit drugs, synthetic and natural hormones, personal care products, disinfection by-products (DBPs), and Antibiotic Resistance Elements (i.e. antibiotic resistant bacteria and genes (ARB&ARGs)). Conventional treatment trains in Municipal Wastewater Treatment Plants (MWWTPs) are poorly effective to remove OMCs, constituting a particular concern when effluents are reused for crop irrigation. In parallel, digitalization of the water sector requires adopting a common data platform for data valorisation and information sharing, supporting smart quantitative water management and conservation through monitoring, and improving transparency and data sharing within the water sector and the public to promote multidisciplinary cooperation.

Objectives: The DIGIT4WATER project addresses the improvement of the resilience and digitalization aspects in municipal water management and treatment systems, and the circular economy concept including the potential deployment of renewable energies, in order to contribute to the environmental objectives of the ecological and digital transitions collected in the EU Regulation 2020/852 of the European Parliament and the Council. DIGIT4WATER will cover various recognized environmental challenges: adaptation to climate change; sustainable use and protection of water and marine resources; and transition to a circular economy.

Achievements in 2023: The kick off meeting took place in Almeria on the 2nd of February 2023. After this meeting, the collection of input (physicochemical characteristics of water matrix, oxidant concentration and radiation dose) and output data (bacteria inactivation) was performed, considering UVC and solar based advanced tertiary treatments, carried out at laboratory and pilot scale. Data were provided to CIMNE, responsible for the creation of digital tools, based on Machine Learning models, to predict removal levels of target parameters. The second meeting was held online on the 4th of October to present the main progresses obtained. The key performance variables for feeding the machine learning models were defined, including different criteria for: (i) *E. coli* (≤ 10 CFU/100 mL), (ii) MCs (> 50 % of degradation of the sum of all contaminants in the secondary effluent), (iii) DBPs (absence or > 90 % of elimination) and (iv) monitoring of the higher variable physicochemical data (turbidity and total suspended solids).

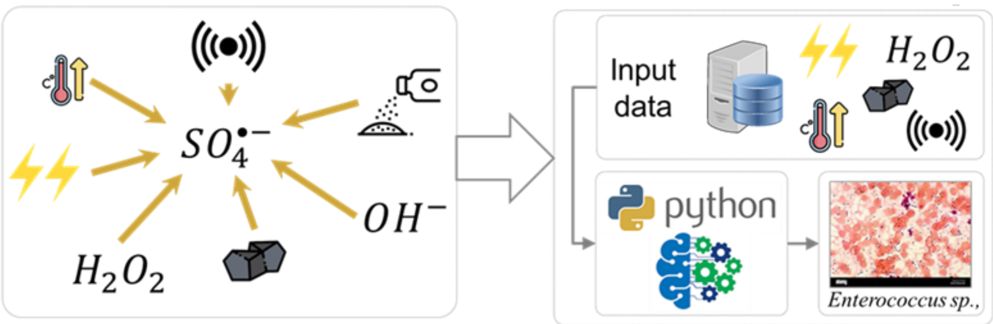


Figure 43. Diagram of how to apply machine-learning tools on the photochemical processes applied to the inactivation of Enterococcus sp. to be replicated for E. coli.

Monitoring and diagnosis of the purification, purification and regeneration of urban water in regions with water stress and development of alternative sustainable treatments to chlorination, MODITRAGUA

Participants: University of Almería (CIESOL), CIEMAT-PSA, Council of the Province of Almería.

Contact: Isabel Oller, isabel.oller@psa.es

Funding agency: Convocatoria de subvenciones a «proyectos de I+D+i» universidades y entidades públicas de investigación (BOJA n.º239, de 15 de diciembre de 2021). Proyectos de investigación orientados a los retos de la sociedad andaluza (Ref. ProyExcel_00585)

Background: Climate change poses a clear threat to humanity and water is the key factor on which achieving true sustainable development will depend. Spain is one of the most vulnerable European countries to the impact of climate change as it suffers from high levels of water stress. 20 % of its territory can already be considered desert and between 75 % and 8 0 % is at risk of desertification. In addition, very important activities for our economy, such as agriculture or tourism, are intensive in water consumption.

Objectives: The general objective of MODITRAGUA is to propose solutions to face the challenges of the urban water cycle, which would make building more resilient cities through sustainable management of water resources possible. The specific objectives that will be addressed in MODITRAGUA are: (i) Definition of the sampling and monitoring plan in different ERAR and PAAP in the province of Almería; (ii) Analysis of physical-chemical parameters and identification of contaminants: massive screening of contaminants of emerging concern (CEC) and disinfection by-products (chlorination) (DBP); (iii) Analysis of microbiological parameters: bacteria and viruses considered in the new regulation of the European Parliament on reuse and the draft of the drinking water supply regulations; (iv) Proposal and evaluation of alternative treatments to chlorination in ERAR and PAAP; (v) Analysis of the monitoring plan and development of a Computer Decision Tool based on machine learning techniques. The project has just begun in December, 2022.

Achievements in 2023: The first coordination meeting of MODITRAGUA project took place in the University of Almería on February 10th 2023. The organization and the definition of the monitoring plan for wastewater regeneration and drinking water treatment plants were established in this meeting. After that, four sampling campaigns that included 6 wastewater regeneration plants and 10 drinking water treatment plants located throughout the entire province of Almeria were carried out during 2023. The data obtained were analyzed in terms of compliance with the most restrictive requirements of the recent EU regulation for water reuse (EU 2020/741) and the EU Directive on the water quality intended for human consumption (2020/2184). Second coordination meeting took place in CIESOL (University of Almería) the 20th of December, 2023, in which the following conclusions were highlighted from the sampling campaign: all the regenerated wastewaters are not fulfilling in some sampling points on turbidity and suspended solids parameters, though all comply with the required quality standard on the regulated *E. coli* inactivation limit.

Advanced tertiary treatments based on combined reduction/oxidation processes and novel photocatalytic materials applied to the simultaneous disinfection and removal of persistent and mobile compounds in urban wastewater, ANDROMEDA

Participants: Universidad de Almería, CIEMAT (Plataforma Solar de Almería)

Contact: M. Inmaculada Polo, inmaculada.polo@psa.es

Isabel Oller, isabel.oller@psa.es

Funding agency: Ministerio de Ciencia e Innovación. Plan Estatal de Investigación Científica, Técnica y de Innovación 2021-2023. Referencia PID2022-140875OB-C32

Background: Despite the efforts carried out to intensify the reclamation and reuse of actual urban wastewater, still important drawbacks need special attention to properly address the challenge of mitigating and avoiding growing pollution of water, with special emphasis on wastewater reclamation for its reuse in agricultural irrigation to comply with EU regulation 2020/741 and paying special interest in chemical contaminants such as Persistent and mobile organic compounds (PMOCs). PMOCs is a group of pollutants that has attracted the attention of the scientific community due to their persistence in the environment, presence in a wide diversity of ecosystems, and they are highly recalcitrant pollutants difficult to remove by conventional water treatments. Therefore, in this context, the scientific community should investigate efficient and affordable solutions to minimize the chemical and microbiological risks associated with reusing wastewater for irrigation in agriculture.

Objectives: The main objective of ANDROMEDA is to develop efficient strategies for urban wastewater reclamation investigating the sequential treatment or combination of new photocatalytic reduction/oxidation advanced tertiary processes and their implementation at a pilot scale. ANDROMEDA will cover different areas including the assessment of novel photocatalysts active under natural solar radiation, kinetic studies (modelling of the mechanistic degradation pathways) at laboratory and pilot scale, techno-economic and environmental risk assessment of advanced reduction/oxidation processes compared to enhanced conventional ozonation treatment, and the design and assessment of new photo-reactors (solar and LED). The project aspires to introduce novel aspects of the development of new photocatalytic systems to be used under reductive and/or oxidative conditions, the assessment of regulated water quality indicators (*Escherichia coli*, coliphages and sores of *Clostridium* spp/sulfate-reduction bacteria) and also the removal of non-regulated and challenging organic microcontaminants (OMC), such as persistent and mobile organic compounds (PMOCs), and antibiotic-resistant bacteria (ARB) and genes (ARG).

Achievements in 2023: The project started in September of 2023, with the kick-off meeting held in Universidad de Almeria on 21st December 2023. During the meeting, the key activities for the correct execution of the project were discussed according to the WPs and tasks described in the project (Figure 44). In this line, a list of potential OMCs and PFAS has been already selected as models of a mix of contaminants to be used as targets for monitoring during the assessment of process/treatment performances. In addition, disinfection and decontamination assays in an ozonation pilot plant located at CIEMAT-PSA facilities have been initiated as the reference of a commonly employed tertiary treatment in UWWTPs. Further activities will include the coupling of this ozonation pilot plant with a solar CPC reactor.

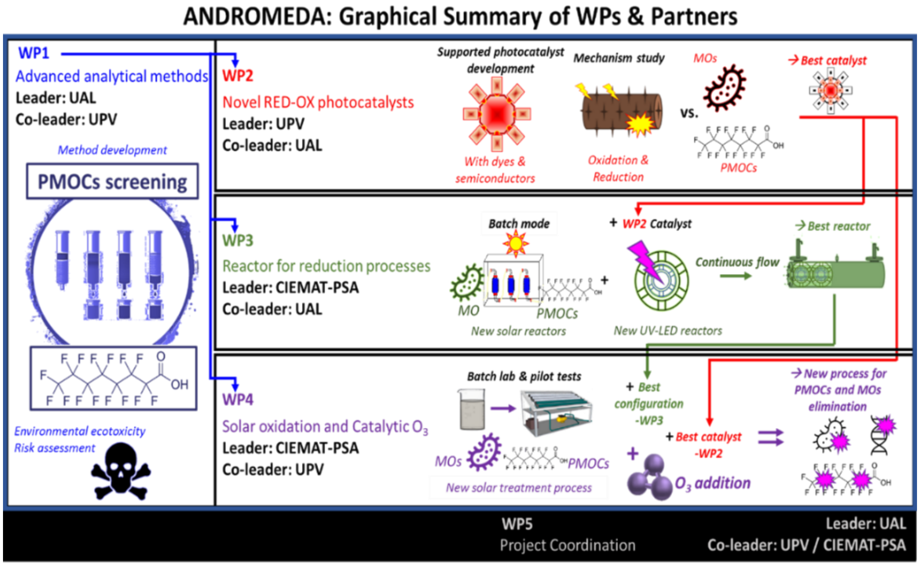


Figure 44. Graphical abstract summarizing WPs and interconnections of ANDROMEDA partners.

Green valorization of CO_2 and Nitrogen compounds for making fertilizers, CONFETI

Participants: UAB (Spain), IMB-CNM-CSIC (Spain), Univ. Antwerpen (Belgium), IMRCP UMR-CNRS (France), Univ. Pisa (Italy), Arkyne tech. (Spain), CIEMAT-PSA (Spain), Iowa State (USA).

Contact: Sixto Malato, sixto.malato@psa.es

Alba Ruiz, alba.ruiz@psa.es

Fundng agency: HORIZON-EIC-2022-PATHFINDERCHALLENGES-01 (EIC Pathfinder Challenges 2022)

Background: The conventional synthetic routes to produce fertilizers (e.g. urea) by the chemical agricultural industry rely on the consumption of large quantities of fossil fuels, the release of an important share of CO_2 to the atmosphere, the release of large concentrations of nitrogen in natural bodies of water that causes eutrophication. Because of their high energy demand and environmental and socio-economic impacts, these methods are not in line with the current European directives of the EU Green Deal and the Zero-pollution action plan adopted by the European Commission (EC) in May 2021, which recommend the transition towards a more sustainable and cost effective agricultural model. Among other compounds, urea is the most popular nitrogenised fertilizer with approximately 180−200 million metric tons of global demand per year worldwide. The search for alternative and environmentally friendly ways to produce and deliver fertilizer is a technological topic of utmost importance.

Objectives: CONFETI aims at developing a lab-scale validated autonomous technology to capture and photo-electrochemically convert CO_2 and N_2 directly from air or flue gases to urea, which will be produced and delivered in situ in the agricultural fields. The technology will be powered through renewable energy sources by combining soil microbial fuel cells (SMFC) and solar panels. The final proof-of-concept system for urea production will result from the combination of three pocket-scale reactors that will pursue the following goals: 1) an electrochemical reactor for capture, storage and transformation of CO_2 and N_2 into urea; 2) A soil fuel cell capable to produce energy from the microorganisms present in the roots of plants to perform the electrochemical reactions; 3) A photochemical cell devoted to the reduction of nitrate (NO_3^-) to ammonia and/or urea based on a sunlight-driven photocatalytic technology.

Achievements in 2023: This project officially begun on 1st November 2023 and it is organised in seven WP, including Coordination, Management & Interdisciplinary Design, CO_2/N Capture & Activation, Electrochemical CO2/N2 Valorisation, Photochemical CO_2/NO_3 Valorisation (coordinated by CIEMAT-PSA), Self-powered fertilization system, Environmental & Economic Impact & System Validation, Dissemination, Communication & Exploitation. The self-powered fertilizing system developed in CONFETI will significantly surpass the performance of most advanced current technologies in term of sustainability and cost-effectiveness. Particularly remarkable is CONFETI's commitment to replace conventional electrolytes and catalyst for greener alternatives not based on critical raw materials, such as smart polymer electroresponsive materials with low-energy regeneration requirements as electrolytes, and novel formulations of catalysts based on N-doped carbon materials, NiP or FeP. Additionally, the CONFETI technology will be the first fully self-sustainable system available for urea production and in-situ fertilization, where both the chemical reagents and the energy are directly extracted from the natural environment.

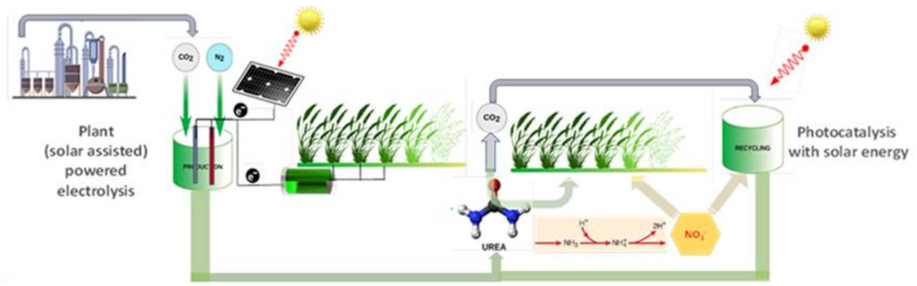


Figure 45. CONFETI approach toward lab-scale production of urea from N (N_2 and/or NO_3^-) and CO_2.

From solar energy to fuel: A holistic artificial photosynthesis platform for the production of viable solar fuels, REFINE

Participants: University of Oslo (Norway), RWTH Aachen (Germany), Aristotelio Panepistimio Thessalonikis (Greece), CIEMAT-Plataforma Solar de Almería (Spain).

Contact: Isabel Oller, isabel.oller@psa.es

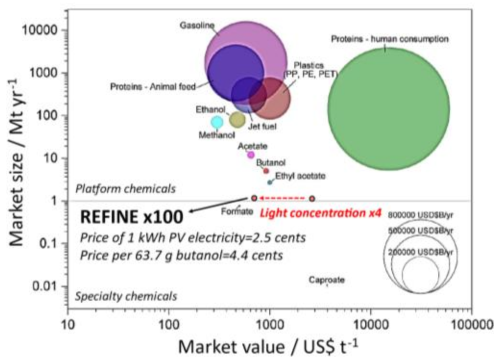
Sixto Malato, sixto.malato@psa.es

Funding agency: European Commission: HORIZON-CL5-2022-D3-03-03. GA 101122323.

Background: Energy, water, and food are the three fundamental requirements that move and progress our societies. Energy and water are necessary to produce food, and both have been exploited inappropriately (take-make-dispose economy model) since the industrial revolution, leading to severe climate changes and political tensions around the globe. Apart from international energy conflicts as well as social and political tensions, the atmospheric CO_2 level is expected to increase to 500 ppm by 2045 leading to ice melting and an increase in the sea level of several meters. This will culminate in the estimated extinction of 24 % of plants and animal species. To impede the impact our energy-intensive societies have on the climate and on the environment, we need to defossilise the energy system, electrify it as much as possible and finally store energy in "molecules".

Objectives: REFINE develops and demonstrates a system of artificial photosynthesis by combining both dark and light-dependent reactions for the direct production of high energy density and essential chemicals, such as alcohols. To achieve this, a direct hydrogen storage into hydrocarbons through CO_2 capture and transformation in an advanced bio-refining system is proposed. In this, hydrogen produced by water photoelectrolysis is combined with captured CO_2 and directly fed to biocultures that selectively produce isopropanol and butanol as high-energy solar fuels, and the only energy input to drive this radical technological system is sunlight.

Achievements in 2023: The kick off meeting of this project was held in the University of Oslo (Norway) from the 13th to the 14th of December, 2023. Along these two days of meeting, the partners presented themselves and their main roles in the project and initial discussions were carried out regarding the next six months activities that should be covered within the project. It was also decided that next coordination meeting will take place in Glasgow by the end of May 2024. In Figure 46, a summary of the position that REFINE products would have in the chemical market, as well as diagram of the renewable pathway to produce butanol and the new one that REFINE would introduce.



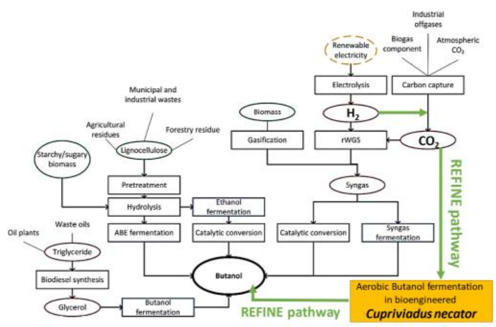


Figure 46. Left: A summary of the chemical market where each circle represents the total market capitalisation. Right: Renewable pathways to produce butanol through various feedstock options and he new pathway introduced in REFINE.

Human footprint on water from remote cold areas to the tropical belt. INtegrated Approach TO secure water QUAlity by exploiting Sustainable processes, IN2AQUAS

Participants: University of Torino (Italy), Universita Degli Studi del Piemonte Orientale Amedeo Avogadro (Italy), Aalborg University (Denmark), Clermont Auvergne INP (France), CIEMAT-Plataforma Solar de Almería (Spain), Panepistimio Ioanninon (Greece), Universidad Politécnica de Valencia-Campus de Alcoy (Spain), Alma Mater Studioum - Universita Di Bologna (Italy), ULTRAAQUA A.S (Denmark), INERIS (France), Institutt for Energiteknikk (Norway).

Contact: Isabel Oller, isabel.oller@psa.es

Sixto Malato, sixto.malato@psa.es

M. Inmaculada Polo, inmaculada.polo@psa.es

Funding agency: European Commission: HORIZON-MSCA-2022-DN-01-01. GA 101119555.

Background: IN2AQUAS is a multidisciplinary and interdisciplinary network aimed to address goals 2 (zero hunger) and 6 (clean water and sanitation) of the UN 2030 Agenda for Sustainable Development, as the mitigation of water and food crisis is a critical challenge for the 21st century. Water stressors are now becoming a primary concern in the management and protection of natural resources pressed by the growing population and the spreading industrialization. New strategies are required for unravel the multiple routes through which pollutants and micropollutants are conveyed to the environment, that may also allow the search for new contaminants that could pose a hazard in the future, and the deployment of targeted actions to treat contaminated water. Besides, environmental sustainability is mandatory and green technologies - in line with the principles of the circular economy - should guarantee a microbiologically and chemically safe water aiming at a zero-waste discharge.

Objectives: IN2AQUAS will train 15 doctoral candidates (DCs) for facing the complex challenge of envisaging the pollutant impact on the environment and of tailoring the proper treatments for the production of safe and clean water -in extreme environments- using green approaches through high quality research, training, management and innovation. This goal will be attained via a structured training through-research program, consisting of original individual research projects and education on technical and transferable skills. Experts from 10-degree awarding universities, 4 national research centers, 1 associated university, 4 companies and a highly qualified mindfulness-in-the-workplace facilitator will join forces to facilitate the successful training program that will allow DCs to be awarded with a double doctoral degree in two different countries. These aims will be pursued by applying different actions, which include the study and development of innovative technologies against the water pollution, paying attention not only to the sustainability of the water management systems (in a circular economy vision), but also to the reuse of water, the recovery of nutrients and the green synthesis of functional materials. The developed technologies will be tailored to variegated scenarios with particular emphasis to three case studies: aquaculture, arid areas and (remote) cold areas. The overall research goals will imply three main steps: 1) the assessment of water quality and the prediction of its response toward the increased environmental stresses; 2) restore water quality while approaching the zero waste discharge and 3) scale up and process integration. The multidisciplinary, interdisciplinary and intersectoral network will forge creative entrepreneurial and innovative scientists, who will be equipped with the skills, tools, insights and flexibility that enable them to be the next generation of Urban Water System management innovators.

Achievements in 2023: The kick off meeting of this project was held virtually being coordinated by the University of Torino (Italy) the 8th of September, 2023. Along the whole meeting, the activities of each one of the WPs were presented by each one of the leaders. CIEMAT-Plataforma solar de Almería is leading WP4 related to Green water treatment technologies and process integration. In addition, two doctoral candidates will be supervised by two persons from the Solar Treatment of Water Research Unit at PSA. The 15 DCs will develop innovative technologies against water pollution, paying attention to a circular economy vision, including processes exploiting materials from exhausted supplies, water reuse, nutrients recovery and green synthesis of functional materials as it is shown in Figure 47.

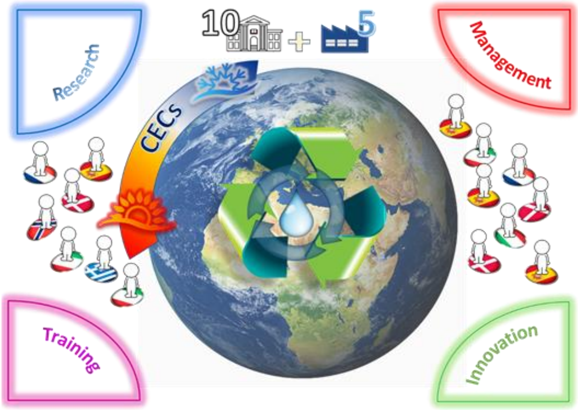


Figure 47. A diagram of the collaborative network among all the partners that will contribute to the successful training of 15 doctoral candidates through join PhD among two European countries each one.

European Twinning for research in Solar energy to water (H2O) production and treatment technologies, Sol2H2O

Participants: Universidad de Evora (Portugal), CIEMAT (Spain), Instituto Tecnológico de Canarias (Spain), Universita degli studi di Palermo (Italy).

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Isabel Oller, isabel.oller@psa.es

Funding agency: European Commission: HORIZON-WIDERA-2021-ACCESS-03-01 – Twinning. GA 101079305.

Background: Clean water and sanitation is one of the Sustainable Development Goals. But water availability itself is essential to achieve most of the Sustainable Development Goals. In particular, industrial and agricultural developments are dependent on a resource that is becoming increasingly scarce: United Nations recognize that 40 per cent shortfall in freshwater resources by 2030 coupled with a rising world population has the world careening towards a global water crisis. The availability of new water resources is of paramount importance to alleviate this crisis. Desalination and wastewater treatment are in increased demand to mobilize new water resources. However, they are associated with large energy consumption. The coincidence of water scarcity with plenty of solar radiation leads to the use of solar energy for guaranteeing the sustainability of desalination and wastewater treatment (WT).

Objectives: Gathering the experience of three non-Widening (TOP) partners presenting some of the most outstanding background and Research Infrastructure (RI), at European level, in the development of Solar-driven water production and wastewater treatment technologies (WP&WT), Sol2H2O aims at supporting the Coordinator (WIDENING) partner (University of Évora), in the development and establishment of high-level research in this field. Based on the outstanding WIDENING RI and background in Solar Energy technologies and on its preliminary experiences in the Water-Energy nexus field, Sol2H2O seeks the development and implementation of a common scientific strategy, with a strong focus on an enhanced capacity building of researchers, going beyond purely scientific capacities and strengthening their research management and administration skills. By means of a common research strategy aiming at further developing Solar-driven Water-Energy Nexus solutions, Sol2H20 aims at creating a reference European facility for the development and testing of Circular Solar-driven Water Production & Treatment technologies, enabling the development of renewable gas or agriculture activities.

Achievements in 2023: This project started on December 2022 and is a three-year project in which the research units of Solar Treatment of Water and Solar Desalination at PSA are collaborating with the main objective of transferring their knowledge to the widening partner, which is the University of Évora in Portugal. This project has two main research and transfer or knowledge lines, one focused on desalination and the other on wastewater treatment and recovery. In this sense, the Solar Treatment of Water Research Unit at PSA is closely collaborating and working with the University of Evora for the installation and testing of a new CPC photoreactor (Figure 48) with the highest tube diameter available in the market to evaluate small concentrations of photocatalysts for the elimination of microcontaminants contained in municipal wastewater treatment plants.

Figure 48. New CPC photoreactor designed in a collaborative action among the Solar Treatment of Water Research Unit at PSA (CIEMAT) with the University of Évora for testing small concentrations of photocatalysts to eliminate microcontaminants present in urban wastewaters.

Building energy performance assessment based on in-situ measurement, analysis and simulation, In-Situ-BEPAMAS

Participants: CIEMAT.

