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Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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1 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.

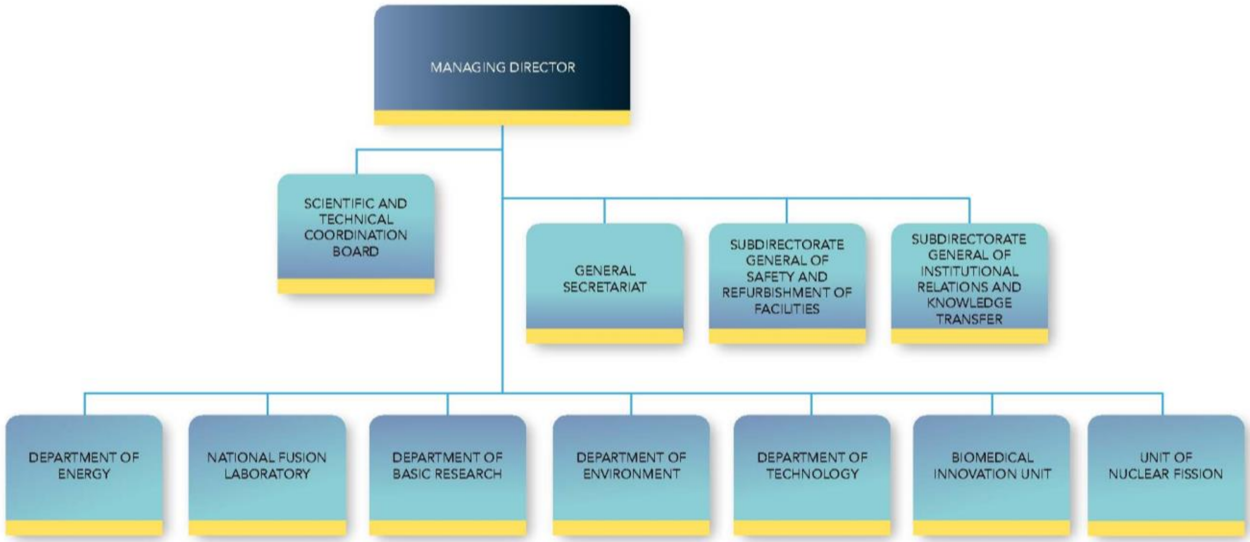


Figure 1. Integration of the PSA in the CIEMAT organization

The following goals inspire its research activities:

- Contribute to establishing a sustainable and clean global supply of energy and water.
- Support the conservation of European energy and water resources, as well as the protection of the climate and environment.
- Promote collaboration among society, public administrations, industry, and academia to support the implementation of the national net-zero strategy.
- Foster North-South technological cooperation on energy and water issues, particularly in the Mediterranean region and Latin American community.
- Encourage open innovation in solar technologies to enhance the water-energy nexus.
- Strengthen cost-reducing technological innovations that help increase market acceptance of solar technologies.
- Assist industry in identifying new applications and market niches for CST (Concentrated Solar Technologies) and solar-driven water technologies.
- Promote the use of solar technologies for seawater desalination and the treatment of urban wastewater effluents as alternative water sources.
- Support public and policy actors in defining the best strategies to reduce the water footprint in agriculture and industry, and to promote circular water management.

Since 2021, research activity at the PSA 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/m^2 (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.

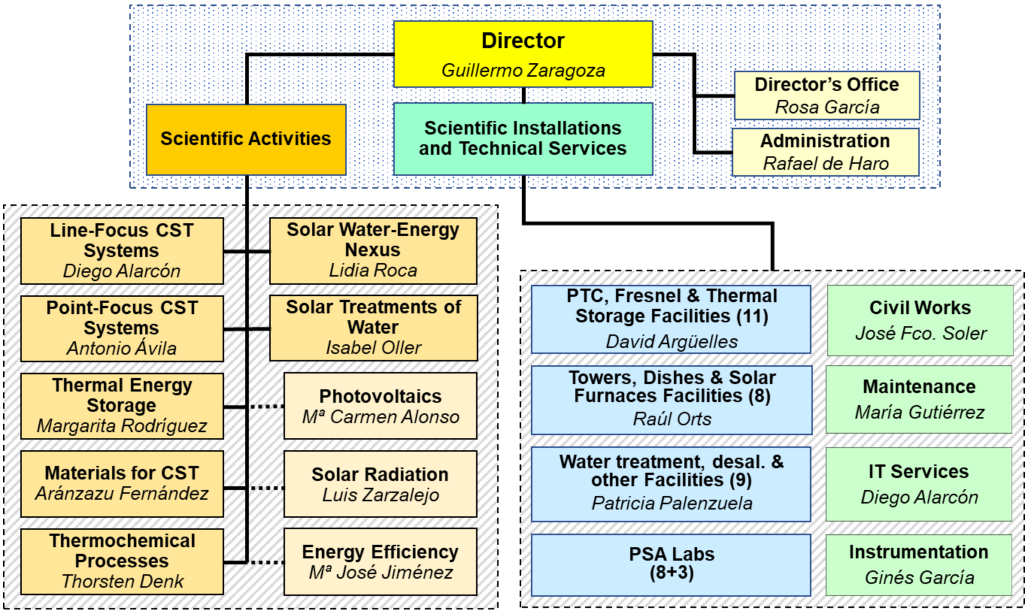


Figure 3. Internal organizational structure of PSA

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 140 people that as of December 2024 made up the permanent staff lending its services to the PSA. 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 122 people who work daily for the PSA, 71 are CIEMAT personnel, 11 of whom are located in the main offices in Madrid.

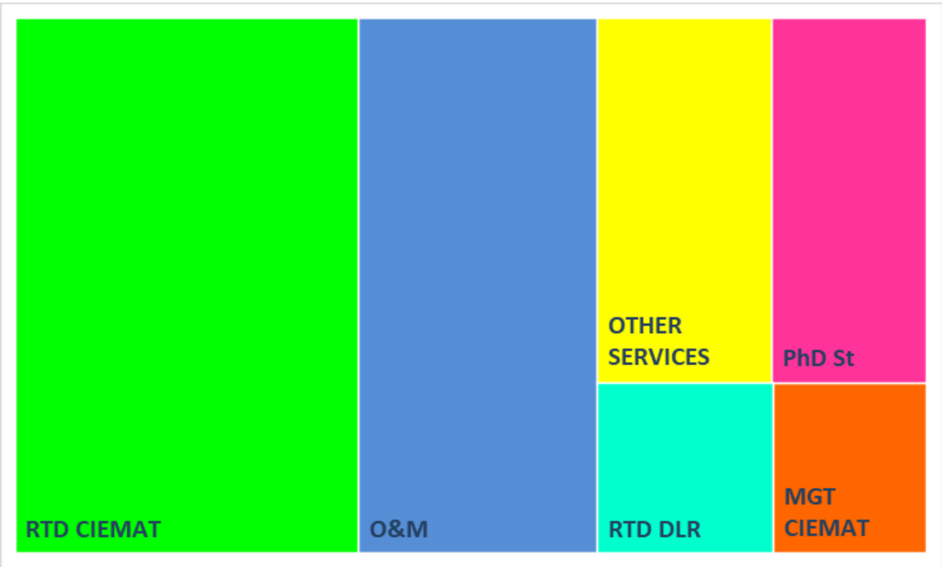


Figure 4. Distribution of permanent personnel at the PSA as of December 2024.

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 4 administrative personnel and secretaries, 8 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 2024 totals 3.8 M Euros (not including R&D personnel or new infrastructure).

Figure 5. Personnel at the PSA

2 Line-focus Concentrating Solar Thermal Technologies Unit

Introduction

The goal of this R&D Unit is to promote and support the increased use of concentrated solar radiation through line-focus solar thermal technologies. To achieve this, 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 work conducted through specific R&D projects, this PSA unit places strong emphasis on dissemination activities. It actively participates —both in person and virtually— in international conferences, workshops, seminars, and master's courses to promote awareness and understanding of line-focus solar thermal technologies and their applications.

During 2024, 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, testing a new silicone fluid for parabolic troughs (Si-CO Project), modelling and simulating power plants with parabolic-troughs 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 project 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 2024. 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 within the meteorological forecasting tool of this company, extending its capacity to the prediction of electricity generation. By the end of 2024, this tool was already in operation in eleven commercial solar thermal power plants, and work was underway to incorporate the simulation tool in more plants during 2025.

List of projects this PSA Unit has been involved in

- Silicone Fluid Next Generation (SING)
- Powering System Flexibility in the Future through Renewable Energy Sources (POSYTYF)
- 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)

Figure 6. Unit staff at PSA (left) and CIEMAT Headquarters in Madrid (right).

3 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 2024 the unit has been working in our main research lines:

- The simulation and development of advanced ceramic and metallic volumetric receivers (ASTERIx-CAESar project, SUNFLOWER project, INTECSOL project, PRINCESS project, COOPERANT project).
- The automation of heliostat characterization and calibration method (LEIA project).
- The development of innovative and cost-effective heliostats (INTECSOL project).
- The analysis and comparison of the existing heliostat characterization methodologies (EU Solaris project).
- The improvement in the measurement of variables of control in real time for power tower plants (LEIA project, HELIOSUN project).
- 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);
- The assistance to industrial stakeholders to achieve an effective development of the technology (ODQA, TEWER, BCB).

List of projects the group has been involved in

- More efficient Heliostat Fields for Solar Towers – HELIOSUN.
- Solar field measurements to Increase performance – LEIA.
- Innovaciones tecnológicas para la mejora de la viabilidad de las plantas termosolares de concentración – INTECSOL.
- Sustainable Near-net-shape Fabrication of Low Environmental impact Receiver materials – SUNFLOWER.
- Analyze Heliostat Field phase II: BCS as a calibration reference system – EU Solaris
- Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage – ASTERIx-CAESar.
- triPly periodic mINimal surfaCEs for Solar plantS – PRINCESS.
- Leading-edge cooperative advances towards the next generation of concentrated solar power (CSP) technology – COOPERANT.
- Solar extinction measurement system commercialization – Ref. 8510/2018.

4 Thermal Energy Storage Unit

Introduction

During 2024, the researchers of this Unit have been actively working in international, national and regional funded projects. The R&D activities of this Unit focus on various 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 reliability enhancement of current commercial systems. Large Installations and power to heat (P2H-Carnot batteries) technologies.
2. Storage prototype testing: both sensible and latent, under real solar operating conditions.
3. Modelling and integration of thermal storage systems
4. Assessment of material viability 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. MOSAICO
- 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

Figure 7. Unit staff at PSA (left) and CIEMAT Headquarters in Madrid (right).

5 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 2024, 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 innovative solar reflectors under several outdoor environments as well as accelerated aging conditions (GREENCOAT, NEMITEC and MIRAGE projects), the accelerated aging of materials for CST technologies under high radiation fluxes in solar furnaces (HIDROFERR, ASTERIX-CAESar, TWINSOLARSURF, HELIOTROPE and SUNFLOWER projects), and standardization of the methodology to measure optical properties of components for CST technologies (reflectors and receiver particles), with participation in the development of new standards in the IEC TC117 committee 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 is being developed 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.
- Impulso a tecnología de producción H_2 por vía termosolar mediante desarrollo y validación de nuevos materiales para receptores cerámicos de durabilidad extendida, HIDROFERR
- Soiling measurement of solar reflectors, SOILING-SP-II
- Technological innovations for improving the viability of concentrating solar thermal plants, INTECSOL

- Desarrollo y análisis de la vida útil de recubrimientos protectores sin plomo para espejos en plantas de energía solar térmica), GREENCOAT
- New concepts for solar mirrors, NEMITEC
- Characterisation and optimisation of high reflectivity mirrors for solar towers, MIRAGE
- 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
- Highly Efficient and Low-Impact Innovative Thermal Storage System for Enhance Dispatchability in Concentrating Solar Tower Plants, HELIOTROPE
- TWINning for SOLAR energy-driven SURFace engineering of metallic parts, TWINSOLARSURF

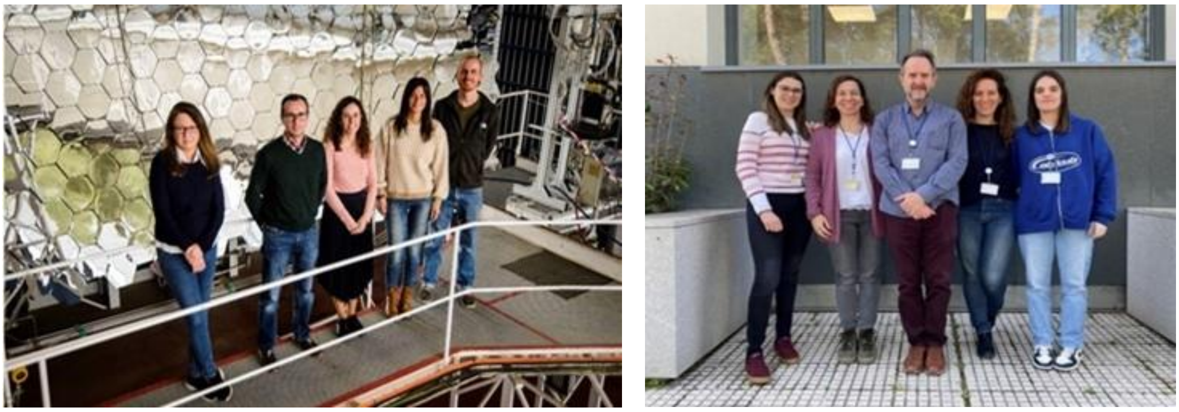


Figure 8. Unit staff at PSA (left) and CIEMAT Headquarters in Madrid (right).

6 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 2024, 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 granted the opportunity to take a leading role in driving an initiative on renewable hydrogen production as part of the esteemed IEA Hydrogen Technology Collaboration Program (Task 45: Renewable Hydrogen). By leading Subtask 3, which focuses on pioneering solar hydrogen production through cutting-edge thermochemical cycles, the Unit is strategically positioned to make a lasting impact in this critical and rapidly evolving field. 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).
- More efficient Heliostat Fields for Solar Towers – HELIOSUN.

7 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.
- Modelling, process optimization and advanced control strategies in solar thermal applications.
- Application of heat pumps to solar thermal processes.
- High-purity water generation via MD for industrial processes, especially in green hydrogen production.

During 2024, research and development efforts focussed on innovative solutions for seawater desalination using solar energy, as well as on brine recovery through a zero liquid discharge approach. In the field of cogeneration schemes in CSP+D, we contributed to the development of innovative desalination technologies, such as the use of compressed air in point-focus CST systems and the Brayton cycle. Efforts also continued on reducing water consumption in CSP plants (based on the Rankine cycle) through innovative cooling technologies and the development of algorithms to optimise their operation. The Unit also focused on evaluating new opportunities for thermal desalination, especially MD, with a strong emphasis on sustainable and decentralized solutions. This includes brine concentration and the integration of MD with green hydrogen production to address both energy consumption and high-quality water needs.

Open innovation remains a key element A workshop on sustainable desalination, co-organized with CIESOL and focused on the use of desalinated water in irrigation, fostered dialogue among stakeholders and the Community of Practice. Through the Rewaise project, a collaboration was established to analyse legal, social and technical barriers to efficient water use, by participating in co-creation workshops on this topic. The unit also collaborated with Almeria City Council on Smart Cities Challenge activities.

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
- Air-based Solar Thermal Electricity for efficient Renewable energy Integration & Compressed Air Energy Storage (ASTERIX - CAESAR)
- Sustainable drinking and irrigation water production from saline alternative water resources, SALTEAU.

Figure 9. Solar Thermal Applications Unit staff in 2024.

8 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 System Integration in task 72 ” Energy Carriers from Solar Powered Photo-Reactors” 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 quaternary treatment for the removal of pollutants of emerging concern and microorganisms, related with SOL2H2O, DIGIT4WATER, ANDROMEDA, 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, and AQUAENGRI projects.
- Evaluating photocatalytic efficiency of new materials under solar light in pilot reactors, related with ENERGICA (Green Deal) and ANDROMEDA project, and SMALLOPS service contract.

- Photocatalytic and photochemical processes for water disinfection in different scenarios related with ENERGICA and MODITRAGUA projects.
- Pilot solar photo-reactors for production of hydrogen and other photo-fuels, related with SolarFuture, SOLCHEM5.0, REFINE, CONFETI and SPECTRUM 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 CO_2 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 (H_2O) production and treatment technologies, Sol2H2O.

Figure 10. Solar Treatment of Water Unit staff in 2024.

9 Projects

Support to the activities of the concentrated solar thermal technology area of the SET-PLAN (CST4ALL)

Participants: DLR (coordinator), ESTELA, CIEMAT, ENEA, METU.

Contacts: Julian Blanco.
Ricardo Sánchez.

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

Background: This project is a coordination and support action aimed at advancing the SET-Plan (Strategic Energy Technology Plan) Implementation Plan (IP) for Concentrated Solar Thermal (CST). The main goals of the project are to provide support and assistance to the Implementation Working Group (IWG) on CST, chaired by Spain, and to foster the creation of strong and sustainable cooperation networks between CST and other SET-Plan IWGs with shared interests and clear synergies. The CST4ALL project began in October 2022 and is scheduled to be completed by September 2025.

Objectives: The main specific 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 2024: CIEMAT-PSA activities in 2024 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 2024, we have the following:

- Strong involvement in the negotiations to integrate low temperature solar heat technologies and applications into CST to create a new IWG fully devoted to Solar Heat (IWG on Solar Heat Technologies). The process was fully endorsed by the European Commission and the SET Plan Steering Group and expected to be completed early in 2025.
- SET Plan contribution and reporting. Reporting exercise related to the CST-IWG and active participation in several SET Plan Workshops and events organized in 2024.
- Contribution with inputs from R&I stakeholders to the Clean Energy Transition Partnership (CETP calls) and Horizon Europe (HE) programmes.
- SET Plan Conference 2024 organized in Budapest. Contribution and support to CST IWG Chair participation.

In addition to WP1 activities, in 2024, CIEMAT started the preparation of the workshop "Future Energy Mix with 100 % Decarbonisation Level", which aims to visualise the important potential role of CST technologies, both in power and process heat generation, that could have in an advanced and full decarbonisation mix. Finished and planned workshops on CST cross-cutting related topics within ETIPs, targeting R&I Actors, are:

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

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

- CST-Photovoltaics (February 2024)
- CST-Bioenergy (May 2024)
- CST-Heat Pumps (October 2024)
- CST-Geothermal (March 2025)
- CST-Energy Storage (t.b.d. 2025)

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

Line-focus Concentrating Solar Thermal Technologies Unit

Powering System flexibility in the future through renewable energy sources (POSYTYF)

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

Contacts: Lourdes González Martínez.

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 2024: 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. CIEMAT has also performed advisory work for the rest of the project partners in relation to solar thermal power plants for the configuration of the VPPs.

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.

Funding agencies: BMWi - Federal Ministry for Economic Affairs and Energy (Sep 2020-Dec 2023).

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®). 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 2024: Although the official conclusion of the project took place in December 2023, it was decided to extend the operation of the experimental facility to complete the remaining 210 hours at high temperature (440 °C/450 °C) in solar mode, in order to conclude the experimental campaign planned in the project.

Figure 11. 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.

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 PSA, mainly at the so-called PTTL test facility.

Achievements in 2024: During this year, the construction and installation of the new innovative 90-metre-long parabolic trough collector prototype was completed at the PTTL test facility at PSA. This large-aperture collector (8 m) has been specially designed to use with the new generation of silicone-based thermal oils for operating temperatures of up to 450 °C. Experiments have been completed for the geometric qualification of facets using photogrammetry and for the mechanical qualification of the prototype using structural torsion measurements.

Figure 12. View of the PTTL pilot plant at the PSA with the Si-PTC prototype

Development of Innovative Concept for a Thermal 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

Contacts: Loreto Valenzuela.

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 2024: During this year, the construction and installation of the new prototype of a large aperture (8 m) parabolic trough collector with a fixed tube has been completed. Its geometric, optical, and thermal characterization and demonstration were one of the main objectives of the project. This new collector concept is designed to operate with molten salts as a heat transfer fluid for temperatures up to 460 °C, with a view to improving the efficiency of electricity generation and green hydrogen production processes. Support has been provided for the detailed engineering and adaptation of the “HTF Lopp” experimental facility at the PSA, to which the aforementioned prototype has been coupled, and the geometric qualification of the facets has been completed, as well as the first steps for the optical qualification of the experimental collector.

Photocatalytic Generation of White Hydrogen (PHOTOHY)

Participants: TEWER Engineering S.L., CIEMAT

Contacts: Loreto Valenzuela.

Funding agencies: CDTI (Programa Misiones, Ciencia e Innovación, 2021). Ref. MIP-20211023 (Jan 2022-Mar 2024)

Background: Renewable hydrogen is emerging strongly as an energy vector of maximum efficiency for those sectors and applications that cannot be covered by direct electrification, providing the future solution necessary for the process of decarbonisation of the economy to meet the principles of climate neutrality in 2050, according to the strategic vision of the European Commission.

Objectives: The PhoToHy project proposes a disruptive technology and process for the production of 100 % clean (white) hydrogen, based on a novel photocatalysis technology with solar concentration. It is a modular, off-grid solution that produces clean hydrogen from only the water molecule and concentrated sunlight. The concept also encompasses the subsequent purification, storage and direct use of hydrogen in consumers or transformed into electrical energy through the use of a novel fuel cell, using its storage capacity, allowing for improved sustainable transport.

Achievements in 2024: During this year, the construction and installation of a new prototype of parabolic trough collector for the production of white hydrogen by means of a photo-thermo-catalytic process (catalytic reaction assisted simultaneously by light and heat) with maximum temperatures of 450 °C has been completed. Despite the official conclusion of the project, qualification and demonstration are still pending and will be carried out at the PSA facilities during 2025.

Development of a novel tube- bundle-cavity linear receiver for CSP applications (DETECTIVE)

Participants: Politecnico di Torino, Absolicon Solar Collector AB, CIEMAT, KTH

Contacts: Diego-César Alarcón-Padilla.

Funding agencies: CET Partnership Joint Call 2022. Proyectos de I+D+i «Proyectos de Colaboración Internacional» Convocatoria 2023-2, Ref. PCI2023-146006-2 (Dec 2023-Nov 2026)

Background: In line with EU energy transition framework, it is mandatory to develop novel and concrete solutions to enhance the current efficiency of linear absorbers used in concentrated solar thermal (CST) plants in Europe, supplying renewable electricity or process heat to the EU nations.

