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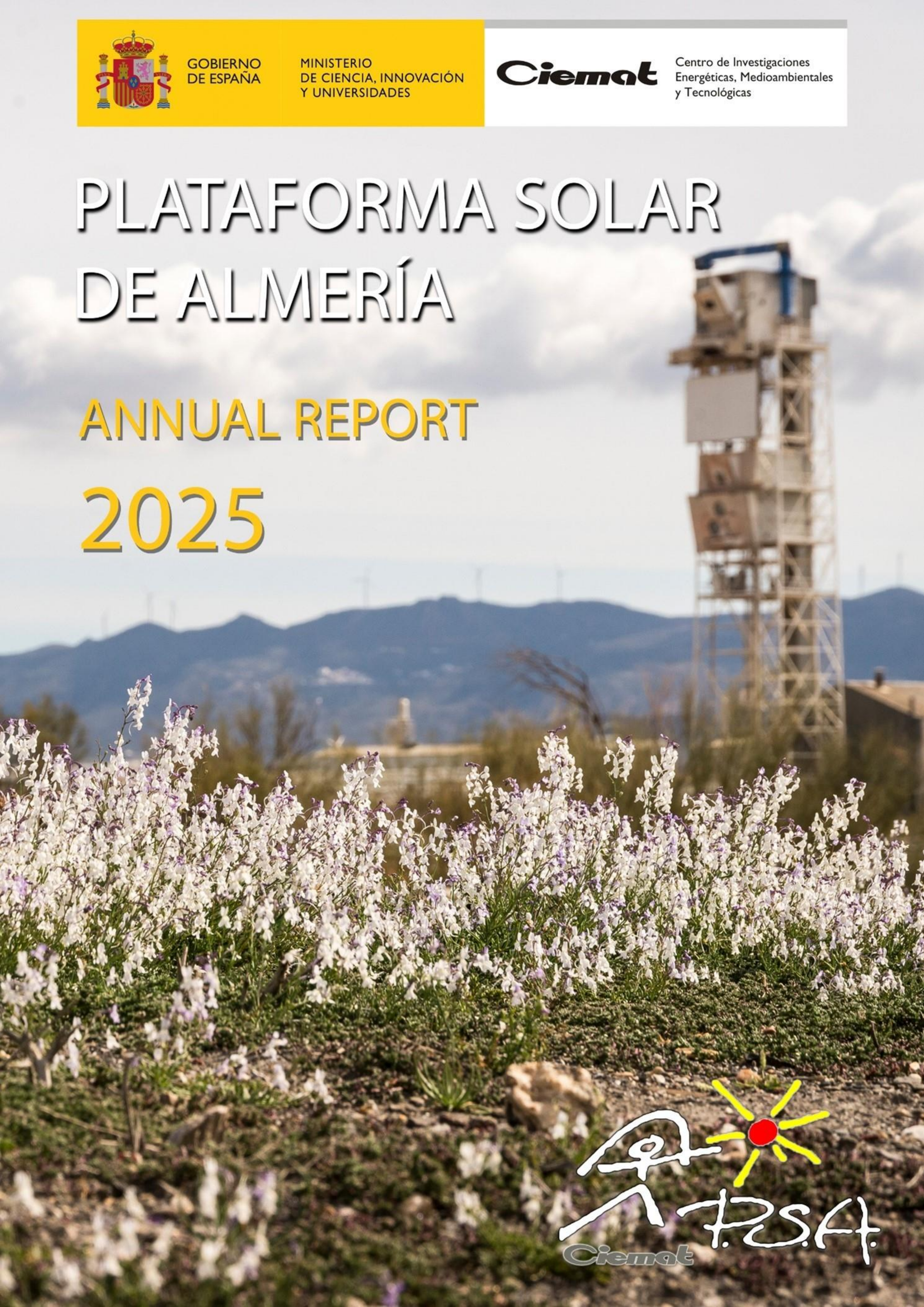
Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

ANNUAL REPORT

2025



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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.

Until 2025, research activity at the PSA has been structured around seven R&D Units, 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:

- 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.

- 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.

- 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.

- 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…).

- *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.

- *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.

- *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.

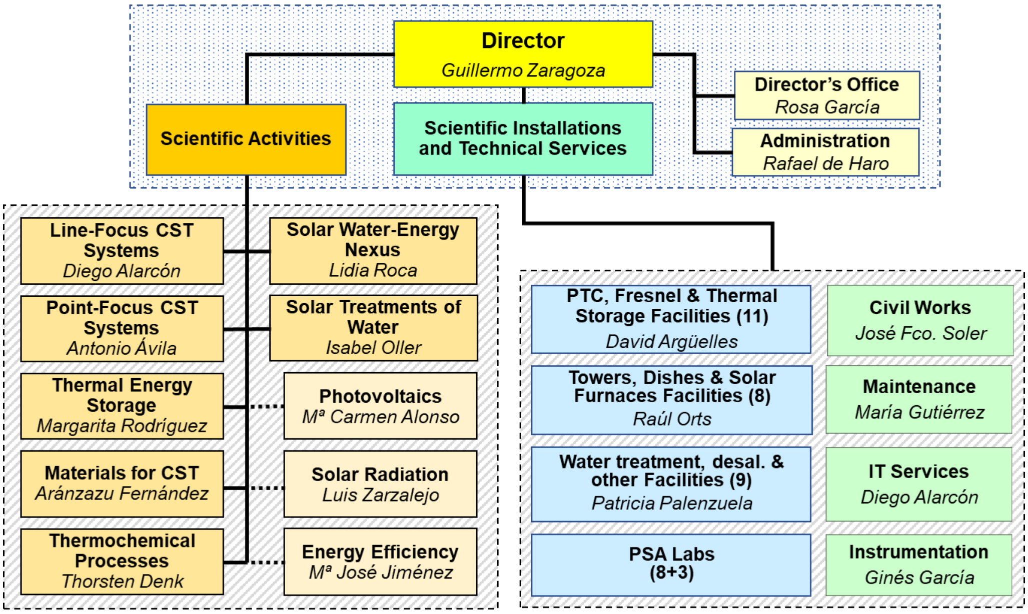

Figure 3. Internal organizational structure of PSA

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 142 people that as of December 2025 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 124 people who work daily for the PSA, 73 are CIEMAT personnel, 11 of whom are located in the main offices in Madrid.

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.

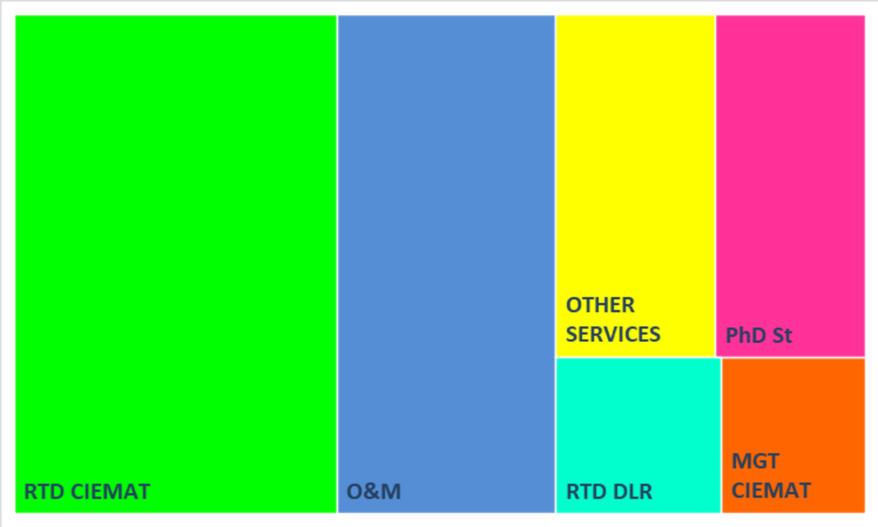

Figure 4. Distribution of permanent personnel at the PSA as of December 2025.

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 2025 totals 3,6M 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 2025, this PSA R&D unit has continued its activities in the field of developing, testing, and evaluating components for line-focus solar collectors (DETECTIVE & REPA-3S Project), modelling and simulating power plants with parabolic-troughs to analyse the impact of anti-soiling and anti-reflective coatings (INTECSOL Project), the application of line-focus technologies for solar process heat (ACES4NET0-CM and SPHERE 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 2025. As in previous years, 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 2025, this tool was already in operation in eleven commercial solar thermal power plants, and new plants will be incorporated during 2026.