Contacts: María José Jiménez, mjose.jimenez@psa.es

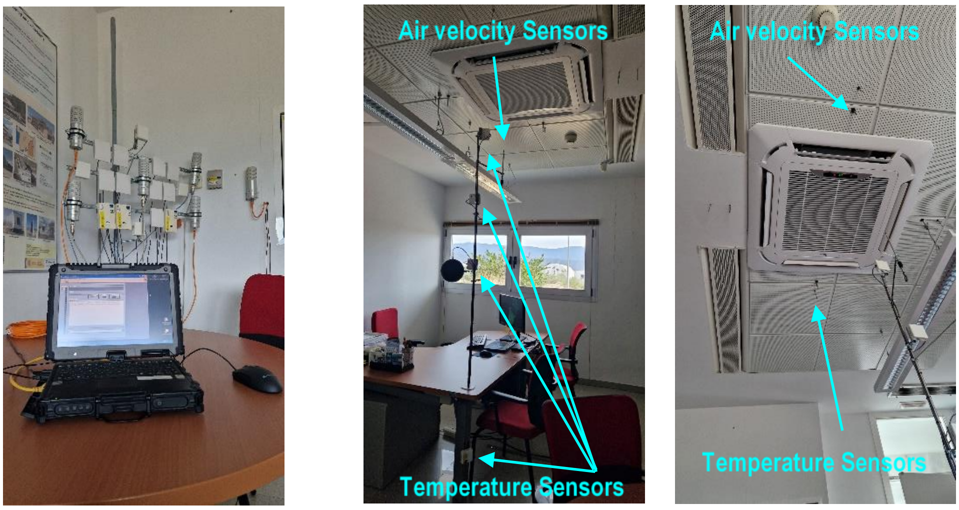
Funding agency: Spanish National Research Agency (Agencia Estatal de Investigación). Call: “Proyectos de I+D+i del Programa Estatal de I+D+i Orientada a los Retos de la Sociedad 2019”. Project reference PID2019-105046RB-I00.

Background: Reliable procedures for building energy performance assessment are essential for: 1. Evaluation of deviations regarding design specifications in as-built new buildings. 2. Comparison to reference values in pre-rehabilitation diagnosis. Most currently used compliance checks based on simulations can deviate significantly from reality. This performance gap must be addressed by research.

Objectives: Application of inverse modelling techniques, assisted by sensitivity analyses applying dynamic simulation tools, to the development of reliable, cost-effective and non-intrusive experimental methodologies, for the in-situ energy performance assessment of the whole building envelope, with applicability to in use-buildings when construction characteristics of buildings are not available or incomplete

Achievements in 2023: The research conducted at the LECE Laboratory at PSA, using stock data previously gathered here, delivered the following in 2023:

Considering the ARFRISOL Building Prototype at PSA: Simulation models have been validated comparing simulated and measured values. Afterwards, the effect of the variation of different parameters and input variables on the heat demands have been analysed. Standardised and bibliographic values as well as those values obtained from test campaigns have been used. This analysis has revealed the effect of the boundary variables on the heat demand, which sorted according to their relevance, are: set point temperatures, climate, air renovation rate due to infiltrations, ground temperature, and occupancy patterns.



(a) (b) (c)

Figure 49. Extended experiment set ups of, (a) calibration benchmark of CO_2 sensors, (b) indoor air velocity and temperature at different heights in the centre of the room, and (c) air velocity and temperature at the output of the air conditioning device.

The robustness of the reference Coheating test conducted to obtain the Heat Transfer Coefficient (HTC) of the Single-zone building and the ARFRISOL Building Prototype at PSA has been assessed. The values of this coefficient obtained using these tests have been used as reference in order to verify the results obtained applying advanced procedures, applicable to in-use buildings, such as RC models and dynamic integrated method, corroborating the consistency of the results.

The set ups giving experimental support to the project have been extended taking into account the results of the previous research conducted in the framework of the project. Particularly, the following devices in an in-use office have been added to the monitoring system: sensors measuring the air velocities and temperatures of the air supplied by the air-conditioning system, a calibration benchmark of CO_2 sensors, air velocity and temperature at different heights in the centre of the room.

11 The European Solar Research Infrastructure for Concentrated Solar Power, EU-SOLARIS

The European Solar Research Infrastructure for Concentrated Solar Power (EU-SOLARIS) is a world-class distributed research infrastructure set up as a central hub responsible for the coordinated operation of national research centres in Concentrating Solar Power/Solar Thermal Energy (CSP/STE) technologies, which shall dedicate part of their research and development capacities to sharing contents, tools and know-how related to these CSP/STE technologies. It aims to achieve a real coordination of Research and Technology Development (RTD) capabilities and efforts in CSP/STE technologies by the European Research Centres. EU-SOLARIS will become the reference for CSP/STE and will maintain Europe at the forefront and leadership of these technologies by providing the most complete, high quality scientific portfolio and facilitating the access of researchers to highly specialised facilities via a single-entry point. EU-SOLARIS will link scientific institutions, academia and industry and will speed up the development of research and innovation due to a closer collaboration model, knowledge exchange management and a wider dissemination of results. It will increase the efficiency of the economic and human resources required to achieve excellence and provide efficient resources management to complement research and avoid redundancies, when identifying new requirements for the improvement of the research facilities, and for the construction of new ones (when needed), and it will optimize and promote the specialization of existing ones.

EU-SOLARIS is supported by its member countries Cyprus, France, Germany, and Spain (statutory seat), with national funds. Portugal participates as an observer.

EU-SOLARIS was formally approved by the European Commission in October 2022 as a European Research Infrastructure Consortium (ERIC) entity to become the European reference with regard to research infrastructures in Concentrating Solar Thermal and Solar Chemistry Technologies.

EU-SOLARIS ERIC started its regular operations in 2023.

Three meetings of the General Assembly took place throughout this year; first one was the Constitutive Meeting, held in Madrid (CIEMAT's premises) on 12th January. The second one was held in virtual mode on the 31st May, and, last but not least, a physical meeting took place in Berlin on 28th November.

Figure 50. CIEMAT's DG hosted the Constitutive Meeting of EU-SOLARIS ERIC on 12 January, 2023.

Furthermore, the Scientific & Technical Committee has been reinforced with the incorporation of two worldwide top-notch researchers in the field of energy, Dr. Vassiliki Drosou (CRES, Greece) and Dr. Nesrin Ozalp (Illinois State University).

In fact, the STC has contributed in the selection of the winning proposal of the first activity promoted and funded entirely by EU-SOLARIS ERIC: the Internal Project 2023. This is a call for proposals to fund a project focused on the RI-related R&D activities.

EU-SOLARIS ERIC also started to participate on winning proposals under Horizon Europe. Actually, we participated in five proposals, being successful in four of them, all under the 'Research Infrastructures' program:

RISEnergy, led by the Karlsruher Institut for Technology (KIT), focused on providing high quality access services to world leading RIs in the field of energy.

Under the title 'Cooperation with LAC', EU-SOLARIS ERIC is a partner in two projects:

CACTUS: Led by CEA-LITEN (FR), which aims to strengthen collaboration between European and LAC RIs in the field of solar energy.

EULAC ENERGYTRAN is a project led by the 'Organización de Estados Iberoamericanos' whose goal is the generation of innovative technological solutions for clean and social energy transition.

Ultimately, the project SOLARIZE, coordinated by EU-SOLARIS ERIC, will fund a pack of measures and activities aiming to ensure the long-term sustainability of the ERIC.

Contacts: Diego Martinez, dmartinez@psa.es

Julián Blanco, jblanco@psa.es

12 Training and educational activities

The ruling principle of the PSA's training program is the creation of a generation of young researchers who can contribute to the deployment of solar thermal energy applications. Through this program, about twenty students of different nationalities are admitted each year so that we can transmit the knowledge in solar thermal technology accumulated at the PSA throughout its over forty years of experience to new generations of university graduates.

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with the University of Almeria (UAL) and with the own program to young researcher of CIEMAT.
- Management of miscellaneous educational cooperation agreements with other entities for sending students to the PSA (Universities of Almería, Polytechnic of Madrid, UNINORTE (Colombia), Gabes (Tunisia), UFRO (Chile), POLIMI (Italy), Antofagasta (Chile), Guanajuato (México), Australian National University, INSA (France), OST-SPF (Switzerland), Technical University Munich (Germany), RWTH-Aachen (Germany), IES Los Angeles, IES Al- Andalus ,etc).

The close and enduring collaboration between CIEMAT and the University of Almería has allowed us to carry out a new edition of the Official Master's in Solar Energy (60 Credits). The hallmarks of this course, along with its quality, make it an attractive proposition for students, both Spanish and from other countries, who want to gain a first-rate qualification in the field of solar energy and its many applications. The Masters in Solar Energy allows its graduates to deepen in the different technologies and applications that currently exist for solar energy.

The SFERA-III project, coordinated by CIEMAT, addresses advanced science challenges and integrated research activities in the field of Concentrating Solar Thermal (CST) by integrating key European research infrastructures into an ambitious wide project aiming to offering the R&D community a new level of high-quality services. In this context, this project is coordinating efforts to train researchers and engineers on CST technologies. Among the networking activities carried out within the framework of this project are an annual seminar for Ph.D. students from the SFERA-III Consortium (Doctoral Colloquium) and a summer/winter school open to the research community.

The 4th Doctoral Colloquium, restricted to SFERA-III members, was held on 11th and 13th September 2023 in Cologne (Germany). Afterward, SFERA-III Summer School (open to a large audience and organized in hybrid mode) was hosted at the same location on 14th and 15th September and it was focused on "Smart CSP: how smart tools, devices, and software can help improve the design and operation of concentrating solar power technologies".

13 Facilities and Infrastructure

Facilities associated with Line-focus solar concentrators

THE DISS EXPERIMENTAL PLANT

This test facility was erected and put into operation in 1998 to experiment with direct generation of high-pressure – high-temperature (100 bar/400°C) steam in parabolic-trough collector absorber tubes. It was the first life-size facility built in the world where two-phase-flow water/steam processes in parabolic-trough collectors could be studied under real solar conditions.

The facility (see Figure 51 and Figure 52) consists of two subsystems, the solar field of parabolic-trough collectors and the balance of plant (BOP). In the solar field, with the upgrade implemented in 2012, feed water is preheated, evaporated and converted into superheated steam at a maximum pressure of 100 bar and maximum temperature of 500°C as it circulates through the absorber tubes of a 1000-m -long row of parabolic-trough collectors with a total solar collecting surface of 5,400 m^2. The system can produce a nominal superheated steam flow rate of 1 kg/s. In the BOP, this superheated steam is condensed, processed and reused as feed water for the solar field (closed-loop operation).

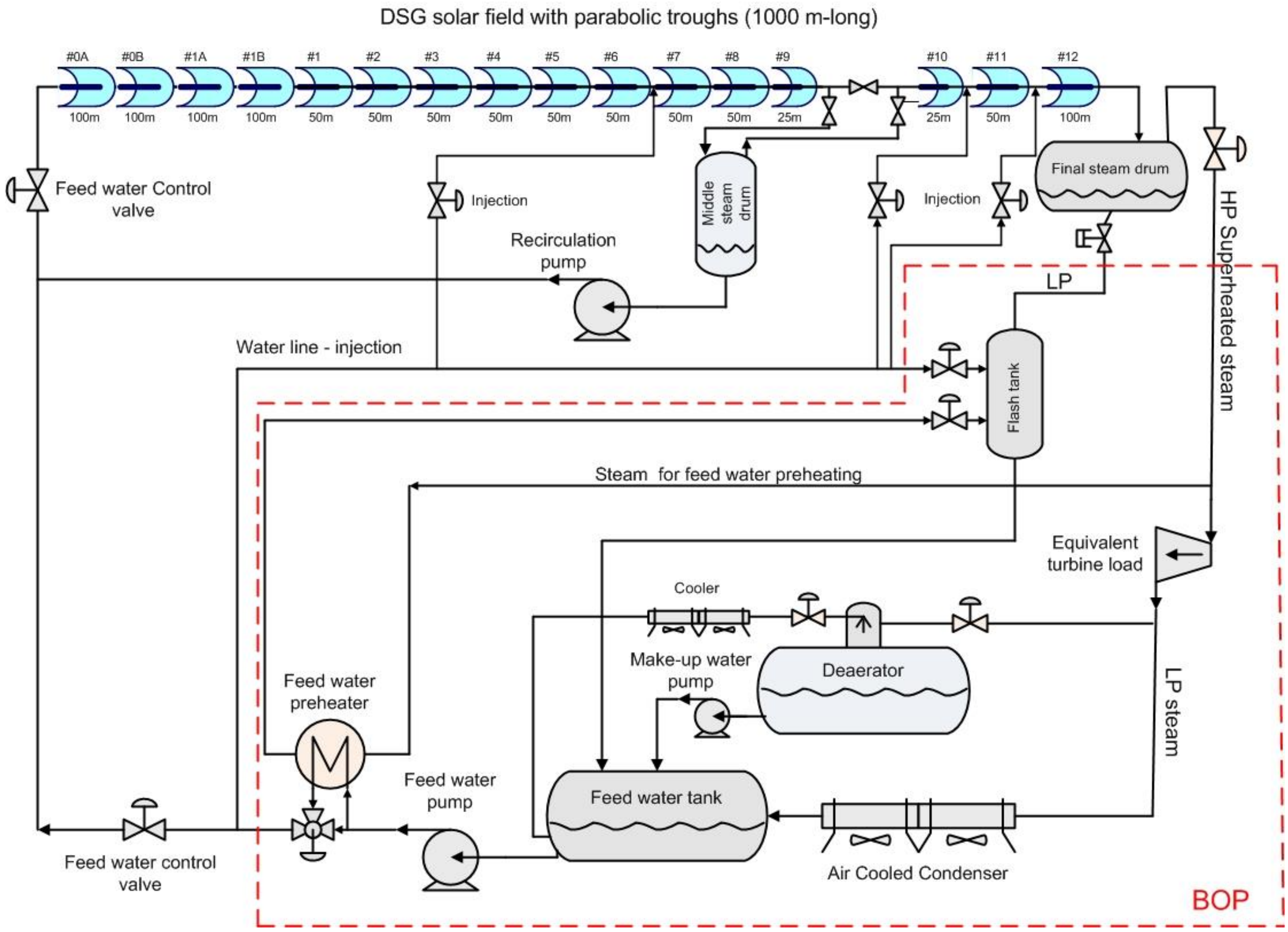


Figure 51. Simplified flow diagram of the PSA DISS loop.

The facility operation is highly flexible and can work from 30 bar up to 100 bar. It is also equipped with a complete set of valves allowing the solar field to be configured for Recirculation (perfectly differentiated evaporation and superheating zones), for Once-Through (the intermediate water-steam separator and the recirculation pump located in the solar field are not used in this operating mode) and Injection mode (feed water is injected in different points along the collector row). The facility is provided with a wide range of instrumentation for full system monitoring (flow rates and fluid temperatures/pressures in the various zones of the solar field, pressure drops in collectors and piping, temperature and thermal gradients in the cross sections of the absorber tubes, etc.) and a data acquisition and process control system which has a database where 5-s process data are recorded 24 hours a day.

Figure 52. View of the DISS plant solar field in operation.

Among the capacities associated with this facility are the following:

- Component testing for parabolic-trough collector solar fields with direct steam generation (DSG) in their receiver tubes (receivers, ball joints or flex hoses, water-steam separators, specific instrumentation, etc.).
- Study and development of control schemes for solar fields with DSG.
- Study and optimisation of the operating procedures that must be implemented in solar fields with DSG for electricity generation.
- Thermo-hydraulic study of two-phase flow of water/steam in horizontal tubes with non-homogeneous heat flux.

THE HTF TEST LOOP

The HTF test loop is an ideal facility for evaluating parabolic-trough collector components under real solar energy operating conditions. The facility is appropriately instrumented for qualification and monitoring of the following components:

- New designs of parabolic trough collectors (up to 75 m long).
- Parabolic trough collector mirrors.
- Parabolic trough collector absorber tubes.
- New designs of ball-joints or flexible hoses for connecting parabolic-trough collectors in the solar field.
- Solar tracking systems.

The facility consists of a closed thermal-oil circuit connected to three solar collectors that are 75 m long and connected in parallel. With the oil pump initially installed, only one collector could be operated at a time, while the additional 45 kW oil pump installed in 2022 can operate several collectors at a time (see simplified diagram of the facility in Figure 53). The east-west rotating axis of the solar collectors increases the number of hours per year in which the angle of incidence of solar radiation is less than 5°. The thermal oil used in this facility (Syltherm 800®) has a maximum working temperature of 420 °C and a freezing point of – 40 °C.

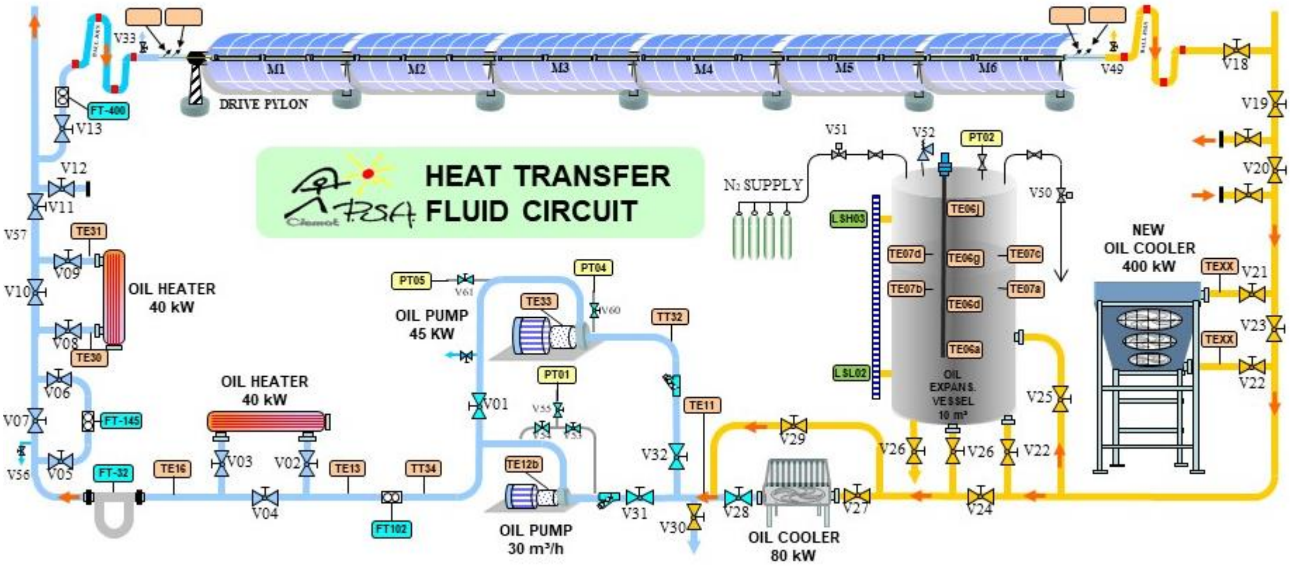


Figure 53. Diagram of the HTF test Loop located at the PSA.

The facility's oil circuit, which has a maximum working pressure of 18 bar, is made up of the following elements:

- 10-m^3-capacity oil expansion tank, with automatic nitrogen inerting.
- Mechanical-draft oil cooler, with airspeed control and 400-kW maximum cooling.
- Centrifugal oil pump, with a flow rate of up to 8.3 L/s.
- 45 kW Centrifugal oil pump.
- Two 40-kW electric oil heaters.

In 1998, the first EuroTrough collector prototype developed by a European consortium with the financial aid of the European Commission, was installed and evaluated under real working conditions at this facilityThis collector is now used to evaluate and qualify new designs of receiver tubes, reflectors and other components for parabolic-trough collectors.

The main activities at the HTF test loop are related to the study of the optical and thermal performance of complete parabolic-trough collectors (optical efficiency, IAM coefficient, and global efficiency/heat losses) and receiver tubes.

PPTL: THE PARABOLIC TROUGH TEST LOOP FACILITY

This large test facility is implemented in a 420 m x 180 m plot of the PSA, and it is composed of two solar fields:

- The North field is designed to install complete parabolic trough collectors with a maximum unit length of 180 m in E-W orientation. Up to four complete collectors can be installed in parallel.
- The South field is designed to install complete loops of parabolic trough collectors (PTC), i.e., several collectors connected in series, with a maximum length of 640 m and orientation North–South. Up to four complete loops can be installed in parallel.

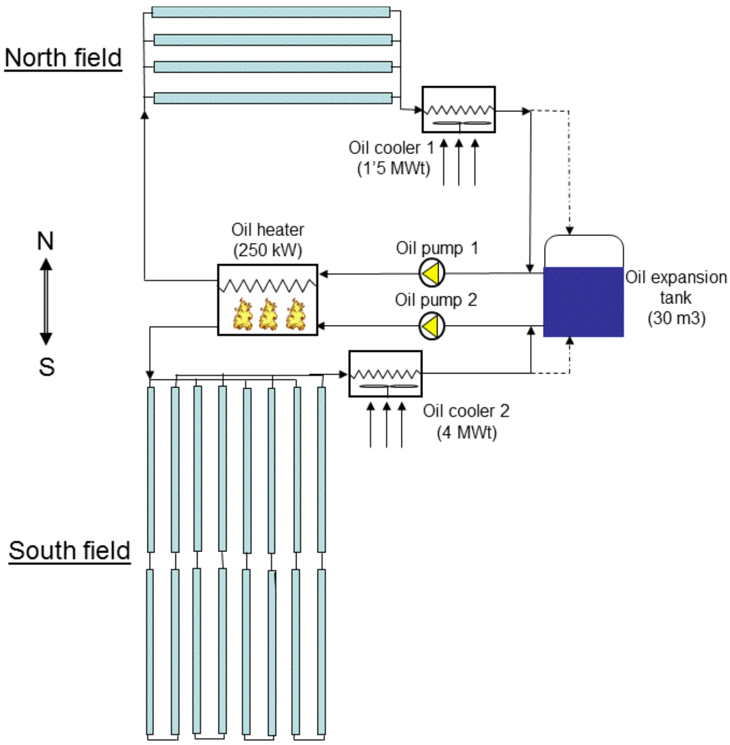


Figure 54. Simplified scheme of the PTTL facility.

Each field is provided with a complete oil circuit installed on a 30 m x 30 m concrete platform between the two fields, and both circuits share: an oil expansion tank with a capacity of 30 m^3, a gas-fired oil heater with a thermal power of 250 kW and a maximum oil temperature of 400 °C, a meteorological station equipped with solar radiation, ambient temperature and wind sensors and the data acquisition system (DAS). Additionally, to these common elements, the oil circuits associated with the North and South fields are composed of:

- North field: one oil pump (75 m^3/h) provided with speed control, one oil cooler refrigerated by air (1.5 MWth) able to cold the oil down to 70 °C when the ambient air temperature is 40 °C, and, oil piping connecting the circuit to the common elements (i.e., expansion tank and oil heater).
- South field: one oil pump (125 m^3/h) provided with speed control, one oil cooler refrigerated by air (4 MWth), and oil piping connecting the circuit to the common elements (i.e., expansion tank and oil heater).

Each oil circuit is also provided with an oil-draining tank big enough to receive all the oil in the circuit, a complete set of instrumentation to monitor oil mass flow, pressures and temperatures, and control valves to regulate the oil flow to desired values according to the tests.

This outdoor life-size test facility offers the following capacities:

- qualification of complete PTC prototypes assessing their optical peak efficiency, incidence angle modifier and thermal losses.
- evaluation of durability and reliability of PTC mirrors, receiver tubes, ball-joints, flex hoses, sun tracking systems and all the elements installed in complete rows of collectors.
- Evaluation of PTC solar field control algorithms.

PROMETEO: TEST FACILITY FOR CHECKING NEW COMPONENTS AND HEAT TRANSFER FLUIDS FOR LARGE-PARABOLIC TROUGHS

This facility is an experimental closed thermal oil loop installed in the Northeast area of the PSA in 2010.

The East-West oriented solar field allows the qualification of all collector components and complete collectors of a length of up to 150 m, i.e., structures, reflectors, receivers from 70 to 90 mm and movable joints. It enables sun tracking covering all solar radiation incidence angles in one day thanks to its orientation. It is equipped with high precision instrumentation and controls for precise, quick and automated measurements. Currently there are two parabolic troughs 100 m-long and with an aperture of 7.5 m, each one installed in the pilot plant.

Figure 55. View of the PROMETEO test facility.

The collector modules can be connected to the balance of plant (BOP) either in parallel or in series configuration using the ad-hoc set valve. The heat transfer fluid used so far in this test facility is silicone oil. A pump circulates the silicone heat transfer fluid (SHTF) with a mass flow similar to that of commercial power plants. Mass flow is measured directly using Vortex and differential pressure flowmeter types. A controlled air cooler unit dissipates the collected thermal energy and ensures a constant HTF temperature (±1 K) at the collector's inlet. Sensors for measurement of inlet and outlet temperatures are highly precise and may be calibrated on-site. A meteorological station delivers accurate radiation and wind data.

TCP-100 2.3-MW$_{TH}$ PARABOLIC-TROUGH FACILITY

This test facility was implemented in 2014, and it is composed of the TCP-100 solar field and a storage tank with 115 m^3 of Santotherm-55 thermal oil.