Objectives: The project will focus on linear cavity concepts, adapted to conventional CST systems though a bundle of pipes receiving the solar radiation, where the slightly higher manufacturing cost would be compensated by increased optical efficiency. The DETECTIVE project will be carried out based on a rational development pathway, including modelling, manufacturing and testing of prototypes, and economic analysis for a fast go-to-market strategy.

Achievements in 2024: During this year, CIEMAT has participated in the design and modelling activities of the new receiver, and after receiving the construction plans for the prototype, the contracting activity for its manufacture has begun. As soon as this is completed, the prototype will be installed in the PSA HTF loop and the experimental campaign will begin.

Developing the Guideline for Testing of Flexible Pipe Connectors for Trough Collector Fields (FlexPipe-REPA Guide)

Participants: DLR, CIEMAT, NREL, UW Madison, SolarDynamics, Protermosolar, Senior Flexonics, Advanced Thermal Systems, VirtualMech

Contacts: Loreto Valenzuela.

Funding agencies: SolarPACES (Dec 2023-May 2025)

Background: It is necessary to get a significant saving in CAPEX and OPEX for solar thermal power plants based on parabolic trough collectors increasing the reliability of rotation & expansion performing assemblies (REPA).

Objectives: The main objective is to establish a relevant collection and database of the flexible pipe connectors experience in terms of design, application, test, field operation and maintenance experience (short-term). The goal is to make such information available to interested stakeholders, particularly the engineers in REPA application. The result of the proposed task shall be a broader and more relevant technical guideline that, as mid-term goal, is to be converted into an international standard in the IEC 68268 series for solar thermal power plants.

Achievements in 2024: During this year, CIEMAT has collaborated in the publication of the Guideline and, in parallel, in activities aimed at generating the first draft of the IEC 62862-3-7 standard.

Flexible pipe connectors with trace heating for parabolic trough power plants. Development, test sequences and standardization (REPA-3S)

Participants: DLR, Senior Flexonics, Winkler AG, CIEMAT (Associated Partner)

Contacts: Rafael López.

Funding agencies: German Federal Ministry for Economic Affairs and Climate Action (Dec 2022-Mar 2026)

Background: Rotation and expansion performing assemblies (REPA) are key components in solar thermal power plants with parabolic trough collectors. They connect the thermally expanding receiver pipe, which is tracked by the collector according to the position of the sun, to the fixed piping of the field. In a typical Spanish power plant with 50 MW, more than 1200 such REPAs are installed. Their function, tightness and durability are of paramount importance for the safe operation of the solar field, yet they are usually subordinated to disproportionate price pressure, accounting for about 1 % of solar field costs.

Objectives: The aim of this project is to develop new flexible connections for parabolic trough collectors for application in plants with thermal oil or molten salts as heat transfer fluid, to test new prototypes of flexible connections and to develop a test guideline for flexible connections to serve as a draft for the development of an international IEC standard.

Achievements in 2024: During this year, CIEMAT has collaborated in the experimental tests for accelerated life-cycle assessment (10,000 cycles) of new development of flexible connections at 393 °C and 35 bar.

Point-Focus Solar Thermal Technologies Unit

More Efficient Heliostat Fields for Solar Tower Plants (HELIOSUN)

Participants: CIEMAT, Universidad de las Islas Baleares.

Contacts: Jesús Ballestrín.

Jesús Fernández-Reche.

Loreto Valenzuela.

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 2024: 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, the intelligent ANN system has been completely developed. The system has been integrated into the main heliostat field control allowing the right pointing of the heliostats with this new procedure.

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 the previous year, the typical year of solar extinction for PSA was obtained from the measurements carried out since June 2017. During this year, solar extinction models have been validated at the PSA using the typical solar extinction year mentioned above. Work has also begun on generating a national solar extinction map using these models.

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. The pointing improvements in the heliostats have also been incorporated into this simulation program.

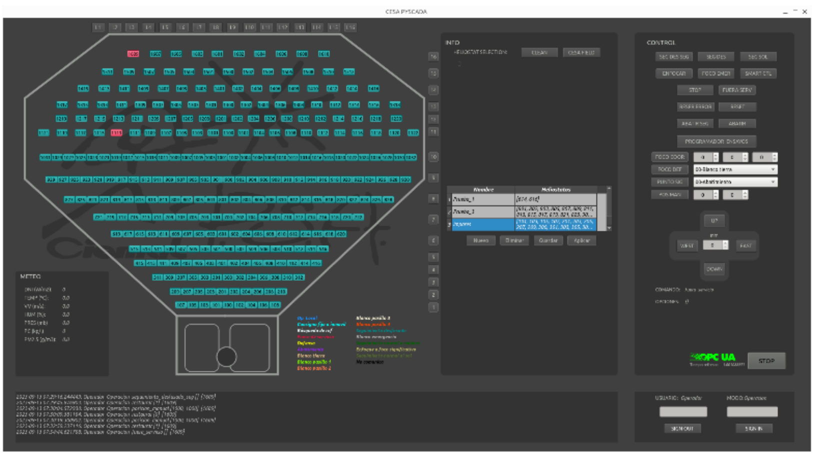


Figure 13. New control system for the CESA I heliostat field

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.

Jesús Ballestrín.

Daniel Sánchez-Señoran.

Rafael Monterreal

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 a heat transfer fluid are the preferred choice for power tower CSP technology. Current commercial plants aim to reduce both operation and maintenance costs, as well as the significant labor required for processes such as heliostat calibration, receiver operation, and control strategies for the solar field and overall plant.

Objectives: The project aims to support the market deployment of next-generation innovative, reliable, and intelligent CSP plants by developing advanced control and Operation & Maintenance (O&M) solutions for central receiver technology using molten salts—recognized as the most cost-effective and high-potential market solution. To achieve this, the LEIA project will develop and test the following innovations at PSA, CENER, and the Cerro Dominador CSP plant:

- Smart heliostat field control solutions to automate and enhance calibration and characterization.
- Smart receiver control solutions to monitor receiver temperature, emittance, and high solar irradiance distribution.
- Solar field O&M control strategies, including automated soiling inspection and a smart energy management system.

Achievements in 2024: CIEMAT-PSA successfully completed the methodologies for the online heliostat field characterization system and high irradiance hybrid measurements, with all reports finalized except for one due in May 2025. As part of the PSA test campaign, the evaluation of heliostat optical performance progressed with the preparation of the experimental setup and the capture of six images from two heliostats in the CESA-1 solar field at different times of the day to analyze optical quality evolution. These images are currently being processed using Computational Optimization Algorithms (COA). In the evaluation of high irradiance hybrid measurement, a pioneering platform integrating three high-irradiance measurement systems —Moving Bar, Calibration Unit, and Cold Finger— was deployed, marking a world-first achievement, though adverse weather conditions prevented testing. Additionally, within the Cerro Dominador - CIEMAT test campaign, CIEMAT received 12 images from Cerro Dominador, which are now being processed using the developed COA methodologies.

Analyze Heliostat Field phase II – BCS as a calibration reference system

Participants: CENER (coordinador), IMDEA Energia, CIEMAT, CYI, DLR.

Contact: Antonio Avila-Marin.

Daniel Sánchez-Señoran.

Rafael Monterreal.

Funding agency: EU Solaris.

Background: Solar tower systems offer significant cost-reduction potential. Advances in heliostat manufacturing and maintenance lower costs and improve competitiveness by reducing the LCOE, while greater efficiency enables further cost declines through mass production and scalability. On-site quality control of heliostat fields is key to CSP plant reliability and efficiency. Precise heliostat alignment maximizes energy capture, minimizes losses, and reduces downtime. Improved solar field qualification methods will lower heliostat requirements, cutting construction and commissioning costs.

Objectives: This collaboration aims to enhance the capabilities of Beam Characterization Systems (BCS) to improve measurement quality and define industry gaps for robust solar field characterization. It will evaluate and compare BCS implementations to establish a unified, open methodology as an industry standard. Research centers will share and optimize BCS algorithms for accuracy, computational efficiency, and hardware requirements. Additionally, a database of BCS images will be developed to facilitate intercomparability of heliostat characterization methods, enabling a replicable system for validating results. This open-access resource will also support researchers without direct access to solar fields, fostering broader collaboration and innovation in the CSP community.

Achievements in 2024: The project was officially funded in December 2024 and launched in January 2025. Since then, a manuscript has been submitted to the SPIE conference, and CIEMAT-PSA has contributed by sharing data on the optical quality of two heliostats and the tracking quality of one, marking important early achievements in the project.

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.

Jesús Fernández-Reche.

Patricia Palenzuela Ardila.

Inmaculada Cañadas Martínez.

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

Background: Efficient solar power conversion and storage are crucial for a sustainable energy future. This project develops a novel high-efficiency CSP concept integrating CAES to enhance conversion efficiency and grid management. The hybrid system supports new operation strategies, producing both electrical and thermal energy for applications like process heat and desalination. By leveraging cheap off-peak electricity for air compression in the Brayton cycle, the plant's peak solar-to-electric efficiency could reach 40 %, doubling that of current CSP technology.

Objectives: ASTERIx-CAESar aims to develop (a) a high-efficiency solar volumetric receiver, (b) optical sensors with AI-based control, (c) optimized CAES with advanced heat exchangers and compressors/expanders, and (d) innovative desalination integration. The project includes techno-economic-environmental optimization under real-world conditions and extensive testing of key components.

Achievements in 2024: In 2024, significant progress was made in the experimental validation and integration of key components for the ASTERIx-CAESar project. The solar receiver prototype underwent extensive testing at the PSA, focusing on airflow regulation, thermal performance, and optical characterization. Cold tests assessed the influence of cup outlet diameter on air mass flow rate, while thermal tests analyzed the efficiency of 9 volumetric absorbers under varying solar flux and temperature conditions. Optical characterization evaluated changes in solar absorptance before and after thermal exposure. In parallel, the development of the CAES and desalination system advanced with the completion of a 3D model, finalization of the Piping and Instrument Diagram (P&ID), and definition of installation requirements. The reverse osmosis plant was designed to integrate with the CAES system, utilizing compressed air to optimize water desalination. A dedicated installation site was prepared at PSA, establishing the necessary infrastructure for seamless integration with the central receiver system. These achievements mark a crucial step toward the realization of the CSP-CAES concept, demonstrating the feasibility of key components under real operating conditions.

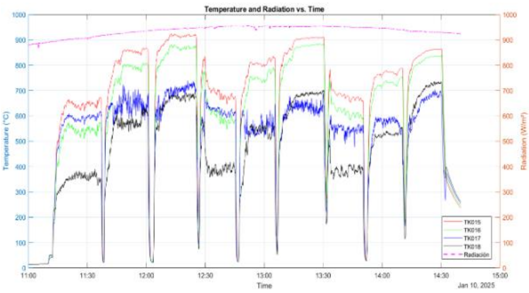


Figure 14. Temperature and Direct Normal Irradiance as function of the time for the absorbers.

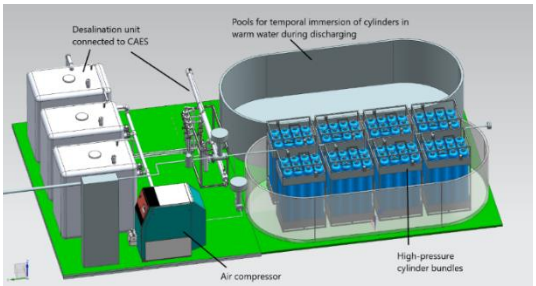


Figure 15. 3D model of CAES and desalination system at ground level.

Triply periodic minimal surfaces for solar plants (PRINCESS)

Participants: PoliMi (coordinador), PoliTo, CIEMAT, KTH, MG sustainable Engineering AB.

Contact: Antonio Avila-Marin.

Angel Morales.

Funding agency: CET Partnership Joint Call 2023. Agencia Estatal de Investigación. PCI 2024-2. Co-funded by the EU.

Background: CSP plants using supercritical carbon dioxide (sCO_2) cycles are seen as the next advancement, offering higher efficiency and potential cost savings compared to traditional cycles. To maximize performance at higher temperatures, efficient receivers and heat exchangers are required. PRINCESS focuses on developing and testing innovative solar receiver modules and air-sCO_2 heat exchangers based on Triply Periodic Minimal Surfaces (TPMS), aiming to improve efficiency, reduce costs, and enhance the competitiveness of CSP technology.

Objectives: The main objectives of the PRINCESS project are to develop innovative solar receivers and heat exchangers using TPMS to enhance efficiency in CSP applications. The project aims to explore new TPMS topologies for improved heat transfer and to adopt a modular approach in the design of heat exchangers to maintain manageable module sizes. It also seeks to deepen the understanding of heat and mass transfer in TPMS structures, contributing to advancements in renewable energy. Additionally, the project will demonstrate the use of additive manufacturing techniques to enhance efficiency in high-temperature and high-pressure CSP processes. The project will enhance techno-economic models to assess the performance, cost, and environmental impact of the new solar receiver technology.

Achievements in 2024: The PRINCESS project officially started in December 2024, and the Kick-off Meeting (KoM) was held in Torino in January 2025, where the PI from CIEMAT attended in person. Following the KoM, the first tasks of the project have already been initiated, marking a strong start and setting the stage for the subsequent phases of development.

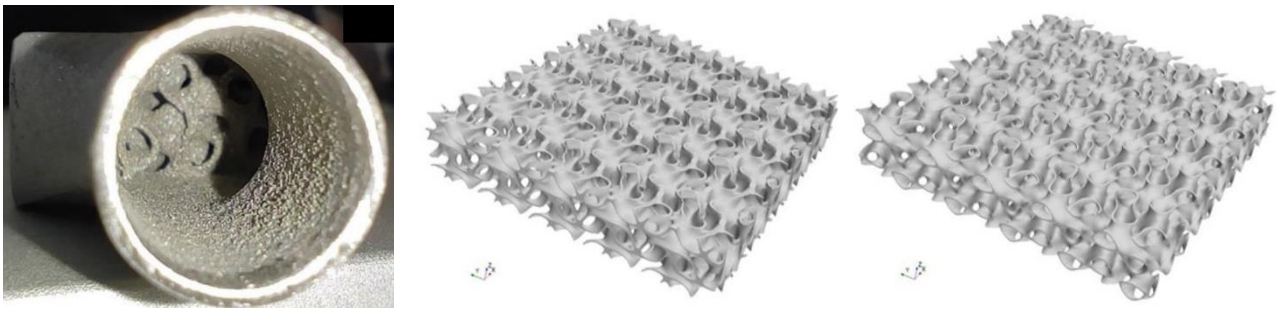


Figure 16. Prototype equipped with SplitP (left), lidinoid TPMS (centre), Split P TPMS (right).

Leading-edge cooperative advances towards the next generation of concentrated solar power (CSP) technology (COOPERANT)

Participants: Idener (coordinador), Kraftblock, Fachhochschule Zentralschweiz, CIEMAT, HOLOSS, Phase Change Material Products, Engicer.

Contacts: Jesús Fernández-Reche.

Antonio Avila-Marin.

Funding agency: European Commission. HORIZON-CL5-2024-D3-01-10. Grant Agreement number: 101172882.

Background: COOPERANT aligns with the SET-Plan objectives for CSP, integrating advanced solutions at material, system, and integration levels. The project focuses on developing high-performance CSP systems to overcome challenges such as material availability, corrosion, and design limitations at high temperatures (~1,000°C). It combines a volumetric solar receiver with tailored morphology and a hybrid packed-bed TES system, using phase-change materials and industrial waste for high-temperature storage. AI tools will enable real-time monitoring and control to optimize performance. COOPERANT also collaborates with industry through the Stakeholder Replicability Board (SRB) to expand dispatchable clean energy, solar fuels, and industrial applications.

Objectives: COOPERANT develops an innovative solution for tower plants, tackling temperature, manageability, cost, and sustainability challenges to ensure efficient and viable solar generation. Operating at ~1,000 °C boosts efficiency but poses material, corrosion, and design challenges. To address these, COOPERANT integrates a volumetric receiver with a hybrid packed-bed TES using advanced storage materials. AI-driven monitoring and reinforced learning-based control will optimize performance, ensuring scalability and replicability. The project also strengthens industry collaboration through the Stakeholder Replicability Board, promoting dispatchable clean energy, solar fuels, and industrial applications.

Achievements in 2024: The project began in October 2024, with CIEMAT-PSA participating in the Kick-Of-Meeting (KOM) held at IDENER's facilities in Seville. A key milestone was reached with the successful delivery of the "CSP-TES requirements for potential key applications" under WP1, establishing the project's foundation by defining critical technical and operational criteria for integrating CSP with advanced thermal energy storage (TES) solutions. Simultaneously, in WP2, significant progress was made on the preliminary design of the volumetric solar receiver. This phase focused on defining key design parameters, evaluating receiver thermal power, assessing different operational scenarios (conservative, typical and aggressive), and determining the receiver size and required number of cups. These achievements mark a solid start for COOPERANT, setting the stage for further development and validation.

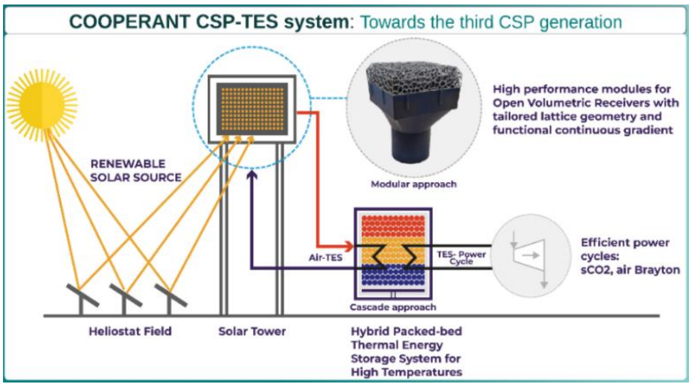


Figure 17. COOPERANT CSP-TES system

Solar extinction measurements system commercialization (Ref. 8510/2018)

Participants: BCB Informática y Control S.L., CIEMAT.

Contact: Jesús Ballestrín.

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 has been transferred to BCB company with the consequent economic consideration to CIEMAT for each one of the installed systems.

Achievements in 2024: As a result of the technology transfer contract to the Spanish engineering company BCB, the second commercial atmospheric extinction measurement system was fully implemented in 2023 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). This year, there has been continued interest in this system from companies in the CSP sector.

Thermal Energy Storage Unit

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.

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

Background: Originally established in 2011, the current phase of the network began in 2023.

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

Achievements in 2024: The network typically holds two annual meetings and one open workshop, during which each partner presents the R&D activities on Thermal Energy Storage related to the topic of the workshop carried out in their corresponding institutions. In 2024, CIEMAT participated exclusively online.

Towards the standardization of molten salt loops': instrumentation and components (MOSAICO)

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

Contact: Margarita Rodríguez.

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 2024: This year no activity is reported since the dissemination activities were already performed in 2023.

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.

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 2024: The project began in September 2023, and in 2024, a face-to-face project meeting was held in Paris, along with a hybrid meeting in Copenhagen. For the tests in MOSA, various components have been acquired. The ALTAYR facility was relocated from Madrid to Almería, where it now benefits from increased space. The facility has been prepared for commissioning and subsequent operation in 2025.

Smart Thermal Storage for Decarbonisation of Energy Sector (STES4D)

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

Contact: Rocío Bayón.

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 2024: During this year, CIEMAT made progress in degradation studies of low-temperature PCMs from the dicarboxylic acid family, with melting points in the range of 130 °C to 180 °C (succinic, suberic, and sebacic acids). These compounds are considered highly attractive as latent heat storage media for industrial applications.

In addition, the thermophysical properties of these materials were studied both before and after the degradation tests. To this end, the project's Principal Investigator (Rocío Bayón) visited the facilities of one of the project partners (UPV-EHU) to carry out DSC and TGA measurements, not only on dicarboxylic acid-based PCMs but also on monocarboxylic acid-based materials previously tested.

Overall, it was observed that, in addition to evaporation, heating above the melting point led to the formation of colored compounds. In particular, some acids, such as succinic acid, undergo dehydration, resulting in the formation of the corresponding heterocyclic anhydride.

Regarding the thermophysical properties, a more in-depth evaluation is still required. However, preliminary analysis has shown that their values tend to decrease after exposure to stress conditions in almost all the PCMs studied.

Some of these results were presented as an oral contribution at the EuroSun 2024 conference held in Limassol, Cyprus.

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.

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 2024: During this year, the Thermal Energy Storage Unit has actively participated in the development of several documents in collaboration with the other project partners. The development of these documents is a commitment within the project and includes the Roadmap entitled: Technology Roadmap for Hybridization of Energy Storage and the Strategic Research and Innovation Agenda on Hybridization of Energy Storage. Furthermore, one of the Unit members, Rocío

Bayón, competitively obtained a Transnational Access (TNA) grant to the AIT laboratory (Vienna) (June 17-28, 2024) to carry out thermophysical characterization of latent heat storage media (PCM). Furthermore, one of the Unit members has initiated a mentoring activity with a young researcher from the University of Saarland (Germany), which will continue until the end of the project.

Materials for Concentrating Solar Thermal Technologies Unit

Components' and Materials' Performance for Advanced Solar Supercritical CO_2 Power Plants (COMPASsCO2)

Participants: DLR (coordinator), CIEMAT, CVR, Dechema, John Cockerill, Jülich, Ocas, Ome, Saing-Gobain, Sugimat, University of Birmingham, VTT.

Contacts: Gema San Vicente Domingo.

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.

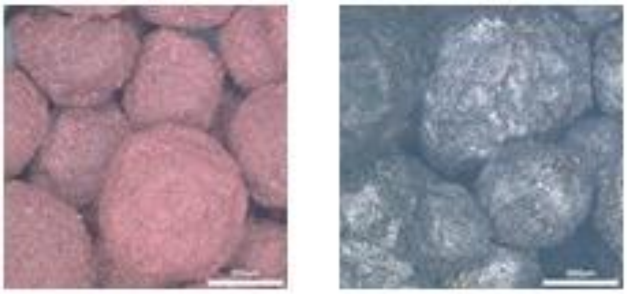


Figure 18. Uncoated FerOx particles(right) and coated FerOx particles with the high absorptance CIEMAT coating (left)

Achievements in 2024: During this year, all tasks of the project were in their final stages. Regarding PSA-CIEMAT's activities, the optimized high-absorptance coatings were successfully applied to the novel 'FerOx' particles developed within the framework of the project. The coated particles were tested to evaluate their behaviour under operating conditions. Some of the tests included thermocyclic exposure tests to assess resistance to thermal cycling, abrasion tests in a rotary furnace to simulate particle-particle and particle-wall interactions at 1,000 °C, and particle impact tests at 950 °C to simulate particle collisions at velocities similar to those occurring in a power plant receiver. The results showed that the coating developed by CIEMAT was the most stable, maintaining the highest solar absorptance values after testing. Solar absorptance values close to 0.97 were achieved.