List of projects this PSA Unit has been involved in

- Development of a Novel Tube-Bundle-Cavity Linear Receiver for CSP Applications (DETECTIVE)
- Developing the Guideline for Testing of Flexible Pipe Connectors for Trough Collector Fields (FlexPipe-REPA Guide)
- Flexible pipe connectors with trace heating for parabolic through power plants development, test sequences and standardization (REPA-3S)
- Technological Innovations for Improving the Viability of Concentrating Solar Thermal Plants (INTECSOL)

- Concentrated solar power for net-zero goals in industrial processes and transportation (ACES4NET0-CM)

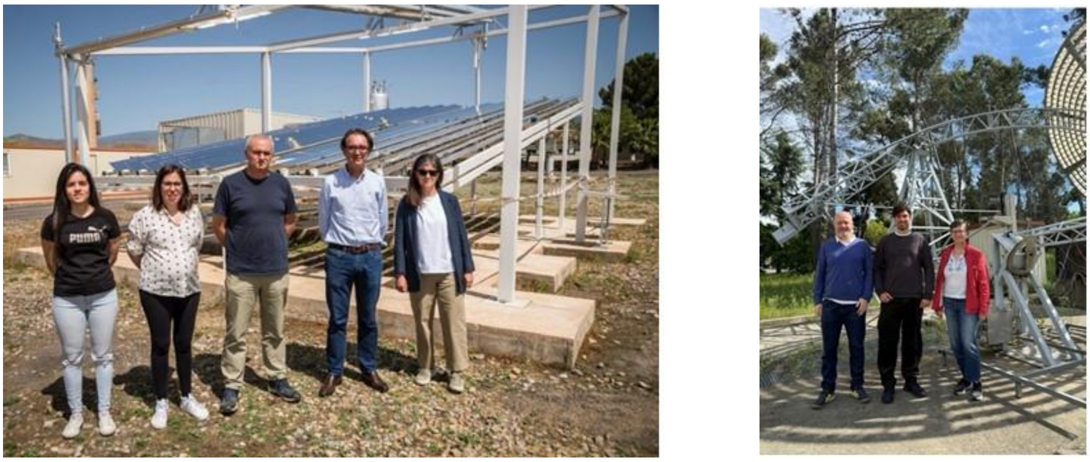

Figure 6. Unit staff at PSA (left) and CIEMAT Headquarters in Madrid (right).

3 Point-Focus Solar Thermal Technologies Unit

Introduction

The objective of the unit is to promote and contribute to the development of Point Focus solar thermal technologies, with particular emphasis on Central Receiver Systems, for the utilisation of concentrated solar radiation for electricity generation and high-temperature process heat applications demanding temperatures above 400 – 500 °C.

In particular, during 2025, the unit has been working along the following main research lines:

- The design, simulation and experimental assessment of advanced ceramic and metallic volumetric receivers, including structured and graded porous concepts (ASTERIx-CAESar, SUNFLOWER, PRINCESS and COOPERANT projects).
- The automation and improvement of heliostat characterisation, calibration and performance assessment methodologies (LEIA project).
- The development and validation of advanced heliostat field control strategies, including AI-based approaches to improve tracking accuracy and reduce CAPEX and OPEX (HELIOSUN and ASTERIx-CAESar projects).
- The analysis, benchmarking and harmonization of heliostat characterization and beam measurement methodologies (EU Solaris project).
- The improvement of real time measurement, monitoring and control variables for power tower plants, including high-irradiance diagnostics and hybrid measurement platforms (LEIA and HELIOSUN projects).
- The integration of solar tower technology with advanced energy storage and hybrid concepts, including compressed air energy storage and desalination (ASTERIx-CAESar project).
- The provision of technical support and experimental validation services to industrial stakeholders to facilitate development and deployment (ODQA, TEWER, DLR, BCB, CSP Services).

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.
- Analyse 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.
- THermal Inertial CAVity receiver – THICAV (industrial contract with TEWER).

- Air-based CSP system demonstrator – ODQA (industrial collaboration at PSA).
- Drone-based heliostat soiling measurement activities – DLR / CSP Services (LEIA-related contract).

4 Thermal Energy Storage Unit

Introduction

During 2025, 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:

- Optimization and reliability enhancement of current commercial systems. Large Installations and power to heat (P2H-Carnot batteries) technologies.
- Storage prototype testing: both sensible and latent, under real solar operating conditions.
- Modelling and integration of thermal storage systems
- 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). In addition, the Thermal Energy Storage unit is highly compromised with industry as can be proven by its participation, amongst others, in international working groups for standards at IEC/TC 117/PT 62862-2-3 ED1 "Solar thermal electric plants". In February 2025, the Unit launched a new project entitled "Protocol for testing sensible and latent thermal energy storage prototypes".

List of funded projects the unit has been involved in

- Red española de almacenamiento de energía térmica. RedTES.
- 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
- Energía solar de concentración para los objetivos net-zero en procesos industriales y transporte, ACES4NET0-CM
- Green Mediterranean through Solar Driven Decarbonization of Industries, GREENOLIVE
- Innovative Strategies for Sustainable and Smart Polygeneration Systems: a Focus on Tailored TES systems, SUSTAIN3
- Thermo-mechanical properties review and lifetime prediction of molten salt storage tanks for central receiver CSP plants, TESTANK


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 2025, we have worked on the development and testing of selective and non-selective absorber coatings and anti-soiling coatings 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, PRINCESS and SUNFLOWER projects), and standardization of the methodology to measure optical properties of components for CST technologies (reflectors, absorbers, receiver glasses, 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 was developed with a view to their future application in high temperature solar thermal plants. A third PhD thesis project is focused on developing anti-soiling 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 durability of the next generation of solar reflectors, based on environmentally friendly materials.

List of projects the unit has been involved in

- Impulso a tecnología de producción H2 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
- TriPly peRiodic mINimal SurfaCEs (TPMS) for Solar plantS, PRINCESS

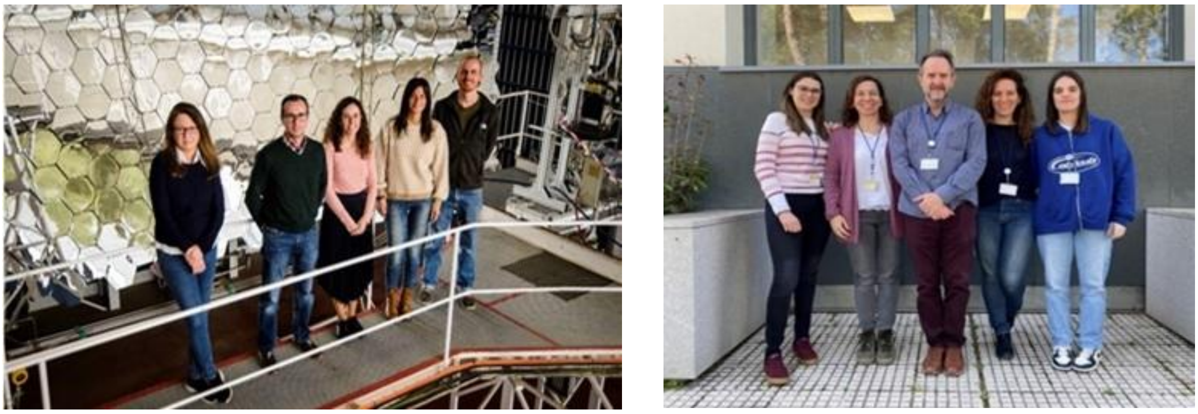

Figure 8. Unit staff at PSA (left) and CIEMAT Headquarters in Madrid (right).

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 and 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 2025, 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.

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 special branch is to use thermochemical processes on the Moon to produce vital resources (such as oxygen) 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).

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).

Figure 9. Unit staff at PSA.

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.
- Application of solar thermal energy to small capacity distillation processes, with special emphasis on membrane distillation (MD).
- Evaluation of technologies to reduce water demand in solar thermoelectric plants.
- Integration of desalination technologies in concentrated solar power and photovoltaic plants (CSP+D, PV+D, CSP+PV+D).
- Evaluation of innovative technologies for cooling on solar thermal plants for electricity production and inland thermal desalination systems.
- 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.
- Development of integrated cogeneration systems for renewable hydrogen production through renewable energy and seawater desalination.

During 2025, 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 water and electricity cogeneration schemes, we contributed to the development of simulation tools to evaluate novel integrations of thermal desalination systems in point-focus CST plants with Brayton cycle. Also, we started to work on an innovative integration, such as the use of compressed air from a CAES (Compressed Air Energy Storage) system to drive Reverse Osmosis units. Efforts also continued focused 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 optimization strategy was successfully tested at the pilot plant and annual simulations have been performed considering a commercial plant. 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 development of integrated cogeneration systems that couple MD with renewable hydrogen production to address both energy consumption and high-quality water needs. In the field of brine concentration using MD, preliminary works have been carried out to optimize the operation in a demonstration-scale membrane distillation plant.

List of projects the unit has been involved in

- European Twinning for research in Solar energy to (2) water (H2O) 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
- Integración de sistemas de desalación en plantas termosolares de torre central y reutilización de salmuera para producción de macroalgas (SOLDESALBIO).
- Integración de la destilación por membranas en la producción de hidrógeno verde para mejorar su sostenibilidad (HYDROMEM)
- Red de Investigación en Ciencia y Tecnología de Membranas para el Tratamiento de Aguas (MEMBRANET).
- Destilación solar por membranas para la valorización de salmueras residuales (MEMBRINE)
- Green valorisation of CO2 and nitrogen compounds for making fertilizers (CONFETI).
- SOLAR-Driven GREEN Ammonia Production from Agricultural Wastewater (Sun4Green).