The solar field is composed of six parabolic-trough collectors, model TCP-100, installed in three parallel loops, with two collectors in series within each loop, see

Figure 56. Each collector is composed of eight parabolic trough modules with a total length of 100 m and a parabola width of 5.77 m. The total solar collecting surface of each collector is 545 m^2. The focal distance is 1.71 m, the geometrical intercept factor is greater than 0.95, and the peak optical efficiency is 77.5 %. Archimede Solar Energy (Italy) delivered the receiver tubes used in this solar field and the working fluid is Syltherm‑800.

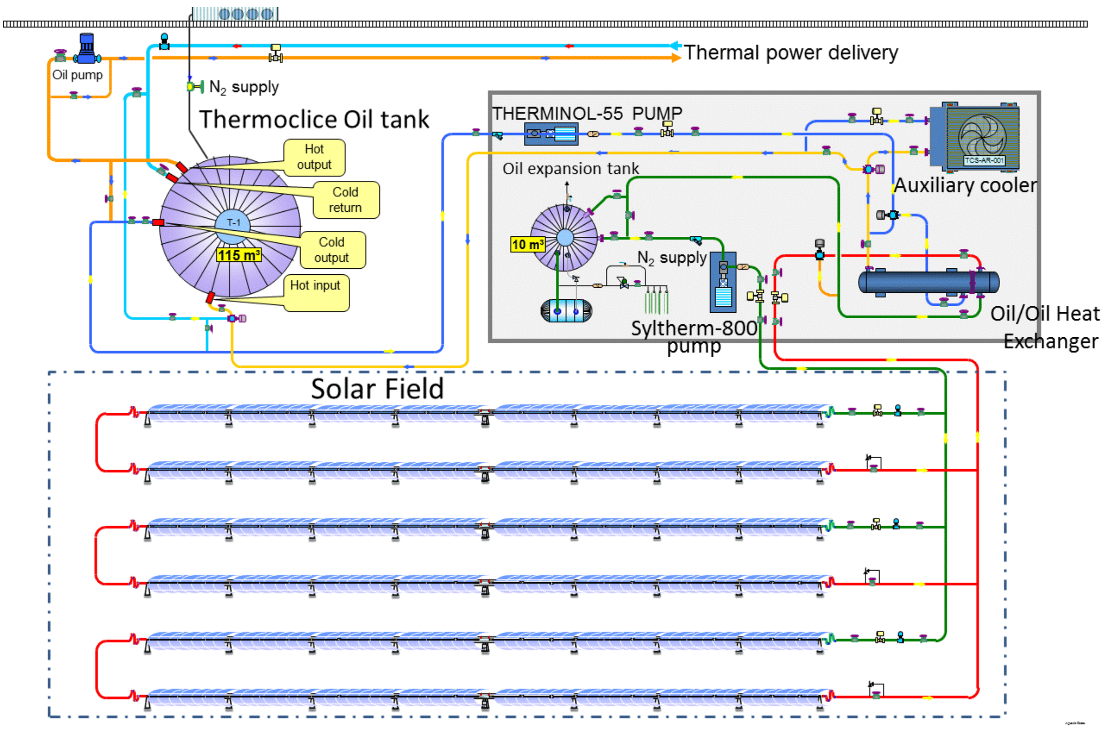


Figure 56. Diagram of the TCP-100 2.3 MW$_{th}$ parabolic-trough facility

The solar field is connected to a 10 m^3 oil expansion tank for a maximum temperature of 400°C. Thermal energy can be transferred from the solar field primary circuit to a thermocline oil storage tank with a total volume of 176 m^3 and 115 m^3 of Santotherm-55 oil with a maximum working temperature of 300 °C.

This test facility is specially designed to perform studies related to control systems for parabolic trough solar fields. For this reason, two collector loops are provided with the solar tracking system developed by PSA, while the third loop is provided with a commercial solar tracking system with continuous movement. Due to some administrative problems, the facility is not in operation at present.

PRESSURISED GASES: INNOVATIVE FLUIDS TEST LOOP IN PARABOLIC-TROUGH COLLECTORS

This experimental facility aims to study the use of pressurised gases as heat transfer fluid in parabolic trough collectors and evaluate their behaviour under a diversity of real operating conditions.

The experimental test loop (see Figure 57) is located north of the DISS experimental plant control building, which also houses the equipment necessary for the control and data acquisition of this experimental test loop.

Figure 57. View of the IFL experimental facility (with parabolic troughs) using compressed gas as heat transfer fluid.

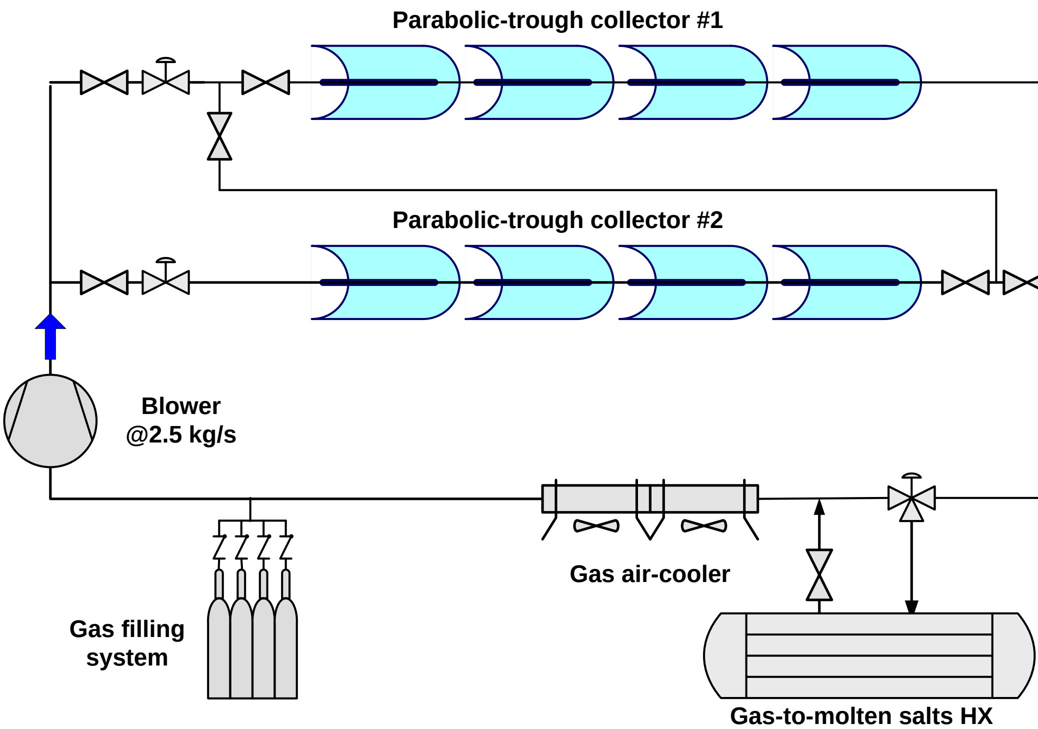


Figure 58. Simplified system diagram of the IFL experimental facility located at the PSA

This innovative fluid loop (IFL) can work at pressures and temperatures of up to 100 bar and 515 °C, and consists of the following components:

- Two east-west oriented EuroTrough parabolic trough collectors, each 50 m long with a 274.2-m² collector surface. The collectors can be connected in series or parallel.
- A 400-kW air-cooler capable of dissipating the thermal energy of the fluid delivered by the collectors. It has two 4-kW motorised fans.
- A blower driven by a 15-kW motor that supplies the gas flow rate necessary to cool the receiver tubes adequately.
- A data acquisition and control system that allows the temperature, flow rate, pressure, beam solar irradiance and humidity in the system to be completely monitored.
- Automatic control valves that allow precise, safe variation in the collector fluid feed flow rate.
- An auxiliary circuit to fill the main test loop with the gas used as heat transfer fluid.

NEP: THE FACILITY FOR POLYGENERATION APPLICATIONS

The purpose of this facility is the preliminary study of the behaviour of a parabolic trough solar field with a small concentration ratio, and the determination of its feasibility as a heat source in polygeneration schemes, particularly in solar thermal electricity + desalination requiring temperatures around 200°C. The solar collectors installed in this facility are PolyTrough 1200, manufactured by NEP Solar. It has a production of 15.8 kW per module (0.55 kW/m^2) under nominal conditions, with a mean collector temperature of 200 °C, and an efficiency over 55 % in the range of 120-220 °C (for 1000 W/m^2 of direct normal irradiance).

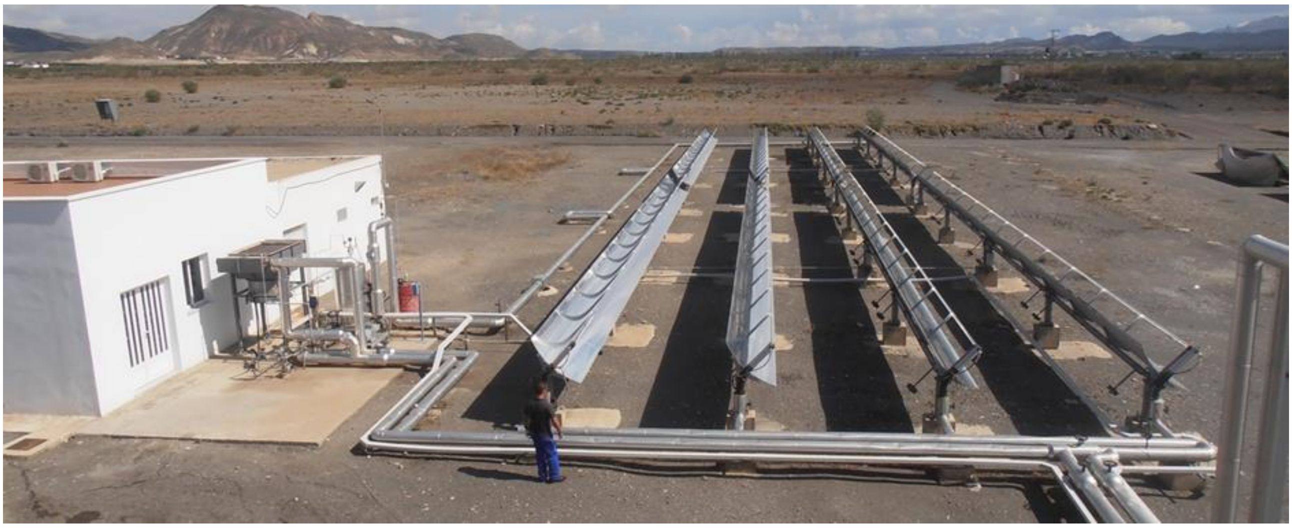


Figure 59. NEP PolyTrough 1,200 solar field.

The field is configured with eight collectors placed in four parallel rows, with two collectors in series within each row. This configuration supplies 125 kW of thermal energy. The temperature of the thermal oil can be up to 220 °C, so different schemes for using the thermal energy for polygeneration can be evaluated.

Currently, the solar field is also being used to generate steam to drive the double-effect absorption heat pump coupled to the PSA MED (Multi-Effect Distillation) plant.

KONTAS: ROTARY TEST BENCH FOR PARABOLIC TROUGH SYSTEMS

A rotary test bench for parabolic trough collector components, KONTAS, was erected at PSA in 2009. The concept was developed by DLR and within the framework of the Spanish-German agreement between CIEMAT and DLR this test facility is now jointly used by both institutions.

Figure 60. Side view of KONTAS test bench and the heating/cooling unit (right side).

The test bench allows the qualification of all collector components and complete modules of up to 20 m length, i.e., structures, reflectors, receivers and flexible joints. It enables tracking at any desired angle of incidence of solar radiation. It is equipped with high-precision instrumentation and controls for precise, quick and automated measurements.

This test bench rests on rails directly mounted on top of the foundation. These rails form an inner and an outer ring. The collector itself is mounted on a steel platform with six steel wheels. The rotation of the platform on the rails around the central bearing is performed by motors driving four of these wheels.

The collector module under testing is connected to a heating&cooling unit, which is also situated on the platform. A pump circulates *Syltherm 800®* thermal oil as heat transfer fluid (HTF) with a mass flow similar to that of commercial plants. Mass flow is measured directly using the Coriolis measuring principle avoiding density uncertainties. The heating and cooling unit dissipates the energy the HTF collects on the way through the receiver tube of the collector module mounted on the rotating platform and ensures a constant HTF temperature (±1 K) at the collector's inlet. Sensors for measurement of inlet and outlet temperatures are highly precise and may be calibrated on-site. A high-precision meteorological station delivers accurate radiation and wind data.

REPAS: ACCELERATED FULL LIFECYCLE TESTS OF ROTATION AND EXPANSION PERFORMING ASSEMBLIES FOR PARABOLIC TROUGHS SYSTEMS

The REPA test facility is another test facility jointly implemented at PSA by CIEMAT and DLR. This facility is now used by CIEMAT and DLR in the framework of a joint agreement.

The test bench is divided into two functional sections: the so-called kinematic unit, which holds and moves the pieces REPAs to be tested, and the balance of plant unit, which supplies the conditioned heat transfer fluid (see Figure 61.left).

The balance of plant unit is composed of a variable speed HTF pump that circulates the HTF through a pipe provided with an adapted collar-type electrical heaters before passing through the REPA to be tested, which is placed in the kinematics unit. The return line runs directly to the suction side of the pump closing the circuit. The system is connected to an expansion vessel able to compensate for the volume difference caused by the density variation of the working fluid when its temperature changes.

The kinematics unit (see Figure 61. right) is prepared to accommodate test samples of ball joints and flexible hoses with varying and adjustable geometries, e.g., focal lengths. It is prepared to accomplish both rotational and translational movements with the following characteristics:

- Drive pylon: modified EuroTrough drive pylon structure.
- The rotating angle is 205° and the stow position is 25° facing down.
- Up to 45° of lateral motion, representing absorber tube thermal expansion.
- Prepared for dimensions of new PTC designs (focal lengths from 1 m to 2.3 m).
- Measurement of the reaction forces and torques of the assemblies under testing.

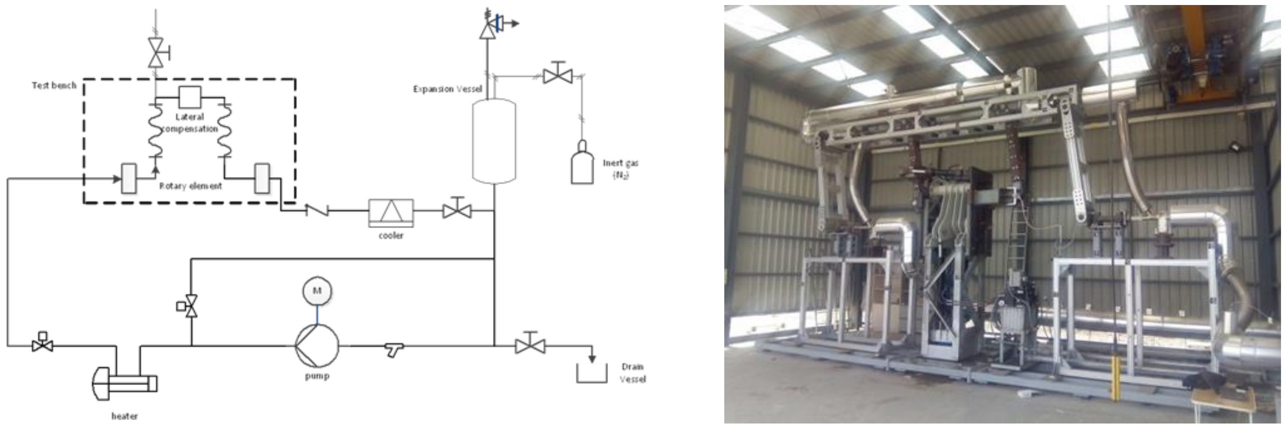


Figure 61. Schematic diagram of the REPA test loop at PSA (left) and north view of the test facility with two flex-hoses mounted for testing (right).

LAVEC: SMALL-SIZED LFC PRESSURISED WATER TEST LOOP

This test facility is specially designed for evaluating and qualifying small line-focus solar collectors using pressurised water as working fluid within the temperature range of 100-250 °C, which is very suitable for industrial process heat applications. This test facility fulfils the current standards for solar thermal collectors testing: ASTM E905–87:2013, SRCC 600 2014–17:2015 and ISO 9806:2017.

The main technical parameters of the LAVEC facility are the following:

- Heat transfer fluid: pressurised hot water (environmentally friendly fluid).
- Operation gauge pressure: up to 4.2 MPa.
- Operation temperature: up to 250 °C.
- Operation flowrate: from 0.05 to 0.5 kg·s^{-1}.
- Expected size of the solar collectors tested: up to 25 m^2 per collector unit.
- The material used for the hydraulic circuit is stainless steel.
- Field length: up to 40 m, in both orientations: East-West and North-South.
- Cooling system capacity: up to 150 kWth, depending on the operating conditions.
- Uncertainty of flowrate measurement: better than 1.0 %.
- Uncertainty of inlet/outlet water temperature: ±0.1 °C to 0.525 °C (0 °C to 250 °C).
- Hot water storage tank of 3 m^3.

Figure 62 shows the simplified scheme of LAVEC with a solar collector connected to the system for qualification/evaluation, while Figure 63 is an overall view of the facility. This facility is provided with innovative equipment to provide the maximum possible accuracy in the assessment of the collector efficiency.

Solar collectors are easily connected to the balance of plant of LAVEC by means of 1” flanges.

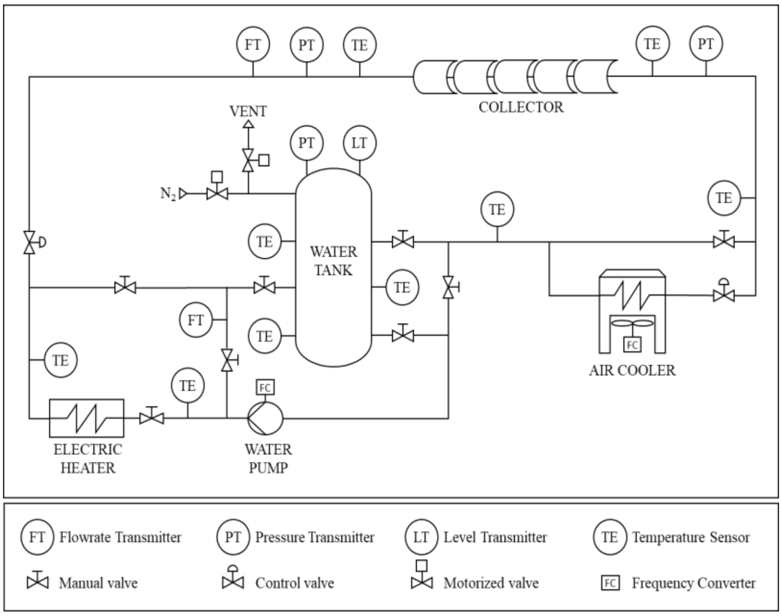


Figure 62. Simplified scheme of the LAVEC facility.

Figure 63. Overall view of LAVEC.

Central Receiver Systems

The PSA has two exceptional facilities for the testing and validation of central system technology, also called power tower technology, components and applications. The SSPS-CRS and CESA-1 facilities enable projects to be undertaken and technologies validated in the hundreds of kilowatts range. They are outdoor facilities specially conditioned for scaling and qualifying systems prior to commercial demonstration.

THE 6 MWTH CESA-1 PLANT

The CESA-1 plant (see Figure 64) was inaugurated in May 1983 to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-1 plant is a very flexible facility operated for testing subsystems and components such as heliostats, solar receivers, thermal storage, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It is also used for other applications that require high photon concentrations on relatively large surfaces, such as in chemical or high-temperature processes, surface treatment of materials or astrophysics experiments.

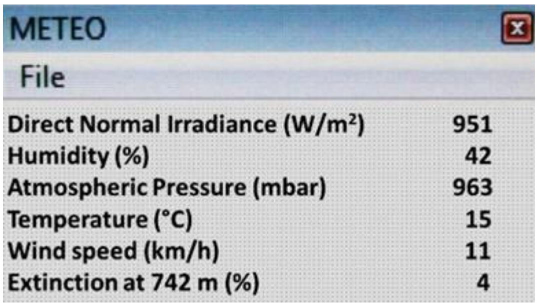
Figure 64. The CESA-I facility seen from the north.

Direct solar radiation is collected by the facility’s 330 m x 250 m south-facing field of 300 39.6-m^2 heliostats distributed in 16 rows. The heliostats have a nominal mean reflectance value of 0.91, the solar tracking error on each axis is 1.2 mrad and the reflected beam image quality is 3 mrad. The CESA-1 facility has the most extensive experience in glass-metal heliostats in the world, with first generation units manufactured by SENER and CASA as well as second generation units with reflective facets manufactured by ASINEL and third generation facets and prototypes developed by CIEMAT and SOLUCAR. Despite its over 20 years of age, the heliostat field is in good working condition due to a strategic program of continual mirror-facet replacement and drive mechanism maintenance and replacement.

To the north of the CESA-1 solar field, there are two additional areas used as test platforms for new heliostat prototypes. One located 380 m away from the tower and the other 500 m away from the tower.

The maximum thermal power delivered by the field onto the receiver aperture is 6 MW_{th} at a typical design irradiance of 950 W/m^2, achieving a peak flux of 3.3 MW/m^2. 99 % of the power is focused on a 4-m-diameter circle and 90 % in a 2.8-m circle.

Currently, the measurement of solar extinction is available on-line in the control room of the CESA-1 facility at PSA, facilitating the daily operation tasks (Figure 65). Note that this is the first time that it occurs in a solar tower plant. The extinction measurement system has been developed by CIEMAT at PSA and it works taking simultaneous images of the same Lambertian target at very different distances using two identical optical systems with suitable digital cameras, lenses and filters.


METEO

File

Direct Normal Irradiance (W/m²)	951
Humidity (%)	42
Atmospheric Pressure (mbar)	963
Temperature (°C)	15
Wind speed (km/h)	11
Extinction at 742 m (%)	4

Figure 65. On-line measurement of the solar extinction in the control room of CESA-1 facility at PSA.

Currently, there is an airborne particle counter in operation from which measurements are of interest for studies of solar extinction, soiling and evaluation of volumetric receivers.

THE SSPS-CRS 2.5 MWTH FACILITY

The SSPS-CRS plant was inaugurated as part of the International Energy Agency's SSPS (Small Solar Power Systems) project in September 1981. Originally conceived to demonstrate continuous electricity generation, it initially used a receiver cooled by liquid sodium that also acted as the thermal storage medium. At present, this test facility is mainly devoted to testing small solar receivers in the 200 to 500 kW_{th} capacity range.

Figure 66. Aerial view of the experimental SSPS-CRS facility.

The heliostat field is composed of 91 39.3-m^2 first generation units manufactured by Martin-Marietta. A second field north of it has 20 52-m^2 and 65-m^2 second-generation heliostats manufactured by MBB 7 and ASINEL.

The original SSPS-CRS heliostat field was improved several years ago with the conversion of all its heliostats into completely autonomous units powered by photovoltaic energy, with centralized control communicated by radio using a concept developed and patented by PSA researchers (Figure 67). This first autonomous heliostat field, which does not require the use of channels or cabling, was made possible by financial assistance from the Spanish Ministry of Science and Technology's PROFIT program.

The nominal average reflectivity value of the field is currently at 90 %, the solar tracking error is 1.2 mrad per axis and the optical reflected beam quality is 3 mrad. Under typical conditions of 950 W/m^2, total field capacity is 2.5 MW$_{th}$ and its peak flux is 2.5 MW/m^2. 99 % of the power is collected in a 2.5-m-diameter circumference and 90 % in a 1.8-m circumference. The 43-m-high metal tower has three test platforms. The two first are located at 28 and 26 m and are prepared for testing new receivers for thermochemical applications. The third test platform is at the top of the tower at 43 m and houses an enclosed room with crane and calorimetric test bed for the evaluation of small atmospheric-pressure volumetric receivers, and solar reactors for hydrogen production. The tower infrastructure is completed with a 4-TN-capacity crane and a 1000-kg-capacity rack elevator.

Figure 67. An autonomous heliostat in the SSPS-CRS field.

The SSPS-CRS tower is equipped with a large quantity of auxiliary devices that allow the execution of a wide range of tests in the field of solar thermal chemistry. All test levels have access to pressurized air (29 dm^3/s, 8 bar), pure nitrogen supplied by cryogenic plant, where liquid N_2 is stored in a liquid tank with a 6 TN capacity. This installation is safe and efficient to operate, and it is extremely versatile to provide all the possible variants. This plant is able to provide N_2 flow rates from 70 kg/hour to 250 kg/hour with autonomy of several days or even weeks. There are also steam generators with capacity of 20 and 60 kg/h of steam, cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from an 8 m^3 buffer tank for use in steam generators or directly in the process, and the data network infrastructure consisting of Ethernet cable and optical fibre.

A hybrid heat flux measurement system to measure the incident solar power that is concentrated by the heliostat field is located at the SSPS-CRS tower. This method comprises two measurement systems, a direct one and an indirect one. The direct measurement system consists of several heat flux sensors with a 6.32 mm front-face diameter and a response time in microseconds. These micro sensors are placed on a moving bar, which is mounted in front of the reactor window. The indirect measurement system works optically with a calibrated CCD camera that uses a water-cooled heat flux sensor as a reference for converting grey-scale levels into heat flux values.