Technological innovations for improving the viability of concentrating solar thermal plants (INTECSOL)

Participants: CIEMAT

Contacts: Aránzazu Fernández García.

Gema San Vicente Domingo.

Antonio Ávila Marín.

Lourdes González Martínez.

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 2024: In the field of solar reflectors, anti-soiling coatings compatible with second-surface glass reflectors were developed, successfully maintaining their optical properties. These coatings are currently undergoing outdoor testing at the PSA under real operating conditions. Additionally, an international exposure campaign (Spain, Turkey, Morocco, and France) was launched to assess UV-induced degradation and its dependence on temperature and humidity. Portable systems for detecting corrosion points and other operational defects were validated. A self-aligned heliostat prototype was also engineered and optimized to reduce labor-intensive operation and maintenance (O&M) efforts. For solar receivers, selective absorbing coatings stable in air at 600 °C were developed, exhibiting excellent optical properties (95.7 % solar absorptance and 10 % thermal emittance at 500 °C). Non-selective coatings were also formulated for metallic wire meshes used in volumetric receivers. Several wire mesh configurations were simulated to evaluate the influence of geometric parameters (wire diameter, porosity, and arrangement) and operational conditions (air inlet velocity, solar flux) on thermal efficiency. A tool for heliostat field design and flux characterization was developed and validated using solar flux images from the CESA-I field at the PSA. Regarding parabolic trough receivers, an innovative glass cover design began real-world testing at the PSA. Additionally, a simulation model was implemented to assess the impact of soiling on energy production, considering meteorological factors such as dust storms, aerosols, rainfall, and scheduled cleaning intervals.

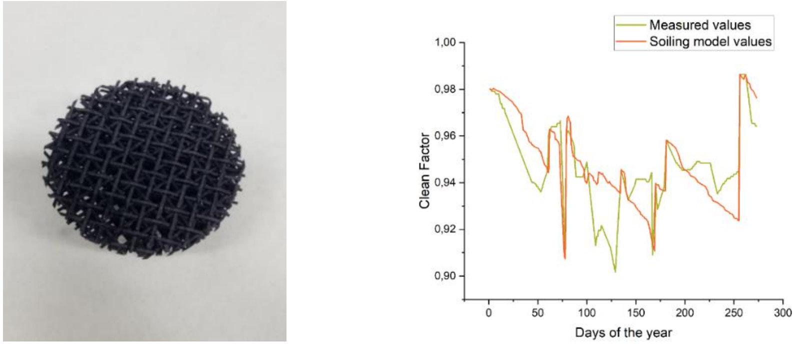


Figure 19. Metal mesh with non-selective absorber coating (right) and comparison between cleanliness factors from real measured data and from the soiling model (left)

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.

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 2024: This project started in April 2023 and is being performed by CIEMAT in cooperation with DLR in the OPAC facility. During this second year, several interviews with a set of key questions were performed to the plant operators in order to acquire enough knowledge of the reflectance measurement protocol currently followed in the commercial CST plants. The information extracted from such interviews is being collected to prepare a report with practical recommendations about the in-field soiling measurements. In addition, several reflector samples were outdoor exposed at the PSA to obtain different representative soiling level (see Figure 20). These samples were measured with both portable reflectometers (see Figure 20) 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 was developed in cooperation with ENEA.


Figure 20. Reflector samples exposed at different inclinations to achieved several soiling levels (Left). Portable reflectometers included in the study of the transfer functions (Right).

Development and lifetime analysis of lead-free protective coatings for mirrors of solar thermal power plants (GREENCOAT)

Participants: DLR, AGC, MIPA, CIEMAT.

Contact: Ricardo Sánchez Moreno.

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 2024: During this third year of the project, a third batch of samples was tested using an improved protective paint formulation that enables solar reflectors to withstand the Copper Accelerated Acetic Acid Salt Spray (CASS) test—one of the most aggressive corrosion tests, commonly used to compare new formulations against existing commercial products. According to the results of these accelerated aging tests, one of the eighteen new configurations demonstrated performance comparable to that of the company's currently marketed product, making it a promising candidate for the next generation of solar reflectors. Additionally, reflector samples exposed at various sites (PSA, Almería; Erfoud, Missour, Zagora; Antofagasta; Sines; and Abu Dhabi) were measured after 24 months of outdoor exposure. So far, the reflectors have shown excellent performance, exhibiting minimal degradation.

New concepts for solar mirrors (NEMITEC)

Participants: Solchem GmbH (coordinator), DLR, CIEMAT

Contacts: Ricardo Sánchez Moreno.

Funding Agency: German Federal Ministry for Economic Affairs and Energy (BMWi)

Background: The durability of solar reflectors affects the efficiency and maintenance costs of CST systems. Conventional reflectors use a copper layer and lead-based paint coatings, but their high cost and environmental concerns drive the search for alternatives.

Objective: To test new solar reflector concepts featuring lead-free and copper-free protective coatings, as well as new reflective layers. These are being subjected to accelerated ageing tests in weathering chambers and outdoor exposure at various sites. The most promising configurations will be installed on a real heliostat at the PSA for testing under real conditions during the final six months of the project.

Achievements in 2024: The first batch of new solar reflectors, received at the beginning of 2024, has been tested in a weathering chamber using accelerated ageing protocols (UV and CASS tests). In this batch, the traditional configuration of solar reflectors used in the market was modified to eliminate copper and lead from the back coatings, while maintaining–or even improving–reflectance levels. Results from the CASS test showed that only one configuration failed completely, leaving the glass without any reflective or protective layers, and two others were partially degraded. Conversely, one of the five configurations passed the test with excellent results and has been identified as the most promising. Regarding the UV test, one of the two configurations tested performed poorly after 300 hours of exposure. This may be attributed to a manufacturing defect and will therefore be retested during the course of 2025.

Characterisation and optimisation of high reflectivity mirrors for solar towers (MIRAGE)

Participants: Bilkent University (coordinator), Sisecam, DLR, CIEMAT

Contacts: Ricardo Sánchez Moreno.

Funding Agency: CSP ERANET

Background: Ensuring the durability of solar reflectors is crucial for concentrating solar thermal systems. Environmental factors like UV radiation, temperature changes, humidity, and mechanical stresses impact their longevity. Manufacturers aim to reduce costs by avoiding expensive contaminant removal processes for glass. However, these contaminants present in the glass can affect the performance and efficiency of the solar reflector.

Objective: This project studies the optical degradation effects on solar reflectors in CST plants, focusing on central receiver systems and heliostat fields. It assesses the durability and optical properties of commercial solar reflectors from Sisecam and a new copper-free, environmentally friendly material developed by Sisecam, subjected to accelerated aging and outdoor exposure tests. The goal is to understand these mechanisms and improve reflector performance.

Achievements in 2024: It has been observed that, in the outdoor test, the presence of iron in the glass of the samples exposed to solar radiation for 12 months affects both the hemispherical reflectance, $\rho\lambda,h$, of the reflector and the hemispherical transmittance, $\tau\lambda,h$, of the glass used to manufacture this solar reflectors, when comparing these properties between the high and low iron content samples. While in the low-iron sample the variation in $\rho\lambda,\ h$ is almost negligible, it becomes more significant in the high-iron sample, where after 12 months of outdoor exposure an increase of 2 pp is observed in λ around 1,000 nm (Figure 21 left). The same behavior is observed in the $\tau\lambda,\ h$ measured on the glass, where the increase in this case is 1 pp (Figure 21 right).

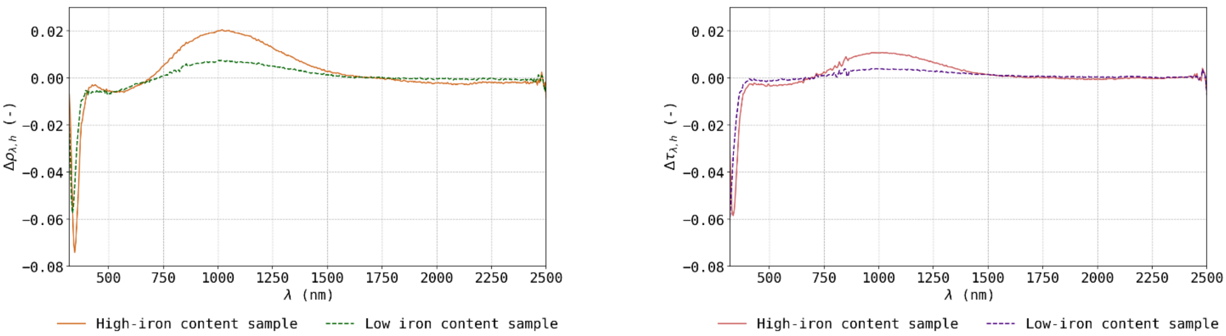


Figure 21. Performance of solar reflectors and their glasses after 12 months of outdoor exposure at PSA: (Left) Hemispherical reflectance difference spectra of the solar reflector samples. (Right) Hemispherical transmittance difference spectra of the glass samples.

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

Participants: Fraunhofer-IKTS (coordinator), Fraunhofer-IFAM, CIEMAT, Aalborg CSP, AMAZEMET, ESK-SiC, CENER.

Contact: Inmaculada Cañadas.

Antonio Ávila-Marin.

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 2024: During the first year of the SUNFLOWER project, CIEMAT-PSA actively contributed to WP3 and WP5. In WP3, simulations were conducted on a metallic wire mesh configuration, analyzing the effects of geometric properties (porosity, wire diameter) and operational parameters (flow velocity, solar flux). A comprehensive analysis has been completed, and a related article is currently in preparation. Building on the results from the CAPTure project, a more complex receiver geometry was studied using a silicon carbide (SiC) foam with similar geometric characteristics (porosity, cell size, strut diameter). This configuration was validated, showing less than 10 % deviation between experimental and numerical results, and will be used to explore additional geometric variables. In WP5, the Accelerated Solar Aging Test Bench (AATB) was upgraded to simulate operational conditions for both ceramic and metallic samples. Preliminary tests were performed on SiC (ceramic) and FeCrAl (metallic) samples with different surface treatments (pre-oxidized and as-sintered). A one-year equivalent test was completed using the 40 kW Solar Furnace (SF40), with optical characterization carried out before and after the tests. Pre-oxidized samples exhibited better initial optical properties than the as-sintered ones. However, after one year of equivalent solar exposure, the as-sintered samples improved and reached similar optical performance to that of the pre-oxidized samples.

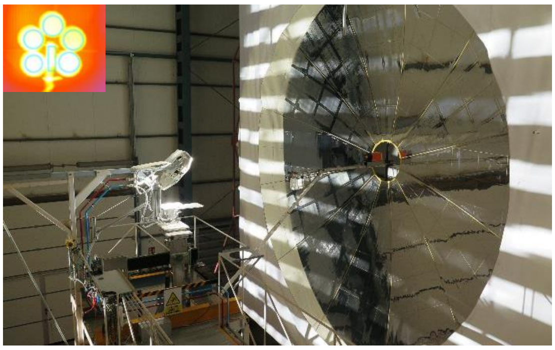


Figure 22. Ageing testing of silicon carbide (SiC) samples SiC) under high concentrated solar fluxes at CIEMAT-PSA's SF40 Solar Furnace. (Left-up) Infrared image of SiC samples at 1,200 ºC

TWINning for SOLAR energy-driven SURFace engineering of metallic parts (TWINSOLARSURF)

Participants: University of West Attica (coordinator), CIEMAT, DLR

Contact: Inmaculada Cañadas Martínez.

Funding agency: EU. HORIZON-WIDERA-2023-ACCESS-02-02. Type of Action: HORIZON-CSA (HORIZON Coordination and Support Actions).

Background: Surface processing techniques are primarily used to protect metallic parts from abrasive wear and to extend their service life under fatigue and/or corrosion conditions. In applications requiring increased resistance to surface mechanical loading, the goal is often to create composite surface layers consisting of a metallic matrix reinforced with ceramic particles—typically carbides such as TiC, WC, or Cr_3C_2. Within the framework of the European SFERA2 and SFERA3 programmes, TriboLab carried out five successful research campaigns (2014-2020) at the CST facilities of CIEMAT-PSA to investigate the feasibility of using solar heat for the *in situ* formation of carbide-reinforced hardfacing layers (see Figure 23). Layers of carbide powders (TiC, WC, and Cr_2C_3) were pre-deposited onto DIN St 37-2 carbon steel substrates and subsequently exposed to concentrated solar irradiation. The resulting composite surface layers were then characterized in terms of their microstructure and tribological performance. These results demonstrated both the feasibility of the proposed approach and the potential to quantitatively relate solar process parameters to the resulting layer properties.

Objectives: The consortium will collaborate on a strategic plan to co-develop a capacity-building programme by sharing knowledge and integrating the expertise and skills of partner institutions during their transformation and evolution. Simultaneously, an exploratory project will be conducted in the field of surface processing of metallic materials for use in aggressive environments (e.g., wear, abrasion, erosion, high temperature), exploiting solar energy. This ambitious yet pragmatic and feasible work plan builds on the partners' previous relevant research efforts. The overall approach is closely aligned with the European Green Deal strategy, promoting green industrial technologies, increasing the penetration of renewable energies, and training skilled researchers capable of tackling global societal, political, and environmental challenges.

Achievements in 2024: During the first three months of the TWINSOLARSURF project, the consortium organized several coordination meetings. Progress has been made in project management, including planning activities for the 2025 summer school, training and mentoring stays, and the joint research test campaigns at the PSA solar furnace, which have now been defined and scheduled.

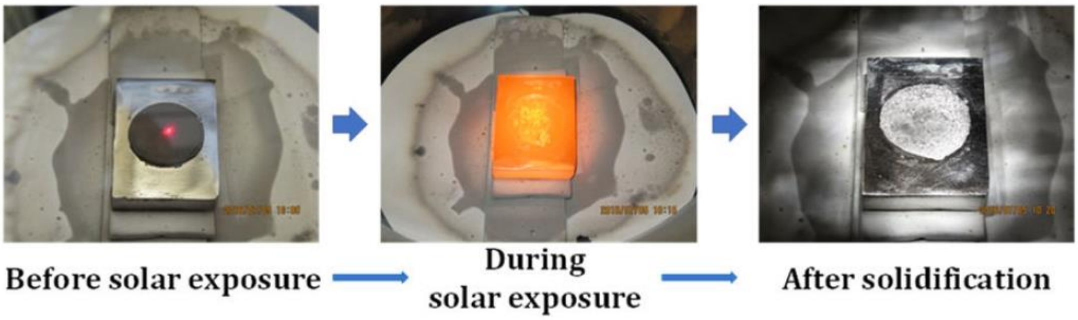


Figure 23. Solar treatment of a representative specimen placed on the insulating substrate; before, during, and after solar testing at CIEMAT-PSA's Solar furnace

Highly Efficient and Low-Impact Innovative Thermal Storage System for Enhance Dispatchability in Concentrating Solar Tower Plants (HELIOTROPE)

Participants: UCM (coordinator), Brightsource, DLR, INTA, VDM, COBRA, Aalborg CSP, Zabala, Tekniker, CIEMAT.

Contact: Aránzazu Fernández-García.

Funding agency: EU HORIZON-CL5-2023-D3-02-02

Background: Current state-of-the-art molten salt central receiver systems are among the most promising CSP technologies. However, these systems are currently limited to operating temperatures of around 600 °C due to the constraints of the solar salt presently in use.

Objectives: To develop a novel molten salt technology that enables CSP plants to operate at temperatures higher than those of existing systems. This project also aims to develop and demonstrate high-performance molten salt technologies, with the goal of increasing the effective power cycle temperature and improving overall system efficiency by raising receiver operating temperatures to up to 850 °C.

Achievements in 2024: The project began in June 2024. During the first six months, we defined the different materials to be tested, including the molten salt compositions, the anti-corrosive inner coatings, and the outer absorber coatings. Additionally, the test matrix was discussed and agreed upon, and the number of samples for each material configuration was determined. Specifically, CIEMAT will conduct several experiments to analyze the durability of the absorber coatings, both under real operating conditions with high radiation fluxes at the PSA SF60 solar furnace and under accelerated aging conditions in weathering chambers (including sandstorm, isothermal, and thermal cycling tests).

Thermochemical Processes for Hydrogen and Feedstock Production Unit

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

Participants: APTL, DLR, Hygear, ENGICER SA, Scuola Universitaria Professionale Della Svizzera Italiana, CEA, Abengoa Hidrogeno S.A., CIEMAT.

Contacts: Alfonso Vidal.

Aurelio González Pardo

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 5,000 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 2024: One of the main tasks of the project was to evaluate new materials and porous structures that could form part of the absorber of the thermochemical reactor, with the aim of improving its efficiency and increasing hydrogen production. To this end, experiments with the semi-cylindrical tubular reactor were continued, in which its ceramic tubes were filled with nickel ferrite pellets, and new tests were conducted in which hydrogen was produced through thermochemical cycles.

On the other hand, continuing with tasks initiated in previous years, the renovation of the facility was completed, achieving significant improvements in its critical components. Specifically, insulation was added to an inner casing of the reactor, which enhanced its thermal insulation and significantly improved heat distribution inside the absorber. The renewal of the absorber material was completed (Figure 24 left), and the entire structure was installed within the corresponding reactor (Figure 24 right).

Additionally, the construction of the new secondary concentrator was completed (Figure 25), addressing the weaknesses of its predecessors. The material used was stainless steel, which allowed operations at higher temperatures compared to aluminium. Furthermore, an improved cooling system was implemented, enabling tests to be performed at very high flux concentrations without noticeable degradation. Subsequently, the concentrator was installed onto the reactor.

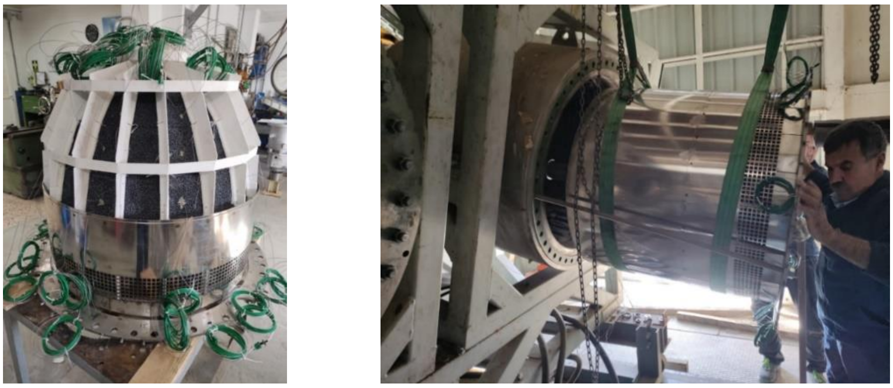


Figure 24. Left. New nickel ferrite absorber. Right: Installation of the absorber within the reactor.

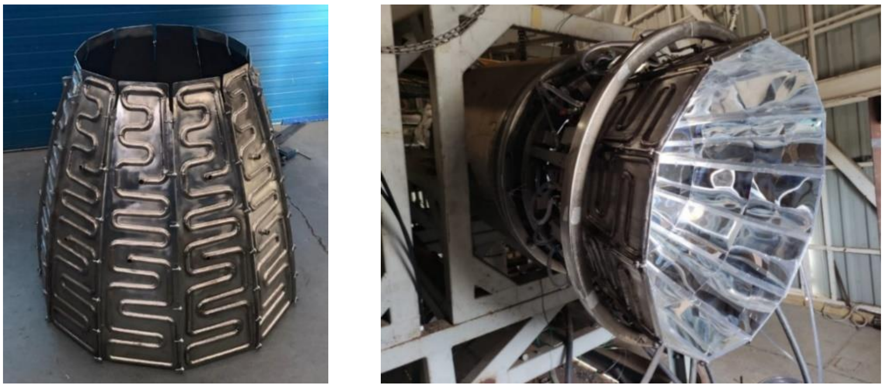


Figure 25. New secondary steel concentrator with an improved cooling system.

After implementing all these improvements, the final test campaign of the project with thermal and chemical tests was carried out (Figure 26). Temperatures exceeding 1,300 °C were reached, along with a hydrogen production rate of 1.45 l/min, demonstrating the viability of this technology.

Figure 26. Hydrosol-beyond reactors in operation.

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, ITC-AICE.

Contacts: Diego Martínez.

Inmaculada Cañadas.

Funding agency: Spanish State Research Agency (PID2020-118599RB-I00)

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 2024: In order to advance the development of ceramic materials with enhanced properties that serve as receivers and catalysts in solar-powered thermochemical hydrogen production process, the HIDROFERR project has completed the selection of advanced ceramic materials to be used as catalysts in the thermochemical generation of H_2 in a solar furnace.

Meanwhile, substrates of different materials and porosities with catalytic coatings are being developed, which are being cycled at high temperatures in the Materlab laboratory. Open-pore ceria foams have also been aged under conditions of high concentrated solar radiation, which are suitable for use as direct catalysts for solar hydrogen production.

Work is underway on the design of the solar receiver where the efficiency of these materials and catalysts will be evaluated under real testing conditions with concentrated solar radiation, for which the necessary components are being acquired for its development and the upcoming start of solar characterization tests.

The development of these processes is being closely collaborated on by personnel from the Solar Materials for CST Units at CIEMAT-PSA, at the Solar Furnace facility and the Materlab laboratory in

Almería, as well as at the OCTLAB laboratory located in CIEMAT Moncloa, and personnel from ITC-AICE (Ceramic Technology Institute) in their laboratories in Castellón (Spain).

Figure 27. Thermal cycling of samples at the focal zone of the SF-40 at PSA

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

Participants: UPM (coordinator), IDENER, NTNU, CIEMAT, IONVAC, HOLOSS

Contact: Thorsten Denk.

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 2024: Achievements in 2024: 2024 has been dedicated primarily to the mechanical design work of the two major components of the project. One of them is the beam splitter mirror needed to create four separate foci in a horizontal plane. The other one is the so-called Sunson-Box, the component that includes all four solar absorbers, the crucibles with the phase-change material (PCM) for thermal storage, and the thermophotovoltaic (TPV) cells for electricity generation. The beam splitter mirror and the Sunson-Box are shown in Figure 28.