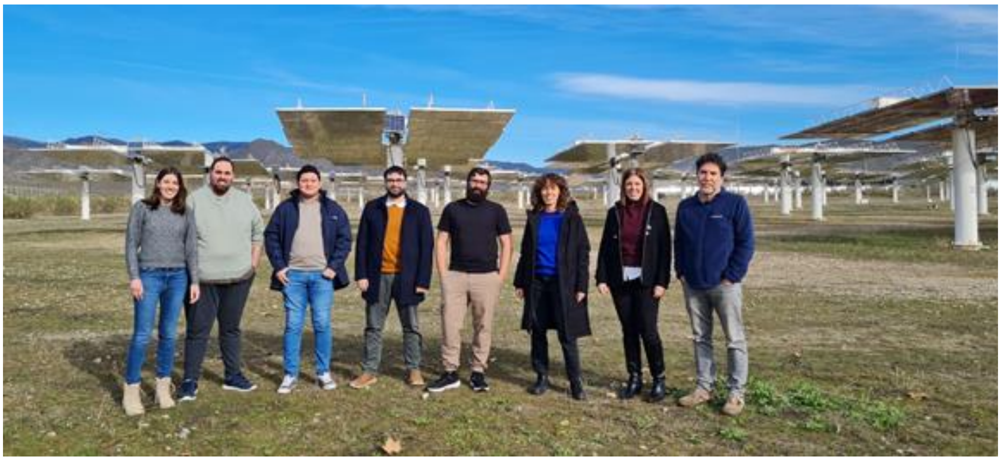

Figure 10. Solar Thermal Applications Unit staff in 2025.

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, AQUACARE and MODITRAGUA projects and IN2AQUAS Marie 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

- 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
- 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 valorisation 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 (H2O) production and treatment technologies, Sol2H2O.
- Identificación, cuantificación y eliminación de contaminantes emergentes en cuencas hidrográficas, AQUACARE.

Figure 11. Unit staff at PSA

9 Projects

Bringing EU-SOLARIS ERIC to its Zenith (SOLARIZE)

Participants: EU-SOLARIS (Coordinator), CIEMAT, CNRS, DLR, Cyprus Institute, LNEG, University of Evora, ENEA, CERTH, CRES, METU, ODTÜ-GÜNAM.

Contacts: [Patricia Palenzuela Ardila.]

Funding agency: European Commission (HORIZON-INFRA-2023-DEV-01).

Background: Concentrated Solar Thermal (CST) technology uses tracking mirrors to focus solar radiation and heat fluids to very high temperatures. Its main application is electricity generation (CSP), but it also supports industrial processes, hydrogen production, and desalination. Its key advantage is low-cost thermal storage. Europe leads CST research through EU-SOLARIS ERIC.

Objectives: The SOLARIZE project aims to strengthen the long-term sustainability of EU-SOLARIS ERIC by expanding membership, involving R&D institutes and national funding bodies, building a strong scientific community, training new researchers, reinforcing international cooperation and science diplomacy, and improving the managerial skills of ERIC staff across its research infrastructure network in Europe.

Achievements in 2025: In 2025, CIEMAT organised the second Doctoral Colloquium under the EU-SOLARIS framework and the first Summer School, which took place in Almería. The Doctoral Colloquium included talks by students and a technical visit to PSA (Figure 12). The Summer School was focused “Sustainable Water Management in CST Plants and included lectures by experts on the subject. In addition, the EU-SOLARIS awards were presented during these events in the categories of “Doctoral thesis” and “Outstanding contribution to the improvement of CST research infrastructures’ capabilities and services”. Likewise, a CIEMAT student has undertaken international mobility at the University of Evora and a course on science communication and dissemination was organised together with the Descubre Foundation. Finally, information has begun to be collected on water consumption in cleaning and cooling by some of the project partners' Research Infrastructures.

Figure 12. Right: Group of visitors at PSA. Left: Student working on an installation.

Support to the Activities of the Concentrated Solar Thermal Technology Area of the SET-PLAN (CST4ALL)

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

Contact: Ricardo Sánchez Moreno.

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 2025: CIEMAT-PSA activities in 2025 were primarily focused on Work Package (WP) 1, providing comprehensive support to the Chair of the CST Implementation Working Group (IWG). This support encompassed interactions and contributions related to European Commission and Member State initiatives influencing Concentrated Solar Thermal (CST) technologies, as well as ensuring that CST IWG strategies appropriately reflected the evolving European heat and power transition landscape. Among the most significant achievements and contributions in 2025, the following deserve particular mention:

- Strong involvement in negotiations aimed at integrating low-temperature solar heat technologies and applications into the CST IWG. This process led to the establishment of a new IWG fully dedicated to Solar Heat–the Concentrated Solar Thermal Technologies Implementation Working Group (CSTT IWG). The corresponding implementation plan was formally approved by the SET Plan Secretariat in October 2025.
- Effective support to the IWG Chairs during the 2025 SET Plan Progress reporting exercises. Close interaction with research and academic stakeholders, primarily through the EERA Joint Programme on CSP (coordinated by Ricardo Sanchez), was instrumental in delivering an accurate and comprehensive overview of implementation plan progress and related activities.
- Contributions incorporating inputs from research and innovation stakeholders to the Clean Energy Transition Partnership (CETP) calls and Horizon Europe (HE) programmes.

In addition to WP1 activities, CIEMAT organized an online workshop on 24 March 2025 entitled "Future Energy Mix with 100 % Decarbonisation Level". The workshop attracted more than 150 unique participants from research, industry, and governmental organizations. Across two dedicated sessions, it addressed the main challenges and opportunities associated with key renewable energy technologies in achieving full decarbonisation, with particular emphasis on the role and potential of CST technologies in this transition. The press release for this workshop is available at internet.

Further information on project activities is available on the project website.

Research Infrastructure Services for Renewable Energy (RISEnergy)

Participants: KIT, AIT, CEA, CIEMAT, CNR, DERlab, DTU, ECCSEL, EERA, EnBW, ENEA, EPL, EU-SOLARIS, FZJ, IMEC, TNO, UCC.

Contact: Ricardo Sánchez Moreno.

Funding agency: European Commission (HORIZON-INFRA-2023-SERV-01-01).

Background: The European Green Deal aims to transform the EU into a modern, resource-efficient and competitive economy with zero net greenhouse gas emissions by 2050. To achieve more efficient, competitive and cost-effective energy systems and devices, RISEnergy fosters a European ecosystem of industry, research organizations and funding agencies aimed at developing novel energy technologies and concepts. RISEnergy brings together a consortium of 69 beneficiaries from 23 countries: ERIC institutions, technology institutes, universities and industrial partners, to jointly improve the economic performance of technologies, while members of the European Energy Research Alliance (EERA) are establishing the core European ecosystem.

Objectives: The project aims to increase energy efficiency, reduce energy technology costs, and promote the use of renewables. RISEnergy will facilitate efficient transnational access to facilities supporting renewable energy technologies and systems, offering guidance to research infrastructure providers, users, and policymakers on issues such as Life Cycle Assessment (LCA), Information and Communication Technology (ICT) development, and networking. It will focus on the eight most relevant fields of PV, CSP/STE, hydrogen, biofuels, offshore wind, ocean energy, integrated grids, and energy storage.

Achievements in 2025: CIEMAT-PSA's activities in 2025 have focused primarily on WP2, "Transnational and Virtual Access to World-Class Research Infrastructures", where we have contributed to the preparation of deliverable D2.4, "Access Policy: Agreement between coordinator, infrastructure owner and user", and to the evaluation process for proposals submitted under the two access calls launched in 2025.

Further information on project activities is available on the project website.

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.

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 2025: 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 started. As soon as this is complete, the prototype will be installed in the PSA HTF loop to conduct the experimental campaign.

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.

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 2025: During this year, CIEMAT has collaborated in the publication of the draft of the guideline and the first draft (committee 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.

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 1,200 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 2025: During this year, CIEMAT has collaborated in the experimental tests for ATS ball joints (10,000 cycles) at 370-393 °C and 40 bar.

Solar Process Heat: Extended Regional Exploration (SPHERE)

Participants: Fraunhofer ISE, CEA, CIEMAT, NREL, ENEA, KTH, IEECAS.

Contacts: Mario Biencinto.

Funding agencies: SolarPACES.

Background: CST systems delivering process heat at medium temperatures (120-400 °C) can already be cost-competitive with fossil-fired systems, with payback periods of 3-10 years, depending on incentives and location.

Objectives: The project will establish a validated methodology for cross-regional techno-economic comparisons of solar process heat generalised based on process parameters (temperatures (in- and outlet), demand curves, capacity factors). It will also provide clear, data-driven references for industrial users, governments, communities and financing bodies to accelerate the adoption of solar thermal systems in the participating regions.

Achievements in 2025: The project just started its first steps in 2025. CIEMAT has started with the selection of the Spanish locations for the study.

More Efficient Heliostat Fields for Solar Tower Plants (HELIOSUN)

Participants: CIEMAT, University of Islas Baleares.

Contacts: Jesús Ballestrín.
Jesús Fernández-Reche.
Loreto Valenzuela.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento) .