At 25 m level, a cantilever with heat shield can be used to position a (optical or IR) camera only a few meters from the aperture.

AORA SOLAR TOWER FACILITY

At the end of 2019, a new tower facility was incorporated to the PSA infrastructures catalogue. The AORA Solar Tower facility is a 35 m tall tower with a pressurized volumetric receiver (porcupine type receiver) installed on it, to heat up air at 15 bar pressure at nominal temperature of 800°C; coupled to a 100 kWe solarized gas turbine from Ansaldo. The 880 m^2 solar field is composed by 55 heliostats with a 16 m^2 reflecting surface on each one of them. Hot air from the turbine exhaust can be used also for cogeneration and/or poli-generation: extra 175 kW_{th} power air is available for driving thermal processes at medium to low temperature (<250°C).

Figure 68. General view of the AORA solar tower facility.

Parabolic DISH Systems

ACCELERATED AGEING TEST BED AND MATERIALS DURABILITY

This installation consists of 2 DISTAL-II model parabolic dish units with 50 kW total thermal power per unit and two-axis sun tracking system. In the DISTAL-II dishes, the initial Stirling motors have been replaced by different test platforms to put the materials or prototypes at small scale of high concentration receivers and perform accelerated temperature cycling. With fast focusing and defocusing cycles, the probes placed in the concentrator focus stand a large number of thermal cycles in a short time interval, allowing an accelerated ageing of the material. These platforms can be used for a large variety of applications: durability testing of materials, air-cooled volumetric receivers' tests (metal or ceramic), tests of small-size receiver prototypes with or without heat transfer fluid, etc.

The DISTAL-II parabolic dishes (Figure 69) were erected at PSA in 1996 and 1997, using the stretched membrane technology. These parabolic dishes have a diameter of 8.5 m and the thermal energy delivered in the focus is 50 kW_{th}. The focal distance is 4.1 m and the maximum concentration is 16000 suns at the focus. These concentrators can be used for any experiment requiring a focus with the characteristics above mentioned (50 kW_{th} maximum and 16000 suns peak concentration at the focus). The tracking consists in a two-axis azimuth-elevation system.

Figure 69. View of a parabolic-dish DISTAL- II with the original Stirling engine

Figure 70. Accelerated aging tests of steel samples at a parabolic-dish DISTAL- II

The test bed for durability and accelerated materials ageing is complemented with the laboratory for the assessment of the durability and characterization of materials under concentrated solar radiation (Materbla) existing at PSA, which is described in the laboratories section of this document (section 30).

EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected (Figure 71), discarding the stretched-membrane technology and applying a moulded composite-material system. These parabolic dishes can be used to test new prototypes of Stirling engines, or to perform any other test requiring a focus with 50 kW_{th} maximum and a maximum concentration of 16000 suns at the focus. The tracking system is azimuth-elevation.

Figure 71. Front and back views of the EURODISH.

Solar Furnaces facility

SF-60 SOLAR FURNACE

The SF60 consists, basically, on a 130 m^2 flat heliostat that reflects the solar beam onto a 100 m^2 parabolic concentrator that in turn concentrates the incoming rays on the focus of the parabola, where the tested specimens are placed. A louvered shutter placed between the heliostat and the concentrator regulates the incoming light. Finally, a test table, which movable on three axes, is used to place the specimens in the focus. The heliostat collects solar radiation and redirects it to the concentrator. The heliostat's reflective surface is made up of flat, non-concentrating facets, which reflect the sun's rays horizontally and parallel to the optical axis of the parabolic-dish concentrator, continuously tracking the sun.

The heliostat associated with the SF-60 consists of 130 flat facets, with 1 m^2 reflecting surface each. These facets have been designed, manufactured, assembled and aligned by PSA technicians. Every facet is composed of a 1 m^2 reflecting surface and 3 mm thick Rioglass flat mirror silvered on its back (second surface mirror). Solar Furnace Technicians are also responsible of a new method of fixation of the facet on a frame that minimizes deformation of the reflecting surface. Figure 72 and Figure 73 show the heliostat installed in this solar furnace and a detail of the backside of the facet, respectively.

Figure 72. HT120 heliostat in tracking.

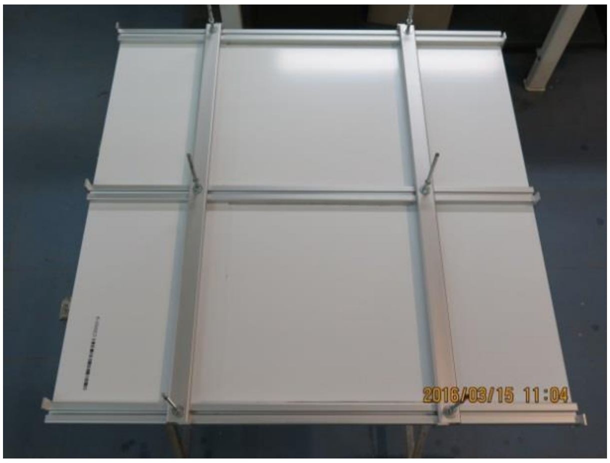


Figure 73. Back side of facet

The parabolic concentrator is the main component of solar furnace. Its function is to concentrate the sunlight reflected by the heliostat, multiplying the radiant energy in the focus. After thirty years in operation, the rectangular facets of the ancient Mc Donnell Douglas concentrator had deteriorated, showing optical defects and large surface undulation that affected its efficiency. That is why we decided to replace them with new ones with lower surface error and higher reflectivity and efficiency, so new facets with hexagonal-shaped mirrors were designed and manufactured at the Solar Furnace.

For the installation of the new facets, the original structure of the Mc Donnell Douglas concentrator was partially used, removing the excess part of the above-mentioned structure, and a new tubular structure was adapted to the remaining part of the original structure and serves to support the assembly. Finally, the facets were attached to the new tubular structure.

The new parabolic concentrator, called FAHEX 100 (Figure 74), is made of 463 facets grouped by their radius of curvature in three groups, depending on their distance from the focus. The facets with the smallest radius of curvature are located around the vertex of the parabola, followed by the facets with an intermediate radius of curvature, and finally, the facets with the largest radius of curvature are in the farthest part from the vertex of the concentrator.

The shutter (attenuator), see Figure 75, consists of a set of horizontal louvers, which turn on their axis to control the amount of sunlight incident on the concentrator. The total energy in the focus is proportional to the radiation that goes through the shutter. The test table is a mobile support for the test pieces or prototypes to be tested that is located under the focus of the concentrator. It moves on three axes (X, Y, Z) perpendicular to each other and positions the test sample with great precision in the focal area.

The combination of all the components described lead to the flux density distribution in the focus that is what characterizes a solar furnace. This distribution usually has a Gaussian geometry and is characterized by a CCD camera hooked up to an image processor and a Lambertian target. The characteristics of the focus with 100 % aperture and solar radiation of 1,000 W/m^2 are: peak flux, 670 W/cm^2, total power, 80 kW, and focal diameter, 22 cm.

Figure 74. Interior view of the PSA SF-60 Solar Furnace in operation.

Figure 75. Shutter of the PSA SF-60 Solar Furnace.

SF-40 SOLAR FURNACE

The SF-40 furnace consists mainly of an 8.5-m-diameter parabolic-dish, with a focal distance of 4.5 m (see Figure 76). The concentrator surface consists of 12 curved fiberglass petals or sectors covered with 0.8-mm adhesive thin-glass mirrors on the front. The parabola thus formed is held at the back by a ring spatial structure to give it rigidity and keep it vertical. The new SF40 solar furnace reaches a peak concentration of 5,000 suns and has a power of 40 kW, its focus size is 12 cm diameter and rim angle a= 50.3°. Its optical axis is horizontal, and it is of the “on-axis” type that is parabolic concentrator, focus and heliostat are aligned on the optical axis of the parabola.

It consists of a 100 m^2 reflecting surface flat heliostat, a 56.5 m^2 projecting area parabolic concentrator, slats shutter, and test table with three-axis movement.

The focus of the SF40 is arranged on the vertical plane. In order to work on the horizontal plane, the beam rays incident into focus are rotated 90°, using a tilted, cooled mirror placed at the focal area, which turn the beam to the horizontal plane. The facility is completed with a gas system and vacuum chamber -MiniVac 2-, which allows tests in controlled atmosphere and vacuum conditions, so that the specimens are not oxidized during tests.

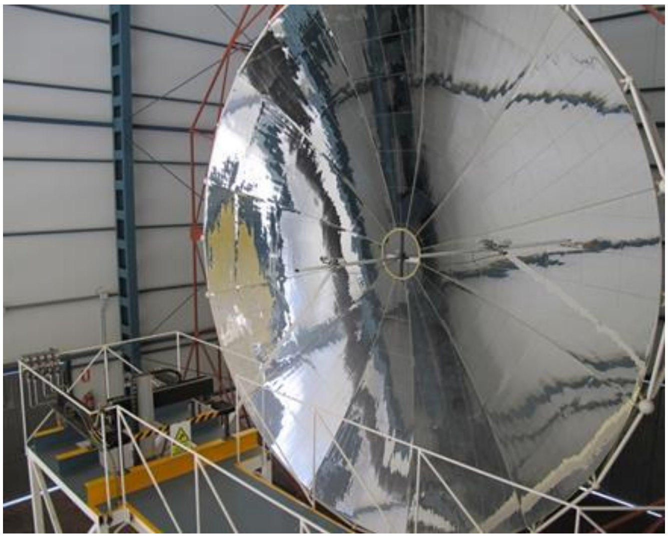


Figure 76. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

SF-5 SOLAR FURNACE

Designed and built at the PSA, this system is in operation since 2012 and is focused on carrying out tests that require high radiant flux, strong gradients, and very high temperatures.

It is called SF5 (Solar Furnace 5), due to its 5-kW power-, reaches concentrations above 7000 suns, its focus diameter is 2.5 cm, and it is mainly devoted to heat treatment of materials at high temperatures, under vacuum and controlled atmosphere conditions, for which a vacuum chamber, called Spherical Chamber, provided with a gas system is used.

It differs substantially from the existing PSA Solar Furnace SF60 and most operating solar furnaces, as it operates in a vertical axis, i.e., parabolic concentrator and heliostat are vertically aligned on the optical axis of the paraboloid, while in most existing solar furnaces, they are horizontally aligned. The main advantage of vertical axis solar furnaces is that the focus is arranged in a horizontal plane, so that the samples may be treated on a horizontal surface, just placing them directly in the focus, without a holder, avoiding problems of loss of material by gravity in those tests in which the treatment requires surface melting of the specimens.

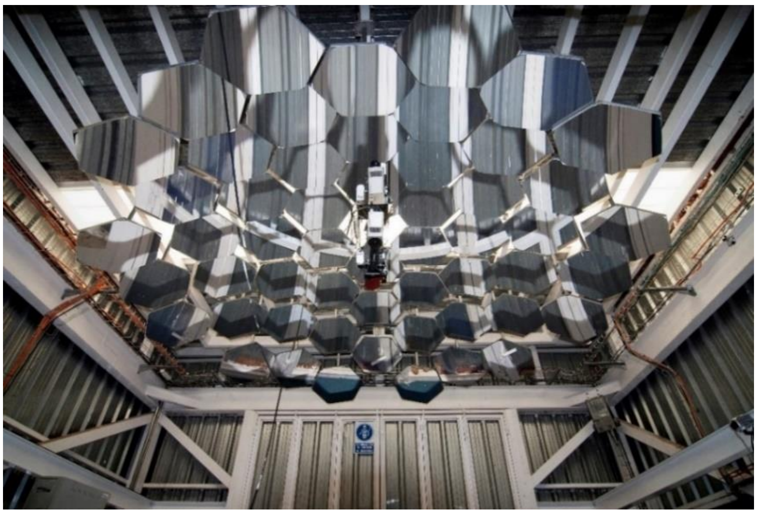


Figure 77. Concentrator of the SF-5 Furnace.

It basically consists of an 8.7 m^2 concentrator mirror, placed upside-down with the reflecting surface facing the floor, on an 18 m high metallic tower; in the centre of the base of the tower there is a 12 m^2 flat heliostat, whose centre of rotation is aligned with the optical axis of the concentrator. At the top of the tower, in the test room, and 2 m below the vertex of the concentrator, there is a test table. Finally, under the test table and at floor level of the test room, a louvered attenuator is placed.

OPAC: OPTICAL CHARACTERIZATION AND SOLAR REFLECTOR DURABILITY ANALYSIS FACILITY

The PSA optical characterization and solar reflector durability analysis facility, which is the result of a joint collaborative project between CIEMAT and DLR, has the necessary equipment to completely characterize the materials used as reflectors in solar concentrating systems. This laboratory allows the evaluation of characteristic optical parameters of solar reflectors and their possible deterioration. The following equipment is available in the laboratory of optical characterization of solar reflectors (see Figure 78 a):

Three portable specular reflectometers, Devices and Services Model 15R-USB, for measuring specular reflectance at 15° incidence angle, 660 nm wavelength and different aperture angles (3.5, 7.5, 12.5 and 23 mrad).

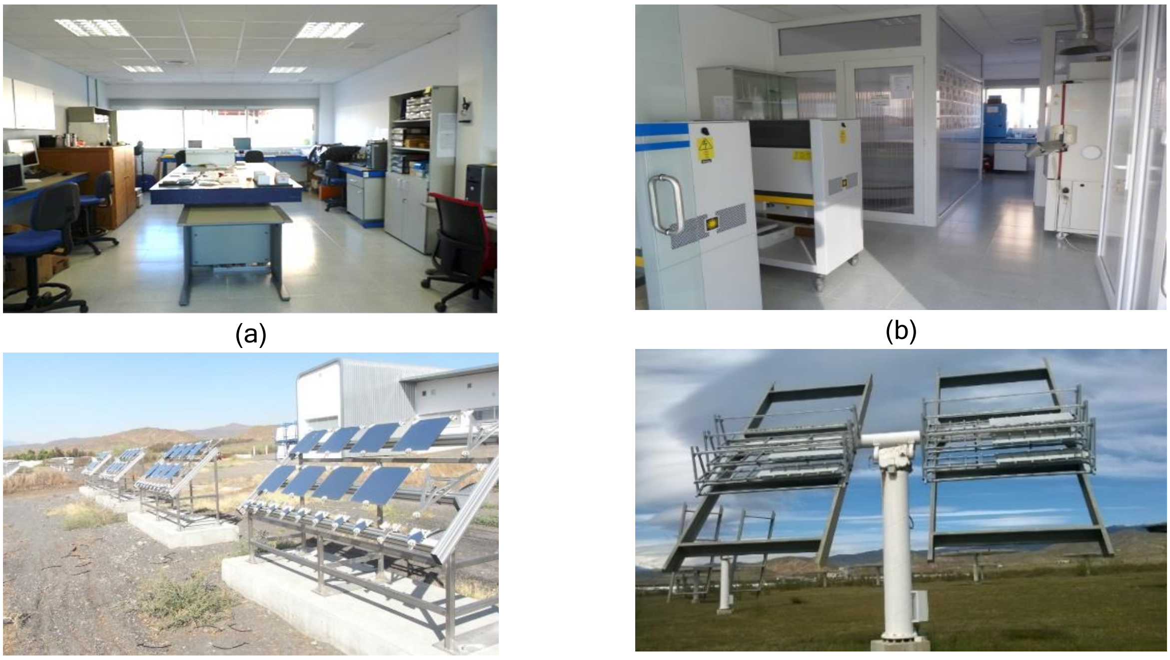
- One portable specular reflectometer, Devices and Services model MWR, for measuring specular reflectance at 15° incidence angle, 460, 550, 650 and 720 nm wavelength and at different aperture angles (2.3, 3.5, 7.5, 12.5 and 23 mrad).
- One portable reflectometer, PSE model pFlex 2.1, for measuring specular reflectance at 8° incidence angle, 470, 525 and 625 nm wavelength, and 67 mrad aperture angle.
- One portable reflectometer, Aragon Photonics model Condor, for measuring specular reflectance at 12° incidence angle, 435, 525, 650, 780, 940 and 1050 nm wavelength and 145 mrad aperture angle.
- One portable reflectometer, Konica Minolta model CM-700d, for measuring hemispherical and diffuse reflectance at 8° incidence angle, and 400-700 nm wavelength.
- Reflectometer prototype for measuring specular reflectance in a 5 cm diameter with spatial resolution of 10 pixel/mm, which measures at various wavelengths and aperture angles (model SR^2, designed and patented by DLR).
- Spectral Specular Reflectometer S2R for measuring specular reflectance spectra in the wavelength range 280-2500 nm at variable incidence angles of 8-70° and discrete acceptance angles of 7.4, 12.3, 14.8, 20.2, 35.9 and 107.4 mrad (designed and patented by DLR).
- Two Perkin Elmer Lambda 1050 spectrophotometers, with two 150-mm integrating spheres and specular reflectance accessory with 0 to 68° incidence angles (URA).
- One infrared spectrometer, Perkin Elmer FT-IR.
- Nikon D3 camera and 90 cm Cubalite kit for photos of specular surfaces without parasitic reflections.
- Zeiss Axio microscope model CSM 700 (with magnifications of 5, 10, 20, 50 and 100) for finding the profiles and roughness of highly reflective surfaces.
- Parstat 4000 impedance system to analyse the corrosion of reflector materials.
- General Purpose Optical bench as accessory for the Perkin Elmer Lambda 1050 spectrophotometer with advanced features for mounting optical devices for the development of new measurement instruments.

- Attension Theta 200 Basic tensiometer for static and dynamic contact angle assessment, which is a key parameter to study the performance of the anti-soiling coatings applied to solar reflectors and receiver tubes.

The solar reflector durability analysis laboratory is designed for accelerated ageing tests of these materials with the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime (see Figure 78. b). To do this, the environmental variables producing degradation of solar reflectors when they are exposed to outdoor conditions are applied in a controlled manner, both separately and in combination. The following equipment is available for these accelerated ageing tests:

- Two ATLAS SC340MH weathering chambers for temperature (from -40 °C to +120 °C), humidity (from 10 % to 90 %), solar radiation (from 280 to 3,000 nm) and rainfall of 340 L.
- Vötsch VSC450 salt spray chamber with temperatures from 10 °C to 50°C (450 L).
- Erichsen 608/1000 L salt spray chamber with temperatures from 10 °C to 50 °C.
- Two ATLAS UV-Test radiation chambers where UV light (with a peak at 340 nm), condensation and temperature can be applied. One of the chambers also includes rain simulation.
- MKF 720 test chamber, where UV light (with a peak at 340 nm) can be applied in combination with a wide range of temperature and humidity conditions.
- Hönle UVA Cube Ultraviolet radiation chamber.
- SC100 heated water bath, to perform the Machu test, according to the Qualitest guideline.
- Vöstch VCC3 0034 weathering chamber to test the material resistance against corrosive gasses (335 L, see Figure 78.b).
- Ineltec CKEST 300 test chamber for humidity and condensation testing with temperatures up to 70°C (300 L).
- Memmert HCP108 weathering chamber to apply humidity (20-95 %) and temperature (2,090 °C) with humidity and 20-160 °C without humidity).
- Two Nabertherm LT 24/12 and LT 40/12 Muffle Furnaces.
- Control Técnica/ITS GmbH sandstorm chamber with wind speeds up to 30 m/s and dust concentrations up to 2.5 g/m³.
- Erichsen 494 cleaning abrasion device to test the degradation due to the cleaning brushes, with several cleaning accessories.
- Taber 5750 linear abraser to check the materials resistance against the abrasion.
- Lumakin A-29 cross-cut tester to analyse the possible detachment of the paint layers.
- Soiling Pipe for simple sand erosion experiments based on DIN 52348. Erodent material hitting the specimen after around 160 cm of free fall under adjustable impact angles (designed by DLR).
- Artificial soiling chamber, equipped with the aerosol generator SAG410/L from TOPAS GmbH and an ultrasonic nebulizer to reach a realistic soiling picture on reflector samples (designed by DLR).
- Several devices for thermal cycles specially designed at the PSA.

Along with these labs, there are a series of outdoor test benches for exposing materials to outdoor weather conditions and comparing their degradation with those found in the accelerated ageing tests, to study the effectiveness of special coatings, to optimize the cleaning strategy and to analyse the soiling rate. In addition, two heliostat test benches were recently installed, one to test the influence of blocking on the coatings lifetime and another one to accelerate the reflectors degradation due to UV radiation under outdoor weather conditions. Finally, the laboratory is equipped with accessories necessary for their proper use, such as precision scales, thermo-magnetic stirrer, drier, ultrasonic bath for sample cleaning, tools for reflector samples preparation (cutting and polishing), safety cabinets, instrumentation for measuring pH, conductivity, oxygen, etc.



(a) (b) (c) (d)

Figure 78. (a) Optical characterization lab, (b) durability analysis lab, (c) outdoor test bench and (d) outdoor accelerated aging test bench at OPAC facilities.

Thermal Storage Systems

MOSA: MOLTEN SALT TEST LOOP FOR THERMAL ENERGY SYSTEMS

This facility is composed by an outdoor test loop with about 40 t of molten solar salt mixture and an indoor test bench that can contain about 115 kg of any salt.

The outdoor loop of MOSA is the largest facility worldwide similar to a commercial thermal energy storage system with a two-tank configuration but on a reduced scale. MOSA facility allows performing different kinds of tests in relevant environment and extrapolated scale. Some applications of this facility are:

- Testing of different circuit component (pumps, flowmeters, etc.) to be used in molten salts conditions.
- Optimization of operation procedures for two-tank storage system configuration.
- Optimization of operation procedures in risky situations for a two-tank storage system configuration and design of recovery procedures.
- Validation of models and simulation approaches for molten salt based thermal systems.
- Characterization of heat exchangers for molten salt/oil.
- Characterization of thermocline tanks.

For more information, see M.M. Rodríguez-García, M. Herrador Moreno, E. Zarza Moya. Lessons learnt during the design, construction and start-up phases of a molten salt testing facility, Applied Thermal Engineering 62 (2) (2014) 520-528, ISSN 1359-4311.

Up to now, the maximum operating temperature of MOSA was 390° C, however, in 2023, this facility has been upgraded with the installation of an electrical heater, which will allow the molten salt mixture to be heated up to about 550° C. Moreover, this heater is expected to be fed by electricity coming from a PV solar field in order to carry out power to heat (P2H) studies in the future.

The indoor test bench is called BES-II and it is especially designed for testing valves, pressure transmitters and other small components of molten salt circuits under quasi real working conditions up to 600°C and 40 bar. Components with nominal diameters from 2” up to 6” can be evaluated in this test bench.

Figure 79. Molten Salt (MOSA) outdoor test loop.

Figure 80. MOSA indoor test bench (BES-II).

For more information see M.M. Rodríguez-García, E. Rojas, M. Pérez, 2016, Procedures for testing valves and pressure transducers with molten salt, Applied Thermal Energy, 101, 139-146.

ALTAYR: ATMOSPHERIC AIR PACKED BED TEST BENCH

This facility is an insulated storage tank of around 0.1 m^3 where different packed bed configurations and materials can be tested using atmospheric air as heat transfer fluid. Provided with a maximum electric power of 15 kW, a charge process with air up to 850 °C is possible. Thermocouples along its length and at different radial positions give an accurate map of the packed-bed temperature.

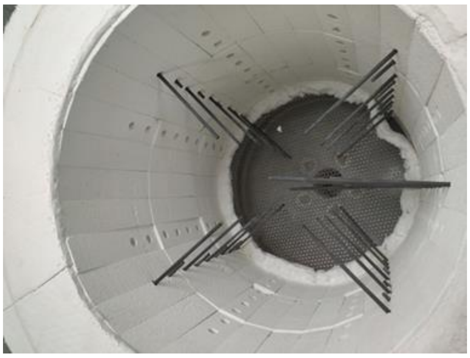


Figure 81. Picture taken from the top of the tank, showing its internal room and thermocouples at different lengths and radial positions.

Figure 82. Researcher adjusting some items from the upper top of the tank.

Test-Bed for Solar Thermal Applications: AQUASOL

The purpose of this facility is the study of the efficiency of large-aperture static solar collectors and its behaviour in the coupling with thermal energy systems 60-90 °C temperature levels.

The collector model installed is an LBM 10HTF with an aperture area of 10.1 m^2, manufactured by Wagner & Co. The static solar field is composed of 60 collectors with a total aperture area of 606 m^2 and a total thermal power output of 323 kW_{th} under nominal conditions (efficiency of 59 % for 900 W/m^2 global irradiance and 75 °C as average collector temperature).

It consists of 4 loops with 14 large-aperture flat plate collectors each (two rows connected in series per loop with 7 collectors in parallel per row), and one additional smaller loop with 4 collectors connected in parallel, all of them titled 35° south orientation. The solar field has rows of moving flat mirrors installed at the south of every row of collectors, they can track the Sun and reflect it, enhancing the radiation on each collector. This way, the effective aperture of the solar field can be augmented by 40 % using the same collector surface area. The five loops of collectors are connected with a thermal storage system through a heat exchanger. The thermal storage system consists of two connected water tanks for a total storage capacity of 40 m^3. This volume allows sufficient operational autonomy for the fossil backup system to reach nominal operating conditions in the desalination plant. The facility has an air cooler that allows the entire energy dissipation from the solar field, which is useful for efficiency tests at different temperature levels.