The beam-splitting optics consists of a mirror made of four facets located 800 mm in front of the focus. The mirror will be installed at an angle of 45° to flip the solar ray from horizontal to vertical. The four facets can be adjusted individually so that four focal spots appear instead of one. The dimensions are chosen to ensure that all four foci receive the same amount of solar radiation. The ray-tracing simulation for this concept led to a rectangular design, with the two upper facets measuring 1.4 m x 1.0 m and the two lower facets measuring 0.7 m x 1.0 m. To simplify fabrication, the upper facets are split into two panels each, resulting in a total of six rectangular panels measuring 0.7 m x 1.0 m each. They have an identical cooling channel configuration but slightly different bevels at the edges. This adjustment is necessary to minimize gaps between the mirrors when tilted.

The adjustment will be made with linear actuators that allow rotation in pitch and roll. As it is technically not possible to locate the joints exactly in the plane of the mirrors, additional linear movement in two axes has been included to make it possible to close the gaps resulting from the rotary movement of the facets.

The detailed design of the Sunson-Box includes, besides the basic components – the solar absorber, crucible with PCM, and TPV – all auxiliary components. These include the housing, insulation, window for solar radiation, and support structure, as well as water cooling for both the TPV cells and the window flange, and an argon flushing system to prevent harmful atmospheric oxygen from entering the interior of the box.

Furthermore, a double mechanism was included for the vertical separation of the three main sub-components from one another. This allows for four different operating modes: A: Charge and discharge: all components are in the upper position and in radiative contact; B: Charge only: the TPV unit is removed from the system; C: Discharge only: both the PCM and TPV are removed from the solar absorbers; D: Storage only: all components are separated. The design ensures that heat transfer between components is maximized when they are together and minimized when they are physically separated.

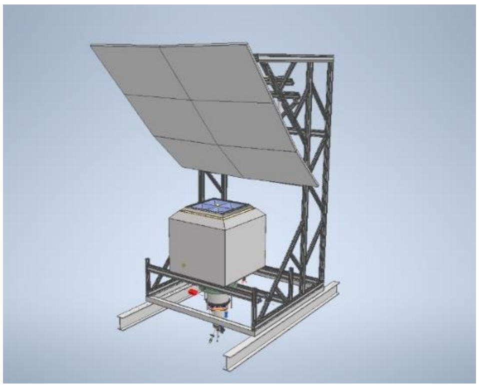


Figure 28. CAD drawing of beam splitter mirror and Sunson-Box with support structure.

The prototype will be installed on the test platform of the Solar Furnace SF60 at the PSA (Figure 29). It will be integrated onto a movable test rig that allows for rapid installation and precise adjustment of its position with respect to the focus of the solar concentrator. The platform will be adapted to allow easy access to all components, including from below. The beam-splitter diagonal mirror will be installed on a separate movable rig, allowing for a "manual defocus" in case of a power blackout, including failure of the UPS. All necessary supplies, such as cooling water, argon, electric power, and an internet connection for data transfer, will be provided.

Figure 29. Simulated view of the Sunson-Box on the test platform of PSA's Solar Furnace SF60, seen from above (left) and below (right). Note the opening in the floor needed for the vertical movement mechanism.

Solar Thermal Applications Unit

Bio-mimetic and phyto-technologies designed 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.

Funding agency: Euroean 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 2024: 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, and Alba Ruiz-Aguirre presented at the 2024 ICAWTM held in PDEU. The project ended in July 2024 and the final report was elaborated, reflecting CIEMAT's contributions to the design of the control strategy and optimization for the industrial pilots, as well as the solar installation specifications and requirements for operation of the BRO/FO systems at PDEU and Lodhva.

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.

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 2024: Experimental campaigns for the characterisation of the nanofiltration pilot system for seawater pre-treatment and of the solar MED unit operating with pretreated seawater and at higher top brine temperatures were finalized. The scale impact on the MED unit was evaluated at different temperatures using a qualitative index. Also, the effect of the Top Brine Temperature increase on the performances indexes (Recovery Ratio, Performance Ratio, specific area) and on the distillate production was determined, both experimentally and theoretically. For the theoretical study, a simulation model of the MED system was developed to evaluate the performance at higher number of effects than the current plant has. All the experimental results have been detailed in Deliverable 3.2 “Report operation & optimization process”. Also, a technical and social study about Case Study 2 and other proposed scenarios at large scale was carried out and included in a scientific paper accepted for publication in Desalination journal.

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.

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 2024: The solar-powered MD pilot plant previously characterized at PSA, had its MD module sent to Castellgali for its integration into the DEMO developed under the framework of the project's WP6. CIEMAT also participated in the Educational Workshop "European Leadership in Action: enabling technologies to boost freshwater preservation" celebrated in February in Birmingham (UK). The results obtained with the solar-powered MD pilot plant were presented at the international conference "Desalination for Clean Water and Energy (EUROMED 2024) celebrated in May in Sharm El Sheikh (Egypt). A project meeting was held in Barcelona (Spain) in May, including a visit to the DEMO in Castellgali, with participation of the CIEMAT team. Finally, the final project meeting was held in Athens (Greek) in October, also with CIEMAT's participation.

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

Participants: CIEMAT.

Contact: Patricia Palenzuela.

Lidia Roca.

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 2024: During 2024, the development of the physical equation based models for the innovative Combined Cooling System (CCS) was completed and validated with experimental data from the pilot plant. The low-level control strategy was adapted to account the non-linearities of the ACHE using a gain scheduling controller which was tested at the pilot plant. As for the high-level control layer, a multi-objective optimization algorithm was implemented and tested under different thermal loads and water consumption constraints. The results were presented at the PID 2024 International Congress.

A standard methodology was developed to reliably evaluate characteristic parameters of MED systems, such as heat transfer coefficients from experimental data. This methodology was applied to one of the commercial case studies: a Combined Cooling System integrated into a solar MED plant. An experimental campaign was performed to evaluate a conventional CCS consisting of Air-Condenser (ACC) and Surface Condenser (SC) coupled to a Wet Cooling Tower (WCT) covering a wide range of condensing powers and ambient temperatures, in order to compare water and electricity consumption with respect to the innovative CCS. The results were presented at the International Conference SolarPACES 2024.

European Twinning for research in Solar energy to water (H_2O) production and treatment technologies (SOL2H2O)

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

Contact: Guillermo Zaragoza.

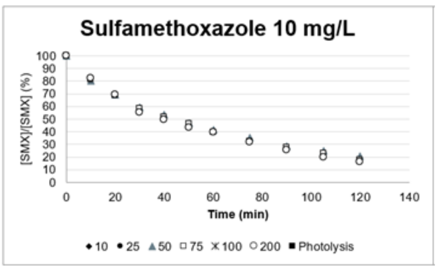
Isabel Oller.

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

Background: SOL2H2O brings together top European partners to support the University of Évora in advancing solar-driven water and wastewater treatment. The project focuses on capacity building, joint research strategy, and creating a reference facility for Circular Solar-driven Water-Energy Nexus technologies, promoting renewable gas and sustainable agricultural activities.

Objectives: SOL2H2O unites top partners to boost excellence in Solar-driven Water-Energy Nexus solutions, enhancing the Coordinator’s research capacity. The project will create a European reference facility for circular solar water technologies, including a zero-liquid-waste desalination system, with CIEMAT contributing membrane distillation expertise.

Achievements in 2024: The Solar Thermal Applications Unit’s main contribution focused on providing the scientific support to the Joint Research Activities related to zero liquid discharge desalination, particularly in the solar-thermal powered membrane distillation unit used for brine concentration at the pilot plant installed in Évora. CIEMAT also participated in the three fast-track schools celebrated in 2024 in Palermo (Italy), Las Palmas de Gran Canaria (Spain) and Évora (Portugal), together with the corresponding consortium project meetings.



Mineralization rate

Photolysis	10 mg/l TiO_2	25 mg/l TiO_2	50 mg/l TiO_2	75 mg/l TiO_2	100 mg/l TiO_2
	54%	59%			

Figure 30. Results on the new CPC performance for the elimination of Sulfamethoxazole as the target contaminant with different concentrations of TiO_2.

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. Different experiments have been carried out with TiO_2 and some target contaminants to compare the performance of this reference and highly efficient photocatalyst for the elimination of contaminants in two different photoreactors, which mainly differ in the tube diameter. Results can be found in the Figure 30.

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

Alba Ruiz-Aguirre.

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

Background: MEIoDIZER'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. MEIoDIZER implements high-performance membranes and modules in strategic applications of membrane distillation (MD), hence providing the decisive step for the success of MD.

Objectives: The project focuses on developing next-gen membranes using green methods, integrating them with energy and control systems for optimal performance. It aims to reduce industrial waste, reuse water, recover resources, and produce drinking water through decentralized MD units, while demonstrating economic, environmental benefits, and sustainable end-of-life management.

Achievements in 2024: CIEMAT unit has participated in the scientific support to Polito for the development of the DEMO 3 consisting of a passive MD powered by solar energy that will be installed in the PSA for its evaluation. CIEMAT also participated in the M18 review meeting held in Brussel (Belgium) in June.

Sustainable drinking and irrigation water production from saline alternative water resources (SALTEAU)

Participants: FCC Aqualia SA (coordinator), CIEMAT, Universidad de Almería, NX Filtration BV, Aquaporin AS, OMYA GMBH

Contact: Guillermo Zaragoza.

Alba Ruiz-Aguirre.

Funding agency: European Commission, LIFE-2023-SAP-ENV-ENVIRONMENT

Background: Water scarcity affects 40 % of Europeans, especially in the south, with annual costs reaching €9 billion. Despite their potential, alternative water resources (AWR) such as reuse and desalination remain underutilized, currently supplying only 1.6 % of the EU's freshwater. Expanding AWR to 5.4 % by 2035 is crucial for ensuring water security.

Objectives: The LIFE SALTEAU project aims to improve saline water treatment using sustainable, cost-effective technologies powered by renewables. It will demonstrate microbial desalination, membrane processes, and mineral recovery at two sites, producing 400,000 m³ of freshwater and recovering 140 tonnes of minerals, with replication planned at 18 additional plants.

Achievement in 2024: The LIFE SALTEAU project started 1st September 2024, so CIEMAT's participation during this year has been limited, especially since the WPs in which it is involved are scheduled to start in 2025. CIEMAT did, however, take part in the kick off meeting held in Dénia (Spain) in October.

Solar Treatment of Water Unit

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

Participants: Technische Universitat Berlin (Coordinator), UNEP-UN, Universite Abdou Moumouni de Niamey, Norges Teknisk-Naturvitenskapelige Universitet, Trialog, Finergreen Africa, Hudara GGMBH, Association Energy Generation, ECOWAS, Fundacion Tekniker, CIEMAT, RISE, The Waste Transformers Nederland, Freetown Waste Transformers, Ecosun innovations, Arenys Inox, Nanoe Madagascar, SACREEE, Club-ER, EACREEE, KPLC, Odit-e, Hive Power, Opibus, Stima sas, Untapped Water Limited, Jokosun, Euroquality.

Contact: M. Inmaculada Polo.

Isabel Oller.

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 CO_2 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 2024: During this year, the assessment of the multi-step cascade reactor (MSCA) of 5 L and 0.5 m^2 of surface, described in previous reports, has continued in CIEMAT facilities to determine, according to the World Health Organization, the capability of the technology to provide potable water. Therefore, the inactivation of the microbial indicators MS2 (virus) and spores of *Cryptosporidium parvum* has been evaluated under different operational conditions, including solar only, immobilized TiO_2 in the Multistep cascade reactors (MSCR) steps and TiO_2 combined with H_2O_2. Simultaneously, the 50 L, 4 m^2 MSCR pilot plant (Figure 31 right) was shipped to Sierra Leone (Waterloo) for field testing and validation of previous results. The testing is currently ongoing using commercial kits for the analysis of several physico-chemical parameters and *E. coli* as a microbial indicator. In addition, the reactor will be coupled with a biodigester plant to supply the electricity required for its operation. (Figure 31).

Figure 31. MSCR of ENERGICA for water treatment: (left) pilot plant of 50 L containing TiO_2 immobilized in stainless steel stairs at CIEMAT facilities and (right) MSCR installed in Sierra Leone.

Solar catalysis for a renewable energy future (SOL-FUTURE)

Participants: Fundación IMDEA Energia (coordinator), ICMM-CSIC, ICIQ, CIEMAT, APRIA Systems S.L., CEPSA.

Contact: Sixto Malato.

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 2024: Glycerol is a by-product in biodiesel production (in the range of $g \cdot L^{-1}$), so its photo reforming by photocatalysis is a way of valorising it. TiO_2 in photocatalysis has been widely studied, although its efficiency is limited by the high energy band gap, and the electron-hole recombination. Its combination with different semiconductors should improve charge separation, extending also the absorption from UV to visible light. Cu and Ni oxides are two of the most efficient low-cost transition metal oxide catalysts.

The results of 2024 present novel insights in determining different combinations of three semiconductors, based on the concentration of each metal on TiO_2 (Me, 5 %, 7.2 % and 10 %) were evaluated. Evonik P25-TiO_2, CuO and NiO were combined by mechanical mixing. Hydrogen was quantified by a micro gas chromatograph, and copper and nickel leaching by ICP-MS. Metal content in solution increased as the reaction progressed, but Ni lixiviation of <0.012 mg L^{-1} was not significant. Significant Cu leaching (>1 mg L^{-1}) was observed. Different metal leaching behaviour points to a different electron pathway for each MeO. These results open an interesting pathway to developing cheap photocatalysts making large-scale solar H_2 production feasible.

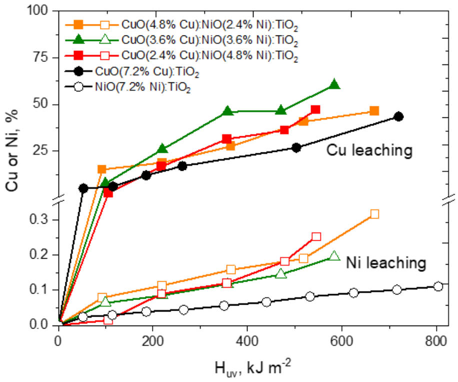


Figure 32. Ni or Cu lixiviation (as percent of the original metal content in each mixture). Reaction conditions: photocatalyst concentration 100 mg·L^{-1}, glycerol = 0.075 M.

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

Participants: Universitat Politècnica de Valencia (coordinator), Universidad Rey Juan Carlos, CIEMAT.

Contact: Sixto Malato.

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 2024: PSA applied advanced oxidation processes for polishing regenerated water from MWWTP to be used in aquaculture (addressing the simultaneous removal of CECs organic microcontaminants, microplastics, dissolved organic matter, metals, inactivation of ARB and effect on ARG). We also evaluated the applied processes for pathogens elimination in aquaculture and hydroponic inlets. To achieve results, different tasks have been developed in parallel and in cooperation with the three coordinated subprojects.

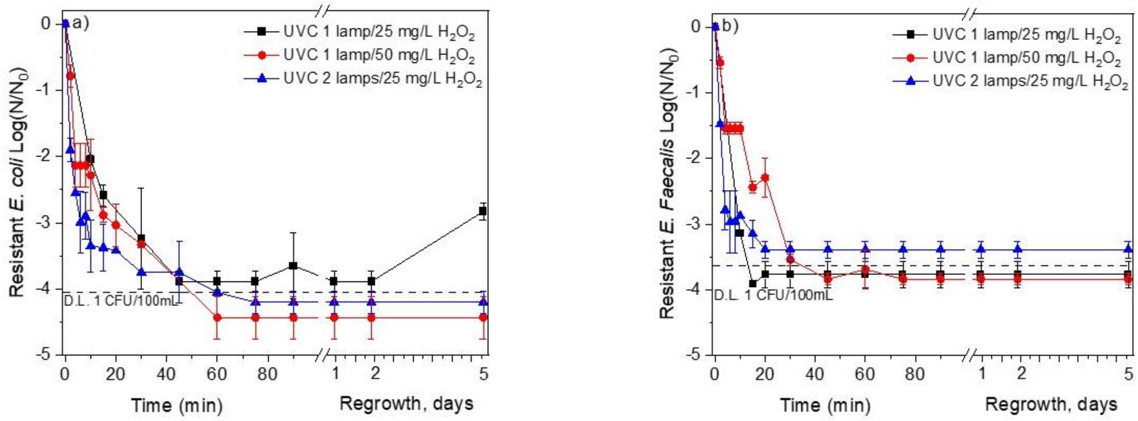


Figure 33. Inactivation of ARB *E. coli* (a) and *E. faecalis* (b) by UVC/H_2O_2 at different hydrogen peroxide dose in MWWTP effluents (DL 1 CFU per 100 m.

Briefly, PSA focused solar photo-Fenton like processes at neutral pH, solar/chlorine and UVC/chlorine. The best treatments and operational conditions were selected and validated by monitoring the absence of the specific microbial requirements in aquaculture systems. The absence of the following fish-pathogens genus has been considered: *Pseudomonas spp., Aeromonas spp., Enterobacter spp, Klebsiella spp, Edwardsiella spp,* and also total coliform bacteria and total heterotrophic bacteria.

Towards Digital Transition in Solar Chemistry: Photoreactors (SOLARCHEM 5.0)

Participants: IMDEA Energy, ALBA-CELLS, ICMM -CSIC, Univesity of Girona, IQF- CSIC, CIEMAT, ICMS-CSIC, UPM, Universidad Rey Juan Carlos

Contact: Sixto Malato.

Diego Alarcón.

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 2024: To improve TiO_2 for H_2 generation, one strategy for the separation of photogenerated charges is the formation of heterostructures with other materials. In particular, NiO is a photocatalyst known for its good stability and low cost. However, no studies at pilot scale using solar energy have been described. Consequently, an evaluation of a physical NiO:TiO_2 mixture at pilot scale (25 L) with natural irradiation and with simultaneous glycerol photoreforming was explored. NiO:TiO_2 50 mg·L^{-1} resulted in the highest hydrogen production, showing an STH = 1.44 %, considering only the UV fraction of the solar irradiation. H_2 and CO_2 production were analysed by on-line GC. Different natural waters gave a systematic lower H_2 production, suggesting that the increase of ionic strength and the corresponding agglomeration and sedimentation of the catalyst particles was the unavoidable cause.

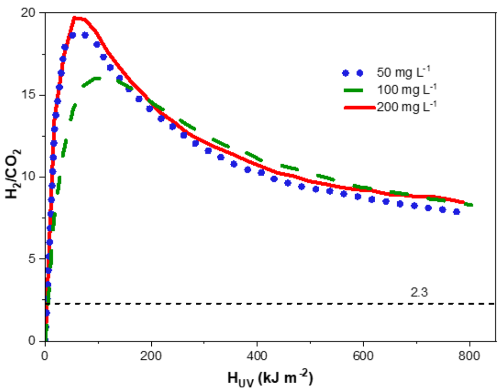


Figure 34. Evolution of the H_2/CO_2 ratio in the glycerol photoreforming process, at different NiO:TiO_2 loadings. Reaction conditions: NiO:TiO_2 1:10, glycerol = 0.075 M.

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 (coordinator), UPM, CIMNE.

Contact: Isabel Oller Alberola.

M Inmaculada Polo López.

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 2024: On January24th, 2024 the coordination meeting took place in UPM, Madrid. The afternoon was dedicated to a workshop, organized within the project, related to “Machine Learning techniques applied to water management”. The Solar Treatments of Wastewater group from PSA gave a talk focused on solar photocatalytic and photochemical processes applied to the urban wastewater regeneration. In addition, and with all the data from experiments carried out by the E48 unit at PSA, CIMNE has implemented and elaborated Machine Learning models to predict the inactivation performance of *E. coli* in wastewater across various AOPs. Specifically, the goal has been to contribute to the design of new AOPs by providing a valuable model that allows testing diverse types of oxidants, concentrations, and radiation times needed to enhance their effectiveness without performing additional experimental trials.

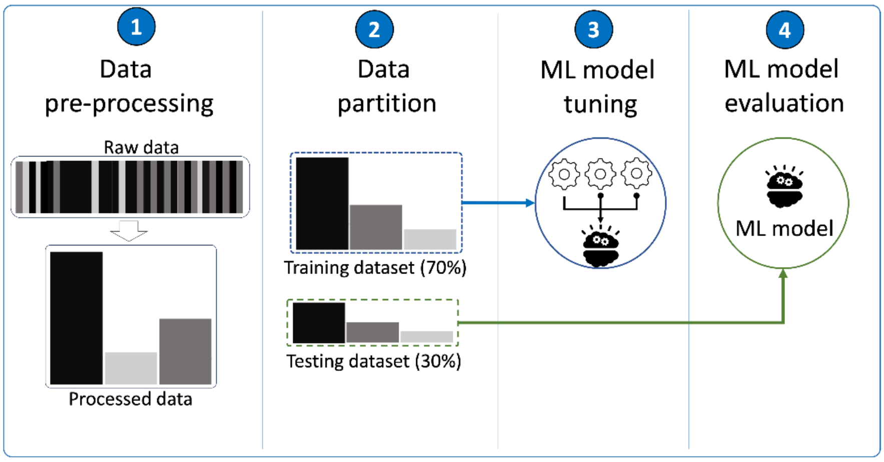


Figure 35. Flowchart of the Machine Learning methodology implemented by CIMNE with the experimental data of E48 at PSA.

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

Participants: University of Almería, CIEMAT, Diputación Provincial de Almería.

Contact: Isabel Oller.

Funding agency: Convocatoria de subvenciones a «proyectos de I+D+i» universidades y entidades públicas de investigación (BOJA n.º 239, 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 2024: Seven water sampling campaigns were carried out along 2024 throughout the Province of Almeria, including 9 drinking water treatment plants and 6 urban wastewater regeneration plants. The data obtained during this period were discussed in the third project meeting at the University of Almería on September 11th, 2024. The main conclusions derived from the annual monitoring indicate that, both regeneration and drinking treatment plants fully comply with the microbiological requirements established in the recent European regulations: EU 2020/741 and EU 2020/2184 for urban wastewater reuse and drinking water, respectively. Nevertheless, some of the plants do not fulfil some of the regulated physicochemical parameters in some of the samples, confirming the trend observed previously, i.e., turbidity and suspended solids in regeneration plants, while not fulfilling nitrite levels in 2 drinking water treatment plants. Moreover, a high frequency of chlorate detection was observed in drinking water. According to these data, four decisions were made at this meeting: i) to inform the drinking water treatment plants operator about the chlorate concentration and the scientific recommendations were transmitted related to the management of hypochlorite solutions to avoid its decomposition; ii) the data obtained until now is enough to select 3 representative regeneration and drinking treatment plants to continue monitoring until the end of the project iii) the frequency of the monitoring can be reduced from monthly to every three months; iv) the three regeneration plants selected are representative of three different treatment conditions (sand filtration followed by chlorination, chlorination followed by ultrafiltration and, cloth filtration + chlorination). For the three drinking water treatment plants selected, they were selected according to three different water sources (melt water stored in a dam, groundwater and, water from a transfer).