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 2025: 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 of CESA I facility 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, the solar extinction model validated at the PSA using a typical solar extinction year has been used on generating a national solar extinction map.

A ray-tracing simulation software, based on OTSun, is 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.

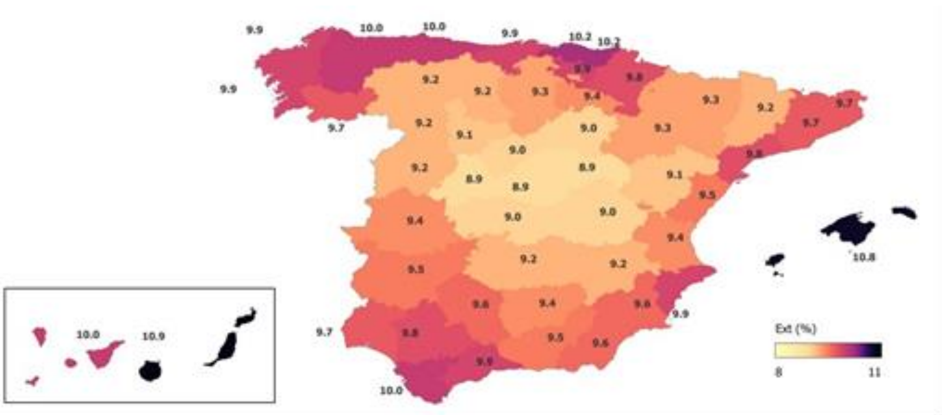

Figure 13. Average annual percentage of solar extinction for 1 km of distance

Solar field measurements to increase performance (LEIA)

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

Contact: Daniel Sánchez-Señorán.
Antonio Ávila Marín.
Rafael Monterreal
Jesús Ballestrín.

Funding agency: European Commission (SP ERA-Net COFUND). Agencia Estatal de Investigación (Proyectos I+D+I "Programación Conjunta Internacional").

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 labour 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 2025: CIEMAT-PSA successfully completed the methodologies for the online heliostat field characterization system and high irradiance hybrid measurements. As part of the PSA test campaign, the evaluation of the heliostat's optical performance evolution was completed for two heliostats of the CESA-1 solar field at different times of the day using Computational Optimization Algorithms (COA). After obtaining confident results with the COA in the previous phase, the evaluation was extended to those two same heliostats for the winter and spring seasons to complete the yearly optical performance evolution. 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, and tested resulting in promising outcomes. Additionally, within the Cerro Dominador - CIEMAT test campaign, CIEMAT received an updated set of images with 41 images from Cerro Dominador, which are now being processed using new image processing tools and the developed COA methodology.

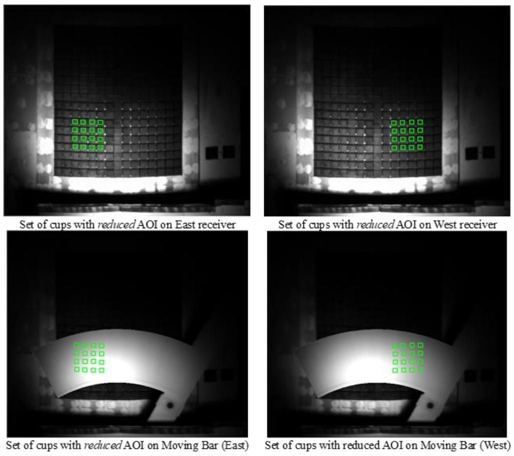

Figure 14. Two high-irradiance measurement systems being tested under high irradiance conditions.

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

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

Contact: Daniel Sánchez-Señorán.
Antonio Ávila Marín.
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 centres 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 2025: The project was officially funded in December 2024 and launched in January 2025. Since then, a manuscript has been published in the SPIE conference, and a poster was presented at the SolarPaces conference. The work has been divided in 3 major clusters, in which CIEMAT-PSA is leading the Cluster 1 addressing the minimal hardware & system design necessary for BCS systems. CIEMAT-PSA also participates in the other two clusters focused on “Image Processing & Analysis” and “Validation, Benchmarking & Simulation”. An open dataset is being created by the consortium for the companies interested in validating their methodologies or BCS systems. Also, a good practice guideline is being developed to be published.

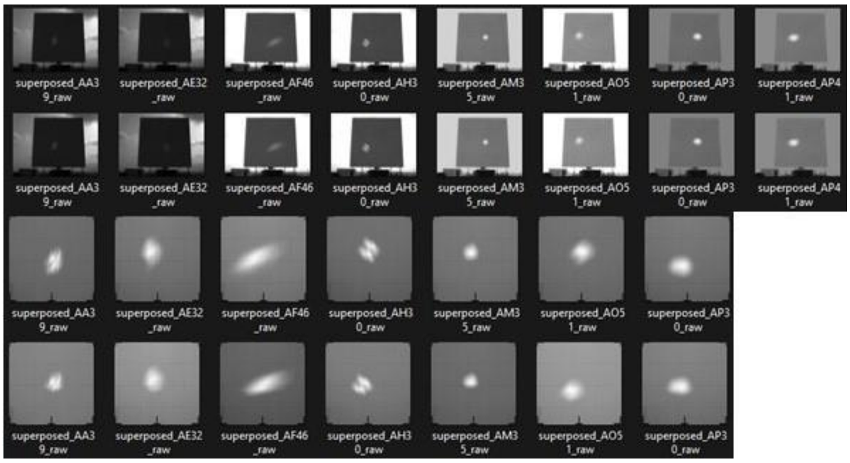

Figure 15. Some examples of the open dataset from the CENER and DLR R&D institutions.

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

Participants: CENER (coordinator), CIEMAT, University of Sevilla, Bluebox, Doosan Skoda Power Sro, University of 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 Ávila Marín.
Raúl Enrique Orts.
Patricia Palenzuela Ardila

Funding agency: European Commission (HORIZON-CL5-2022-D3-03-01).

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 2025: During 2025, CIEMAT contributed to WP2 through the optical and thermal evaluation of nine different volumetric absorbers and three outlet cup orifice configurations, complemented by full receiver CFD simulations considering updated cup sizes. These activities supported the definition of the reference outlet cup geometry, which was finally set to an opening of 250 × 180 mm. Based on the experimental campaign, a ranking of the absorber configurations was performed to identify the most promising options, providing the basis for the selection of the foam material to be subsequently tested in a 2 × 2 receiver array at IMDEA Energía and, from there, to define the final absorber configuration for the prototype. In parallel, within WP6, CIEMAT completed the installation and integration of the main components on the tower, including the turbine, heat exchanger, new piping connections and thermal insulation. Additionally, within WP1 and WP6, CIEMAT developed a physical-based model of the integrated CAES-desalination system, coupling the CAES unit, the air-liquid pressurization system and the reverse osmosis unit, and performed system-level simulations to assess performance over a representative range of operating conditions in terms of production, operating stability and energy efficiency.

triPly periodic mINimal surfaCEs for Solar plantS (PRINCESS)

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

Contact: Antonio Ávila Marín.
Ángel Morales.

Funding agency: European Commission (CET Partnership Joint Call). Agencia Estatal de Investigación. (Proyectos de Colaboración Internacional).

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 2025: During 2025, CIEMAT contributed to the design phase of the PRINCESS project through the development and assessment of a modular solar receiver concept based on triply periodic minimal surface (TPMS) structures as the heat sink medium. The work covered the complete design chain, from cell-scale topology optimization to module-scale receiver definition, supported by CFD modelling. Several TPMS topologies (Diamond, Gyroid and SplitP) were analysed at different porosity levels, applying thermo-hydraulic simulations under periodic boundary conditions and second-law-based performance indicators. Exergy efficiency was used as the main KPI for lattice selection, leading to the identification of the SplitP1 topology as the most suitable configuration for the targeted operating conditions. Based on these results, a full receiver module was designed for the PSA solar furnace, adopting a hexagonal geometry to match the focal spot and internal TPMS filling, and its performance was evaluated under representative CSP heat flux levels. The numerical results demonstrated robust thermo-hydraulic behaviour and confirmed the suitability of the selected TPMS configuration for high-temperature solar receiver applications, providing a solid basis for subsequent experimental validation and further design refinement.

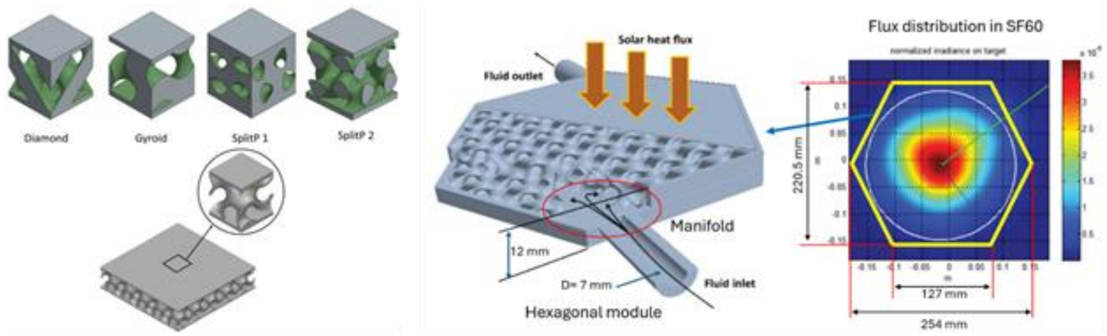

Figure 16. Left: 3D structural configuration of TPMS lattices developed in the cell-scale study: Right: Design of the PRINCESS module and its relation with the target heat flux available in SF60

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: Antonio Ávila Marín.