Figure 83. Aerial view of the 606-m^2 large-aperture flat plate solar collector field (AQUASOL-II).

The flexibility of the solar field allows the operation of each loop independently, through their own valves and pumping system. Each loop is connected to an individual heat exchanger that offers the possibility of coupling it with any low-temperature thermal energy-consuming device for testing purposes. Two of these loops are currently connected to heat distribution systems to supply thermal energy to membrane distillation test-beds and brine concentration pilot plants.

Experimental Solar Desalination Installations

MULTI-EFFECT DISTILLATION FACILITIES

SOLAR MULTI-EFFECT DISTILLATION FACILITY

This facility is composed of the following subsystems:

- A 14-stage multi-effect distillation (MED) plant
- A water-based solar thermal storage system
- A double effect ($LiBr$-H_2O) absorption heat pump
- A fire-tube gas boiler

The multi-effect distillation unit is made up of 14 stages or effects, arranged vertically with direct seawater supply to the first effect (forward feed configuration). At a nominal 8 m^3/h feedwater flow rate, the distillate production is 3 m^3/h, and the thermal consumption of the plant is 190 kW_{th}, with a performance ratio (number of kg of distillate produced per 2326 kJ of thermal energy consumed) over 9. The saline concentration of the distillate is around 5 ppm. The nominal temperature gradient between the first cell and the last one is 40°C with a maximum operating temperature of 70°C in the first cell. The system heat transfer fluid is water, which is heated as it flows through flat-plate solar collectors of the facility AQUASOL (see the description in section Test-Bed for Solar thermal Desalination Applications), being the energy collected and then transferred to the storage system. The hot water from this storage system provides the MED plant with the thermal energy required for its operation.

(a) (b) (c)

Figure 84. The PSA SOL-14 MED Plant (a) double-effect $LiBr$-H_2O absorption heat pump (b) and 606-m^2 flat plate solar collector field with tracking mirrors(c).

The MED plant can also operate coupled with a double effect (LiBr-H_2O) absorption heat pump, which is connected to the last effect of the MED plant. The low-pressure saturated steam (35°C, 56 mbar abs) generated in this last effect supplies the heat pump evaporator with the thermal energy required at low temperature, which would otherwise be discharged to the environment, cutting in half the thermal energy consumption required by a conventional multi-effect distillation process. The fossil backup system is a propane water-tube boiler that ensures the heat pump operating conditions (saturated steam at 180°C, 10 bar abs), as well as operating the MED plant in the absence of solar radiation.

MULTI-EFFECT VACUUM EVAPORATOR

The fully plastic Multi-Effect Vacuum Evaporator stands for Cartridge EVAPorator (CEVAP). This technology follows the Multi-Effect Distillation principle for water treatment. Distillation under vacuum can be driven by low-grade heat input below 40°C, as vacuum lowers the boiling point of liquids. The use of multiple distillation steps allows for the heat to be used several times to produce distillate, where each step boils at a lower pressure. This unit has 4 effects. The main innovation is the use of self-wetting evaporation surfaces packed in compact, low-cost, replaceable units, called cartridges. Cartridges can be easily replaced and do not require chemical cleaning, allowing for maximum uptime and minimising maintenance costs. The application of the CEVAP technology is the treatment of industrial waste water with chemicals that cannot be treated with other membrane-based processes, as well as the concentration of high salinity solutions which can scale on non-plastic surfaces. CEVAP is currently being evaluated for desalination brine concentration with the use of solar thermal energy, connected to the AQUASOL solar thermal field.

MEMBRANE DISTILLATION TEST BED

The installation is designed for evaluating solar membrane distillation applications. There are two solar fields of flat-plate collectors available: one of 20 m^2 with two parallel rows of five collectors in series (Solaris CP1 Nova, by Solaris, Spain), and another one of 40 m^2 with four large-aperture collectors in parallel (LBM 10HTF, by Wagner Solar, Spain). Both fields are connected to water storages of 1,500 and 2,500 litres respectively, acting as heat buffers for thermal regulation and storage; they also have a distribution system that enables simultaneous connection of several units. The test-beds allow for a stationary heat supply using the thermal heat storage or for direct supply of solar energy without buffering. The installation is fully automated and monitored (temperatures and flows) and allows for heat flow regulation. The maximum thermal power is 7 kW_{th} in one case and 14 kW_{th} in the other, and hot water can be supplied with temperature up to about 90°C.

Figure 85. Internal (Left) and external (Right) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility.

Figure 86. V-MEMD unit.

The installation has a separate water circuit that can be used for cooling (about 3.5 kW_{th}) in the desalination units and as a device for supplying simulated seawater, with the possibility of working in an open or closed loop. In the latter case, both the distillate and brine flows are collected and mixed to be fed again into the desalination units after passing through a heat dissipation system. The installation currently operates with Membrane Distillation modules and has a wide range of different commercial and pre-commercial units from different commercial manufacturers. The list of MD pilots that have been evaluated or are under evaluation is:

- Plate and frame air gap (AG) MD commercial modules from Scarab (total membrane area 2.8 m^2).
- Two plate and frame permeate-gap (PG) MD prototypes from Keppel Seghers (both with total membrane area 9 m^2), a compact one (M33) and another which is split in three separate modules connected in series for higher energy recovery (PT5).
- Spiral-wound PGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
- Two spiral-wound AGMD modules from Aquastill with membrane areas of 7 m^2 and 24 m^2 each.
- WTS-40A and WTS-40B units from Aquaver, based on multi-effect vacuum membrane distillation technology using modules fabricated by Memsys (5.7 m^2 and 6.4 m^2 total membrane area respectively).
- Two units to evaluate spiral-wound modules from Aquastill operating in vacuum-enhanced air-gap configuration with membrane areas of 7.2, 24 and 26 m^2 respectively.
- A vacuum multi-effect membrane distillation (V-MEMD) unit with a 4-effect module with a total membrane area of 6.72 m^2.

PILOT PLANT FOR STUDYING COMBINATIONS OF FORWARD OSMOSIS AND REVERSE OSMOSIS/NANOFILTRATION

The plant has three different units that can be coupled in different ways between them: (i) Forward Osmosis; (ii) Reverse Osmosis/Nanofiltration; (iii) Microfiltration (Figure 87). The Forward Osmosis (FO) unit uses 12 hollow fibre modules (Aquaporin HFF02) 0.2 mm long with 2.3 m^2 total membrane area each one, operating in counter-current flow, inside-out, laid out in a flexible rack that allows combining them in series or parallel configuration. The nominal flow rate is 3.6 m^3/h. The Reverse Osmosis (RO) unit has one 8" and two 4" pressure vessels that can be connected in series or parallel, each of which able to host four membranes. The nominal flow rate is 3 m^3/h and the pumping system can work at different pressures up to a maximum of 80 bar (RO)/16 bar (NF). Finally, there is an MF unit with 3 m^3/h nominal flow rate. The installation is completely monitored with pressure sensors, conductivity and flowmeters, and it is designed in a flexible way regarding the interconnection of the units so that FO can be used as a pre-treatment for RO, or NF can be used in combination with FO, and even the FO can be used in PRO mode using the pumping system of the RO unit.

Figure 87. Test bed for FO-RO combination research.

REAL SEAWATER CONTAINERS

The system is composed of three storage tanks connected in series containing a total volume of 300 m^3 of real seawater (Figure 88). The containers are connected to a hydraulic distribution circuit that can supply feed water to the different desalination pilot plants at the required flow rate of each. The circuit also returns the brine and the distilled water back to the containers, so that the total mass and the salinity are conserved. A heat dissipation circuit using a compression chiller maintains the temperature constant in the containers.

Figure 88. Containers filled with real seawater for desalination tests in closed loop.

CSP+D test facilities

CSP+D TEST BED: INTEGRATION OF MED THERMAL DESALINATION & SOLAR THERMAL POWER PLANTS

This facility is devoted to the research of the coupling between concentrating solar power (CSP) plants and Desalination (CSP+D). The testing facility is composed of two steam generators (250 kW and 500 kW) fed by thermal oil coming from a parabolic trough solar field able to deliver thermal oil with temperatures up to 400 °C and an auxiliary electrical power system that raises the temperature if required. The steam generators can produce steam at different pressures, which allow recreating any of the typical intermediate extractions or the exhausted steam available at a turbine of a thermal power plant. The low-pressure steam is obtained by making the steam from the generators to flow through two different pipe sections (12-inch diameter) equipped with control valves, which allows achieving saturated steam at two different levels: 0.074 bar/42 °C (nominal flow rate of 119 kg/h, maximum flow rate of 360 kg/h) and at 0.16 bar/58 °C (nominal flow rate of 195 kg/h, maximum flow rate of 360 kg/h).

Both, the high- and low-pressure steam can be used as motive and entrained vapour, respectively, in a train of four steam ejectors coupled to the PSA MED plant, simulating the behaviour of a MED plant working with thermal vapour compression (TVC-MED). The steam ejectors can work in a wide range of pressure conditions for the motive steam (40 – 6 bar; 4 – 2 bar), which also makes this test bed useful for the characterization of such kind of devices. The low-pressure steam can also be condensed through two conventional air condensers without passing by the steam ejectors, with the aim of allowing research in CSP cooling topics. The flexibility of the test facility also allows the on-site evaluation of innovative dry coolers prototypes for their comparison with respect to the conventional air condensers currently available at the market.

Figure 89. View of the outside of the CSP+D test bed building with the air coolers (left) and partial view of the interior of the CSP+D test bench (right).

VOMBINED COOLING PILOT PLANT

This test facility is a completed equipped pilot plant to evaluate innovative cooling systems for CSP plants. The innovative cooling system is a combined cooling system composed of a wet cooling tower and a dry cooling tower (Air Cooled Heat Exchanger). The hydraulic circuit of the test bench has been designed to enable the testing of the wet and dry cooling separately and the series and parallel configurations. The testing facility also can compare this kind of combined cooling system with conventional ones composed by a wet cooling tower and an air-cooled condenser.

The combined cooling test facility consists of three circuits: cooling circuit, exchange circuit and heating circuit. In the cooling circuit, cooling water circulating inside the tube bundle of a surface condenser is cooled down through a hybrid cooler composed of an Air Cooled Heat Exchanger (200 kW_{th}) and a Wet Cooling tower (200 kW_{th}), functional prototypes that have been built by the French company Hamon D'Hondt. In the exchange circuit, an 80 kW_{th} steam generator produces saturated steam (in the range of 120-300 kg/h) at different temperatures (42-60°C), which is then condensed in the surface condenser while releasing the condensation heat to the cooling water that is heated. The condensate from the surface condenser goes to a tank that supplies the water to the steam generator by a pump when needed. In the heating circuit, the AQUASOL-II large-aperture flat plate solar collector field provides the hot water to drive the steam generator. In order to compare with conventional air-cooled condenser, there is a bypass installed in the exchange circuit so that the steam generator can provide the steam either to the surface condenser connected to the hybrid cooler or to the Air-Cooled Condenser (335 kW_{th}).

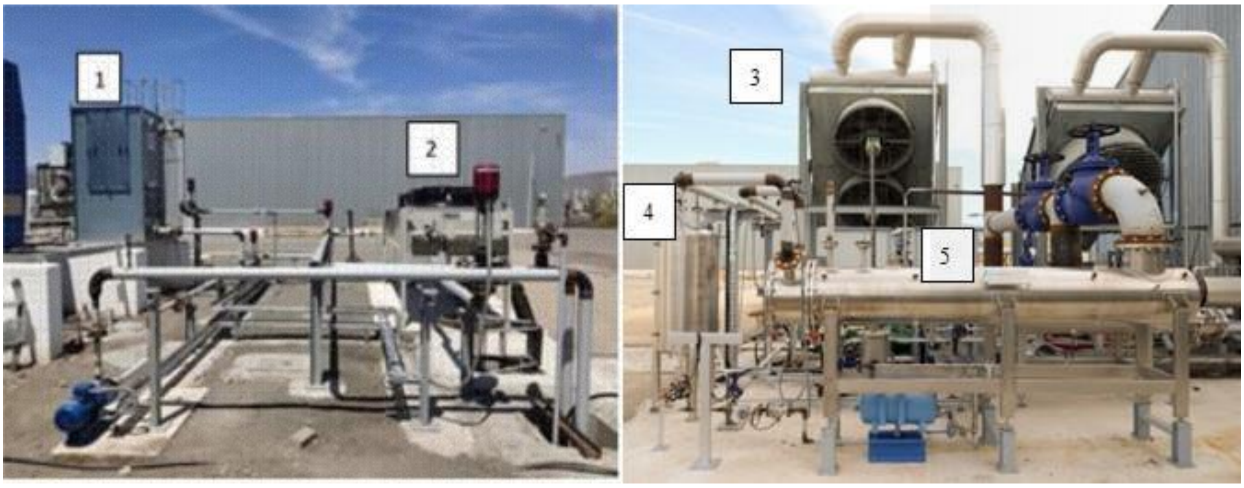


Figure 90. General view of the hybrid-cooling test bed: (left) Cooling circuit: wet cooling tower (1) and air- cooled heat exchanger (2). (Right) Exchange circuit: air-cooled condenser (3), condensate tank (4) and surface condenser (5).

Experimental Solar Decontamination and Disinfection Installations

The main facilities related with solar water purification are listed and described below:

- Solar CPC (compound parabolic collector) pilot plants.
- Open solar pilot photoreactors: raceway pond reactors.
- Solar simulators.
- UVC-pilot plant.
- Solar Waterfall reactor.
- UV-LED lab system.
- Ozonation pilot plant.
- Solar CPC with direct injection of ozone.
- Nanofiltration pilot plant.
- Pilot plant for photocatalytic production of hydrogen based on solar energy.
- Wet Air oxidation pilot plant.
- Electro-oxidation pilot plant
- Solar UVA monitoring equipment
- Pilot plant for physicochemical pre-treatment of wastewaters
- Pilot plants for biological treatment.
- Membrane Distillation (MD)/Crystallizer pilot plant.
- Experimental culture camera.

SOLAR CPC PILOT PLANTS

Since 1994, several CPC pilot plants have been installed at PSA facilities (Figure 91). Basically, the solar pilot plants are built by modules which can be connected in series. Each module consists of a number of photo-reactors placed on the focus of an anodized aluminium mirror with Compound Parabolic Collector (CPC) shape to optimize solar photons collection in the photo-reactor tube. The modules are placed on a platform titled 37° horizontally to maximize the global solar collection of photons through the year. In addition, the pilot plants are equipped with added systems for different purposes, such as: sedimentation tanks (for catalyst recovery), heating and cooling systems for temperature control during the experiments, coupling with other treatment technologies like bio-treatment, ozonation, etc. A summarize of the already installed solar CPC reactors is shown in Table 1.

Figure 91. View of several CPC photo-reactors for purification of water. (top) CPC facilities I, (bottom) CPC facilities II.

As mentioned in Table 1 ,CADOX photo-reactor is completely monitored (pH, T, ORP, O_2, flow rate, H_2O_2) and controlled (pH, T, flow rate). Besides, and connected to this photo-reactor, there is a biological water treatment system consisting of three tanks: a 165 L conical tank for wastewater conditioning, a 100 L conical recirculation tank and a 170 L flat-bottom fixed-bed aerobic biological reactor. The fixed-bed reactor is filled with Pall®Ring polypropylene that takes up 90-95 L and can be colonized by active sludge from a MWWTP.

A 2 m^2 CPC collector (Figure 92) with 10 borosilicate glass tubes (50 mm diameter), illuminated volume of 22 L and a total volume of 75 L is connected to four electrochemical cells for experimental research on electro-photo-Fenton processes for decontamination and disinfection of water.

In 2016, a new pilot plant with two modules of 2 m^2-collectors with different mirror shapes (CPC and U mirror type) has been installed at PSA (Figure 93). It is composed by a feeding polypropylene tank of 192 L of total volume and a preparation tank of 92.5 L, connected by gravity to the CPC and U type photo-reactors. The last presents 1.98 m^2 of irradiated surface with a recommended operating volume of 53 L. The whole pilot plant is equipped by a UVA solar sensor and automatically controlled. In addition, the pilot plant is equipped with a solar water-heating panel that allows increasing water temperature prior to filling the photo-reactors.

Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added systems/ Characteristics
1994	3x3	250/108	Flow	50	-
2002	15	300	Flow	32	-
2004 (CADOX)	4	75/40	Flow	50	- 50 L ozonation system - Biological water treatment system - Monitoring (pH, T, ORP, O2, flow rate, H2O2, O3), control (pH, T, flow rate)
2007 (SOLEX)	3.08(x2)	40/22	Flow	32	- Twin prototypes - Plexiglass screen - Monitoring dissolved O2 and temperature - Specially developed for photo-Fenton applications
2008 (FIT)	4.5	60/45	Flow	50	- Monitoring (pH, T, O2, flow rate) and control (T (20-55°C), flow rate). - 100 L sedimentation tank for catalyst separation
2010 (FIT-2)	4.5	60/45	Flow	50	- Monitoring (pH, T, O2, flow rate) and control (T (20-55°C), O2, flow rate)
2011 (HIDRO- CPC)	2.1	25/14.24	Flow	32	- Coupled with H2 generation pilot plant
2011 (CPC25)	1	25/11.25	Flow	50	-
2013 (ELECTROX)	2	40/25	Flow	50	- Coupled with electro-photo-Fenton plant
2013 (NOVO75)	2	100/75	Flow	75	- Monitoring (pH, T, O2, flow rate) and control (T, O2, flow rate)
2013 (CPC25)	1	25/11.25	Flow or static	50	- Variable volume, versatile for different volume of water
2013 (SODIS- CPC)	0.58 (x2)	25/25	static	200	- Low cost, no recirculation system
2016 (NOVO 75 V1.0)	2.03 (x2)	34 or 53	Flow or static	75	- Two modules of collectors: CPC versus U-mirror type alternatively used - Tubes installed in vertical position - Air injection in tubes - Monitoring (pH, T, O2, flow rate) and control (T, O2, flow rate) - Automatic control system for filling the system accordingly to incident energy - Solar panel for water heating

Table 1. Summarize of CPC pilot plants at PSA facilities

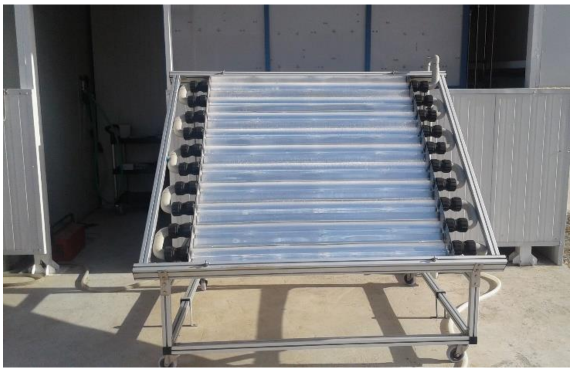


Figure 92. View of 2 m^2-CPC coupled to Electro-Fenton pilot plant (ELECTROX).

Figure 93. View of new CPC and U-type photoreactors (NOVO 75 V 1.0).

Raceway pond photoreactors

Two Raceway Pond Reactors (RPR) pilot plants are available in the facilities of the Solar Treatment of Water Research Unit at PSA. These are open, closed-loop photoreactors made of PVC with 0.97 m of length and equipped with a paddle wheel connected to an engine to recirculate the water in a turbulent flow mixing regime (mixing time around 2.5 min) with total capacities ranging from 15 to 90 L at 5-15 cm of liquid depth.

Figure 94. Raceway Pond Reactor with capacities of (left) 15 L and 5 cm of liquid depth and (right) 90 L and 15 cm of liquid depth.

Solar simulators

Along with these pilot-plant facilities, there are two solar simulators provided with xenon lamps for small-scale water decontamination and disinfection experiments. In both systems, the radiation intensity can be modified and monitored. One of the solar simulators XLS+, contains a UV filter (Suprax) with a wavelength limitation of 290 nm, simulating external solar radiation. Temperature can also be modified and controlled in both systems by a cooling system (SUNCOOL).

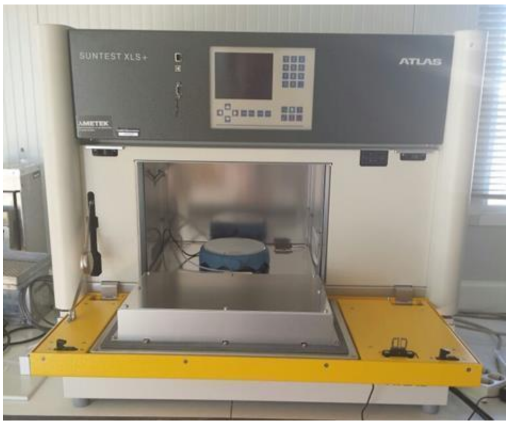


Figure 95. Solar simulator SUNTEST XLS+.

UVC pilot plants

Ultraviolet (UV) pilot plant was designed to treat and disinfect water for research and comparison with the solar technologies. This plant consists of three UV-C lamps (max. flow rate 25 $m^3 \cdot h^{-1}$, 254 nm peak wavelength, 400 $J \cdot m^{-2}$ max. power) connected in series, with the flexible configurations for single lamp, two or three lamps in recirculating batch mode or continuous flow mode. Lamps power and flow rate can be regulated according to the needs of the water. Furthermore, the plant is equipped with a dosage system of reactants (acid, base, and hydrogen peroxide). The total volume per batch is 200 - 250 L, with illuminated volume and area of 6.21 L and 0.338 m^2 per lamp module, respectively. The system is equipped with pH and dissolved oxygen sensors in-line and connected to a PROMINENT controller for automatic data acquisition of both parameters (Figure 96 (a)).

Figure 96. (Left) UVC pilot plant installed at PSA facilities and (Right) recent improvements.

The UVC pilot plant was improved (Figure 96 (b)) not so long ago. A new UVC module with capacity for 3 UVC lamps (model UV Lamp Dulcodes 3 x 230 LP; Max. flow rate 86 $m^3 \cdot h^{-1}$; Lamp power 3 x 260 W; Connected load 825 W; Radiation chamber length 1185 mm) was installed. The new module was connected to the impulsion system (pump) and recirculation circuit (pipes and tank) of the existing plant. There is also a new control panel for monitoring and values registration of the new 3 lamps with six radiation sensors inserted in the frame (Transmittance sensor UVX-SE sensor, Spectral sensor ranges UVC 200 – 280 nm).

A second pilot plant of UV disinfection/filtration system consisting of a UV-C lamp and a 25 μm filter to remove microbiological contamination from tap water before further water treatment assays is also available in the facilities of the Solar Treatment of Water Research Unit at PSA.

SOLAR WATERFALL REACTOR

The solar waterfall reactor (Figure 97) is based on a waterfall AISI 316L stainless steel structure with polypropylene pipes. Water is distributed from a tank (12 L) to the open waterfall structure by a centrifugal pump (Panworld NH10PX-T) where it will have contact with natural sunlight and a catalyst supported in 5 L-shaped supports with an irradiated surface of 0.42 m^2 (steps, stainless steel AISI-316L 0.8 mm thick). A tubular diffuser has been installed at the top of the reactor for uniform water distribution. A water rotameter (50-500 L/h) and a PT-100 temperature probe are also included. The optimized total and illuminated water volumes are 5 and 1.6 L, respectively.

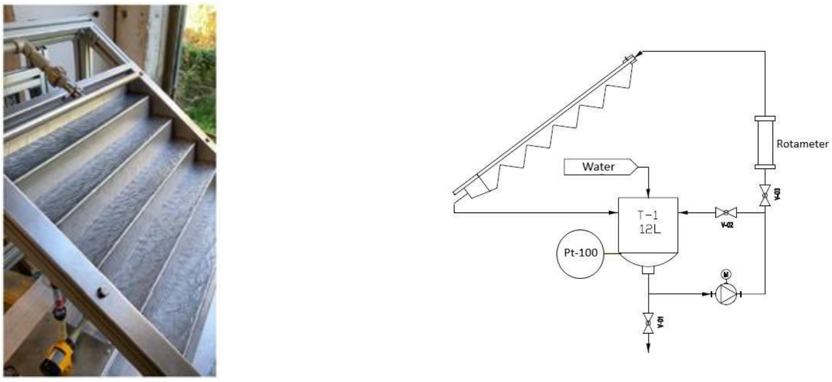


Figure 97. Solar waterfall reactor photography (left) and scheme (right).

UV-LED LAB SYSTEM

The UV-LED system at lab scale (LED275-0.01/300-0.03/365-1/450-1cb, provided by APRIA Systems S.L.) consists of the following parts (Figure 98):

- A collimation system. It includes 4 Lamps, concretely, 1 UV-C (λmax = 275 nm), 1 UV-B (λmax = 300 nm), 1 UV-A (λmax = 370 nm) and 1 VIS (λmax = 300 nm) LEDs. Each type of light has an independent control system (on/off and adjustable total radiated power). The system allows simultaneously working with 1, 2, 3 or 4 types of LEDs in different reactors.
- Collimation tubes. 2 collimator tubes (Ølens = 5.08 cm) + 1 collimator lens (λ = 250 – 350 nm, Ø = 5.08 cm, focal length = 6.00 cm); and 2 collimator tubes (Ølens = 5.08 cm) + 1 collimator lens (λ = 350 – 700 nm, Ø = 5.08 cm, focal length = 3.20 cm).
- External shell for the system protection and manipulation including: 4 holes for placing Petri dishes (Ø= 5 cm, V ≈ 35 mL, unsterilized), rings for regulating the distance from the lamp to the reaction device (0 to 3 cm), a console with a control panel for regulation and monitoring the power consumed by the LEDs. LEDs´ temperature is monitored through four PT-100 probes.