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 (coordinator), CIEMAT

Contact: M. Inmaculada Polo.

Isabel Oller.

Funding agency: Ministerio de Ciencia e Innovación. Plan Estatal de Investigación Científica, Técnica y de Innovación 2021-2023. Reference 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 2024: During this year, several new photocatalysts have been assessed under oxidative conditions at lab and pilot scale (CPC reactor) for water disinfection and decontamination, including TiO_2, TiO_2/GO (1 and 5 % GO), allophan nanoclays (modified with TiO_2, Fe and ZnO), zero-valent iron (ZVI) mesh and ZVI obtained from agro-industrial residues. In addition, the capability of the ozonation treatment (at pilot plant) coupled with a solar CPC reactor (Figure 36), have been evaluated including: (i) the assessment of ozone alone for UWW reclamation and (ii) catalytic and photocatalytic ozonation carried out in demineralized water using ZVI (magnetite) for the removal of two organic contaminants (paraquat and diquat). For reductive conditions analysis, preliminary assays have been carried out using newly synthesized metallic iron nanoparticles (nZVI), TiO_2:CuO and TiO_2:NiO for pollutants removal. The current studies include the assessment of new commercial carbon-encapsulated iron nanoparticles produced from olive mill wastewater and supported on a polypropylene mesh (provided by the company SMALLOPS S.L. (Extremadura, Spain)) both under oxidative and reductive conditions (by adapting atmospheric conditions) in the solar CPC reactor (Figure 36) for removal of selected PMOCs (Benzotriazole, Saccharin, Triclosan and Diuron).

Figure 36. Ozone (left) and solar CPC reactor (right) pilot plants used in Andromeda for assessing novel photocatalytic materials for water purification.

Green valorization of CO_2 and Nitrogen compounds for making fertilizers (CONFETI)

Participants: UAB (coordinator), IMB-CNM-CSIC, University of Antwerpen, IMRCP UMR-CNRS, University of Pisa, Arkyne tech.S.L., CIEMAT, Iowa State.

Contact: Sixto Malato.

Alba Ruiz.

Funding 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 2024: This project is organised in seven WP and WP 4 (Photochemical CO_2/NO_3 Valorisation) is coordinated by CIEMAT-PSA. WP4 team have synthesised a series of photocatalysts to reduce NO_3 into NH_4^+ under sunlight irradiation. In addition, methods have been developed to test the efficiency of these photocatalysts both on the lab and pilot plant scale, considering both the effect of several operating conditions: the presence or absence of sacrificial agents, NO_3^- and photocatalyst concentration, and irradiation time. From these experiments, an optimal photocatalytic system (CuO-TiO_2 (10:1)) and operating conditions (40 mg/L NO_3^-, 0.01 M of glycerol, 100 mg/L photocatalyst, 5 h of sun exposure) have already been identified, which will be applied to the combined photoreduction of CO_2 and NO_3^- to produce urea in the forthcoming months. A new CPC photoreactor has been designed for photocatalytic conversion of CO_2/NO_3^- into NH_4^+ or/and urea. Part of the CPC reactor has been already assembled, while the rest of the device is under construction and will be completed by October 2025. Photocatalyst has to be removed from the water prior to its discharge or reuse. For that, sedimentation or assisted sedimentation with flocculation/coagulation will be applied for the recovery of photocatalyst for a possible reutilization of it.

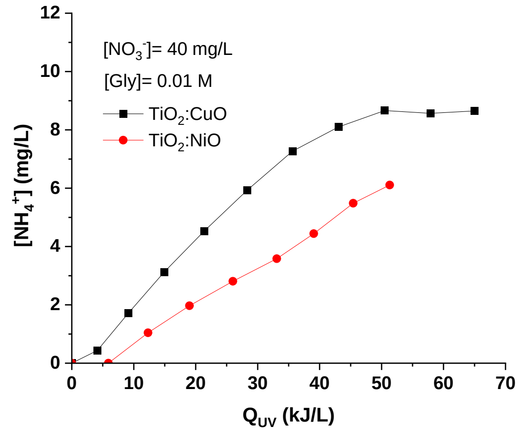


Figure 37. NH_4^+ production with the irradiation dose using TiO_2-CuO and TiO_2-NiO as photocatalysts at 40 mg/L of initial NO_3^- concentration and 0.01 M of glycerol.

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

Participants: University of Oslo (Coordinator), RWTH Aachen, Aristotelio Panepistimio Thessalonikis, CIEMAT.

Contact: Isabel Oller.

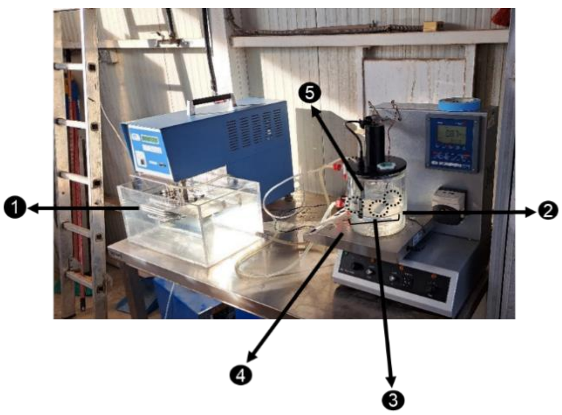
Sixto Malato.

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 2024: A bioreactor prototype has been designed, developed, and tested by the team of E48 research unit, to evaluate both the growth of *C. necator* H16 ΔphaCAB and its isobutanol tolerance under autotrophic conditions. The experiments were conducted in minimal medium with a gas flow ratio of H_2:CO_2:O_2 (8:1:1). When 2 % (v/v) isobutanol was added, the bacterial population initially decreased but subsequently recovered, suggesting the strain's ability to utilize isobutanol as a carbon source. The demonstrated capacity of C. necator H16 ΔphaCAB to grow autotrophically using CO_2 as the sole carbon source and H_2 as an energy source indicates promising potential for isobutanol production. Subsequently, the evaluation of the newly engineered strain *C. necator* ΔphaCAB (pPhaC1-kivD-yqhD), developed by OUH, for both autotrophic growth and isobutanol tolerance in the bioreactor is being performed at PSA. Additionally, E48 research group will investigate alternative carbon sources that may enhance isobutanol production, including pyruvate, fructose, and their combinations. Methods for precise quantification of isobutanol production have been also explored with the support of CIESOL analytical group.



Parts

1. Thermotatized bath
2. Glass jacketed reactor
3. 3 ceramic gas diffusers
4. Magnetic stirrer
5. Dissolved Oxygen probe

Figure 38. Reactor set-up for autotrophic growth of *C.necator* in REFINE project, made by E48 team.

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 (Coordinator), Universita Degli Studi del Piemonte Orientale Amedeo Avogadro, Aalborg University, Clermont Auvergne INP, CIEMAT, Panepistimio Ioanninon, Universidad Politécnica de Valencia, Universita Di Bologna, ULTRAAQUA A.S, INERIS, Institutt for Energiteknikk.

Contact: Isabel Oller.

Sixto Malato.

M. Inmaculada Polo.

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 2024: The 1st IN2AQUAS Networking Symposium took place the 13th and 14th of March, 2024 in Torino, where the doctoral candidates already enrolled in the project already presented themselves (in person or virtually) and their preliminary plan of work for obtaining a double PhD label from two universities. In the case of the E48 research unit at PSA, two Doctoral Candidates are assigned within the WPs 3 and 4. In addition the Winter School organized in the frame of this project under the title “Analytical and toxicological methods. Fundamentals of mass spectrometry and recent approaches for trace compounds analysis in complex matrices”, took place from the 11th to the 13th of March, 2024, also in Torino. In this Winter School, Isabel Oller, responsible of E48 at PSA and leader of WP4 in this project, gave the class titled “Toxicity tests: methods and relevance for water/wastewater treatment by AOPs”. The mid-term coordination meeting and revision with the project officer took place the 3rd of September, 2024, in Lillestrom (Norway) organized by the partner IFE. The 4th of September, each doctoral candidate presented the updates on their PhD program as well as a summary of each WP leader. Finally, the Summer School scheduled in the frame of IN2AQUAS project, took place the 5th of September in Lillestrom, in which Isabel Oller and Sixto Malato gave two talks; “Circular Economy: Holistic approach and applied to the wastewater recovery scene” and “Upscaling water treatment technologies: Definition and understanding of TRL, challenges and examples of upscaling”, respectively. In the figure below, a picture of some of the partners and doctoral candidates during the last meeting is shown.

Solar polygeneration collector for combined heat, power, hydrogen fuel and wastewater treatment. (SPECTRUM)

Participants: LNEG (coordinator), MG Sustainable Engineering AB (MG Sweden), Imperial College Of Science Technology And Medicine, FRAUNHOFER, Universita di Bologna, Högskolan I Gävle, Solarus Renewables AB, IST-ID, CIEMAT, BELGIUM VOLT.

Contact: Sixto Malato.

Ilaria Berruti.

Funding agency: European Climate, Infrastructure and Environment Executive Agency (CINEA). HORIZON-CL5-2024-D3-01-10 (HORIZON-RIA).

Background: The main challenge lies in the decarbonisation of industrial heat consumption: i) several renewable heat technologies for low-to-medium temperature processes are available on the market but are not cost-effective when compared with fossil fuel-based technologies; ii) renewable technologies for high temperature heat production are limited and further development is needed. SPECTRUM takes the opportunity created by this challenge by demonstrating the feasibility of harnessing solar radiation and using wastewater to generate, in a single solar powered device, three energy vectors required by the industrial sector: electricity, heat and renewable fuels, in this case hydrogen. SPECTRUM will boost the sustainability of industrial wastewater treatment, converting waste into a valuable solar fuel, through an efficient photocatalytic remediation process coupled with H_2 cogeneration.

Objectives: The SPECTRUM project aims to develop, test and validate an innovative solar concentrating collector that co-generates heat, power and H_2, in a cascade-like conversion of the concentrated sunlight. Matching the energy grade between the solar spectrum and the conversions, the system uses the UV for photocatalytic H_2 production with synergistic degradation of pollutants, infrared (IR) for generating thermal energy and visible (VIS)-near infrared (NIR) light for photovoltaic (PV) electricity, allowing to achieve higher solar conversion efficiency. Spectral splitting solutions will be developed to separate IR part of the solar spectrum allowing the PV cells to be thermally decoupled from the thermal absorber, generating high temperature heat without compromising the electrical efficiency. Low cost and sustainable nanostructured photocatalysts will be developed with focus on dual-functional photocatalysis processes, i.e H_2 production and pollutants degradation.

Achievements in 2024: This project begun in October 2024, and the Kick-off meeting took place at National Laboratory of Energy and Geology (LNEG ; Portugal). There are no results of CIEMAT during 2024.

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

Participants: CIEMAT.

Contacts: María José Jiménez.

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 2024: This project has concluded, making a significant contribution to the development and improvement of methodologies for the experimental energy performance assessment of full-scale, in-use buildings. The most notable achievements include the adaptation of existing methodologies to warm, sunny climates; the proposal of validity indicators; their application to the conducted assessments; and the identification of the dependence of these indicators on the duration of the test campaigns and other driving variables.

The research was supported by experimental campaigns carried out on several buildings, starting with a 1 m^3 simplified structure and progressively scaling up to a single-zone in-use building, an office building in use, and an urban environment. A wide range of inverse modelling techniques were employed to identify the characteristic parameters of the building envelope. All methodologies are based on the energy balance equations applied to the tested structures.

On one hand, techniques based on integral approaches (such as Coheating and Dynamic Integrated methods) were used, which are highly reliable but require relatively long test campaigns. On the other hand, techniques based on differential approaches (such as RC and ARX models) were applied, which allow for a significant reduction in test duration but demand more complex methods to accurately extract the required characteristic parameters from the recorded data.

10 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 and Greece participate as Observers.

EU-SOLARIS was formally approved by the European Commission in October 2022 as a European Research Infrastructure Consortium (ERIC) entity and started its regular operations in January 2023.

The governance scheme of EU-SOLARIS ERIC is shown in the figure below:

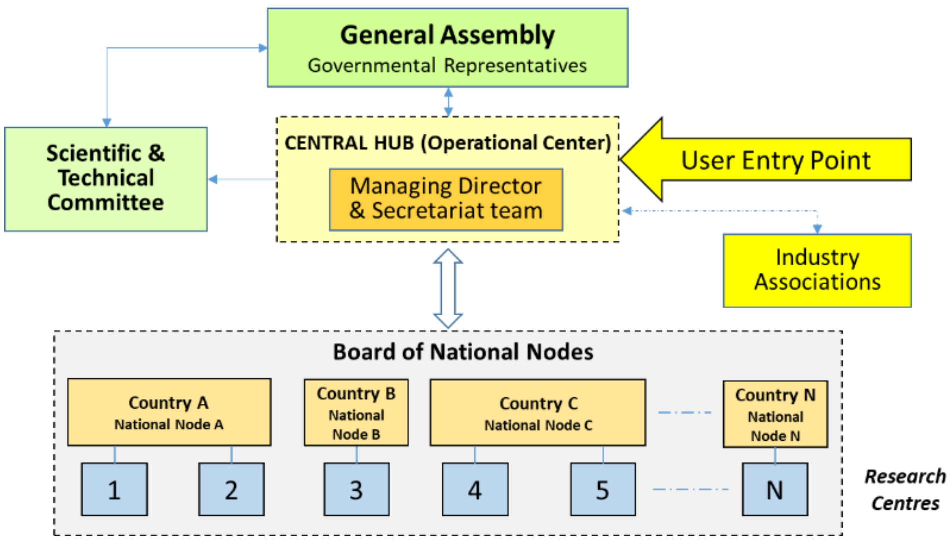


Figure 39. Governance framework of EU-SOLARIS ERIC

The Scientific & Technical Committee has been reinforced in year 2024 with the incorporation of two worldwide top-notch researchers in the field of applications of solar thermal energy, Dr. Lourdes García (Seville University, Spain) and Dr. Simona de Iuliis (ENEA, Italy). 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 2024. This is an annual call for proposals to fund a project focused on the RI-related R&D activities. This year's winning proposal is led by the Spanish CENER, with the participation of several international partners and titled: 'Analyze Heliostat Field phase II: BCS as a calibration reference system'.

EU-SOLARIS ERIC started to participate on winning proposals under Horizon Europe. Actually, we already participated in six proposals, being successful in four of them, all under the 'Research Infrastructures' Work Program of Horizon Europe.

Among them, the project SOLARIZE (Bringing EU-SOLARIS to its Zenith, #101131982) is particularly relevant for the consortium. SOLARIZE is coordinated by EU-SOLARIS ERIC and it will fund a pack of measures and activities aiming to ensure the long-term sustainability of the ERIC. 1st July has been the official starting date of the project, with the kick-off meeting held at PSA premises on 23rd July.

Figure 40. SOLARIZE Project's kick-off meeting on 23 July, 2024.

Among the most relevant activities already carried out within SOLARIZE it is worth mentioning the organization of the 'Doctoral Colloquium 2024', held at the PROMES-CNRS premises, in Odeillo (France).

SOLARIZE will be running until mid-2027 and a number of activities aimed to enhance the cohesion of the CSP R&D community are already planned. Learn more about the program at the project's web site.

Contact: Diego Martínez.

11 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-five students of different nationalities are admitted each year so that we can transmit the knowledge in solar thermal technology and water-energy nexus accumulated at the PSA throughout its over forty years of experience to new generations of university graduates.

The main feature of this training program is managing the miscellaneous educational cooperation agreements and research stays with other entities for sending students to the PSA, such as: Universities of Almería, A Coruña, Pontificia Católica (Chile), Politecnico di Torino (Italy), Piamonte Orientale (Italy), Antonio Nariño (Colombia) University Köln (Germany), RWTH-Aachen (Germany), Esslingen University of Applied Sciences (Germany), Coimbra (Portugal) IES Los Angeles, 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.

Following the great success of the four doctoral colloquia organized under the SFERA-III project, EU-Solaris ERIC (coordinated by CIEMAT) took over the initiative and organized the Sollab Doctoral Colloquium. This event was open to all PhD candidates working in the field of concentrating solar technologies. The colloquium took place from July 3rd to 5th and was hosted by PROMES-CNRS at the 1 MW Solar Furnace in Odeillo, France. The origin of this doctoral colloquium lies in the desire of the Sollab laboratories to bring together their PhD candidates for advanced training, fostering the exchange of cutting-edge knowledge in the concentrating solar field while also allowing participants to discover the facilities of partner institutions. These colloquia also provide valuable opportunities for PhD candidates to present their work to world-leading experts and to network with peers working on similar topics.

12 Outreach activities

In terms of scientific outreach, various activities were carried out during 2024. Particularly noteworthy is the fact that more staff members are involved in these activities each year, which is of great importance for bringing the science and technology we develop closer to society.

Most of these activities have been conducted within the framework of two dissemination projects led by CIEMAT's Outreach Unit: MEDNIGHT and Estrategia de Comunicación CIEMAT 2024/2025. PSA researchers have also taken part in activities organised by the University of Almería and the Fundación Descubre. Special mention should be made of the activities carried out by the PSA Visitors' Centre (CAV).

Projects (only those running in 2024)

Mediterranean Researchers' Night 2024 and 2025 Editions (MEDNIGHT)

Participants: UNIME, SciCo, ECD, SciCoCy, KHAS, MUDIC, EWORA, MSP, CIEMAT, ATHENA RC, MCAA, CHUT, GPOL, INSERM.

PSA contact: Lidia Roca.

Funding agency: EU, HORIZON-MSCA-2023-CITIZENS-01

Background: Five hundred million people across 24 Mediterranean countries share common challenges like climate change, pollution, and youth unemployment. Despite cultural differences, they are united by geography and history. MEDNIGHT promotes Mediterranean science to engage the public—especially youth—in addressing these shared issues through research, innovation, and regional collaboration.

Objectives: MEDNIGHT promotes Mediterranean science as a source of well-being, social progress, and environmental awareness. It highlights science's daily relevance, supports women in research, encourages STEM among youth, and showcases diverse scientific careers. Emphasizing collaboration, open science, and personal researcher stories, it builds public trust and inspires future scientists.

Estrategia de divulgación CIEMAT 2024/2025

Participants: CIEMAT.

PSA contact: Lidia Roca.

Funding agency: FECYT, F Lidia Roca CT-23-18992.

Background: CIEMAT promotes science communication to foster scientific culture and critical thinking against misinformation. In 2023, it created the Scientific Outreach Unit to centralize and coordinate efforts, involving staff from all departments. This strengthens the connection between science, society, and sustainability, showcasing CIEMAT's impact and commitment to public engagement in Spain.

Objectives: This project focuses on inspiring scientific vocations by engaging young students through role models and career visibility. It promotes scientific culture by bridging the gap between science and society, encouraging critical thinking. Additionally, it supports science teachers by providing resources and events to enhance pre-university science and technology education.

Resume of outreach activities

- European Research Night 2024: a total of 23 people from PSA (researchers and technicians) participated in the most important outreach activity in Spain. We covered all our research lines related to solar concentrating systems and water, using models and digital tools to engage visitors. This activity was performed at the same time in Almería and Madrid.

Figure 41. PSA staff during European Research Night 2024 in Almería.

- CIEMAT at your school: during 2024, a total of 7 activities were performed in different schools of Almería and Madrid.
- V Feria de la Innovación y la Ciencia de Almería 2024. PSA researchers participated in this event organized by University of Almería with two projects “Solar energy in Almería: Creating a sustainable Future” (developed by students of IES Carmen de Burgos, Huércal de Almería) and “Exploring the potential of materials: solar energy and seawater” (developed by students of IES Gaviota, Adra).
- International Water Day 2024: to celebrate this day, PSA researchers developed two activities (experiments with five-year-olds and a scavenger hunt with 17-year-olds, both related to solar energy and water) at the Parque of Sciences in Granada.
- International Day of Women and Girls in Science: On February 11, women from PSA-CIEMAT participated in different activities. At IES Murgi (El Ejido, Almería) three talks were given related to materials in solar concentrating technologies, water solar treatments and water in solar concentrating technologies. CIEMAT researchers, together with other universities and research centres, participated in “Girls in control”, a STEM initiative to explain control engineer in an entertaining way. In addition, two activities were carried out with five-year-olds related to solar energy and water.
- XIII FERIA madridesciencia: PSA researchers participated in the CIEMATesCiencia stand explaining to visitors why solar energy could be key to a sustainable future.
- ‘Thesis in 3 Minutes’: participation in this competition, organised by the University of Almería, in which Cristobal Valverde, a PSA researcher, was awarded second place for his outreach presentation, ‘Microwave FM: Cooking the Future of Renewable Energies’.
- Hackathon por el Planeta de la Fundación Coca-Cola: PSA participated in this activity by giving a Masterclass on how to optimise the transport and storage of packaging.
- MEDNIGHT Tales: one of the winning tales about science organised by the MEDNIGHT project was the one by the PSA researcher María Elena Carra.
- Participation in the DMAX documentary “Curiosidades De La Tierra: España” (Chapter 3).

PSA Visitors Centre (CAV)

The activities carried out by the PSA Visitors Centre (CAV) are essential for explaining both the PSA facilities and the science behind our centre's technologies to the public. In 2024, a total of 3,869 visits were managed by the CAV. As shown in Figure 42, more than 85 % of the attendees were students, and among them, almost 13 % were high school or university students from abroad.

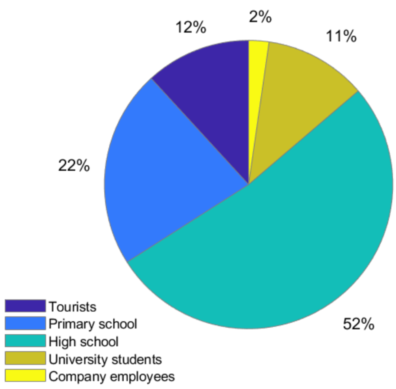


Figure 42. Percentage of visitors managed by the CAV during 2024.

Dissemination events

6th February 2024

Dissemination visit

Visit to PSA of students from the Lycée Français International Georges Pompidou (Dubai, UAE). Patricia Palenzuela and Lidia Roca gave a presentation about concentrating solar energy and desalination.

9th February 2024

Dissemination event

Patricia Palenzuela participated in an educational workshop for children in CEIP Mar Mediterráneo (Almería) to celebrate the International Day of Women and Girls in Science.

14th February 2024

Scientific dissemination

Ilaria Berruti, Isabel Espinoza Pavón, Paula Serrano Tarí and Alba Hernández Zanoletty gave talks in High Schools in the Province of Almería to celebrate the International Day of Women and Girls in Science.