Funding agency: European Commission (HORIZON-CL5-2024-D3-01-10).

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 2025: During 2025, CIEMAT developed the preliminary concept of the volumetric solar receiver and contributed to the definition of the project’s digitalization framework. In parallel, CIEMAT received a total of 40 volumetric absorber samples covering six different topologies and five pore configurations, including constant pore sizes (large, medium and small) and two graded porosity designs with front-to-back pore size increases of 1.5- and 2-times. Experimental testing of these absorbers started during the last quarter of 2025 and is expected to be completed during the first quarter of 2026. In parallel, CFD simulations of the received absorbers were initiated, focusing on pressure drop and heat transfer coefficient assessment to support the interpretation of experimental results and the refinement of the receiver design.

Figure 17. Sample set of the Voronoi topology developed for the COOPERANT project

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 2025: 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 Inertial CAVity receiver (THICAV)

Participants: TEWER (coordinador), CRNS, University West, Procada.

Subcontract: CIEMAT, TEWER.

Contact: Antonio Ávila Marín.
Raúl Enrique Orts.

Funding agency: CDTI (Eurostars 3 program).

Background: Tubular solar receivers operating under high solar flux are prone to the formation of local hot spots, which can limit operational flexibility, accelerate material degradation and reduce component lifetime. The THICAV concept addresses this challenge through the introduction of a thermal inertia layer designed to smooth temperature gradients on the receiver surface and enhance thermal stability under transient operating conditions

Objectives: The objective of the project is the development and experimental validation of the THICAV receiver concept, focusing on the mitigation of hot spots on tubular receivers by means of an integrated thermal inertia layer. CIEMAT participates through the execution of experimental tests at PSA and the evaluation of thermal and operational data obtained from a receiver panel prototype.

Achievements in 2025: During 2025, experimental testing of the THICAV receiver prototype was carried out at the PSA. CIEMAT supported the test campaign by operating the experimental setup and analysing the data obtained from the receiver panel under representative operating conditions. The results provided valuable insight into the thermal behaviour of the concept and its potential to reduce temperature non-uniformities on tubular solar receivers, supporting further development and optimization activities.

Figure 18. THICAV receiver prototype at the CESA-1 tower: (left) detailed view of the receiver panel installed on the tower; (right) general view of the CESA-1 tower during the test campaign.

Odqa System Demonstrator – Air-based CST System

Participants: ODQA Renewable Energy Technologies (coordinator), CIEMAT.

Contact: Raúl Enrique Orts.
Antonio Ávila Marín.

Background: Heavy industries — mining, metals, cement, ceramics — are among the hardest sectors to decarbonize. They depend on high-temperature heat, typically generated by burning gas or heavy fuel oil, and have had few credible alternatives. ODQA Renewable Energy Technologies, a spinout from the Oxford University Thermofluids Institute, is addressing this directly. Its approach replaces fossil-fuel combustion with concentrated solar energy, using a patented air-based receiver to heat air to over 800 °C — effectively a carbon-free synthetic flame that can be injected directly into industrial processes.

Objectives: The objective of the demonstrator programme at the PSA, was to install, integrate and experimentally validate this end-to-end system under real solar conditions. The scope encompasses the full process chain: solar heat generation via the air-based receiver, thermal storage and delivery of high-temperature air to an industrial end-use application. CIEMAT supported the programme by providing access to the CESA-1 facility, participating in the installation and commissioning, and conducting experimental testing and performance evaluation.

Achievements in 2025: 2025 was a significant milestone for ODQA's air-based CST. The integrated system was successfully installed and commissioned at CESA-1, and an extensive experimental campaign was completed under representative solar conditions. The campaign achieved a verified air output temperature of 800 °C, validating ODQA's receiver design and confirming suitability for high-temperature industrial applications. Critically, the demonstrator was operated end-to-end, with the thermal output used to dry real customer materials, proving the concept not just as an engineering system but as a viable industrial process. The results provide a robust operational dataset covering system behaviour, thermal stability, and integration across the receiver, storage, and process equipment, directly informing ODQA's commercial scale-up activities.

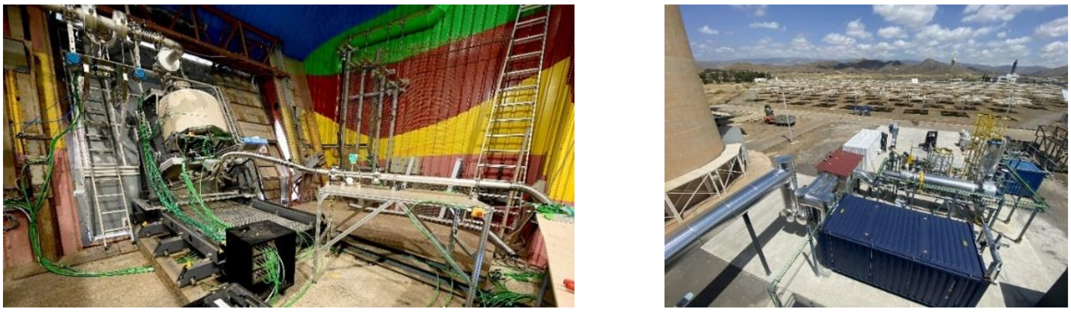

Figure 19. Right: Odqa's air-based receiver inside the CESA-1 tower. Left: Odqa's high temperature CST industrial demonstration system

DLR Soiling Measurement Activities

Participants: DLR, CSP Services GmbH, CIEMAT.

Contact: Raúl Enrique Orts.
Antonio Ávila Marín.

Background: Soiling of heliostat mirrors is a key factor affecting the optical performance and operational costs of central receiver CSP plants. Reliable, spatially resolved and cost-effective methods for quantifying soiling losses across large solar fields are essential to optimize cleaning strategies and reduce O&M costs. DLR is developing advanced image-based methodologies to assess heliostat soiling under real operating conditions.

Objectives: The objective of this collaboration is to support the experimental validation of drone-based soiling measurement techniques by providing access to PSA facilities and operational support during dedicated measurement campaigns. CIEMAT contributes by enabling access to the Radiometric Laboratory, the solar furnace and the CESA-1 heliostat field, and by operating the heliostat field under controlled conditions to facilitate the acquisition of high-quality experimental data.

Achievements in 2025: During 2025, several experimental campaigns were carried out at PSA in collaboration with DLR and CSP Services, including drone-based measurements over the CESA-1 heliostat field and complementary activities in the Radiometric Laboratory and the solar furnace. CIEMAT supported these campaigns by operating the heliostat field with predefined configurations and providing relevant operational data. The experimental work enabled the generation of spatially resolved soiling data under representative conditions, contributing to the validation and further development of image-based soiling assessment methodologies for CSP solar fields.

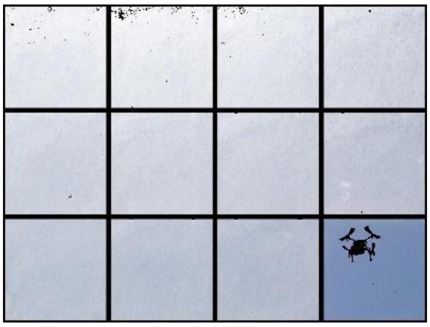

Figure 20. Drone image of a heliostat at CIEMAT's PSA with one cleaned facet

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.

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 2025: 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 2025, CIEMAT participated in the internal workshop, hosted by UC3M.

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 fibre optic thermometry.

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

Achievements in 2025: Throughout his year various components have been acquired and the fibre-optic sensors were installed in the Hot Salt Tank of the MOSA facility. Test have been performed with salt at different temperature ranges. The ALTAYR facility has been commissioned and prepared for the sensors installation and testing in 2026.

Some of the results were presented as two oral contributions: One in the 31st International Symposium on Concentrated Solar Power and Chemical Energy Systems. Almería, Spain. 23-26 September, and another in the Tempmeko SHM 2025, 20-24 October 2025 REIMS, France.

Smart Thermal Storage for Decarbonisation of Energy Sector (STES4D)

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

Contact: Rocío Bayón.

Funding agency: Agencia Estatal de Investigación (Proyectos de Transición Ecológica y Transición Digital).

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 aimed 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 2025: During the last year of this project, CIEMAT continued the studies of thermal degradation for mid-temperature PCMs based on dicarboxylic fatty acids (melting points between 130 °C and 180 °. In collaboration with one of the project partners (UPV-EHU), the thermal degradation of succinic acid (T_{melt}= 186 °C, Δh_{melt}=328 kJ/kg) was studied in detail, finding that immediately after melting it undergoes a dehydration reaction that leads to the formation of the corresponding anhydride, resulting in a drastic decrease of both T_{melt} and Δh_{melt}. Some of these results were presented as an oral contribution at the 14CNIT conference held in Zaragoza (4-6 June 2025).