Figure 98. UV-LED lab system available at PSA facilities.

OZONATION PILOT PLANT

The ozonation pilot plant is equipped with an oxygen generator (Anseros SEP100), ozone generator (corona-discharge, Anseros COM-AD02), two non-dispersive UV analysers (BMT 964) to measure inlet and outlet ozone concentration in gas phase, a flowmeter for inlet air regulation, reagents dosing system and pH automatic control. Moreover, the pilot plant is equipped with a pH sensor inserted in the recirculation line. In 2016, new instrumentation was added: (i) equipment for humidity elimination in the ozone gas outlet; (ii) Thermo-catalytic residual ozone destructor; and (iii) a dissolved ozone sensor.

Figure 99. Pictures of the improved parts of the ozonation pilot plant: a) New 580L contact column reactor; b) Pressurized tank; c) HP pump for nano-bubbles generation; d) Venturi for micro-bubbles injection and e) complete view of the new ozonation pilot plant.

In 2020, the ozonation pilot plant was improved with the main objective of increasing the gas-liquid mass transfer of the system. It can be operated in different modes: (i) Bubble column (from 20 to 580 L total volume) (Figure 99 (a)); (ii) nano-bubble with HP pump (EBARA MVP 9-550/10, 5.5 kW) (from 50 to 110 L in batch mode operation) (Figure 99.(b) and (c)); (iii) HidroV mode with a venturi for the generation of micro-bubbles of ozone to be injected in the pressurized tank (110 L) (pump EBARA CDXM/A 90/10, 1.2 kW); (iv) HidroVT with a venturi for micro-bubbles injection into an intermediate tank of 2 L working in recirculation flow with the 110 L pressurized tank (pump EBARA CDXM/A 90/10, 1.2 kW) (Figure 99 (d)). This ozonation system is prepared to work in batch mode allowing its combination with other technologies such as, CPC photo-reactors, photocatalysts and the UV pilot plant.

SOLAR CPC WITH DIRECT INJECTION OF OZONE

The solar photo-reactor pilot plant, provided by Arenys Inox S.L., consists of three aluminium anodized CPC modules provided with diffusers inside the tubes to allow the direct injection of ozone in water (coming from the ozone generator previously described). Each module has a surface of 0.28 m^2 with three borosilicate tubes of 50 mm diameter (2.5 mm thickness and 700 mm length). At the inlet of each borosilicate tube, there is a stainless-steel gas diffuser AISI-316L (2-micron pore). Water is driven by a Pan World NH50PX 220 V AC and 45 W electromagnetic pump (flow rate of 25 L·min-1). This design contemplates working with one, two or three CPC modules in series, allowing the equipment to operate at different volumes of water from 12 to 25 L. The plant includes data acquisition equipment for pH (HACH), dissolved oxygen, dissolved ozone (model UV-106-W cleaning system, patented MicroSparge™ technology) and temperature (PT-100). The control system SC200 is provided by HACH. The plant includes a thermo-catalytic ozone destructor.

Figure 100. Solar CPC with direct injection of ozone available at PSA facilities

NANOFILTRATION PILOT PLANT

The nanofiltration (NF) system has two working modes, in series and in parallel. The basic system consisted of three FILMTEC NF90-2540 membranes, connected in parallel, with a total surface area of 7.8 m^2. These polyamide thin-film composite membranes work at a maximum temperature of 45°C, a maximum pressure of 41 bar and a maximum flow rate of 1.4 $m^3 \cdot h^{-1}$, whereas operation pH range is 2 - 11. pH control permits the cleanings and to evaluate the separation of different compounds in the membranes depending on the pH value. A dosing pump is also included for studying the effect of biocide addition. It has a feeding tank of 400 L (Figure 101. left). In 2016, the nanofiltration system was automatized by including electro-valves and automatic acquisition of the different instrumentation signals (flow, pressure, conductivity, temperature, etc.) with the final aim of stablishing a P&ID control system (Labview interface was implemented, Figure 101 (right) for controlling the required quality of the permeate flow generated as well as the concentrated stream.

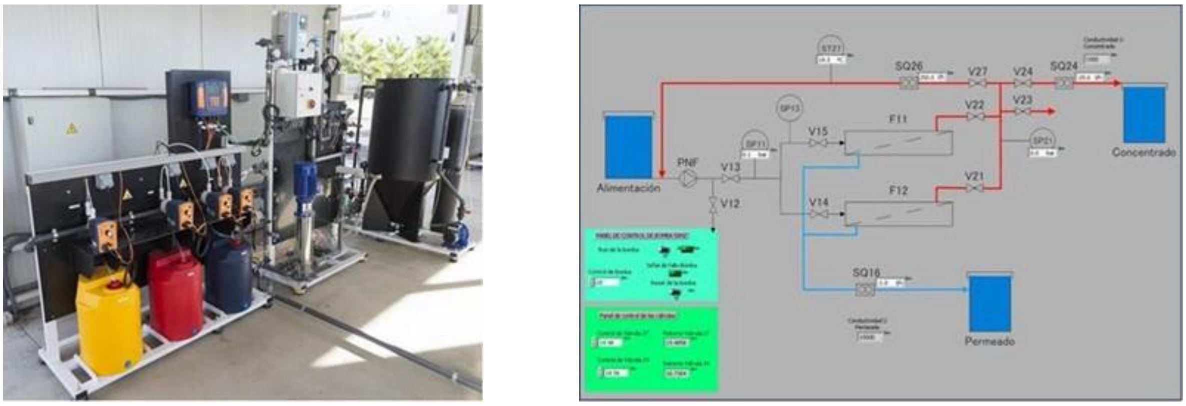


Figure 101. Left: Nanofiltration pilot plant. Right: New labview interface for control and automatic operation of the pilot plant.

PHOTOCATALYTIC GENERATION OF HYDROGEN PILOT PLANT

The pilot plant for photocatalytic hydrogen generation is composed by a closed stainless-steel tank of 10 L connected to a CPC photo-reactor for the simultaneous removal of organic contaminants from aqueous solutions and hydrogen generation (Figure 102

Figure 102). The tank is fitted with gas and liquid inlet and outlet and a sampling port. Two parallel mass flow controllers are used to control the desired N_2 gas flow into the reactor headspace during the removal of O_2 to achieve the reduction conditions as well as to drag the hydrogen produced. A centrifugal pump (PanWorld NH-100PX) with a flow rate of 20 $L \cdot min^{-1}$ is used to recirculate the aqueous slurry from the tank to the tubes of the CPC. The photo- reactor is composed of 16 Pyrex glass tubes (inner diameter 28.5 mm, outer diameter 32 mm, irradiated length 1401 mm) mounted on a fixed platform tilted 37° (local latitude). The total area and volume irradiated is 2.10 m^2 and 14.25 L, respectively. The composition of the gas stream is quantified by a MicroGC 490, using Argon as gas carrier.

Figure 102. Left: Solar pilot plant for photocatalytic generation of hydrogen; Rigth: Gas (N_2 and Ar) conduction systems.

WET AIR OXIDATION PILOT PLANT

A pilot plant was designed and installed in 2016 as a harsh pre-treatment to reduce the complexity of industrial effluents and reaction time of a subsequent solar advanced oxidation process (AOPs) (Figure 103). This pilot plant operation allows different combinations of temperature and pressure, various proportions of oxygen and nitrogen, oxidants as peroxide and peroxymonosulfate before heating and/or pressurized the system, and the use of different metallic salts as catalyst. The Wet Air Oxidation pilot plant consists of a stainless-steel reactor with a total volume of 1 L, a magnetic stirrer, a breakup disk, liquid reagents injector prepared to operate under 200 bar and a maximum temperature of 300°C, thermo-probe, pressure sensor (until 250 bar) and a cooling-heating jacket, all made of stainless steel. The Wet Air Oxidation pilot plant includes an automatic system of control and data acquisition of diverse parameters such as pressure, temperature, reagents dosses and agitation velocity.

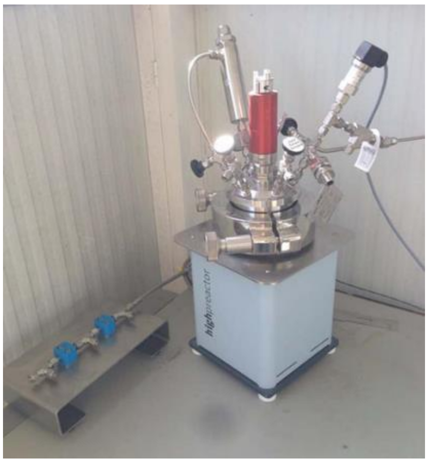


Figure 103. Wet Air Oxidation Pilot plant.

ELECTRO-OXIDATION PILOT PLANT

Electro-oxidation pilot plant consisted of four undivided commercial electrochemical cells (Electro MP Cell from ElectroCell) conformed by a boron-doped diamond film on a niobium mesh substrate (Nb-BDD) as anode and a carbon-polytetrafluoroethylene (PTFE) gas diffusion electrode (GDE) as cathode, both with 0.010 m^2 effective area single-sides. Electrodes were connected to a Delta Electronika power supply and water from a reservoir is recirculated through the system by centrifugal pumps (Figure 104).

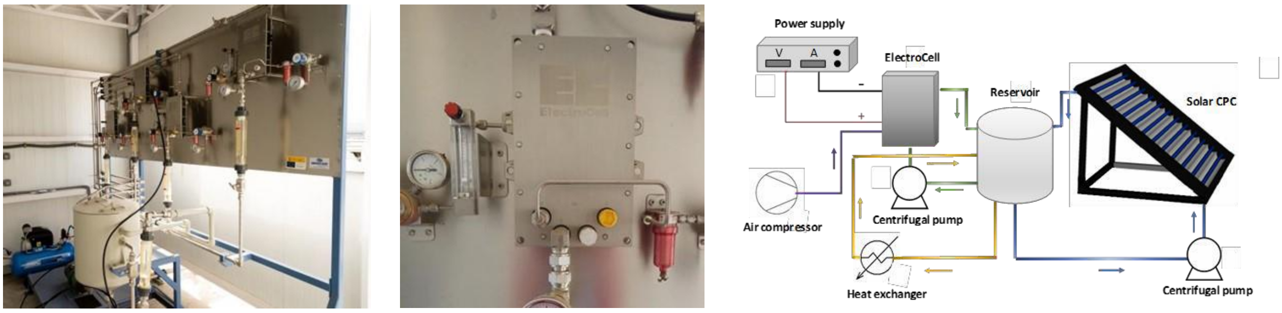


Figure 104. Left: Electro-oxidation pilot plant; Centre: Electrochemical cell of the solar-assisted electrooxidation pilot plant; and Right: Schematic diagram of the solar-assisted electrooxidation pilot plant.

SOLAR UVA MONITORING EQUIPMENTS

UV and global solar radiation data monitoring and storage system is composed by different pyranometers (Figure 105), including global solar radiation in the range of 310–2,800 nm (Kipp and Zonen CMP-6 with sensitivity 5-20 $V \cdot W^{-1} \cdot m^{-2}$, max. value: 2000 $W \cdot m^{-2}$), and the global UVA radiation in the range of 300–400 nm (Kipp and Zonen CUV-5 with sensitivity 1 $Mv \cdot W^{-1} \cdot m^{-2}$, max. value: 100 $W \cdot m^{-2}$). Besides this, a spectral photometer with double channel was installed to monitor the solar spectral irradiance at the location of the solar tests. This equipment (AVANTES) has UVA sensors and filters to measure in the whole spectral range of 200 – 1100 nm.

Three portable UVA radiometers (320 to 400 nm) Solar Light Co., Inc (Philadelphia), model PMA2111 with a resolution of the measurement 0.01 W m^{-2} are also available for monitoring the solar resource.

Figure 105. CUV-5 radiometer (left). View of all solar UV radiometers, horizontal (centre) and inclined (right) setup used in the Solar Treatment of Water Unit.

PILOT PLANT FOR PHYSICOCHEMICAL PRE-TREATMENT OF WASTEWATERS

A pilot plant based on physicochemical pre-treatment of wastewaters consisting of a coagulation-flocculation unit and a filtration stage (sand filter and two microfilters of 25 and 5 µm) that allow working with a maximum water flow of 1 m^{-3} h.

PILOT PLANTS FOR BIOLOGICAL TREATMENT

A biological pilot plant with a double depuration system (Figure 106) consists of a 60 L feeding tank; three Immobilized Biomass Reactors (IBR) of 20 L each one; and two Sequencing Batch Reactors (SBR) of 20 L each one. These modules use the same reception tank (200 L) as well as pH and dissolved oxygen control systems and electronic equipment. In addition, this plant can be operated in continuous or in batch mode. For the batch operation, two conical decantation tanks (40 L) are used. Data acquisition of three MULTIMETERS (M44 CRISON) is available by means of programmable relays and the main parameters are monitored by a SCADA system.

Figure 106. Biological pilot plant installed at PSA facilities.

MEMBRANE DISTILLATION (MD) / CRYSTALLIZER PILOT PLANT

The pilot plant is composed by a MD module integrated into a system consisting of two hydraulically separated loops, one for the hot solution and the other for the cooling solution. A 150 L PP feeding tank provided with a 3 kW_{th} electrical resistance heating system with a feeding pump (Q_{max} = 1.1 m^3 h^{-1}, T = 80°C) area available. An internal coil thermostated by a chiller (Q_{max} = 15.5 L min^{-1}, 2750 W, range = -10 - 40°C) is incorporated to the tank. Refrigeration is controlled by an external temperature sensor and the cooling pump helps to ensure homogeneity by recirculating it into the tank. Two level ultrasound sensors are installed for measuring the permeate volume produced (T = -20 - 60°C, P = 0.7-3 bar). The facility has a PLC to register the variables and a control to be able to work for 48 hours. Moreover, the system is prepared to work with acids and bases, and it has a pH regulation system consisting of a tank (HDPE 50 L), a pump (Q_{max} = 20 L h^{-1}, P_{max} = 3 bar, PP), a pH controller and a pH sensor (Range: 0 - 14, P_{max} = 3 bar, T = -5 - 70°C). Finally, the system has a 25 L jacketed borosilicate crystallizer with a stirrer inside (range: 0/30 - 1000 rpm, P: 60 W, material: PTFE) with a pump (flowmeter range: 90 - 900 L h^{-1}). The temperature control is carried out by a control system formed by a chiller (Q_{max} = 15.5 L min^{-1}, 2750 W, range = -10 - 40°C) and an external Pt100 temperature sensor (Figure 107).

Figure 107. MD + crystallizer pilot plant developed by Apria Systems S.L.

CULTIVATION CHAMBER

The culture crop chamber of 30 m^2 is used for treated wastewater re-use experience since 2014 (Figure 108). This chamber is made of 10 mm polycarbonate thick to avoid ultraviolet radiation supported by white rolled steel (Sendzimir). The shoulder height is 2.5 m with a roof slope of 40 %. The camera consists of four 3 m^2 x 2.5 m^2 individual areas. Each area is equipped with temperature and humidity sensors, and a cooling and heating system. The crop camera is equipped with a global solar radiometer for measuring the incident solar radiation. So, through this probe an opaque plastic cover located on the top of the camera can be automatically fold and re-fold to reduce the incidence of irradiance inside the crop camera. Finally, the roof slope of each area acts as windows which can be automatically opened and closed to favour the airflow inside each area and enhance the efficiency of the temperature control. Sensors' registration (temperature, humidity and solar radiation) and temperature control of each individually area (by the cooling and heating system, windows and top plastic cover) is made by using the Ambitrol® software which permits to keep a comfortable temperature for crops of approximately 25 °C during the different seasons. A new modification was tackled in 2021 consisting in the installation of automatic drip irrigation in the 4 rooms and the cooling system replacement (model HEF3-CAD, Q_{max} =2200 $m^3 \cdot h^{-1}$).

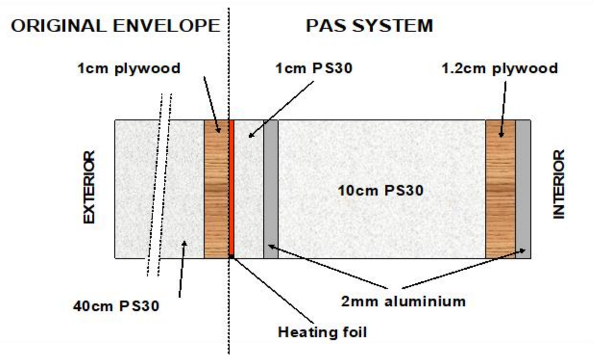
Figure 108. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

Experimental Installations for the Evaluation of the Energy Efficiency in Buildings

The Building Component Energy Test Laboratory (LECE) is one of the facilities at the PSA. Its personnel are ascribed to the Energy Efficiency in Building R&D Unit (UiE3) in the CIEMAT Energy Department's Renewable Energies Division. The UiE3 carries out R&D in integral energy analysis of buildings, integrating passive and active solar thermal systems to reduce the heating and cooling demand. This unit is organised in two lines of research focusing on Energy Analysis in Urban Environments, and Experimental Energy Analysis of Buildings and Building Components. The test facilities described are under the last of these. They integrate several devices with different capabilities as summarised below:

- Test cells. The LECE has five test cells, each of them made up of a high-thermal-insulation test room and an auxiliary room. The test room's original south wall can be exchanged for a new wall to be tested. This makes experimental characterisation of any conventional or new building envelope possible.
- PASLINK Test cell. The Spanish PASLINK test cell incorporates the Pseudo-Adiabatic Shell (PAS) Concept. This system detects heat flux through the test cell envelope by means of a thermopile system and compensates it by a heating foil device. The inner surface of the test room consists of an aluminium sheet which makes it uniform in order to avoid thermal bridging. It also has a removable roof that enables horizontal components to be tested. The cell is installed on a rotating device for testing in different orientations.
- CETeB Test cell. This is a test cell for roofs. The design of this test cell solves some practical aspects related to roof testing, such as accessibility and structural resistance. An underground test room that allows easy access to the test component is used for this.
- Solar Chimney. This was constructed for empirical modelling experiments and validating theoretical models. Its absorber wall is 4.5 m high, 1.0 m wide and 0.15 m thick, with a 0.3-m-deep air channel and 0.004-m-thick glass cover. A louvered panel in the chimney air outlet protects it from rodents and birds. The air inlet is protected by a plywood box to avoid high turbulences from wind. The inlet air flow is collimated by a laminated array so that the speed component is in the x-direction only.
- Single-zone building. This is a small 31.83 m^2 x 3.65 m high simple single-zone building built in an area free of other buildings or obstacles around it that could shade it, except for a twin building located 2 m from its east wall. Its simplicity facilitates detailed, exhaustive monitoring and setting specific air conditioning sequences that simplify its analysis for in-depth development and improving energy evaluation methodologies for experimental buildings.

(a)



(b)

(c)

(d)

Figure 109. (a) CIEMAT's PASLINK test cell carrying out a thermal test of a electrocromic window (left: outdoors; right: indoors), (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

(a)

(b)

(c)

(d)

Figure 110. (a) ARFRISOL Building Prototype in use, (b) Solar Chimney, (c) Reference single-zone building, (d) Ventilated façade tested in a Test Cell. Configurations with dark external face.

The PSE ARFRISOL C-DdIs are fully instrumented Energy Research Demonstrator Office Building Prototypes which are in use and monitored continuously by a data acquisition system. The CIEMAT owns 3 out of 5 of these “Contenedores Demostradores de Investigación, C-DdIs” (Research Energy Demonstrators Building Prototypes), built under the ARFRISOL Project. Each of them is an office building with approximately 1,000 m^2 built area. One of them is at the PSA and the others in different locations representative of Spanish climates. These C-DdIs are designed to minimize energy consumption by heating and air-conditioning, whilst maintaining optimal comfort levels. They therefore include passive energy saving strategies based on architectural and construction design, have active solar systems that supply most of the energy demand (already low), and finally, have conventional auxiliary systems to supply the very low demand that cannot be supplied with solar energy, using renewable energy resources, such as biomass insofar.

These prototypes were built for high-quality measurements recorded during monitoring to support research activities on energy performance assessment of the buildinbg fabric, thermal comfort, building energy evaluation and both active and passive systems integrated in the buildings.

14 Laboratories

Laboratory for the geometrical characterization of solar concentrators - GeoLab

The concentrators used in solar thermal systems (heliostats, parabolic-trough collectors, parabolic dishes, Fresnel lenses, etc.) require high precision concentration of the solar radiation for it to be suitable and for most of it to fall upon the receiver component (receiver tubes in parabolic-trough collectors, receivers in tower systems, parabolic dishes, Fresnel lenses, etc.). This laboratory has a specific activity line for the geometric characterization of these concentrators. Photogrammetry is used to quantify the optical quality of:

- Parabolic-trough collector facets
- Parabolic-trough collector modules
- Heliostat facets
- Heliostats
- Fresnel lenses and reflectors
- Parabolic dishes
- Structural frames
- …

Photogrammetry consists of three-dimensional modelling of any object from photographs that capture it from different angles. Based on these photographs, the three-dimensional coordinates (x, y, z) can be calculated for the points of interest on the object being modelled. Photogrammetry modelling is precise up to 1:50000 (precisions on the order of 0.1 mm for parabolic-trough collector facets and 0.6-0.7 mm for 12-m-long parabolic-trough modules).

The equipment allocated to this activity at PSA is composed of:

- CANON EOS5D MarkII 22-Mpixel Camera.
- CANON EF 20 mm f/2.8 USM and CANON EF 24 mm f/2.8 USM lenses.
- Photomodeler Scanner 2017 photogrammetry software.
- LEYCA P20 laser scanner

Additionally, a software package for model analysis and calculation of relevant parameters for 2D and 3D geometries in the MatLab environment was developed in house.

Among the parameters that can be calculated from the model built by photogrammetry are:

- Deviations of real from theoretical surface on coordinates x, y, z.
- Gravity deformation between different concentrator orientations.
- Angular deviation from the normal vector to the surface compared to the theoretical normal vector.
- Deviation of reflected rays on the reflective surface of the module compared to the theoretical concentrator focus.
- Intercept factor.
- (Calculation of other relevant parameters by request).

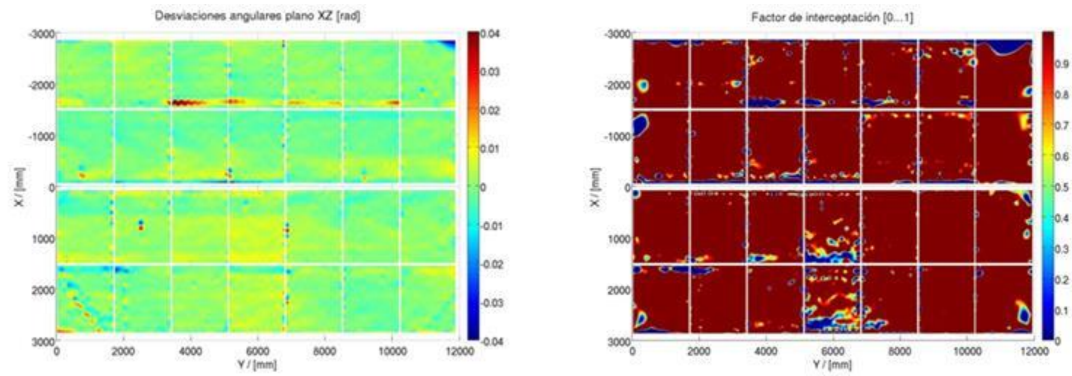


Figure 111. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry.

Radiometry laboratory – RadLab

The activity line devoted to Radiometry came out from the need to verify measurements of highly important radiometric magnitudes associated with solar concentration. These magnitudes are solar irradiance ("flux" in the jargon of solar concentration) and surface temperature of materials (detection by IR). At the PSA, different systems are used to measure high solar irradiances on large surfaces. The basic element in these systems is the radiometer, whose measurement of the power of solar radiation incident on the solar receiver aperture depends on its proper use. The measurement of this magnitude is fundamental for determining the efficiency of receiver prototypes evaluated at the PSA and for defining the design of future central receiver solar power plants. Calibration of radiometers is performed in a specific furnace for this purpose.

Figure 112. View of the PSA Radiometry equipment.

The calibration of the reference radiometer is radiant calibration referenced to blackbody simulators as source standards. The calibration of the reference radiometer is transferred to the commercial sensors by comparison in a calibration furnace that uses a graphite plate that radiates homogenously and symmetrically when an electrical current passes through it. The calibration constant obtained with this method translates voltage to irradiance on the front face of the sensor. The accuracy of gages calibrated in this way is within ±3 % with repeatability of ±1 %. A black body can be used as a source of thermal radiation for reference and calibration of IR devices (infrared cameras and pyrometers) that use thermal radiation as the means of determining the temperature of a certain surface.