16^{th} February 2024

Dissemination event

Patricia Palenzuela and Lidia Roca participated in an educational activity at IES Murgi (El Ejido, Almería) to celebrate the International Day of Women and Girls in Science explaining the importance of water in Concentrating Solar Energy.

19^{th} February 2024

Dissemination event

Alba Ruiz-Aguirre participated in an educational activity at IES Gádor - Francisco Javier Román (Gador, Almería) under the framework of the activity “El CIEMAT en tu instituto” for 1st and 2nd ESO students about the problems of water scarcity and the existing alternatives to face this problem.

7^{th} to 9^{th} March 2024

Dissemination activity

Rocío Bayón. Taller: El sol como fuente de energía renovable y sostenible. Madrid es ciencia, IFEMA, Madrid.

15^{th} March 2024

Dissemination event

Alba Ruiz-Aguirre participated in an educational activity at IES Cerro Milano (Alhama de Almería, Almería) under the framework of the activity “El CIEMAT en tu instituto” for 1st year high school students about the importance of science and technology in society explained through the problem of water scarcity.

20^{th} to 22^{nd} March 2024

Scientific dissemination

Members of the Solar Thermal Application and Solar Water Treatment units participated in 13th European Meeting on Science, Technology and Innovation, Transfiere 2024.

21st March 2024

Dissemination event

Isabel Requena and Lidia Roca participated in an educational activity at Parque de las Ciencias (Granada) to celebrate the International Water Day.

5th April 2024

Dissemination activity

Margarita Rodríguez, Cristóbal Valverde. Taller: Explorando el potencial de los materiales: energía solar y agua de mar, Feria de la Innovación y la Ciencia 2024, Universidad de Almería.

23rd April 2024

Dissemination event

Participation of members of the Solar Thermal Application and the Thermal Energy Storage units in the activity “IV Feria de la Ciencia Almería”.

9th May 2024

Award

Naia Barandica, has been awarded with the first prize in the category of PhD students of the EXPERIMAT-24 video award, organised by MATERLAND, and financed by the Spanish Foundation for Science and Technology (FECYT) through the call for grants for the promotion of scientific, technological and innovation culture. Title: “Antisoiling coatings for solar components”

10th May to 11th June 2024

Dissemination activity

Cristóbal Valverde. Concurso Tesis en 3 minutos, Microondas FM: Cocinando el futuro de la energía renovable, Universidad de Almería, Teatro Apolo. 2nd prize.

1st June 2024

Dissemination activity

Rocío Bayón, Javier Hernández. Taller: El sol como fuente de energía renovable y sostenible. Ventuciencia, Ayuntamiento de Venturada del Campo, Venturada, Madrid.

23rd September 2024

Dissemination event

Lidia Roca and Patricia Palenzuela participated in the activity “Noche en las aulas” at IES Mar Serena (Pulpí, Almería) explaining the importance of water to increase the sustainability of solar thermal processes

26th September

Dissemination event

Lidia Roca and Patricia Palenzuela participated in the activity “Noche en las aulas” at IES Villa de Vícar (Vícar, Almería) explaining the importance of water to increase the sustainability of solar thermal processes

27th September

Dissemination event

Participation of PSA in the “European researcher’s night”.

189h December 2024

Workshop

S. Nahim-Granados. Regeneración sostenible de agua residual urbana y reutilización en riego agrícola” in the XVIII Maratón Científico de la EEZA, Almería (Spain).

19th December 2024

Dissemination event

Members of the Solar Thermal Application and Solar Water Treatment units participated in the XVIII Maratón Científico de la EEZA.

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 43 and Figure 44) 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 1,000-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).

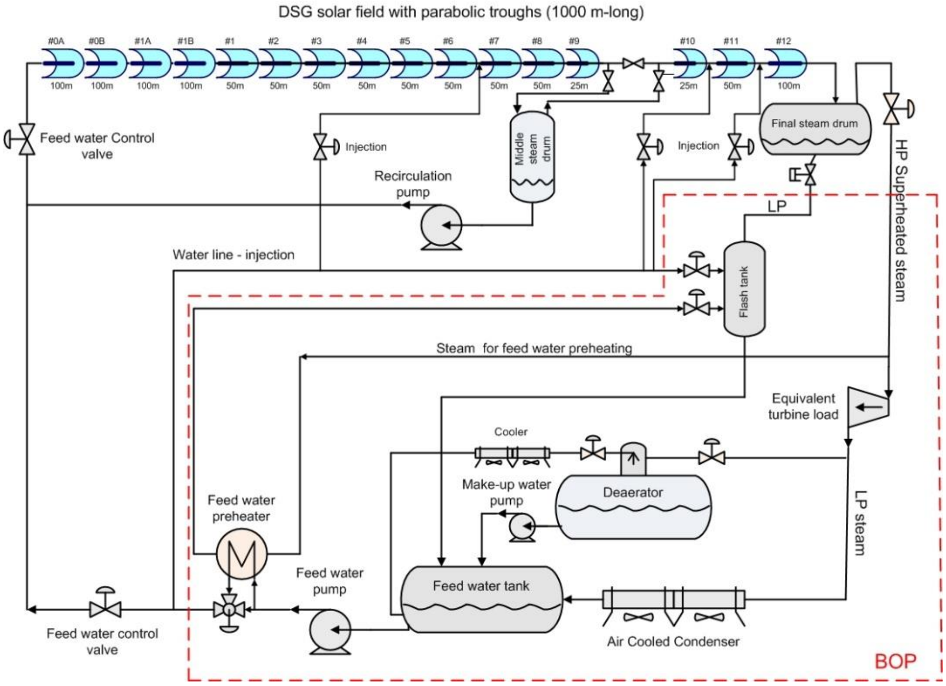


Figure 43. Simplified flow diagram of the PSA DISS loop.

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 h a day.

Figure 44. 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 45). 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.

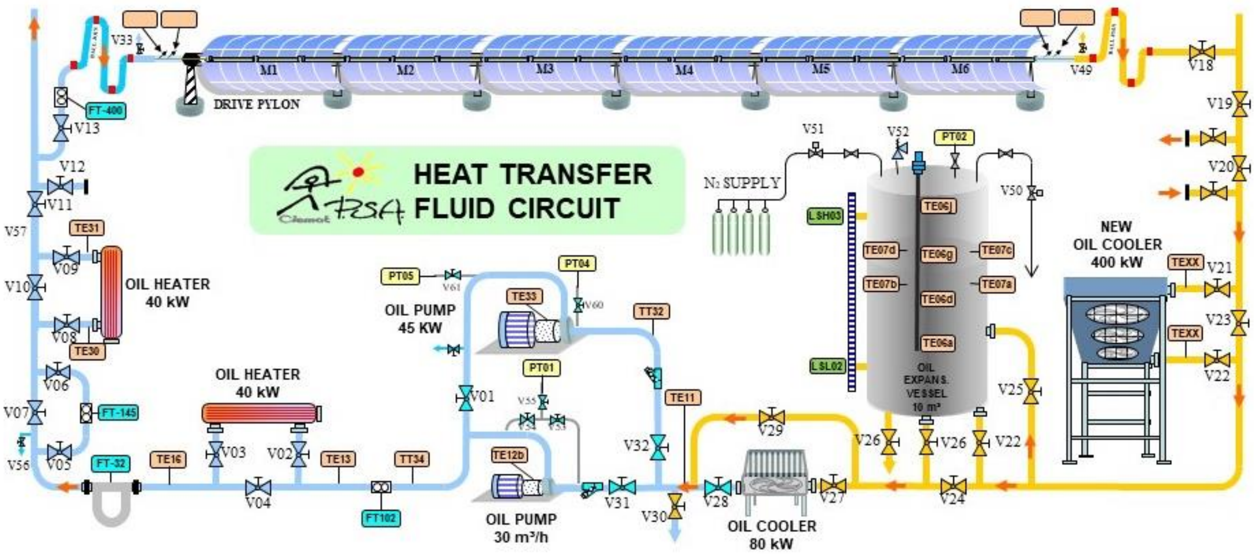


Figure 45. Diagram of the HTF test Loop located at the PSA.

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 litres per second.
- 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 facility. This 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.

THE PARABOLIC TROUGH TEST LOOP (PTTL) 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 (PTCs), 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.

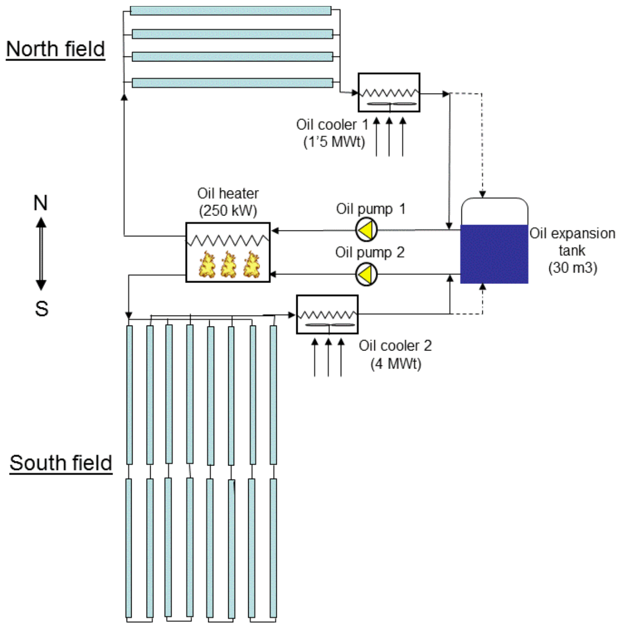


Figure 46. Simplified scheme of the PTTL facility.

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 47. 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-MWTH 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 48. 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.

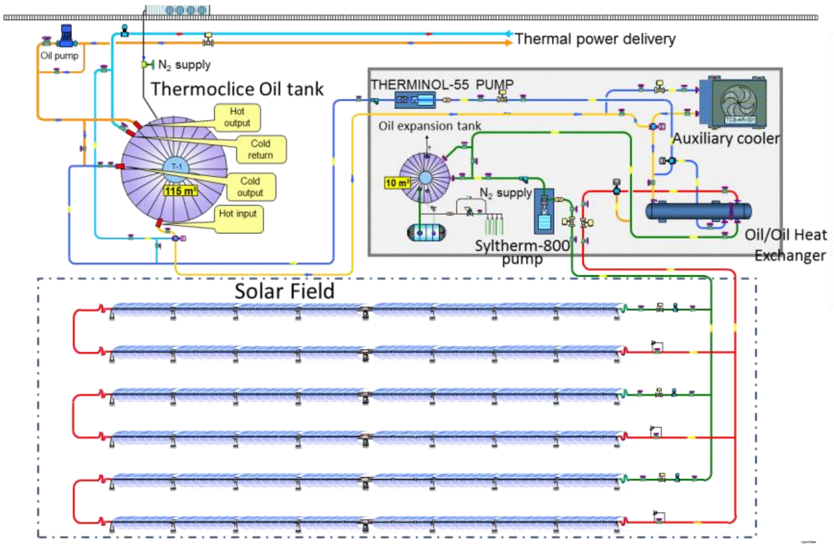


Figure 48. Diagram of the TCP-100 2.3 MW_{th} parabolic-trough facility

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.

INNOVATIVE FLUIDS TEST LOOP (PRESSURISED GASES) 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 49) 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 49. View of the IFL experimental facility (with parabolic troughs) using compressed gas as heat transfer fluid.

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 m^2 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.

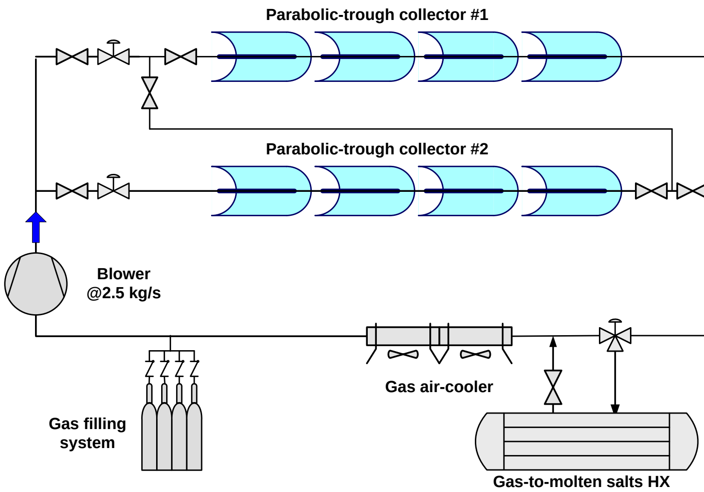


Figure 50. Simplified system diagram of the IFL experimental facility located at the PSA

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 1,000 W/m^2 of direct normal irradiance).

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.

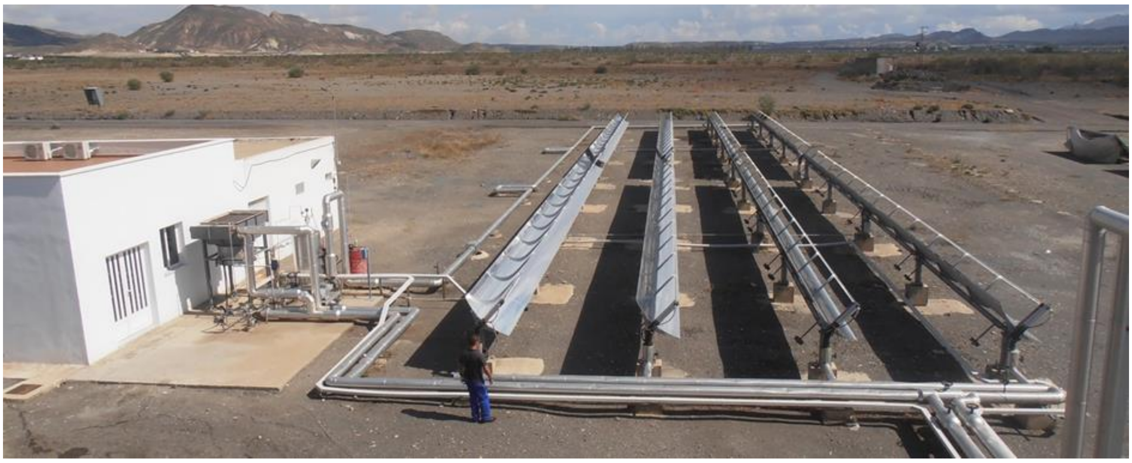


Figure 51. NEP PolyTrough 1,200 solar field.

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.

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.

Figure 52. Side view of KONTAS test bench and the heating/cooling unit (right side).

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 53.a).

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 53.b) 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.

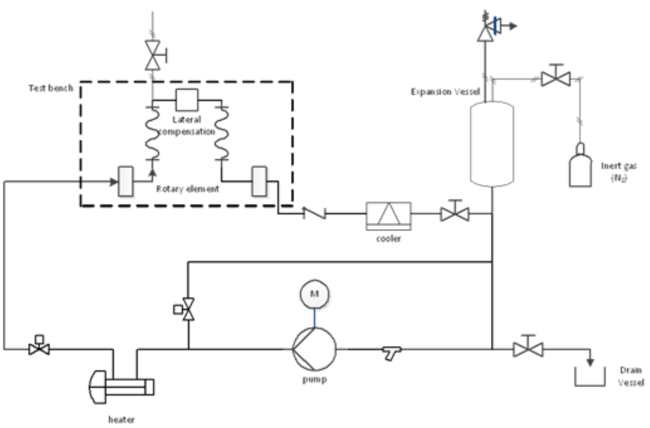


Figure 53. Schematic diagram of the REPA test loop at PSA (left) and north view of the test facility with two flex-hoses mounted for testing (right).

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.

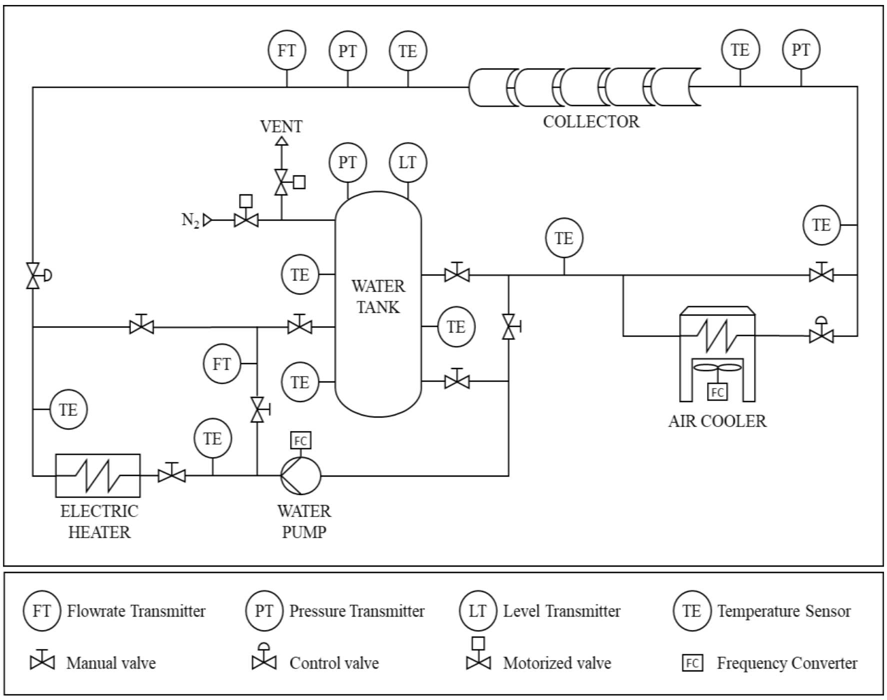


Figure 54. Simplified scheme of the LAVEC facility.

Figure 54 shows the simplified scheme of LAVEC with a solar collector connected to the system for qualification/evaluation, while Figure 55 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 55. 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 56) 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 56. 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 57). 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.

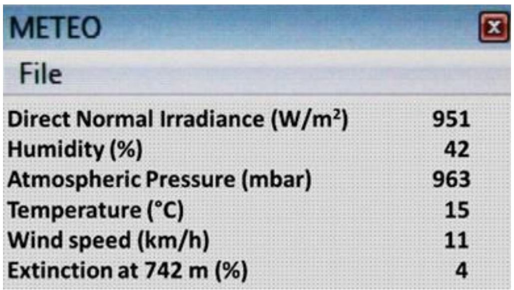


Figure 57. On-line measurement of the solar extinction in the control room of CESA-1 facility at PSA.

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.

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 59). 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.

Figure 58. Aerial view of the experimental SSPS-CRS facility.

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 59. 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 pressures 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 60. General view of the AORA solar tower facility.

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.

Throughout last year, the facility was upgraded with the installation of an electric heater, which will allow the molten salt mixture to be heated up to 500 °C. During 2024, the commissioning of this component was completed. Moreover, the heater is expected to be powered with electricity from a PV solar field, enabling future power-to-heat (P2H) studies.

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 61. MOSA outdoor test loop

Figure 62. 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.

Altayr is designed to support material testing under realistic operating conditions, allowing the evaluation of a wide range of materials such as ceramics, rocks or whatever material and shape designed to be a packed-bed filler. Comparing to conventional lab-scale setups, a significant advantage of Altayr is its ability to operate under conditions closer to real world applications, which enables more reliable extrapolation of the experimental results. These enhancements position Altayr as a valuable research platform for advancing packed-bed TES technology, and optimizing thermal storage solutions for renewable energy integration.

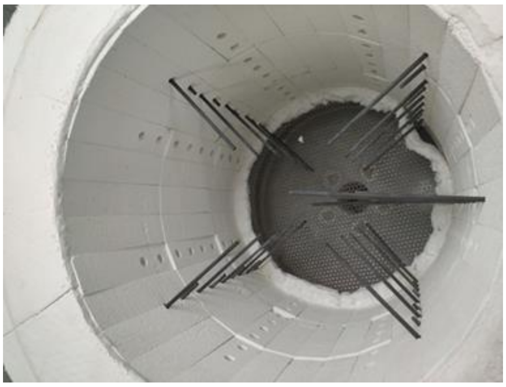


Figure 63. Picture taken from the top of the tank, showing its internal room and thermocouples at different lengths and radial positions.

Figure 64. Altayr tank

During 2024, the facility was relocated from Madrid to Almería. Upon arrival, instrumentation and maintenance work began. This included the reinstallation and calibration of all equipment, such as thermocouples, valves, electrical components, and the flowmeter. In addition, a technical inspection and system cleaning were carried out to ensure proper functionality and to remove any dirt or particles remaining from previous tests.

Parabolic DISH Systems

ACCELERATED AGEING TEST BED AND MATERIALS DURABILITY

This installation consists of a DISTAL-II model parabolic dish unit 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 65) 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 16,000 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.

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 (MATERlab) existing at PSA, which is described in the laboratories section of this document (section 14)

Figure 65. View of a parabolic-dish DISTAL- II with the original Stirling engine.

Figure 66. Accelerated aging tests of steel samples at a parabolic-dish DISTAL- II

EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected (Figure 67), 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 67. 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 68 and Figure 69 show the heliostat installed in this solar furnace and a detail of the backside of the facet, respectively.

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 designed a new concentrator which replaces the rectangular facets 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.

Figure 68. HT120 heliostat in tracking.

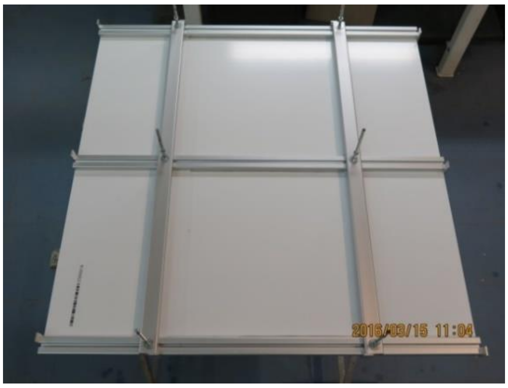


Figure 69. Back side of facet

The new parabolic concentrator, called FAHEX 100 (Figure 70), 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 71, 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 70. Interior view of the PSA SF-60 Solar Furnace in operation.

Figure 71. Shutter of the PSA SF-60 Solar FurnaceSF-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 72). 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.