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: European Commission (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 was 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 2025: In the last year of the project, the Thermal Energy Storage Unit actively participated, together with the other project partners, in the finalization of the compromised documents: Technology Roadmap for Hybridization of Energy Storage, the Strategic Research and Innovation Agenda (SRIA) on Hybridization of Energy Storage and the chapter entitled: “Repurposing Coal-Fired Power Plants Integrating the Use of Second-Life Batteries, Flywheels, and High Temperature Molten Salt Storage” in book named “Hybrid Energy Storage. Case Studies for the Energy Transition” R. Scipioni et al. Eds. Springer Nature, with. Furthermore, the Unit members elaborated two lectures for the “Online Courses for Workforce from Academia and Industry” STORIES project platform entitled: Sensible Thermal Energy Storage by Esther Rojas and Latent Heat Storage: Towards Validation of PCM by Rocío Bayón. Finally, one of the Unit members (Esther Rojas) continued with the mentoring activity to a young researcher from the University of Saarland (Germany).

Website where Roadmap and SRIA can be downloaded from internet.

Green Mediterranean through Solar Driven Decarbonization of Industries (GREENOLIVE)

Participants: eCAMPUS university (coordinator), Universitat de Barcelona, Cukurova Üniversitesi, CIEMAT, ASCHEM Petrokimya, R2M Solutions SAS, Al Quds University, AAsTMT,

Contact: Margarita Rodríguez.

Funding agency: European Commission and participating countries (Interreg Next-Med).

Background: GREENOLIVE is committed to build a novel solar energy pilot partially addressing process heat of the plastic industry, which must undergo a deep energy transformation. The pilot plant at ASCHEM, covering 12-15 % of the process heat demand for polymer production, will reduce natural gas consumption by about 18-22 %. The team will develop a training kit for capacity building to enhance solar energy systems knowledge among education, end users, and technology professionals.

Objectives: The aim of the project is to develop, build and demonstrate an innovative solar energy system to partially meet the process heat energy needs of the plastics industry. The solar system will use a 1-MW peak electricity production photovoltaic plant to heat oil to 300 °C using a system based on microwaves and electric resistors. When there is excess solar energy, a thermocline-based packed bed thermal storage system will be used, sized to store the heat that will be used when there is no sun. Findings will be compiled into a white paper for a greener Mediterranean.

Achievements in 2025: The project began in September 2025. During the first project months the KoM took place in Rome, and several decisions were adopted. The thermal oil proposed by CIEMAT was selected as thermal oil for the project.

Following the KoM, on November 21st, the Workshop “Power-to-X technologies for the decarbonization of the industrial sector” took place at eCampus University in Rome where a talk was given (Margarita Rodríguez García) on “Power to Heat Systems”.

The project was presented as a poster contribution in the 31st International Symposium on Concentrated Solar Power and Chemical Energy Systems. Almería, Spain. 23-26 September.

Innovative Strategies for Sustainable and Smart Polygeneration Systems: a Focus on Tailored TES systems (SUSTAIN3)

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

Contact: Rocío Bayón.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento).

Background: Sustain3 strives to advance the evolution of intelligent, sustainable, and economically viable polygeneration systems, positioning them as transformative solutions within energy supply and management systems for both industrial settings and energy districts/communities. Recognizing the pivotal role of economic and environmental considerations, as well as physical limitations, the project addresses three primary challenges that will pave the way for a broader implementation of these systems, thereby contributing to the decarbonization of society.

Objectives: The Sustain3 project's main objective is to advance the development of smart, sustainable, and economically viable polygeneration systems. To achieve this, the project is structured around three fundamental pillars: Comprehensive Environmental Approach: Integrating Life Cycle Assessment (LCA) criteria; Predictive Control and Artificial Intelligence: Utilizing optimization models and machine learning (AI) techniques; and Thermal Energy Storage (TES). Within the latter, the project focuses on Latent Heat Storage (LHTES) using phase-change materials (PCMs), prioritizing materials with low environmental impact, such as by-products or waste materials, ensuring their economic feasibility and sustainability within the LCA framework. CIEMAT participates in the project as part of the research team of UPF-EHU by developing activities within the line of thermal energy storage and focusing on the study of the degradation kinetics of PCMs based on compounds with low environmental impact (sugar alcohols, carboxylic acids, paraffins, etc.) as latent heat storage media for the applications defined within the project.

Achievements in 2025: Thermal degradation of succinic acid (T_{melt}= 186 °C, Δh_{melt}=328 kJ/kg) was studied using different strategies, such as isothermal furnace tests under stress conditions and thermal analysis with DSC and TGA techniques. In collaboration with EHU, it was found that immediately after melting succinic acid undergoes a dehydration reaction that leads to the formation of the corresponding anhydride, resulting in a drastic decrease of both T_{melt} and Δh_{melt} values. Some of these results were presented as an oral contribution at the 14CNIT conference held in Zaragoza (4-6 June 2025).

Thermo-mechanical properties review and lifetime prediction of molten salt storage tanks for central receiver CSP plants (TESTANK)

Participants: IEECAS, (coordinator); NEPDI, Cosin, NREL, CIEMAT. CSP Energies, DLR.

Contact: Esther Rojas.

Funding agency: SolarPACES.

Background: In sunny countries, thermal storage systems with solar salt and a two-tank configuration are currently the most cost-effective long-term and long-duration energy storage systems. The unique thermo-fluid conditions to which the tanks are exposed in these systems are not currently included in tank manufacturing standards. Some tower CSP plants have reported failures, primarily in the tank storing solar salt at nearly 600 °C (the so-called 'hot tank'). The scientific community and companies are addressing this absence of standards based on prior experience by sharing experiences and simulation models, among other measures. This project forms part of the strategy to address the issue in hot tanks for tower CSP plants.

Objectives: The aim of the project is to study the durability of storage tanks in solar thermal power plants in terms of their corrosion in molten salts and their thermomechanical properties. The task of the Thermal Energy Storage Unit, in close collaboration with the Technology Department, consists of advising on lifetime prediction modelling.

Achievements in 2025: A series of telecommunications meetings have been scheduled to establish the course of action required to achieve the anticipated outcomes. CIEMAT has participated in all of these meetings and has reviewed several of the reports that were prepared by the consortium.

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

Participants: CIEMAT.

Contacts: Aránzazu Fernández García.
Gema San Vicente Domingo.

Funding agency: Agencia Estatal de Investigación (Proyectos Generación del Conocimiento).

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 2025: During this third year, all activities have made significant progress. Regarding the anti-soiling coatings for second-surface glass reflectors, a 15-month outdoor exposure campaign at PSA has been completed. The analysis of the results indicates a clear benefit from applying the coating, especially when higher soiling levels are present. In the field of solar reflectors, the international outdoor exposure campaign (Spain, Turkey, Morocco, and France) has continued in order to assess UV-induced degradation and to study de solarization phenomenon. Portable systems for detecting corrosion points and other operational defects, based on digital camera and microscope image analysis, were validated. A custom automatic analysis program was developed for that during a Master thesis. A self-aligned heliostat prototype was also engineered and optimized to reduce labour-intensive operation and maintenance (O&M) efforts. For solar receivers, selective absorbing coatings stable in air at 600 °C developed previously in this project with excellent optical properties

(95.7 % solar absorptance and 10 % thermal emittance at 500 °C) were tested in a solar oven showing good thermal stability at high temperature. Non-selective coatings were also formulated for metallic wire meshes used in volumetric receivers with good thermal durability. Several wire mesh configurations with and without absorber coatings were tested at high temperatures under high solar fluxes to determine its ability to withstand high operational temperatures. The tool for heliostat field design (HEFESTO) was improved with new features for the analysis of aiming strategies, receiver flux mapping and additional receiver geometries (Figure 21). Several soiling models for parabolic-trough solar thermal power plants, including simplified approaches, a custom model based on limited meteorological inputs (AOD and precipitation), readily available from satellite data, and the effect of soiling on the receiver glass envelope, were compared and assessed in terms of accuracy of electricity production forecasting.

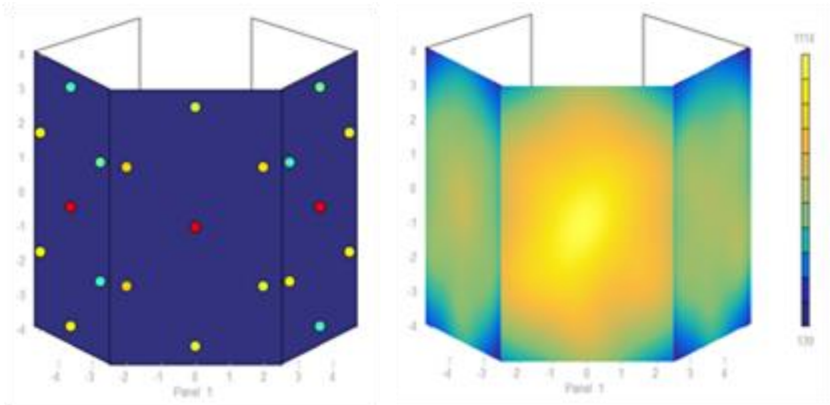

Figure 21. Example of aiming points (left) and flux mapping (right) for a multi-panel receiver in HEFESTO.