The equipment associated to this activity also includes three black bodies used as references for calibrating IR sensors devoted to temperature measurement with guaranteed traceability between 0 and 1700°C:

- The MIKRON 330 black body is a cylindrical cavity which can provide any temperature from 300 °C to 1,700 °C accurate to ±0.25 % and a resolution of 1 °C. Its emissivity is 0.99 in a 25-mm-diameter aperture.
- The MIKRON M305 black body is a spherical cavity that can supply any temperature between 100 °C and 1,000 °C accurate to ±0.25 and with a resolution of 1 °C. Its emissivity is 0.995 in a 25-mm-dia. aperture.
- The MIKRON M340 black body is a flat cavity and can provide any temperature from 0 °C to 150 °C accurate to ±0.2 °C and a resolution of 0.1 °C. Its emissivity is 0.99 in a 51-mm-aperture.

These black bodies have a built-in PID control system, and the temperature is checked by a high-precision platinum thermocouple.

Figure 113. IR sensor calibration using a black body.

Laboratory for the assessment of the durability and characterization of materials under concentrated solar radiation - MaterLab

The activity line of this Laboratory is focused on the study and evaluation of how the concentrated solar radiation affects the performance and durability of materials. This is especially important for materials used for central receivers, thus requiring an accelerated ageing to study the durability of the most critical components of solar thermal power plants, not only absorbent materials, but also surface treatment and coatings that increase their absorptance. It is therefore necessary to find out and study the mechanisms of the physical degradation and breakage of these materials at high temperatures under concentrated solar radiation.

The equipment associated to this activity is composed of devices located indoor, apart from several solar-dish concentrators located close to the PSA solar furnaces building. The indoor devices are devoted to the metallographic preparation and the analysis of test pieces treated with concentrated solar radiation and eventually thermal cycling for accelerated aging, and characterization of solar test by thermogravimetry. These devices are inside the Solar Furnaces control building and located in four rooms, each of them dedicated to different kind of analyses:

- The Metallography Room

- The Microscopy Room
- The Thermogravimetry Room
- The Thermal Cycling Room
- The Electronic microscope Room
- The laboratory equipment located in these rooms is listed below.

METALLOGRAPHY ROOM

This room is equipped for the metallographic specimen preparation and the particle size determination:

- Automatic cut-off machine: Struers Secotom
- Manual cut-off machine: Remet TR60
- Mounting press: Struers Labopres-3
- Vacuum impregnation unit: Struers Epovac
- Polisher: Tegrapol-15 automatic with Tegradoser-5 dosing system
- Metallographic polisher 2 plates: LS1/LS2 (Remet)
- Grinder: Remet SM1000
- Ultrasonic bath: Selecta Ultrasons-H 75 °C with heater
- Fume cupboards: Flores Valles VA 120 960 M-010-02
- Power Source programmable: Iso-Tech IPS 405 for electrochemical attack
- Analytical sieve shaker: Retsch AS 200 Control (Sieves: 20, 10, 5, 2.5 and 1.25 mm, and 710, 630, 425, 315, 250, 160, 150, 90, 53 and 32 μm)
- Digital
- Camera with reproduction table

Figure 114. View of the Metallography Room in the Solar Furnaces building.

MICROSCOPY ROOM

Microscopy, hardness and solar reflectance measurement equipment for optical and surface characterisation of materials is available in this room:

- 3D Optical Surface Metrology System: Leica DCM 3D
- Leica DMI 5000 optical microscope with Leyca-IM50 image acquisition system and motorized table.
- Olympus optical microscope Union MC 85647.
- 410 Solar Portable Reflectometer

- ET100 IR Portable Emissometer
- Struers micro hardness tester Duramin HMV-2 with visualization system and software micro-Vickers hardness tester HMV-AD 3.12.
- Manual hardness tester
- Surface Finish Measuring Unit ZEISS Surfcom 480 with data processor
- Balance: Mettler E2001/MC max 60 kg
- Balance: Mettler Toledo classic max 320 g/min 10 mg

THERMOGRAVIMETRY ROOM

The thermogravimetric Balance SETSYS Evolution18 TGA, DTA, DSC (temperature range from ambient to 1,750 °C) was redesigned some years ago to be prepared for Hydrogen production test including the equipment and connections needed. This TGA-DTA-DSC balance is equipped with a compact recirculating cooler (Julabo FC1600T) and a thermostatic line to 200 °C, with a security box for tests in presence of H_2, and adapted to connect a controlled evaporator mixer and a with an external connection to connect a microGC simultaneously to the equipment. Its design allows different possibilities of tests:

- Tests under any gas atmosphere up to 1,750 °C, including:
- Tests under pure Hydrogen atmosphere
- Tests under pure Oxygen atmosphere
- Tests under H2O steam with other gases simultaneously.
- Tests under corrosive atmosphere up to 1,000 °C

This room is also equipped with:

- CEM System (Controled evaporator mixer system) for steam supply.
- Fixed Gas Detector: Dräger Polytron SE Ex, with a control system Regard 1.

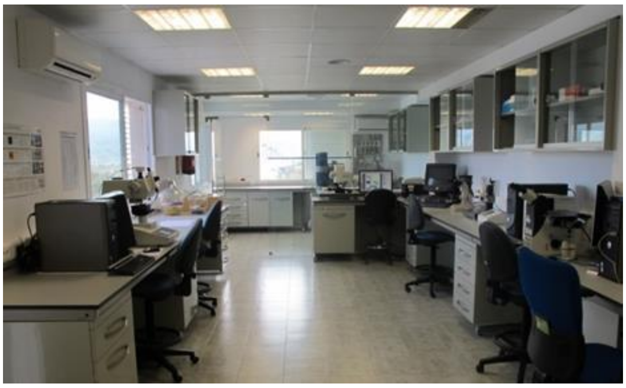



Figure 115. View of the Microscopy Room (left) and the thermogravimetric balance inside of its room (right).

THERMAL CYCLING ROOM

It includes the instrumentation necessary for thermal cycling:

- two muffle furnaces
- a high-temperature kiln

- a weathering chamber
- an air-cooled volumetric receiver test loop and associated instrumentation

Laboratories associated with line-focus solar concentrators

HEATREC AND RESOL

There are two test benches at PSA for the testing of linear receivers: a) a test bench called HEATREC (see Figure 116 left), for measuring heat loss of single receiver tubes under indoor laboratory conditions, and b) an outdoor test bench called RESOL (see Figure 116 right), for measuring optical efficiency of single receiver tubes under natural solar radiation. Heat loss measurements can be done in HEATREC under vacuum conditions to avoid convection outside the glass tube, thus obtaining a more uniform temperature along the receiver section and looking to assess heat loss by radiation. In addition, it is possible to determine heat loss at different vacuum levels in the space between the metallic absorber tube and the glass envelope. The emissivity of the selective coating can then be inferred from these thermal loss measurements.

HEATREC device allows characterising heat losses of receiver tubes with an inner diameter greater than 62 mm and a tube length smaller than 4.5 m. Measurements can be performed for absorbing temperature ranging from 100 °C to 500 °C. The vacuum in the test chamber can be set up to around 10^{-2} mbar. RESOL is currently configured to measure standard receiver tubes for parabolic troughs, i.e., tubes 4060 mm long and with an absorber tube diameter of 70 mm.

Figure 116. View of the HEATREC test chamber to measure heat losses in solar receiver tubes (left) and RESOL test bench to measure the receiver's optical efficiency (right).

The optical efficiency tests performed with RESOL are based on evaluating the slope of the temperature of a fluid (water) circulating inside the receiver tube vs the time during an interval of steady-state solar radiation when heat losses are null. The optical efficiency is calculated from the energy balance of the system. The test provides in one measurement the receiver optical efficiency, i.e., the combined value of the absorptance and transmittance of the receiver tube.

Both HEATREC and RESOL, are equipped with tools and devices for proper manipulation and monitoring of receiver tubes.

Advanced Optical Coatings Laboratory - OCTLAB

This laboratory line is devoted to the development and complete study of new selective coatings for absorbent materials used in solar concentrating systems at medium and high temperature (up to 700°C), as well as coatings for glass covers (anti-reflective, anti-soiling. etc) used in some receiver designs, such as receiver tubes in parabolic-trough collectors. The equipment devoted to this activity line is sufficient to characterize and evaluate coating developments, and to asses the behaviour of other treatments available on the market or developed by other public or private institutions. The equipment associated to this line may be also used for optical characterization of solar reflectors, thus complementing the equipment specifically devoted to the activity line of testing and characterization of solar reflectors.

A summary of the equipment available for advanced optical coatings is given below:

- Perkin Elmer LAMBDA 950 Spectrophotometer equipped with a 150 mm integrating sphere (Figure 117).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 117).
- LEICA DM4 M optical microscopy with image acquisition system and software for image analysis (Figure 117).
- KSV CAM200 goniometer for measuring static contact angles (Figure 117).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 117).
- Rotational Viscometer SELECTA.
- BRUKER DektakXT stylus profilometer with optical camera and software for surface analysis (Figure 117).
- TABER linear abrader model 5750, equipped with different types of abrasive materials to measure the abrasion resfistance of coatings and materials (Figure 117).
- TABER oscillating abrasion tester, Model 6160, to measure the relative abrasion resistance of the materials to surface abrasion and / or marring produced by sand movement. Different types of standardized sands are available (Figure 117).
- Two dip Coating machines for producing thin films. This machine controls the speed of substrate withdrawal from solution using a programmable high-precision motor and coatings up to 40cm long can be prepared.
- UV light curing system DYMAX with intensities of 75mW/cm^2 to cure coatings.
- Kilns. There are three kilns for thermal treatment:
- 120x100x300 mm^3 kiln with a maximal temperature of 1,200 °C.
- Controlled atmosphere kiln with a maximal temperature of 800 °C.
- 500x400x600 mm^3 forced convection kiln with a maximal temperature of 550 °C.

Figure 117. Advanced optical coatings laboratories equipment.

Porous media laboratory for solar concentrating systems - POMELAB

The porous media laboratory located in CIEMAT-Moncloa (Madrid) comprises three main facilities, and some other techniques for the characterization of porous materials used for central receiver systems with air as heat transfer fluid.

Thermal characterization of volumetric absorbers.

Its main component is a test bench designed for the thermal test of new volumetric absorbers and configurations and its ageing in steady and dynamic conditions. The main components installed in this test bench (Figure 118) are:

- A 4 kWe solar simulator made up of a Xenon lamp and a parabolic concentrator that can reach fluxes of up to 1,500 kW/m^2;
- Receiver sub-system: with 24 K-type thermocouples, 2 surface thermocouples and an infrared camera;
- Helicoidal Air-Water Heat Exchanger sub-system: with 4 PT100 sensors, a water mass flow-rate measurement, a water pump and 2 surface thermocouples; and
- Extraction system: with 1 k-type thermocouple, 1 PT100 sensor, an air mass flow-rate measurement, and an air blower.

This test bench has the flexibility to study the extinction coefficient of different mediums, which can be used as a tool to approximate radiation analysis in semi-transparent mediums following the Bouger's law.

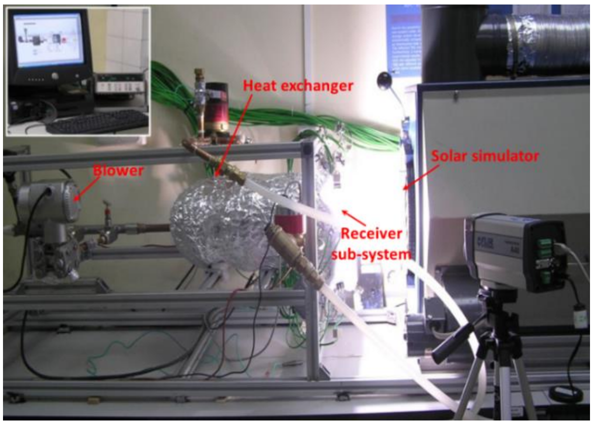


Figure 118. Test bench for volumetric receiver testing

MEASUREMENT OF THE PRESSURE DROP UP TO 300 °C.

This facility measures the pressure difference across porous materials, such as volumetric absorbers or filler materials, for different fluid velocities. Moreover, it can measure the pressure difference at ambient temperature and for air temperatures up to 300 °C.

Then the main properties described by the Forchheimer extension to Darcy's law are derived: viscous permeability coefficient and, inertial permeability coefficient. The main components are:

- Sodeca Blower with velocity control
- Hastinik ball valve of 1 ½".

- Airflow anemometer
- Nabertherm heating resistor
- Honeywell pressure difference-meter

Moreover, different techniques have been developed for the evaluation and measurement of several important geometric parameters of porous materials such as the porosity and specific surface area.

Figure 119. Test bench for pressure difference measurement with configuration up to 300 °C.

Laboratory of Thermal Energy Storage

In order to support the R&D&I activities at the PSA on the feasibility of materials as storage media, the following set-ups are available:

HDR: Small vertical oven under ambient air with a cylindrical ceramic cavity where the sample can be allocated. Its upper part can be covered with a double glass trap (Fig. 2. right), for condensing the evolved gases. It allows performing consecutive thermal cycles up to 500 °C and isothermal stand-by periods. Sample temperature can be monitored and sample mass can be in the range of 1-10 g.

Figure 120. HDR.

SUBMA: Small closed device located inside a furnace. It can accommodate samples of 30-40 g that can be tested under inert atmosphere (N_2, Ar). During the tests, furnace temperature and gas flow can be controlled and sample temperature can be monitored. It allows performing thermal cycles up to 500 °C and isothermal stand-by periods.

Figure 121. SUBMA.

AgH: Oven under ambient air atmosphere with an accurate control of both heating and cooling rates. It allows performing consecutive thermal cycles up to 350 °C and isothermal stand-by periods. Sample temperature can be monitored and sample mass can be in the range of 10-20 g.

Figure 122. AgH.

PSA Desalination Laboratory

BENCH-SCALE UNIT FOR TESTING MEMBRANE DISTILLATION APPLICATIONS IN AIR-GAP, PERMEATE-GAP AND DIRECT CONTACT CONFIGURATIONS

The installation consists of a test plant (Figure 123) that can be used for evaluating direct-contact, air-gap or permeate-gap membrane distillation. It can use plate and frame or hollow fibre modules. The plate and frame modules are made of polypropylene and designed so that the membrane can be replaced very easily. They have a condensation plate on the cold side to operate on air-gap configuration but it can be closed at the bottom to operate on permeate-gap keeping the distillate inside the gap or spared to operate on direct-contact mode. There are two modules, with effective membrane surface areas that measure 25x15 cm^2 and 11x7 cm^2. The hollow fibre module is 50 cm long and 4 cm wide.

The installation has two separate hydraulic circuits, one on the hot side and another on the cold side. On the hot side, there is a tank of 80 litres equipped with an electric heater (3 kW) controlled by a thermostat (90 °C maximum), and circulation is made from the storage and the feed side of the module by a centrifugal pump. On the cold side, there is a chiller (800 W at 20 °C) controlled by temperature and water is circulated between a cold storage of 80 litres and the module. The circuit is heat insulated and fully monitored for temperature, flow rate and pressure sensors, connected to a SCADA system.

Figure 123. Bench-scale unit for testing membranes on isobaric MD.

Figure 124. Bench-scale unit for testing MD with flat-sheet membranes.

BENCH -SCALE UNIT FOR FLAT SHEET MEMBRANE DISTILLATION TESTING

The facility is a high precision laboratory grade research equipment (Figure 124) designed for testing fundamental and feasibility test trials on membrane distillation. It possesses the following unique features that are essential for representative and scalable results:

1) Cell format with representative flow distribution. The plate and frame cell size (effective membrane surface 220 mm x 150 mm) is sufficient for flow distribution and regime to be applicable to full-scale MD technology.
2) Smaller plate and frame cell (effective membrane surface 100 mm x 60 mm) and HF cell (50 cm long) for testing materials and solutions.
3) Adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VAGMD).
4) Temperature precision of 0.5 °C.
5) Driving force temperature difference controllable.
6) Fully automated control system and large range of possible parameter settings by touch screen PLC.

BENCH -SCALE UNIT FOR TESTS WITH 2-STAGE FORWARD OSMOSIS AND PRESSURE-RETARDED OSMOSIS

The installation consists of a test bed with two small plate and frame modules of forward osmosis (FO) which can be connected in series or parallel (Figure 125). There is, therefore, one pump for the draw solution and two for the feed solution, each with variable flow and flow-rate measurements. The hydraulic circuit has been modified so that the modules can be operated in pressure-retarded osmosis (PRO) mode. For that purpose, steel pipes and a high-pressure pump (3 L/min; up to 17 bar) are installed in the draw side, and cells with operational pressure up to 15 bar are used. The cells each have a total effective membrane area of 100 cm^2, and hydraulic channels in zigzag 4 mm wide and 2 mm deep. The system uses one container for the draw solution and two for the feed solutions, each placed on a balance in order to measure changes in the mass flow rates of the draw solution and the feed solution of each module. The containers have an automatic dosing system to keep the salinities constant. The system has two conductivity meters for low salinity and one for high salinity, as well as pressure gauges in each line and temperature readings.

Figure 125. Bench-scale unit for testing FO and PRO.

PSA Water Technologies Laboratory - WATLAB

Within the scope of the SolarNova Project funded by the Ministry of Science and Innovation within the Special State Fund for Dynamization of Economy and Employment (Fondo Especial del Estado para la Dinamización de la Economía y el Empleo – Plan E) a new laboratory was built in 2009. Since them, acquisitions of new instrumentation have been done within the SolarNova Project. The PSA water technologies laboratory consists of 200 m^2 distributed in six rooms: (i) a 30 m^2 room for chemicals and other consumables storage. It is organized on numbered and labelled stainless steel shelving with refrigerators and freezers for samples and standards keeping; ii) A 17-m^2 office with three workstations where visiting researchers can analyse the data from the experiments carried out at the PSA. In addition, (iii) 4 technical rooms are also part of the laboratory and are listed and described below:

- General laboratory
- Chromatography laboratory
- Microbiology laboratory
- Microscopy laboratory

GENERAL LABORATORY

The main laboratory is 94 m^2 (Figure 126). It is equipped with four large work benches, two gas extraction hoods, three heaters, a kiln, ultrasonic bath, three centrifuges, four UV/visible spectrometers (one of them portable), a fluorimeter, a vacuum distillation system, ultrapure water system, pH meters (five of them portable), turbidimeter, luminometer, conductivity-meter (one portable), a precision-scale table with two precision scales, an electronic scale and a mini-chiller. In addition, it has a centralized gas distribution system, UPS, three-pin plugs connection and safety systems (extinguishers, shower, eyewash, etc.). The laboratory is also equipped with suspended and supported activated sludge respirometry (BMT) toxicity and biodegradability measurement devices and required equipment for the analysis of biological oxygen demand (BOD), toxicity and phytotoxicity tests (acute and chronic) and chemical oxygen demand (COD). In addition, a Jar-Test system is also available for the optimization of physicochemical separation studies.

Figure 126. General view of the new PSA Water Technologies Lab.

CHROMATOGRAPHY LABORATORY

This laboratory (Figure 127 (b)) is equipped with three high performance liquid chromatographs with diode array detectors (one of them also with a florescence detector,HPLC-DAD,UPLC-DAD, UPLC-DAD-FLD) with quaternary pumps and automatic injection; an Automatic Solid Phase Extraction (ASPEC) which allows working with low concentration of pollutants (Figure 127 (c)) and two ion chromatographs (Figure 127 (a)): one configured for isocratic analysis of amines and cations (Metrohm 850 Professional IC), and another for gradient analysis of anions and carboxylic acids (Metrohm 872 Extension Module 1 and 2) with conductivity detectors (Methrom 850 Professional IC detector). Two total organic carbon (TOC) analysers by catalytic combustion at 670 °C and total nitrogen (TN) analyser with autosampler, are also available. In addition, an AB SCIEX TripleTOF 5600+ was acquired to detect and identify non-targeted or unknown contaminants present in wastewater or generated (transformation products) during the water treatments: Triple TOF by a DuoSpray Source combining Turbo Ion Spray and APCI (Atmospheric Pressure Chemical Ionization) modes. Besides, the system includes metabolomics statistical package to analyse multiple samples from multiple experiments and identified possible chemical and biological markers (Figure 127 (d)). In 2021, an Ultra Pressure Liquid Chromatograph coupled to a triple quadrupole-linear ion trap mass spectrometer SCIEX EXION (SCIEX Triple Quad 7500 System) was acquired (Figure 127 (e)). This equipment consists of a binary pump for working in constant flow or constant pressure modes, column oven (thermostated from 10 to 80 °C), automatic autosampler (for more than 100 samples), mass spectrophotometer, UPS, nitrogen generator (Peak Infinity 1032), data station (SCIEX OS).

MICROBIOLOGY LABORATORY

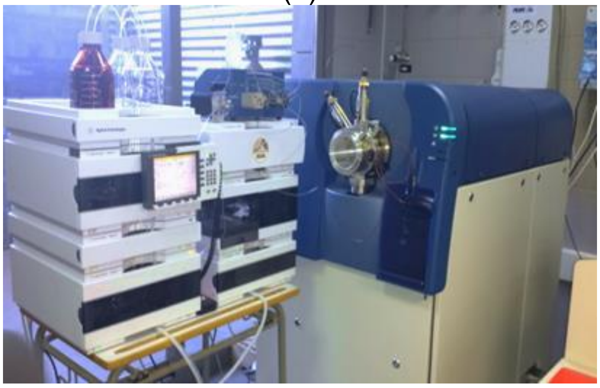
47-m^2 microbiology laboratory with biosafety level 2 (Figure 128) is equipped with five microbiological laminar flow (class-II) cabins (four double and one simple), three autoclaves, four incubators (one with temperature ramp), a fluorescence and phase contrast combination optical microscope with a digital camera incorporated. Besides, automatic grow media preparer and plaque filler, two filtration ramps with six positions and a dishwasher are available.

This lab is also equipped with ultra-fast real-time quantitative PCR (Polymerase Chain Reaction) equipment, fluorospectrometer and NanoDrop spectrophotometer for genetic quantification of micro-volumes. A ‘Fast Prep 24’ was also acquired; it is a high-speed benchtop homogenizer for lysis of biological samples, needed for further analyses of genetic material samples. Homogenizer stomacher 400 Comecta equipment was acquired to blend food samples, stirring and storing in a reproducible way without any risk of cross contamination between samples.

(a)

(b)

(c)



(d)

(e)

Figure 127. (a) Metrohm Ion chromatograph System. (b) General view of the chromatography lab at PSA facilities. (c) Agilent Ultra-fast UPLC-DAD analyzer. (d) AB SCIEX TripleTOF 5600+ equipment. (e) AB SCIEX 7500 QTRAP Ready LC/MS.

Figure 128. General view of the microbiology lab at PSA facilities.

MICROSCOPY LABORATORY

The microscopy laboratory has two optical microscopes: i) a fluorescence and phase contrast combination optical microscope and, ii) a FISH microscope (Leyca) with a fluorescence module to develop the FISH (Fluorescent in situ hibrydation) technique for visualization of DNA hibrydation with specific probes in live cells used for monitoring key microorganisms within a heterogeneous population (Figure 129).

In addition, the system is completed with a station for photographic documentation, consisting on a UV-trans-illuminator to detect and visualize DNA, RNA and proteins. It also includes a documentation station with a camera to take images of DNA, RNA and proteins.

Figure 129. Optical microscope for FISH technique

PSA radiometric net

The PSA has had a meteorological station since 1988, primarily for measuring integral solar radiation (global, direct and diffuse radiation) but also for other generic meteorological variables (temperature, wind speed and direction, relative humidity and atmospheric pressure, accumulated precipitation, etc.). The old station was completely remodelled in 2005 following the strictest requirements of quality and precision in the measurement of solar radiation according to the Baseline Surface Radiation Network guidelines. This station is called METAS station since 2012 (Figure 130).

The METAS station instruments are in the highest range of solar radiation measurement. All the radiation sensors are ventilated-heated and have a temperature measurement sensor. This equipment provides the best information on solar radiation and more general atmospheric variables and can be used for filtering input data and validating spectral models. They are used for:

- Measurement of the terrestrial radiation balance. Incoming and outgoing shortwave and long-wave radiation is measured at 30 m
- Solar radiation component characterization: (global, direct and diffuse)
- UV and PAR spectral bands
- Vertical wind profile: wind speed and direction at 2, 10 and 30 meters
- Vertical temperature and humidity profile at 2 and 10 meters
- Miscellaneous weather information: rain gauge, barometer and psychrometer

Figure 130. General view of METAS station.

Additionally, a set of complementary structures for the calibration of radiometers has been installed near to this meteorological station following the standardized international procedures (ISO-9059 and ISO-9846). On the one hand, a high-performance tracker with the possibility of carrying 2 reference pyrheliometers (absolute cavity radiometer PMOD PMO6-CC) and a total of 19 field pyrheliometers have been installed close to METAS; on the other hand, 3 calibration benches, with capacity to carry 20 pyranometers each one, have been placed 50 meters away from METAS (Figure 131). These facilities are operated in collaboration with the Instrumentation Unit.

Figure 131. Calibration facilities.

Since the beginning of 2018, there are seven new fully operational radiometric stations around the PSA area (Figure 132). All these stations are equipped with first-class pyranometers and pyrheliometers, 2-axis solar trackers and have data acquisition systems Campbell CR1000 (METAS has a CR3000).

Figure 132. PSA radiometric stations.