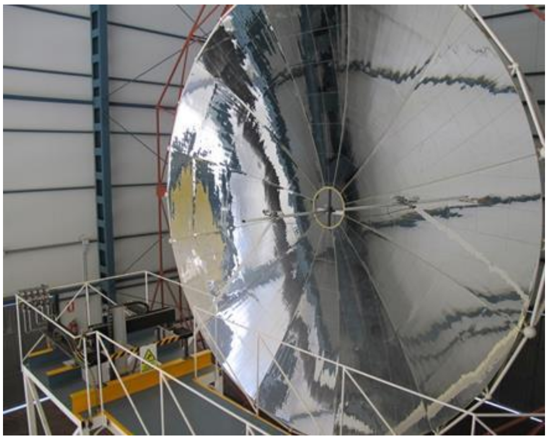


Figure 72. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

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 73. 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 materials 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 in components of concentrating solar thermal systems (reflectors, receivers, transparent covers, receiver particles, etc.). This facility allows the evaluation of characteristic optical parameters of solar components and their possible deterioration. The following equipment is available in the laboratory of optical characterization of solar components (Figure 74.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, Zepren 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.
- One portable glossmeter, Zehntner model 1130, for indirect measurements of solar reflectance, at 20, 60 and 85° incidence angle.
- One 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 SR2, designed and patented by DLR).
- One 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 spectrophotometers, Perkin Elmer model Lambda 1050, with 150-mm integrating sphere for measuring hemispherical reflectance, absorptance and transmittance at 8º incidence angle, and a specular reflectance accessory with 0 to 68° incidence angles (URA).
- One infrared spectrometer, Perkin Elmer Frontier FTIR, with a 76.2-mm diameter Pike integrating sphere for measuring emittance at 12° incidence angle in the wavelength range 2-14 µm.
- Nikon D3 camera and 90 cm Cubalite kit for photos of specular surfaces without parasitic reflections.
- One 3D microscope, Zeiss Axio microscope model CSM 700, with magnifications of 5, 10, 20, 50 and 100 for finding the profiles and roughness of optical surfaces.
- One 3D microscope, Leica model M250 C, with magnifications in the range of 7.8 to 160.
- One Parstat 4000 impedance system to analyse the corrosion of reflector materials.

- One tensiometer, Attension Theta model 200 Basic, 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.
- A 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.

The four laboratories for the solar components 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 74.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:

- One weathering chamber, Vöstch model VCC3 0034, to test the material resistance against corrosive gasses (H_2S, Cl_2, NO_2, SO_2) in combination with temperature and humidity (335 L), see Figure 74.c.
- Two weathering chambers, ATLAS model SC340MH, for temperature (from -40 °C to +120 °C), humidity (from 10 % to 90 %), solar radiation (from 280 to 3,000 nm) and rainfall (340 L).
- One weathering chamber, Binder model MKF 720, where UV light (with a peak at 340 nm) can be applied in combination with a wide range of temperature and humidity conditions.
- One weathering chamber, Memmert model HCP108, to apply humidity (20-95 %) and temperature (20-90 °C with humidity and 20-160 °C without humidity).
- One weathering chamber, Ineltec model CKEST 300, for humidity and condensation testing with temperatures up to 70 °C (300 L).
- One salt spray chamber, Vötsch model VSC450, with temperatures from 10 °C to 50 °C (450 L).
- One salt spray chamber, Erichsen model 608/1000 L, with temperatures from 10 °C to 50 °C.
- Two radiation chambers, ATLAS model UV-Test, where UV light (with a peak at 340 nm), condensation and temperature can be applied. One of the chambers also includes rain simulation.
- One Ultraviolet chamber, Hönle model UVA Cube.
- One SC100 heated water bath, to perform the Machu test, according to the Qualitest guideline.
- One sandstorm chamber, Control Técnica/ITS GmbH, with wind speeds up to 30 m/s and dust concentrations up to 2.5 g/m³.
- One cleaning abrasion device, Erichsen model 494, to test the degradation due to the cleaning brushes, with several cleaning accessories.
- Two linear abraser, Taber model 5750, to check the materials resistance against the abrasion.
- One cross-cut tester, Lumakin model A-29, to analyse the possible detachment of the paint layers.
- One pull-off tester, DeFelsko model PosiTest AT-A, to analyse the possible detachment of the paint layers.
- One 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).

- One 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 by CIEMAT and DLR.

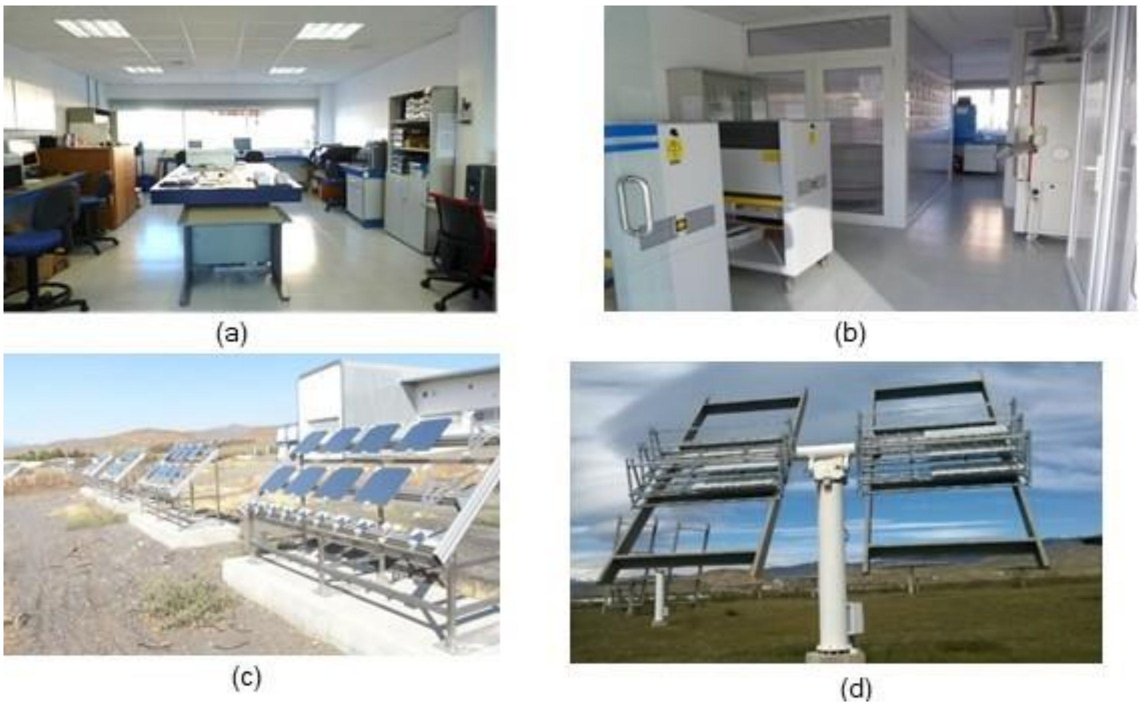


Figure 74. (a) Optical characterization lab, (b) durability analysis lab, (c) outdoor test bench and (d) outdoor accelerated aging test bench at OPAC facilities

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 have been developed by the group, 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 samples preparation (cutting and polishing), safety cabinets, instrumentation for measuring pH, conductivity, oxygen, etc.

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

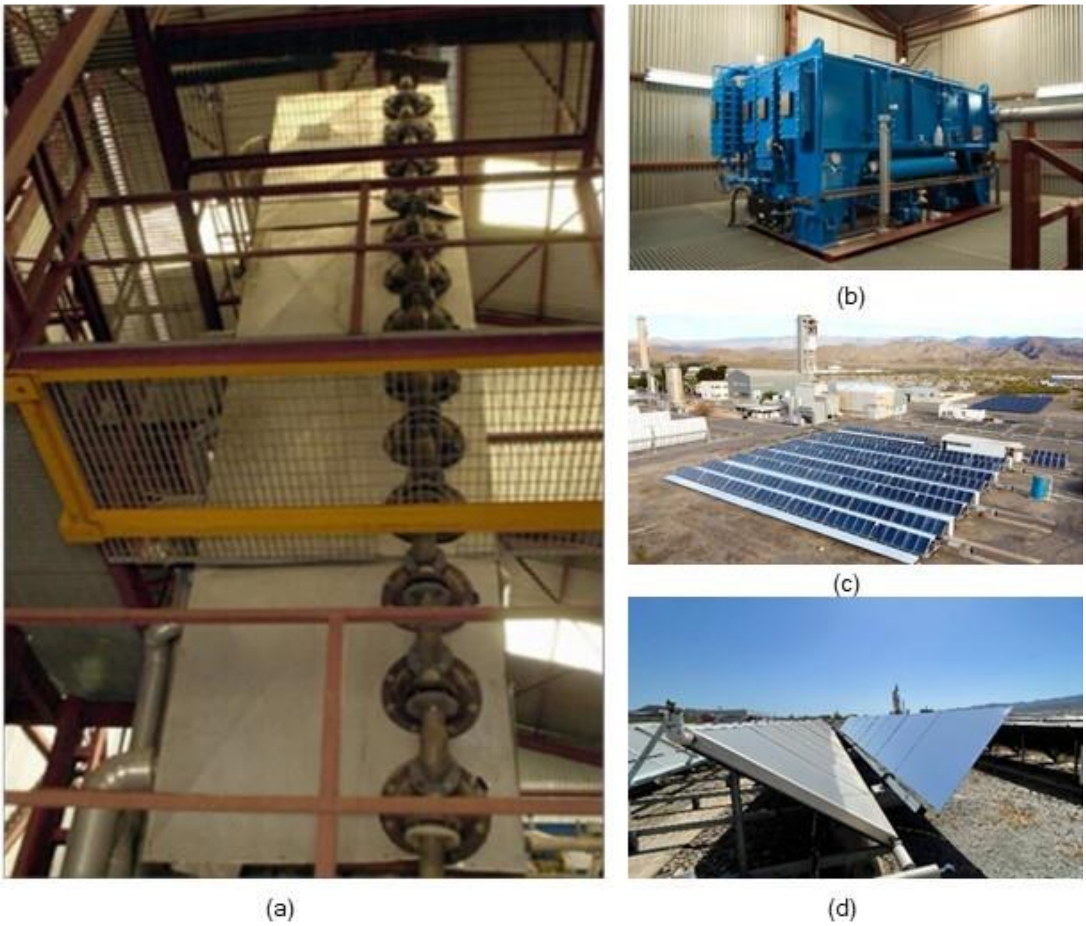


Figure 75. The PSA SOL-14 MED Plant (a) double-effect LiBr-H_2O absorption heat pump (b) and 606-m^2 flat plate solar collector field with tracking mirrors (c and d).

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.

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 L 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 76. Internal (Left) and external (rigth) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility.

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 6.4^2 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.

Figure 77. V-MEMD unit.

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 78). 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 78. 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 79). 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 79. Containers filled with real seawater for desalination tests in closed loop.

COOLING FACILITIES

This facility is composed of different cooling systems: an Air Cooled Heat Exchanger (200 kWth), a Wet Cooling tower (200 kWth) and an Air Cooled Condenser (335 kWth). All of them are connected to a steam generator (80 kWth) driven by solar thermal energy, which produces saturated steam (in the range of 120-300 kg/h) at different temperatures (42-60 °C), simulating the exhaust steam from a turbine in a power cycle. The cooling systems can be evaluated either separately, or combined, having two options within the latter: 1) a conventional combined cooling system composed by an Air Cooled Condenser in parallel with a Wet Cooling Tower plus a Surface Condenser; 2) an innovative combined cooling system composed by an Air Cooled Heat Exchanger and a Wet Cooling Tower, both sharing a Surface Condenser. In the last case, the hydraulic circuit allows to evaluate series and parallel configurations, and different flow rate percentages in the parallel ones.

Figure 80. The PSA Cooling Facility. (lef) Wet Cooling tower and Air Cooled Heat Exchanger (Innovative Combined Cooling System); (centre) Steam generator connected to the Air Cooled Condenser and to the Surface Condenser; (right) General view of the Cooling Facility

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 81). 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.

(b)

Figure 81. View of several CPC photo-reactors for purification of water (up) CPC facilities I (down) 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 82) 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 83). 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 (m²)	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 82. View of 2 m²-CPC coupled to Electro-Fenton pilot plant (ELECTROX).

Figure 83. 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 84. 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).

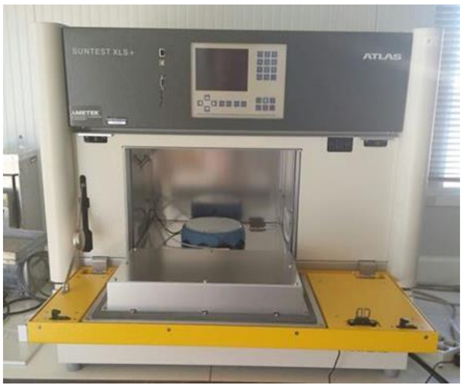


Figure 85. Solar simulator SUNTEST XLS+.

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 86.a).

Figure 86. UVC pilot plant installed at PSA facilities (left) and recent improvements (right).

The UVC pilot plant was improved (Figure 86.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 87) 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.

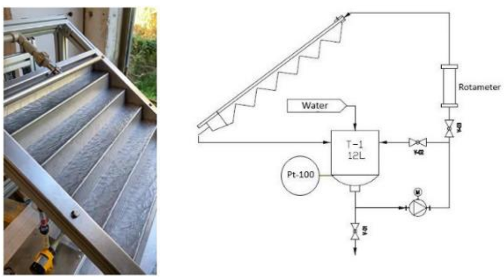


Figure 87. Solar waterfall reactor photography (left) and scheme (right).

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 88):

Figure 88. UV-LED lab system available at PSA facilities.

- 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.

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.

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 89.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 89.b and Figure 89. 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 89.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.

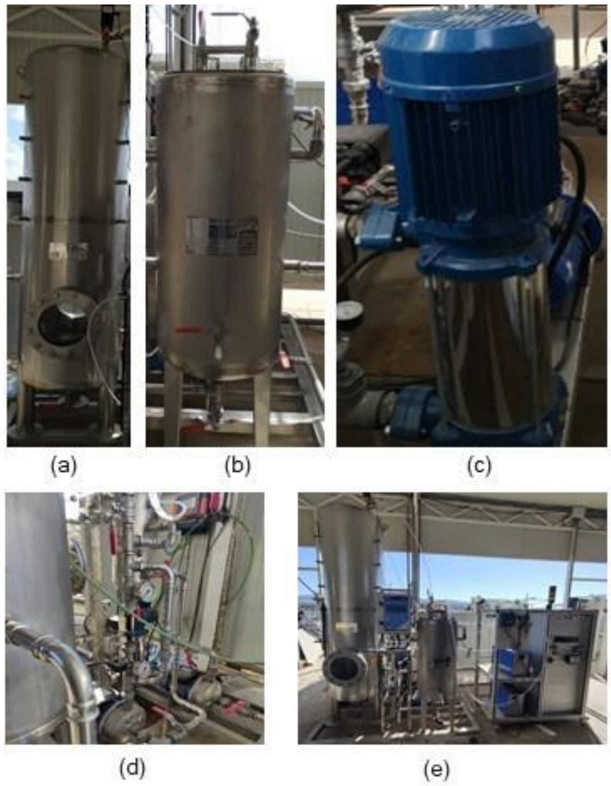


Figure 89. Pictures of the improved parts of the ozonation pilot plant a) New 580L contact column reactor; b) Pressurized tank; c) HP pump for nano-bubbles generation; d) Venturi for micro-bubbles injection and e) complete view of the new ozonation pilot plant.

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 90. 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 91.a). 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 91.b) for controlling the required quality of the permeate flow generated as well as the concentrated stream.

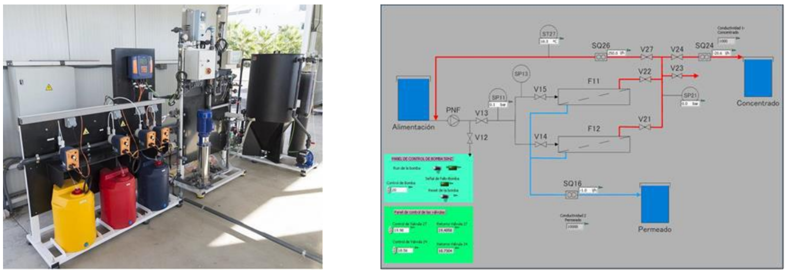


Figure 91. Nanofiltration pilot plant (left) and labview interface for control and automatic operation of the pilot plant (right).

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 92). 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 92. Solar pilot plant for photocatalytic generation of hydrogen (left) and gas (N_2 and Ar) conduction systems (right).

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 (AOP) (Figure 93). 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.

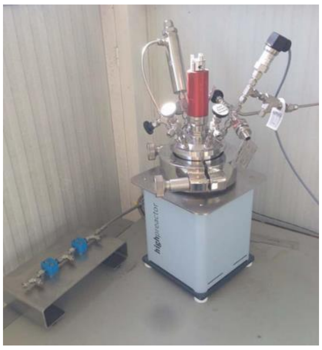


Figure 93. Wet Air Oxidation Pilot plant.

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 94).

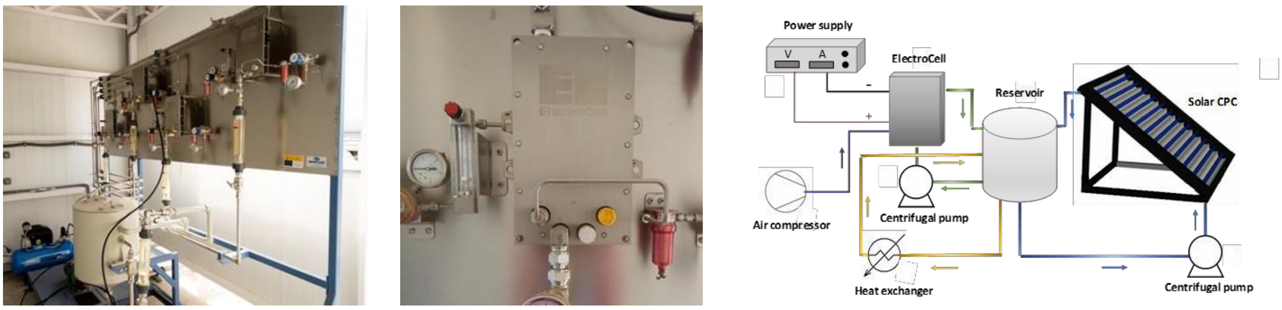


Figure 94. Electro-oxidation pilot plant (left); Electrochemical cell of the solar-assisted electrooxidation pilot plant (centre) and schematic diagram of the solar-assisted electrooxidation pilot plant (right).

SOLAR UVA MONITORING EQUIPMENTS

UV and global solar radiation data monitoring and storage system is composed by different pyranometers (Figure 95), 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.

Figure 95. CUV-5 radiometer (left). View of all solar UV radiometers, horizontal (centre) and inclined (right) setup used in the Solar Treatment of Water Unit.

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.

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 96) 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 96. 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 97).

Figure 97. 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 98). 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 98. 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.

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 building fabric, thermal comfort, building energy evaluation and both active and passive systems integrated in the buildings.

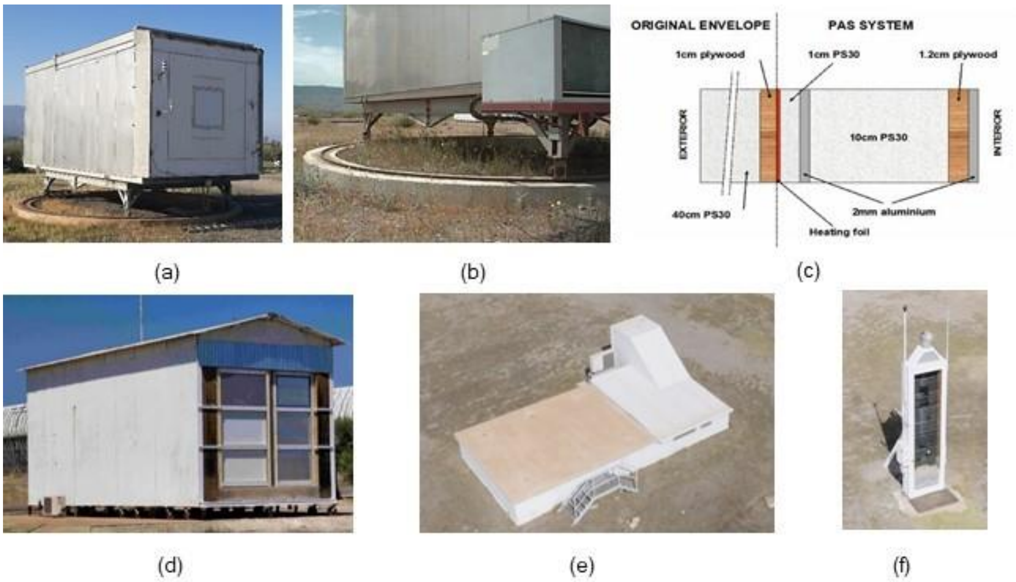


Figure 99. (a) Prefabricated industrialised modules being tested at the PASLINK Test Cell, (b) Detail of the rotating device, (c) Schematic drawing of the PAS system, (d) Set of prefabricated industrialised modules being tested at a CESPA Test Cell, (e) Exterior of the CETeB Test cell, (f) Solar Chimney.

Figure 100. (left) ARFRISOL Building Prototype in use, (right) Reference single-zone building.

14 Laboratories

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 101.left), for measuring heat loss of single receiver tubes under indoor laboratory conditions, and b) an outdoor test bench called RESOL (see Figure 101.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 101. 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.

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.

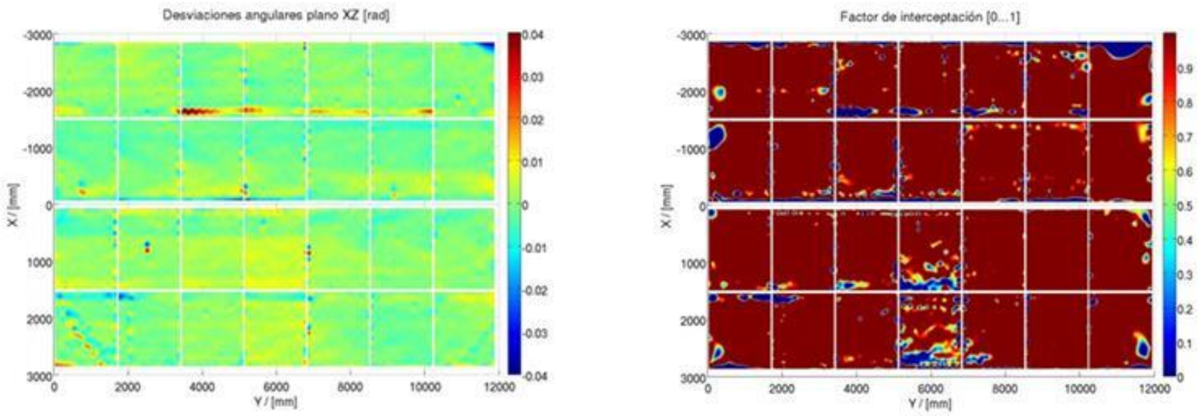


Figure 102. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry.