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-Energía.

Contacts: Johannes Wette.

Funding agency: SolarPACES.

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 2025: This project started in April 2023 and is being performed by CIEMAT in cooperation with DLR in the OPAC facility. The project is intended to finalize by April 2026 with the completion of the new guideline version. During 2025, the tasks of the different work packages were finished leaving the respective reports to be finished for 2026. Interviews with industry stakeholders were evaluated and a report with recommendations and open questions prepared. The main focus during this period was on the development of correlations to improve the significance of in-field reflectometer measurements to laboratory reference measurements. A set of correlation parameters was determined for all commercial reflectometers to translate their results to the most significant reflectance of interest for a plant under PSA conditions. These results were published in an international journal. The reflectometers included in this study and an exemplary set of correlations for the devices are displayed in Figure 22. The remaining work packages are focused on the status of alternative soiling measurement techniques, their evaluation and the development of a new setup for advanced laboratory reflectance measurements. The results of all work packages will serve as the input for the new updated guideline version.

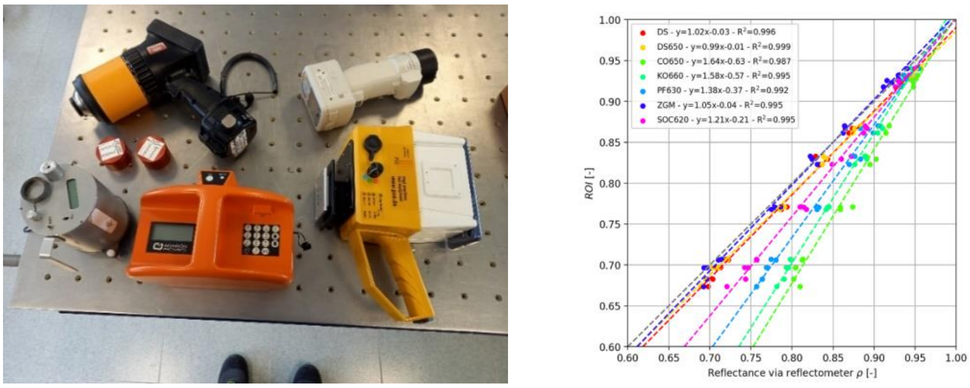

Figure 22. Left: portable reflectometers included in the study of the transfer functions. Right: example correlations between reflectometers and reflectance of interest (ROI).

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: German Federal 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 2025: During this third year of the project, the third batch of samples with optimized lead-free MIPA paints applied at AGC using the filmography and at MIPA using a spray process, were tested under 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. The test revealed delamination, which was observed exclusively at the cut edges of the MIPA-optimized coatings applied by AGC, despite good spot corrosion resistance, an aspect not detected in the samples applied at MIPA and tested in both MIPA and OPAC laboratories. However, these samples did not meet the criteria established in the draft standard IEC TC 117/PT 62862-3-6 for the condensation and damp-heat tests. Additionally, reflector samples exposed at PSA and Almería were measured after 36 months of outdoor exposure. In this most recent assessment, evidence of degradation was detected in the lead-free samples placed in Almería, attributable to the more severe environmental stressors associated with the site's coastal proximity compared with the conditions at PSA.

Figure 23. Photograph of leaded-containing sample (left) and lead-free sample (middle) after 36 months of exposure in Almería.

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 2025: The second batch of new solar reflectors, received at the beginning of 2025, has been tested following the draft standard IEC TC 117/PT 62862-3-6. Particularly, the UV and CASS tests have been carried on the samples. In this second batch, an improvement of the protective coating paints used in first batch was made. Mirrors with Dual-Sol technology and a palladium bonding layer show approximately 0.3 % better reflection properties than the state-of-the-art. They also demonstrate excellent durability that is significantly superior to the state-of-the-art. This was proven in CASS tests lasting up to 960 hours and UV tests lasting up to 4000 hours. Within this reporting period, the CASS test up to 960 hours and the UV test up to 3000 hours were repeated with samples from the second coating test under industrial conditions at the mirror manufacturer AGC. The results from the first industrial run were validated.

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

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

Contacts: Ricardo Sánchez Moreno.

Funding Agency: European Commission (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 2025: 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 1000 nm (Figure 24 left). The same behaviour is observed in the $\tau\lambda,h$ measured on the glass, where the increase in this case is 1 pp (Figure 24 right).

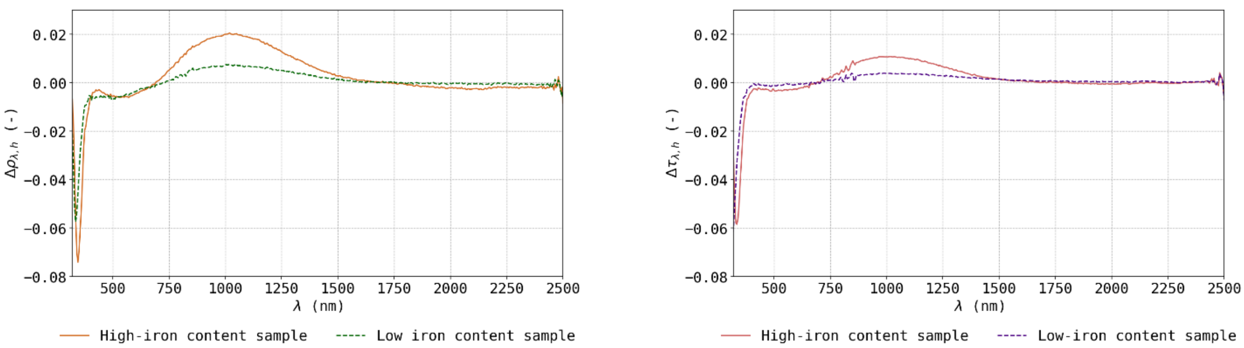

Figure 24. Performance of solar reflectors and their glasses after 12 months of outdoor exposure at PSA Left: Hemispherical reflectance difference spectra of the solar reflector samples. Right: Hemispherical transmittance difference spectra of the glass samples.

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 Martínez.
Antonio Ávila Marín.

Funding agency: European Commision (CET Partnership). Agencia Estatal de Investigación (Programación Conjunta Internacional).

Background: SUNFLOWER is targeting the development of optimized absorbers for highly efficient open-volumetric air receiver (OVAR) in concentrated solar power (CSP) plants. By combining the expertise of solar thermal receiver design with raw material processing, absorber material development, absorber fabrication and the numerical and experimental evaluation, the main objective of the project is to develop optimized absorber structures with high durability, high thermal efficiency, recyclability, and low environmental impact.

Objectives: The strategic development line of this project is the analysis and optimization of novel air-based hybrid CSP-CAES plants, focusing on the solar receiver, in particular on the 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 2025: During this year, CIEMAT-PSA actively contributed to simulations conducted on a metallic wire mesh design, where the effects of geometric properties (porosity, wire diameter) and operational parameters (flow velocity, solar flux) were analysed. A more complex receiver geometry was studied using a SiC foam with similar geometric characteristics (porosity, cell size, strut diameter). The development and production of the absorber structures based on this is ongoing.

The first compact test bodies (IFAM, IKTS) made of SiC and FeCrAl were produced. The stability of the materials and their optical properties was examined during 365 load cycles (simulation of an application period of one year) in the solar furnace SF40 at the project partner CIEMAT-PSA. Both materials show the formation of a passivating oxide layer, and, in the case of suitable pre-oxidation, also stable optical properties analysed in OPAC and Materlab.

The improvement of the reflective surfaces at the PSA-SF40 have been carried out in order to get necessary high solar energy fluxes and higher temperatures. New SiC and FeCrAl samples with improved recipes were supplied to CIEMAT. They have been optically characterised, and a second accelerated ageing test campaign has been started at the PSA-SF40 Solar Furnace.

Figure 25. Test bench for silicon carbide (SiC) accelerated ageing at CIEMAT-PSA's SF40 Solar Furnace, with improved reflective surfaces. (Left corner) Infrared image of SiC samples at 1,200 ºC

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

Participants: Panepistimio Dytikis Attikis - University of West Attica (coordinator), CIEMAT, DLR.

Contact: Inmaculada Cañadas Martínez.

Funding agency: European Commission (HORIZON-WIDERA-2023-ACCESS-02-02).

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.

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.

An exploratory project will be conducted by UNIWA and CIEMAT in the field of development of surface processing of metallic materials to be used in aggressive environments (e.g., wear, abrasion, erosion, high temperature), using concentrated solar energy.

Achievements in 2025: During this first year of the TWINSOLARSURF project, the consortium organised several coordination meetings and activities, including a summer school, training and mentoring stays, and joint research testing campaigns in the PSA solar furnace.