15 Events

2nd February 2023

Visit

Visit of the ENGIE team involved in the solar plant installed at the factory of Heineken in Seville. The purpose of this visit was to get information about the PSA facilities with parabolic trough collectors and discuss some technical questions about their O&M requirements.

9th February 2023

Visit

Visit to the PSA of the Japan Science and Technology Agency to get information about the Concentrating Solar Thermal Technologies

11th February 2023

Dissemination event

Juan Miguel Serrano participated in the activity FIRST LEGO League at University of Almería.

13th February 2023

Dissemination event

Lidia Roca participated in an educative workshop for children to celebrate the International Day of Women and Girls in Science.

17th February 2023

Dissemination event

Patricia Palenzuela and Juan Miguel Serrano participated in an educative activity at IES Pablo Ruiz Picasso (El Ejido, Almería) to explain the research being carried out in desalination with solar thermal energy at the Plataforma Solar de Almería.

21st February 2023

Meeting

A co-creation meeting was held with the Community of Practice of the Sustainable Desalination Living Lab to present and evaluate the Augmented Reality Application.

Scientific dissemination

Alba Hernández Zanoletty e Ilaria Berruti. "Actividades de divulgación en centros educativos de ESO y Bachillerato" dentro del proyecto Nacional Español SOL-préndete, Didáctica y Divulgación de la Energía Solar térmica de Concentración con nuevas tecnologías de realidad aumentada y virtual, in Almería, Plataforma Solar de Almería-CIEMAT.

Dissemination event

Isabel Requena participated in an educative activity at IES Cerro Milano (Alhama de Almería) to explain the use of solar energy to obtain drinking water.

22nd February 2023

Lectures

Lecture given by Sixto Malato and Inmaculada Polo "Theoretical training on solar Photocatalytic Oxidation" in Cross-border Know-how transfer - Training of trainers, held in Universidad de Murcia, Murcia, Spain.

Dissemination events

Javier Bonilla, José Antonio Carballo and Juan Miguel Serrano participated in an educative activity at IES Cerro Milano (Alhama de Almería) to explain the use of artificial intelligence in concentrating solar plants and the use of automatic control to obtain sustainable drinking water.

Technical Meeting

Technical meeting at PSA with engineers from the companies: Global First Power, Aalborg CSP, Virtualmech and Increscendo to explore the possibilities of molten-salt storage for small nuclear power units.

24^{th} February 2023

Project Meeting

The Solar Treatment of Water Research Unit organized the 8^{th} consortium meeting of AQUACYCLE was at CIEMAT-PSA. Partners from ESAMUR (Spain), Université Libanaise UU (Lebanon), Centre des Recherches et des Technologies des Eaux (CERTE) & Centre International des Technologies de L' Environnement de Tunis (CITET) (Tunisia) and Centre for Research and Technology-Hellas CERTH (Greece) assisted to the meeting.

27^{st} March 2023

International visit

The Product Development manager of the Australian company Vast Solar, Bruce Leslie, and our colleagues from CENER, Marcelino Sanchez and Javier Garcia has a technical visit to PSA last March 27st, to explore potential lines of collaboration.

27^{th} March 2023

International visit

A delegation from NREL and SANDIA visited PSA facilities to strengthen collaboration activities between the institutions.

28th March 2023

International visit

Visit of DLR General Director, Dr. Kaysser-Pyzalla, to know the PSA facilities and the joint activities developed by CIEMAT and DLR.

28-29th March 2023

Lecture

Rocío Bayón gave two lectures in the Master de Materiales avanzados, nanotecnolgía y fotónica at the Universidad Autónoma de Madrid.

10th April 2023

Dissemination event

Isabel Requena and Lidia Roca participated in an educative activity at IES Río Aguas (Sorbas) to explain the use of solar energy to obtain drinking water.

11th April 2023

Lecture

Lecture given by Gema San Vicente Domingo as Invited Speaker titled “Advances in Optical Coating materials for CST” in the “Spring Meeting & Exhibit of the Materials Research Society (MRS2023)”, San Francisco (USA).

13th April 2024

Visit

Visit of the Subdelegado del Gobierno en Almería to know the PSA activities and facilities.

19th April 2023

Lecture

Invited lecture given by Guillermo Zaragoza: “Innovación para la desalación sostenible” in the workshop “La desalación y los cultivos marinos en la estrategia andaluza de economía azul sostenible”, organized by the General Secretariat of Sustainability, Environment, Water and Blue Economy of Junta de Andalucía in Almería (Spain).

24th April 2023

Lecture

Invited lecture given by Guillermo Zaragoza “Recent advances in the performance of membrane distillation at large scale” in 3rd International Workshop on Membrane Distillation and Innovating Membrane Operations in Desalination and Water Reuse (Sorrento, Italy).

24th April 2023

Dissemination visit

Visit to PSA of students from the Lycée Français International Georges Pompidou. Patricia Palenzuela and Lidia Roca gave a presentation about concentrating solar energy and desalination.

25th April 2023

Lecture

Lecture given by María José Jiménez “From building physics to mathematical models” in “DYNASTEE Building Performance Measurement Spring School 2023”, Univ. Salford (United Kingdom).

25th -27th of April 2023

Short-term Training

The Solar Treatment of Water Research Unit organized a short-term Training for technical staff and scientists in the framework of the SFERA III project. The main focus of this training event was on solar photo-reactors using Compound Parabolic Collectors (CPC) combined or not with other conventional and advanced technologies for wastewater (urban and industrial) treatment/ disinfection and reuse in different applications (crops irrigation, industrial processes, etc.)

3rd May 2023

Dissemination event

Isabel Requena participated in an educative activity at IES Sol de Portocarrero (La Cañada de San Urbano, Almería) to explain the use of solar energy to obtain drinking water.

4th and 5th May 2023

Scientific dissemination

Several members of the Solar Thermal Application unit and the Solar Tratment of Water unit participated in the “III Feria de la Ciencia Almería”.

22nd May 2023

Lecture

Invited lecture given by Guillermo Zaragoza “Decarbonizing desalination and brine treatment” in workshop “ Solutions for a successful implementation of small-scale desalination”, Limassol (Cyprus).

24th May 2023

Workshop

Esther Rojas participated in the workshop entitled “Europe’s corner: workshop on European research on TES” and organized within the Eurotherm 2023 Conference by presenting where she presented the activities developed by CIEMAT in two European projects and related to thermal energy storage.

25th May 2023

Workshop

Rocío Bayón and Esther Rojas participated in the workshop organized by Women+ in Concentrated Solar & ATA Insights entitled “How thermal energy storage makes variable renewables dispatchable”.

26th May 2023

International Training

Lidia Roca and Guillermo Zaragoza participated in the Educational Workshop “Solar-powered high-recovery groundwater desalination with salt-tolerant crop cultivation for integrated brine management", organized by the INDIA-H2O project in Limassol, Cyprus.

31st May 2023

International Training

Guillermo Zaragoza participated in a training organized by Laboratorio de Investigaciones Medioambientales de Zonas Áridas Arica (Chile).

1 June 2023

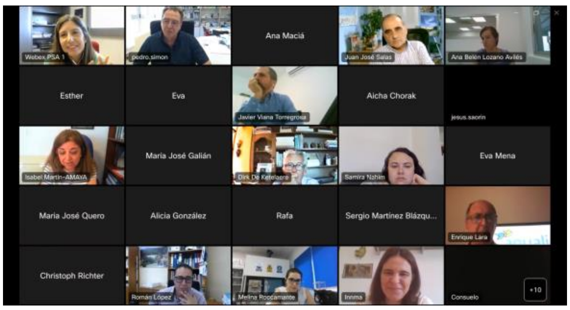
Lecture

Invited lecture given by Guillermo Zaragoza "Tecnologías solares de desalación y concentración de salmueras" in Universidad de Tarapacá (Chile).

6th June 2023

Workshop

The Solar Treatment of Water Research Unit and ESAMUR organized the 3ª "stakeholders" Workshop in the framework of the AQUACYCLE project. Dr. Isabel Martín (Agencia de Medio Ambiente y Agua, AMAYA), Enrique Lara (AQUALIA) and Isabel Rodríguez (Diputación de Almería) were speakers at this event whose main focus was to discuss potential actions and financing plans for the reclamation of wastewater treated through eco-innovative treatment systems.



Seminar

"Funciones de la Secretaría en el Comité Internacional de IEC" presented by Lourdes González and "Norma de ensayo de uniones cinemáticas para centrales termosolares con captadores cilindroparabólicos" by Loreto Valenzuela at the Online workshop "Normalización en el sector Termosolar", organised by UNE, PROTERMOSOLAR and SolarConcentra.

12th June 2023

Meeting

Last 12th June, the Plataforma Solar de Almería hosted the first face-to-face meeting of the European project LEIA (soLar field mEasurements to Increase performAnce), a European project coordinated by CIEMAT's Point Focus Solar Thermal Technologies Unit.

13th and 14th June 2023

Workshop

Last 13th and 14th June 2023, Point-Focus Unit of PSA organized, in the framework of the SolarPACES funded project "Analyze Heliostat Field", the "1st Workshop on SolarPACES Task

III Project: Analyze Heliostat Field". Thirty people representing the main research centres and companies of the CSP sector attended the Workshop, such as NREL, SANDIA, TieTronix, John Cockerill, ACCIONA, CENER, TEWER, TEKNIKER, IMDEA-Energia, Magtel, CSP Services, DLR, Australian National University, University of Queensland and CIEMAT.

14th June 2023

Thematic panel

Patricia Palenzuela participated in the Thematic Panel "Energías Renovables y Cambio Climático en el marco de la Estrategia Andaluza de Economía Azul Sostenible" in Sevilla (Spain), with the presentation "Innovación en desalación con energías renovables".

15th June 2023

Dissemination event

Guillermo Zaragoza participated at Parque de las Ciencias de Granada in the activity "Cafés en el Jardín" introducing the Sustainable Desalination Living Lab.

16th June 2023

Dissemination events

Javier Bonilla and José Antonio Carballo participated in an educative activity at IES Sol de Portocarrero (La Cañada de San Urbano, Almería) to explain the use of artificial intelligence in concentrating solar plants. Alba Ruiz participated in the activity explaining the sustainability of water.

19th June 2023

Round Table

Isabel Oller participated in the Round Table of the Mediterranean Basin: Regenerated and desalinated waters and the circular economy organized by AgroGo, AgroBank y Tecnova in the Parque Tecnológico de Almería (Almería, Spain).

21st June 2023

Dissemination events

Cristóbal Valverde participated in the Ted-Talks organized by the University of Almería where he presented in 3 min the work he is developing for this PhD.

22nd-24th June 2023

Conference

Final conference in the frame of the project AQUACYCLE organized by the University of Lebanon. The members of the project from the Solar Treatment of Water Research Unit at PSA attended jointly with the final coordination meeting.

29th June 2023

Lecture

Lecture given by Inmaculada Polo "Proyecto AQUACYCLE, Tratamiento Sostenible y Reutilización de las Aguas Residuales en la Región del Mediterráneo" in workshop Water reuse in Agriculture: A visión from Andalucia, held on Global Omnium Auditorium in Seville, Spain.

3rd July 2023

Lecture

Javier Bonilla participated in the Workshop on the application of artificial intelligence at CIEMAT's projects with the presentation "Energy: Experience on Artificial Intelligence (AI)".

4-6 July 2023

Meeting

The meeting of project SOL2H2O was held at PSA.

27th July 2023

Lecture

Keynote presentation by Guillermo Zaragoza "Opportunities for membrane distillation technologies in polygeneration" in VII International Conference on Polygeneration. Bali (Indonesia).

11th-13th September 2023

Doctoral Colloquium

Kelly J. Castañeda gave an oral communication titled "Assessment of two solar photoreactor´s design for water decontamination using photo Fenton reactions" and Joyce G. Villachica gave the communication titled "Hydrogen production improvements by glycerol photoreforming under natural radiation at pilot scale", both in the 4th Doctoral Colloquium within SFERA-III project-Solar Facilities for the European Research Area in Cologne (Germany).

14th September 2023

Lecture

Invited lecture given by Guillermo Zaragoza "Solutions for a successful implementation of small-scale desalination" in webinar "Small Scale Desalination" organized by European Desalination Society (online).

15th September 2023

Round Table

Isabel Oller was invited by the University of Torino to participate in the round table "Water Reuse: EU Regulation and tecnological challenges" and "Water Reuse in Spain: Drivers and barriers in Murcia and Almería region" in the 2nd International School on Water Reuse.

29th September 2023

Dissemination event

Lidia Roca and Patricia Palenzuela participated in the activity "Noche en las aulas" at IES Bahía (Almería) explaining the importance of water in solar thermal plants.

29th September 2023

Scientific dissemination

Several members of the Solar Thermal Application unit, the Solar Tratment of Water unit and the Thermal Storage unit participated in the “European Researchers' Night”. (HORIZON-MSCA-2022-CITIZENS 01) in Almería.

5th October 2024

Visit

Visit to the PSA of the EU-25 Research Council. E. Zarza explained to the visitors the PSA facilities devoted to line-focus technologies.

10th October 2023

Lecture

Margarita Rodríguez gave a plenary lecture at 29th SolarPACES Conference, where she presented the current R&D activities that are being carried out by different institutions in relation to thermal storage for CSP applications.

13th October 2024

Event

E. Zarza receives, together with R. Pitz-Paal, the SolarPACES Lifetime Achievement Award-2023.

17th October 2023

Invited Lecture

Isabel Oller was invited by the Instituto de Reales Academias de Andalucía to give a talk in the event “El manejo de la Luz. Información luminosa y sus aplicaciones” titled “Tecnologías Solares para la regeneración de aguas residuales urbanas” in the Parque de las Ciencias de Granada (Granada, Spain).

24th October 2023

Workshop

Margarita Rodríguez participated in the Workshop organized in the framework of MOSAICO Project entitled “Characterization of components for CSP molten salt plants”. She gave various lectures reporting on the results obtained in both SFERA III project and SolarPACES working groups in relation to the characterization of components for molten salt circuits such us valves and pressure sensors.

24th October 2023

Round Table

Isabel Oller was invited by Cinco Días newspaper meeting on the occasion of the event “Ciclo del Agua: Nuevas tecnologías e innovación para la sostenibilidad del aguan en la industria energética”, which was held in Madrid (Spain),

26th October 2023

Seminar

Samira Nahim-Granados and Isabel Oller gave a seminar titled “Desinfección de agua mediante tratamientos solares” and “Eliminación simultánea de microcontaminantes y patógenos mediante tecnologías solares de oxidación para regeneración de aguas”, respectively, to the students of the Chemistry Program in the Facultad de Ciencias Básicas de la Universidad de la Amazonia. Florencia (Colombia).

1-3 November 2023

School

Samira Nahim-Granados, Isabel Oller and Sixto Malato participated in the 1st Latin America School on Environmental Applications of Advanced Oxidation Processes giving the seminars titled “Water/wastewater disinfection by AOPs”, “Fundamentals and applications of ozonation process” and “Conventional vs new photo-Fenton processes”, respectively, in the Facultad de Ciencias Básicas de la Universidad de la Amazonia. Florencia (Colombia).

13rd-14th November 2023

Workshop

Esther Rojas participated in the REdTES Workshop entitled “Retos sociales e industriales en el almacenamiento de energía térmica” where she presented the R&D activities of the Thermal Energy Storage Unit of CIEMAT-PSA.

13th-15th November 2023

International visit

Samira Nahim was selected to be in the delegation of the Ministry of Science and Innovation of the Government of Spain as Young Spanish Researchers for their visit to the Joint Research Center of the European Commission (JRC, Joint Research Centre) in ISPRA, Italy.

14th and 15th November 2023

Meeting

The kick-off meeting of the ASTERIx-CAESar project: Air-based Solar Thermal Electricity for Efficient Renewable Energy Integration & Compressed Air Energy Storage was held in Pamplona last 14 and 15th November 2023. The project focuses on the development of a novel high-efficiency solar thermal power plant concept with an integrated electricity storage solution. The project combines air-based central receiver Concentrated Solar Power (CSP) and Compressed Air Energy Storage (CAES) to maximize conversion efficiency and power grid energy management, enabling a new operation strategy and business model.

17th November 2023

Lecture

Lecture given by Gema San Vicente Domingo titled "Codification activities with CSP materials" in the Workshop "INNOVATIVE STRUCTURAL MATERIALS FOR FISSION AND FUSION (INNUMAT)", Madrid (Spain).

17th November 2023

Lecture

Invited lecture given by Guillermo Zaragoza "Sea Mining case studies in Water Mining project" in workshop "Critical Raw Materials from unconventional water sources: Ensuring supply through Circular Economy", Barcelona (Spain).

28th November 2023

Dissemination event

Lidia Roca participated in the activity "Charlas en el Aula" at University of Almería explaining the importance of automatic control in solar thermal power plants.

15th December 2023

Award

The PROA prize "Conocimiento Azul" was awarded to the Solar Thermal Applications Unit by Clúster Marítimo Marino de Andalucía.

17th December 2023

Workshop

Esther Rojas participated in the SFERA-III Internal Workshop on Key Results project by presenting some of the key results obtained in the WP-6 of the project.

22th December 2023

Prize

Samira Nahim received the award for the best Doctoral Thesis awarded by the Chair of Water in Agriculture, Irrigation and Agri-Food of the University of Almería. Call 2022.

16 Publications

PhD Thesis

Francisco Buendía Martínez. Lifetime estimation of materials for solar reflectors. Universidad de Almería, Almería. Supervisor: Aránzazu Fernández-García.

Melina A. Roccamante. Nuevas tecnologías solares aplicadas a la eliminación de contaminantes de preocupación emergente presentes en aguas naturales. (Tesis Doctoral Inédita). Universidad de Almería, Chemical Engineering Department. 23rd January, 2023. Supervisors: Prof. Sixto Malato Rodríguez and Sara Miralles Cuevas.

Line-focus Concentrating Solar Thermal Technologies Unit

SCI PUBLICATIONS

Alcalde-Morales, S., Valenzuela, L., Serrano-Aguilera, J.J. Heat losses in a trapezoidal cavity receiver of a Linear Fresnel collector: A CFD approach. **Heliyon** 9 (2023):e18692. https://doi.org/10.1016/j.heliyon.2023.e18692

Carra, M.E., Setién, E., Valenzuela, L., López-Martín, R., Amador, C., Caron, S., Ballestrín, J., Fernández-Reche, J., Carballo, J.A., Ávila, A. 2023. Study of parameters influence on the measurement of vacuum level in parabolic trough collectors' receivers using infrared thermography. **Infrared Physics and Technology** 131 (2023):104657. https://doi.org/10.1016/j.infrared.2023.104657

Sandá, A., Moya, S.L., Valenzuela, L., Cundapí, R.A., 2023. Coupling of 3D thermal with 1D thermohydraulic model for single-phase flows of direct steam generation in parabolic-trough solar collectors. **Applied Thermal Engineering** 229 (2023):120614. https://doi.org/10.1016/j.applthermaleng.2023.120614

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Biencinto, M., González, L., Valenzuela, L. Simulation and economic analysis of an innovative linear Fresnel collector coupled to two industries processes with low and medium temperatures. **AIP Conference Proceedings** 2815 (2023), 140003. https://doi.org/10.1063/5.0148769

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Oral presentations

Arias, I., Battisti, F.G., Cardemil, J., Valenzuela, L., Zarza, E., Escobar, R. Green hydrogen co-generation through a hybrid Gen3 Solid-Particle CSP + PEM system. **29th SolarPACES Conference**. Sydney, Australia, October 10-13, 2023. Oral.

Carballo, J.A., Bonilla, J., Fernández-Reche, J., Ballestrín, J., Valenzuela, L. Smart Heliostat Tracking System based on Artificial Intelligence. **29th SolarPACES Conference**. Sydney, Australia, October 10-13, 2023. Oral.

Valenzuela, L., Saliou, G., Hilgert, C., Schickedanz, K., Jung, C. Application of silicone based heat transfer fluids in parabolic trough collectors. **2023 MRS Spring Meeting – Symposium EN05-Advances**

in Materials for Concentrating Solar Thermal Technologies. San Francisco (USA), April 10-14, 2023. Oral.

Posters

Saliou, G., Klenin, M., García-Segura, A., López Martín, R., Lüpfert, E. Flex with confidence: vibration study of rotary flexible hose assemblies for solar parabolic trough plants. **29th SolarPACES Conference**. Sydney, Australia, October 10-13, 2023. Poster.

Point-Focus Solar Thermal Technologies Unit

SCI PUBLICATIONS

Cañadas I. Oliveira F.A., Rodríguez J., Shohoji N. Thermal decomposition of δ-MoN and ε-Fe2N synthesized under concentrated solar radiation in NH3 gas stream. ***Thermochimica Acta.*** https://doi.org/10.1016/j.tca.2022.179394

Sanchez-Señoran D., Reyes-Belmonte M.A., Fernandez-Reche J., Avila-Marin A.L. Numerical simulation of convective heat transfer coefficient in wire mesh absorbers with fixed porosity. ***Results in Engineering.*** https://doi.org/10.1016/j.rineng.2022.100830

Estremera-Pedriza N., Fernández-Reche J., Carballo J. Optical Characterization of a New Facility for Materials Testing under ConcentratedWavelength-Filtered Solar Radiation Fluxes. ***Solar.*** https://doi.org/10.3390/solar3010007

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Zaversky F., Fernández-Reche J., Casanova M., Monterreal R., Enrique R., Avila-Marin A., Martínez S., Schmitz M., Castellanos A., Mallo R., Herrero S., López S., Mesonero I., Pérez I., McGuire J., Berard F. Experimental Testing of a 300 kWth Open Volumetric Air Receiver (OVAR) Coupled with a Small-Scale Brayton Cycle. Operating Experience and Lessons Learnt. ***AIP Conference Proceedings.*** https://doi.org/10.1063/5.0148723

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Campos L., Wilbert S., Carballo J., Meyer zu Köcker J., Wolfertstetter F., La Casa J., Borg E., Schmidt K., Zarzalejo L.F., Fernandez-Garcia A., Norde Santos F., García G. Autonomous measurement

system for photovoltaic and radiometer soiling losses. ***Progress in Photovoltaics: Research and Applications.*** https://doi.org/10.1002/pip.3650

Costa-Oliveira F.A., Sardinha M., Galindo J., Rodríguez J., Cañadas I., Leite M., Cruz-Fernandes J. Manufacturing and Thermal Shock Resistance of 3D-Printed Porous Black Zirconia for Concentrated Solar Applications. ***Crystals.*** https://doi.org/10.3390/cryst13091323

Zervaki A.D., Lambrakos S.G., Mourlas A.G., Papantoniou I.G., Rodríguez J., Psyllaki P.P. Inverse Thermal Analysis as a Tool for Optimizing Concentrated Solar Energy Elaboration of Wear Resistant Surface Layers. ***Metals.*** https://doi.org/10.3390/met13050942

Domingos G., Garcia Pereira J.C., Rodrigues Rosa P.A., Rodríguez J., Guerra Rosa L. Experimental Validation of Double Paraboloid Reflection for Obtaining Quasi-Homogeneous Distribution of Concentrated Solar Flux. ***Energies.*** https://doi.org/10.3390/en16093927

Ebadi H., Cammi A., Difonzo R., Rodríguez J., Savoldi L. Experimental investigation on an air tubular absorber enhanced with Raschig Rings porous medium in a solar furnace. ***Applied Energy***. https://doi.org/10.1016/j.apenergy.2023.121189

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PRESENTATIONS AT CONGRESSES

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Hanrieder N., Blume K., Gonzalez Rodriguez S., Deuerlein L., Gloria N., Gramitzky K., Klaas-Witt T., Kühn P., Fernández-Reche J., Zarzalejo L., Röger M. Long-term Analysis of two-dimensional Aerodynamic Conditions within a Real-Scale Heliostat field. ***29th SolarPACES Conference*** (Sydney, Australia). 10-13/10/2023.

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Sanchez-Señoran D., Kinzel M.P., Reyes-Belmonte M.A., Avila-Marin A.L. Evaluation of the efficiency and pressure drop in metallic wire meshes with stagger pattern for solar tower technology. ***29th SolarPACES Conference*** (Sydney, Australia). 10-13/10/2023.

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Cañadas I., Sanchez-Perez M., Wette J., Farchado M., Morales A., Rodriguez J., Sutter F., Reyes D.F., Rojas T.C., Escobar-Galindo R., Sanchez Lopez J.C. Solar aging of solar selective coatings based on CrAlN multilayers for high temperature applications. ***FEMS EUROMAT 2023 - 17th European Congress and Exhibition on Advanced Materials and Processes.*** 03-07/09/2023.

Posters

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Farchado M., San Vicente G., Barandica N., German N., Avila A., Fernandez-Garcia A., Morales A. Temperature Effect on Individual Layers Constituting a SelectiveAbsorber for Solar Thermal Receivers. ***29th SolarPACES Conference*** (Sydney, Australia). 10-13/10/2023.

Cañadas I., Galindo F.J., Garcla-Ten F.J., Lorente-Ayza M., Martinez-Plaza D., Morales A., Planelles-Arago J., Rodriguez-Garcia J. Preliminary solar ageing of new advanced ceramic materials for solar receivers. ***FEMS EUROMAT 2023 - 17th European Congress and Exhibition on Advanced Materials and Processes.*** 03-07/09/2023.

Thermal Energy Storage for Concentrating Solar Thermal Technologies Unit

SCI PUBLICATIONS

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