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 103. 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 1,700 °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 104. IR sensor calibration using a black body.

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.
- 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.
- 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 105. HDR.

Figure 106. SUBMA.

Figure 107. AgH.

- MICROWAVE LABORATORY. To investigate the use of microwaves as a method for heating solar salt, the Thermal Energy Storage Laboratory uses a variety of instruments, including a Phoenix Black multimode microwave oven equipped with two magnetrons operating at 2.45 GHz and delivering a combined output of 3500 W.
  Temperature measurements are obtained via thermography using an Optris PI 640i infrared camera. The setup also includes K-type thermocouples and a DT85 Series 4 data logger, which enables the recording of solar salt temperatures after the magnetrons are turned off. This configuration allows for the determination of the sample's emissivity using the known temperature method, by adjusting the emissivity setting on the thermal camera accordingly.
  An SCT-013 electronic power meter, connected to an IoT microcontroller, is installed in the microwave oven. This setup allows for a comparative analysis of energy consumption and heating time with respect to a Nabertherm L 40/11 muffle furnace, which operates at 6000 W.
  To comply with current electromagnetic radiation safety regulations, all experiments are carried out under continuous monitoring for potential leakage using a PCE-EM 29 radiation detector.

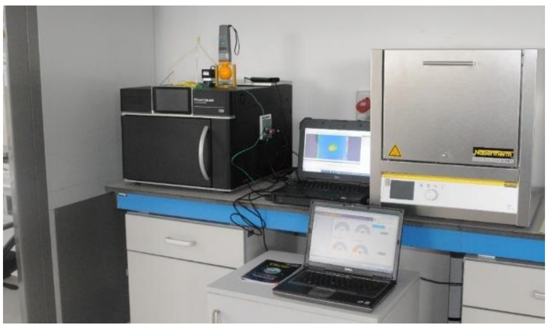


Figure 108. Microwave experimentation set up.

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 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)

Figure 109. 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 H_2O 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.

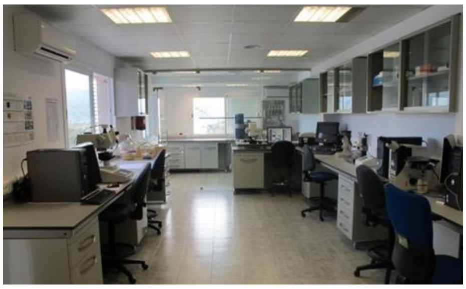


Figure 110. View of the Microscopy Room (left) and the thermogravimetric balance inside of its room (right).

THERMAL CYCLING ROOM

- It includes the instrumentation necessary for thermal cycling:
- Three muffle furnaces
- a high-temperature cycling furnace.
- A particle erosion tester at high temperature
- an air-cooled volumetric receiver test loop and associated instrumentation

OPTICAL EQUIPMENT

A portable solar reflectometer (410 Solar) and emissometer (ET100) are available at Materlab to characterise the optical properties of samples aged in the Solar Furnaces or in the Materlab thermal cycling room.

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 assess 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.

Figure 111. Advanced optical coatings laboratories equipment.

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 111).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 111).
- LEICA DM4 M optical microscopy with image acquisition system and software for image analysis (Figure 111).
- KSV CAM200 goniometer for measuring static contact angles (Figure 111).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 111).
- Rotational Viscometer SELECTA.
- BRUKER DektakXT stylus profilometer with optical camera and software for surface analysis (Figure 111).
- TABER linear abrader model 5750, equipped with different types of abrasive materials to measure the abrasion resistance of coatings and materials (Figure 111).
- 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 111).
- 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.

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 112) 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 112. Bench-scale unit for testing membranes on isobaric MD.

BENCH-SCALE UNIT FOR FLAT SHEET MEMBRANE DISTILLATION TESTING

The facility is a high precision laboratory grade research equipment (Figure 113) 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:

- 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.
- Smaller plate and frame cell (effective membrane surface 100 mm x 60 mm) and HF cell (50 cm long) for testing materials and solutions.
- Adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VAGMD).
- Temperature precision of 0.5 °C.
- Driving force temperature difference controllable.
- Fully automated control system and large range of possible parameter settings by touch screen PLC.

Figure 113. Bench-scale unit for testing MD with flat-sheet membranes.

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 114). 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 114. 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 115). 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 115. General view of the PSA Water Technologies Lab.

CHROMATOGRAPHY LABORATORY

This laboratory (Figure 116.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 116.c) and two ion chromatographs (Figure 116.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 116.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 116.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).

Figure 116. (a) General view of the chromatography lab at PSA facilities. (b) Metrohm Ion Chromatographic System. (c) Agilent Ultra-fast UPLC-DAD analyzer. (d) AB SCIEX TripleTOF 5600+ equipment. (e) AB SCIEX 7500 QTRAP Ready LC/MS.

MICROBIOLOGY LABORATORY

47-m^2 microbiology laboratory with biosafety level 2 (Figure 117) 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.

Figure 117. General view of the microbiology lab at PSA facilities.

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.

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 hybridization) technique for visualization of DNA hybridization with specific probes in live cells used for monitoring key microorganisms within a heterogeneous population (Figure 118).

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 118. 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 119).

Figure 119. General view of METAS station.

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 m
- Vertical temperature and humidity profile at 2 and 10 m
- Miscellaneous weather information: rain gauge, barometer and psychrometer

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 120). These facilities are operated in collaboration with the Instrumentation Unit.

Figure 120. Calibration facilities.

Since the beginning of 2018, there are seven new fully operational radiometric stations around the PSA area (Figure 121). 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 121. PSA radiometric stations.

15 Events

6th January 2024

Award

Isabel Oller was awarded with the "Royal Academy of Sciences Foundation Awards for Young Female Scientific Talent" promoted by the Royal Academy of Sciences Foundation of Spain (FRACE), as part of its mission to promote the development of science in Spain, in the "Applications of Science to Technology" category.

22nd to 24th January 2024

Workshop

Kelly Castañeda Retavizca gave a talk titled: "Urban wastewater treatment by ozonation: pathogens and microcontaminants removal, byproducts formation and toxicity evaluation" in the Workshop on Photo-irradiation and Adsorption based Novel Innovations for Water-treatment, organized in the frame of PANIWATER project in CSIR-National Environmental Engineering Research Institute, Nagpur, 440 020, Maharashtra (India).

22nd to 26th January 2024

Research stay

Cristóbal Valverde. University of Cartagena, Cartagena Simulación multifísica y modelizado del calentamiento por microondas.

6th February 2024

Visit

Rocío Bayón, Esther Rojas. Feria de Energía - GENERA. IFEMA, Madrid.

21st February 2024

Workshop

Organisation and participation in the workshop "Use of desalinated water for irrigation", organized by the Sustainable Desalination Living Lab in the University of Almería.

22nd February 2024

Lecture

Invited lecture by Alba Ruiz-Aguirre ("Future perspective of thermal desalination") at a workshop on European Leadership in Action: enabling technologies to boost freshwater preservation in Birmingham, United Kingdom.

28th February 2024

Task meeting

Solar Paces Task II meeting (online). Members of the SolarPACES Task II discuss a potential collaborative knowledge-sharing activity with Task IV and reviewed the SolarPACES Task Funding call, which was due on March 2, 2024.

1st March 2024

Lecture

Invited lecture by Alba Ruiz Aguirre ("Membrane distillation, beyond thermal desalination") at 3rd International Conference on Advances in Water Treatment and Management (ICAWTM-24) in Gandhinagar, Gujarat (India).

7th to 12th March 2024

Training activity

Esther Rojas, Rocío Bayón. Almacenamiento térmico y otras aplicaciones de la radiación solar concentrada. Máster en Energía Solar UAL-CIESOL.

14th to15th March 2024

Workshop

Sixto Malato was invited to give six hours of lectures in the International Workshop on Chromatographic and Mass Spectrometry Analysis: New Technologies for Water Treatment. Universidade Federal de Santa Maria, Brazil.

18th March 2024

Lecture

Invited lecture by Guillermo Zaragoza ("Application of solar energy to desalination") in a Spotlight Talk of the European Federation of Chemical Engineering.

18th to 23rd March 2024

Symposium

Sixto Malato was invited to the "XV simpósio latino americano de química analítica ambiental e X encontro nacional de química ambiental - XV LASEAC e X ENQAmb" in Ouro Preto, Minas Gerais, Brasil.

19th March 2024

Workshop

HYDROSOL-beyond WORKSHOP. Solar Hydrogen and other technologies. CIESOL, Universidad de Almería.

20th March 2024

Invited talk

Sixto Malato was invited to give a talk related to "Strategies for Detecting and Removing Contaminants of Emerging Concern from Environmental Matrices". Universidade Federal de Minas Gerais, Brasil.

22nd March 2024

Workshop

Isabel Oller was invited by the "Cátedra del Agua de AQUALIA y UAL" to give a talk titled "Regeneración de aguas como opción viable y disponible para la lucha contra la escasez hídrica", in the Water Worldwide Day.

18th April 2024

Workshop

Materiales para producción y uso del hidrogeno. Jornada sobre materiales para producción y usos de hidrógeno. Plataforma Tecnológica Española de Materiales Avanzados y Nanomateriales, CIEMAT, April 18, 2024.

18th April 2024

Master

Sixto Malato was invited to give two hours of lecture in "Título de Experto en Farmacontaminación" Universidad del País Vasco.

26th April 2024

Training activity

Margarita Rodríguez García. Prácticas de campo en la PSA. Máster en Energía Solar UAL-CIESOL.

7^{th} May 2024

Training activity

Esther Rojas. Course: Almacenamiento térmico de energía. ITE: Instituto Tecnológico de la Energía.

27^{th} May 2024

Award

Ilaria Berruti was awarded with the “Best PhD thesis awarded by the Catedra of AQUALIA and UAL related to the integral water cycle.

31^{st} May 2024

Invited Talk

Sixto Malato and Isabel Oller were invited to give a talk in a course organized by the PhD program on Analytical Chemistry in the University of Almería related to the topic “La vida más allá del doctorado: empleabilidad de un doctor en Ciencias”.

31^{st} May 2024

Visit

Visit to the PSA by students of the Master's Degree in Energy 2023/24 of the Universidad Autónoma de Madrid.

4^{th} June 2024

Seminar

Sixto Malato was invited to the V Seminario de Tratamiento de Aguas within the frame of the project ANID/FONDECYT/1230704.” In the Universidad Tecnológica Metropolitana (UTEM), Santiago de Chile, Chile.

9-12^{th} July 2024

Invited expert

Sixto Malato was invited as expert in the Security Enhancement for Climate Changes impacting Urban Resources – SECCURe. NATO Advanced Research Workshop ARW G6276. Montelibretti – Roma (Italy).

11^{th} June 2024

Award

Mention for the Best Patent by a Woman Inventor at the 3^{rd} Edition of the Awards for the Best Invention Protected by Industrial Property Rights of the Spanish Patent and Trademark Office (OEPM), to Loreto Valenzuela Gutiérrez, for her patent P202090004 entitled "Adaptable linear Fresnel solar collector". The award ceremony was held at the Escuela de Organización Industrial in Madrid.

14^{th} June 2024

International congress

The third technical session of the 4th IFAC Conference on Advances in Proportional-Integral-Derivative Control was held at the PSA.

17th to 28th June 2024

Research stay

Rocío Bayón. Access to the TherStore lab with the project THERMADEG-PCM "Effect of THERMAl DEGradation on the thermophysical properties of organic PCM". AIT, Vienna (Austria).

19th June 2024

Network event

Guillermo Zaragoza organized the meeting of the Renewable Energy Desalination Working Group in the Water Innovation Europe event of the Water Europe Platform. He also presented the Sustainable Desalination Living Lab in the Water-oriented Living Lab network event.

26th June 2024

Network event and lecture

Webinar ("Implementation of Solar Desalination in Islands") organized with Greening the Islands Foundation, and presentation of the "White Paper on implementation of solar desalination in islands" by Guillermo Zaragoza.

8th to 10th July 2024

Network event

Networking activity organized by the CIEMAT energy department in the territorial center for renewable energy development located in Soria (Spain).

15th July 2024

Invited Speaker

Lecture given by Meryem Farchado Dinia as Invited Speaker titled "High-performance air-stable solar selective absorber for CSP applications up to 450 °C" in the 7th International Conference on Materials Science & Nanotechnology (ICMSN 2024), Vienna, Austria.

15th to 17th July 2024

Invitation to Join the HelioCon Board of Advisors

Invitation extended to Antonio Luis Avila Marin to attend the FEDSM-SHTC-ES 2024 Conferences in Los Angeles, California, USA as a member of the HelioCon Board of Advisors.

9-11th September 2024

Invited professor

Sixto Malato was invited to give a talk in the international school on water reuse (ISWR) - 3rd edition. In the Molecular Biotechnology Centre, University of Torino (Italy).

11th to 18th September 2024

Summer School

Participation of María José Jiménez as Member of the Organising Committee and Lecturer on the "DYNASTEE Summer School on Dynamic methods for whole building energy assessment". Organised by INIVE-DYNASTEE and PSA-CIEMAT in collaboration with Solar Energy Research Centre CIESOL in Almería, Spain.

19th September 2024

Lecture

Invited lecture ("Decarbonisation of desalination with solar energy") by Guillermo Zaragoza in the webinar "Desalination and non-conventional Water Sources for Resilient Development", organized by Agence Nationale de Dessalement de l'Eau, CRTSE, and RSDT (Algeria).

20th September 2024

Visit

Participants of the "DYNASTEE Summer School", and the Seminar "Building Modelling in the Urban Environment" of Working Group 3 of

URBAN MOME Network held in Almería, visited the *Plataforma Solar de Almeria*.

1st-4th October 2024

Course

Isabel Espinoza-Pavón gave a talk titled: “Evaluación multiparamétrica de reactores solares fotocatalíticos de bajo coste para desinfección y descontaminación de aguas” in the “I Escuela de Doctorado en Fotocatálisis”, organized by the National Network InterPhot in A Coruña (Spain).

2nd October 2024

Lecture

Invited lecture (“Living Lab Desalación Sostenible”) by Guillermo Zaragoza in I Jornada “Evolución de la Universidad hacia Infraestructuras de Living Lab: Innovación, Investigación y Aprendizaje conectados con la Sociedad y el Entorno” organized by Universidad Rey Juan Carlos (Madrid).

3rd to 4th October 2024

Workshop.

Solar towers’ performance enhancement and cost reduction by the development and implementation of innovative on-site measurement & characterization tools. Invitation to Antonio Luis Avila Marin to deliver a talk on “Most Critical Technological Challenges Facing Solar Tower Technology.Invitation to Rafael Monterreal Espinosa to give a talk on “Beam Characterization System (BCS) and its role in R&D centers”

07th October 2024

Task meeting

Task II Meeting held during the Solar Paces Conference, to highlight progress and reinforced collective commitment to advancing solar chemistry energy initiatives. Country reports presented by each National Coordinator.

07th October 2024

Workshop

IEA 45 Workshop, “Renewable Hydrogen”. Rome, organized by members of Task 45/ST3 and SolarPACES/Task 2 to advance in the definition of the final template to prepare the technology briefs for subtask 3 “Solar thermochemical cycles”.

17th October 2024

Workshop

Samira Nahim-Granados and Isabel Oller were invited to perform two talks titled: “Reutilización de agua residual urbana: evaluación de riesgos” and “Integración de tecnologías convencionales y sistemas avanzados de oxidación para el tratamiento y regeneración de aguas residuals”. In the workshop organized by the National Network HOLIWATER oriented to companies related to “Aproximación holística a la recuperación de recursos del agua residual”, Madrid (Spain).

4-6th November 2024

Invited professors

Sixto Malato, Samira Nahím Granados and Isabel Oller were invited as professors in the 4th European School on Environmental Applications of Advanced Oxidation Processes, which took place in the Aristotle University Research Dissemination Centre, Thessaloniki (Greece).

11th to 12th and 26th to 28th November 2024

Research stay

Rocío Bayón. Access to UPV-EHU, Bilbao, with the project Medidas DSC de PCM basados en ácidos grasos degradados térmicamente.

14th November 2024

Symposium

Ana Ruiz Delgado, Isabel Espinoza and Paula Serrano, presented their PhD work in the "XIII Simposio de investigación en ciencias experimentales". University of Almería (Spain).

18th November 2024

Seminar

Maria Inmaculada Polo-López gave a talk titled "Desinfección del agua mediante tratamientos solares" in an online seminar organized by the Universidad de la Frontera (Chile).

3rd Dec 2024

Visit

Visit to the PSA by students of the Engineering Degree in Energy 2023/24 of the Universidad de Málaga.

27th December 2024

Lecture

Invited lecture given by Patricia Palenzuela "Solar Thermal Desalination Technologies for Zero Liquid Discharge processes" in the International Symposium "Innovations in Solar Desalination and Water Management-Challengues, Opportunities and Perspectives for a Sustainable Future" organized by ENSI University (Tánger, Morocco).

16 Publications

PhD Thesis

Dennis Deemter. Application of Advanced Integrated Technologies (Membrane and Photo-Oxidation Processes) for the Removal of CECs contained in Urban Wastewater rales. Universidad Politécnica de Valencia, Escuela Politécnica Superior de Alcoy. 9th February 2024. Supervisors: Sixto Malato Rodriguez and Ana Mª Amat Payá (UPV).

Line-focus Concentrating Solar Thermal Technologies Unit

SCI PUBLICATIONS

Arias I.; Battisti F. G.; Romero-Ramos J. A.; Pérez M.; Valenzuela L.; Cardemil J.; R. Escobar. Assessing system-level synergies between photovoltaic and proton exchange membrane electrolyzers for solar-powered hydrogen production. **Applied Energy**. 2024. 368, 123495. https://doi.org/10.1016/j.apenergy.2024.123495

BOOK CHAPTERS AND NOT SCI JOURNALS

Valenzuela L.; López-Martín R.; Hernáiz J.; González J.; Arana J.; Mendizabal G. Thermo-Mechanical Cycling of the ROTAJOINT Flexible Interconnection Installed in a Parabolic Trough Test Facility. **SolarPACES Conference Proceedings**, Vol. 1. 2024. 1. https://doi.org/10.52825/solarpaces.v1i.672

Ebadi, H., Alarcón-Padilla D.C., Contreras J.J., Guedez R., Trevisan S., Valenzuela L., Zarza E., Savoldi L. Optical analysis and optimization of a new receiver for solar parabolic trough collectors (DETECTIVE). Proceedings of ASME 2024 **18th International Conference on Energy Sustainability**. 2024, V001T05A001. https://doi.org/10.1115/ES2024-130019

González, L., Biencinto, M., Valenzuela, L., Arribas, L., Polo, J. Modelling of Solar Thermal Electricity Plants in the POSYTYF Research Project for an Extensive Integration of Renewable Energy Sources. **SolarPACES Conference Proceedings, Vol.1**. 2024. 1. https://doi.org/10.52825/solarpaces.v1i.716

López-Martín, R., Valenzuela, L., Amador-Cortés, C.M. Device for Measuring Forces and Torques in Flexible Connections Joints for Parabolic Trough Collector. **SolarPACES Conference Proceedings, Vol.1**. 2024. 1. https://doi.org/10.52825/solarpaces.v1i.724

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Arias I., Battisti FG, Romero-Ramos JA, Valenzuela L, Gonzalez-Portillo LF, Cardemil J, Escobar R (2024). System-level assessment of Green Hydrogen Production via SOEC-Solar Thermal Integration. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

Ebadi, H., Alarcón-Padilla, D., Contreras-Keegan, J.J., Guedez-Mata, R.E., Trevisan, S., Valenzuela, L., Zarza, E., Savoldi, L. Optical Analysis and Optimization of a New Receiver for Solar

Parabolic Trough Collectors (DETECTIVE). **ASME 2024 18th Int. Conference on Energy Sustainability**. Anaheim, California, USA, July 15-17, 2024. Paper No. ES2024-130019, V001T05A001. https://doi.org/10.1115/ES2024-130019.

Sallaberry F, San Miguel E, García de Jalón A, Mariblanca A, Cubero S, Valenzuela L. Road-map of Standardization for Concentrating Solar Plants in Industrial Processes. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

POSTERS

Ballestrín, J., Valenzuela, L., Fernández-Reche, L., Pujol, R., Cardona, G., Carballo, J.A., Bonilla, J., Estremera-Pedriza, N., Carra, E., Simal, N., Monterreal, R., Marzo, A. More Efficient Heliostats Fields for Solar Tower Plants: The HELIOSUN Project. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

Ebadi H, Alarcón-Padilla DC, Guedez-Mata RE, Mahnoodi H, Trevisan S, Valenzuela L, Savoldi L. Numerical investigation of a new absorber for parabolic trough collectors using tube bundle cavity concept. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

López-Martín R, Valenzuela L, Amador-Cortés C. Torque in the Rotation Axis of a Parabolic Trough Solar Collector due to Wind Loads. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

Lüpfert E, Kallio S, Hilgert C, Dicke N, Valenzuela L, López-Martín R, Price H, Shininger R, Monaco J, Saur M, Conrad M, Valverde J, Kesseli D. Developing the Guideline for Testing of Flexible Pipe Connectors. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

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Carra E, Alarcón D, Valenzuela L, López-Martín R, García G. Evaluation of small torsion angles in parabolic trough collectors. **30th SolarPACES Conference**. Rome, Italia, October 8-11, 2024.

Point-focus Concentrating Solar Thermal Technologies Unit

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Mortazavi A., Avila-Marin A.L., Ebadi H., Gajetti E., Piatti C., Marocco L., Savoldi L. Experimental investigation of Triply Periodic Minimal Surfaces for high-temperature solar receivers. **Case Studies in Thermal Engineering**. https://doi.org/10.1016/j.csite.2024.104771

Polo J., Poddar S., Simal N., Ballestrín J., Marzo A., Kay M., Carra E. Solar tower power generation under future attenuation and climate scenarios. **Renewable and Sustainable Energy Reviews**. https://doi.org/10.1016/j.rser.2024.114997

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Estremera-Pedriza N., Fernández-Reche J., Ariza M.J. Typical Year of Atmospheric Extinction of Solar Radiation at Plataforma Solar de Almería. Validation of Extinction Models and Maps in areas of interest for thermoelectric solar tower plants. **CIES 2024, XIX Congreso Ibérico y XV Congreso Iberoamericano de Energía Solar** (Évora, Portugal).

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Thermal Energy Storage Unit

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