The first Joint Summer School, entitled 'Introduction to Concentrated Solar Thermal (CST) Technologies', was held at UNIWA in Egaleo, Greece, exceeding the participation target set as a KPI by almost 100 %.

Three long-stay visits (2 weeks) of young researchers from TribLab at PSA facilities were implemented, including the training with the operation of large-scale real facilities, specifically of the Solar Furnace SF60 at CIEMAT-PSA. Joint experimental campaigns were performed to produce hardened coatings at CIEMAT-PSA SF60, under controlled extreme thermal conditions using concentrated solar energy close to 2,000 °C. Additionally, two senior researchers from UNIWA's team have conducted short-stay visits (one week) at CIEMAT-PSA facilities.

UNIWA's research management and administration skills were enhanced by the first TWINSOLARSURF workshop on EU proposal opportunities, held on 4 June 2025 in UNIWA.

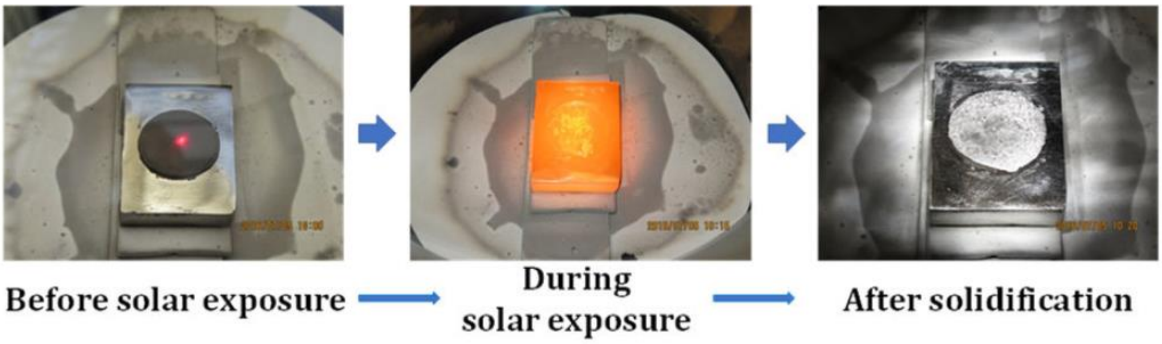

Figure 26. Solar treatment of a representative specimen placed on the insulating substrate; before, during, and after solar testing at CIEMAT-PSA's Solar furnace

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: European Commission (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 2025: During this second year of the project, all the equipment and test facilities needed to analyse the durability of the innovative absorber coatings were developed and set-up and the PSA. In particular, the muffle furnace for the isothermal test was provided with an alumina platform resistant to temperatures higher than those of the experiment, so that the samples do not touch the thermal resistors. This modification was performed to avoid an increase in the sample temperature with respect to the set point indicated in the muffle furnace control system. In addition, the cycling muffle furnace to perform the thermal shock tests was modified with a track for inserting and removing samples, controlling its speed and the temperature inside the muffle furnace. Finally, a test bench was developed to perform durability tests of the absorber samples under real high concentrated solar radiation conditions in the CIEMAT-PSA Solar Furnace SF60. This test bench was provided with a new flux homogenizer which significantly improved the temperature distribution of the 6 tubular samples to be tested at the same time, to monitor the possible differences in the degradation of several different absorber materials.

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 Martínez.

Funding agency: Agencia Estatal de Investigación (Proyectos de I+D+i).

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

Objectives: 1. Advance the knowledge in the hydrogen production process via solar thermochemical water splitting. 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 for further working. 5. Promote a long-lasting inter-institute collaboration.

Achievements in 2025: The HIDROFERR team has completed the selection of advanced ceramic materials to be used as catalysts for thermochemical H_2 generation in a solar furnace. The contribution of ITC-AICE, as experts in ceramic materials, has been crucial in this activity. Their role included proposing candidate materials, preparing the samples to be thermally cycled at PSA, and assisting in the evaluation of sample degradation after testing.

At the current stage of the project, work is focused on the manufacturing of the solar receiver and its ancillary systems, mainly related to input-output gas processing. Once the system is completed, solar characterization tests will begin in order to validate the performance of the receiver and the selected materials under real operating conditions.

The development of these processes is led by the 'Solar Production of Fuels and Commodities Unit', being closely collaborated on by personnel from the Solar Materials for CST Unit 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).

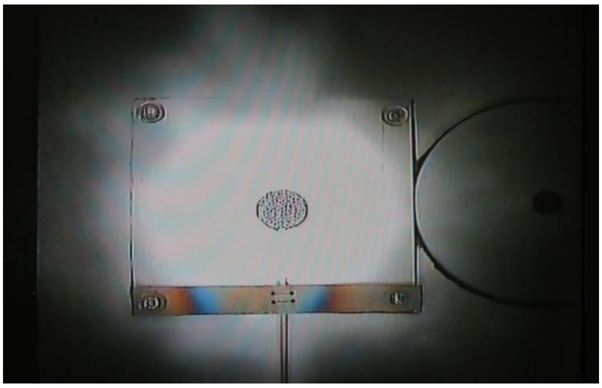

Figure 27. Hidroferr's Ceria volumetric receiver testing under highly concentrated solar energy flux

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

Participants: UPM, 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 prototype will be designed, developed, and validated as a modular and ultra-compact solution for dispatchable solar power generation with 10x less volume than current CSP technologies that efficiently store solar energy as heat for electricity conversion on demand.

Objectives: A prototype of the proposed technology integrating optics for beam down CST technology, high-temperature (>1,200 °C) latent heat storage, and thermophotovoltaic conversion will be demonstrated. Furthermore, SUNSON entails the development of smart digital tools for design, management and replicability purposes. It will also provide features for dissemination, exploitation, and communication actions.

Achievements in 2025: This year has been dedicated primarily to the fabrication of the two major components of the project, the beam-splitter and the so-called Sunson-Box.

The beam-splitter (Figure 28 left) consists of a mirror made of four facets located 800mm in front of the focus. The mirror will be installed at a 45° angle 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 ensure that all four foci receive the same amount of solar radiation. The concept consists of a rectangular design, with the two upper facets measuring 1.4m × 1.0m and the two lower facets 0.7 m × 1.0 m. The adjustment is 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 Sunson-Box (Figure 28 right) is the component that includes all four solar absorbers, the crucibles with the phase-change material for thermal storage, and the thermophotovoltaic cells for electricity generation.

Figure 28. Left: Beam Splitter mechanism. Right: Sunson-Box (open).

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).

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 2025: During 2025, the physical equation-based model of the innovative Combined Cooling System (CCS) was used to develop a data-driven model (based on Gaussian-Process Regression) obtaining a Mean Absolute Error below 0.97 °C for temperatures and 19.4 l/h for water consumption. This model was integrated within an optimization strategy to minimize the daily cost operation, while ensuring the stablished cooling demand. The optimization strategy (see Figure 29) was successfully tested at the pilot plant.

The CCS physical equation-based model was scaled to a commercial 50 MW_e CSP plant, and an annual analysis was conducted to evaluate the optimal CCS strategy in comparison to WCT-only cooling system. The results indicated that implementing the CCS can reduce the specific cooling costs by up to 80 %.

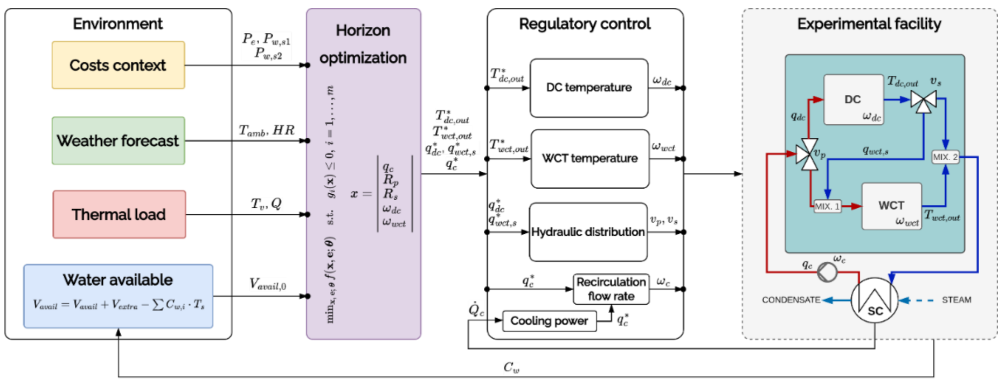

Figure 29. Implementation of the optimization strategy in the real facility.

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

Participants: University of Évora, 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).

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 2025: 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 third fast-track school celebrated in 2025 in Évora (Portugal), together with the corresponding consortium and reviewed project meetings. A pre-doctoral researcher from CIEMAT carried out a 3 months stay at Evora, from 19th September 2025 to 19th December 2025, during which the operation of the MD pilot plant was carried out in batch mode, reaching a feed salinity concentration of 175 g/L and achieving a process recovery ratio of 86 %.

The CIEMAT team has been involved in the preparation of 3 scientific papers in collaboration with University of Évora (Portugal), Instituto Tecnológico de Canarias (Spain) and Universita degli studi di Palermo (Italy) that will be sent to an indexed journal in 2026.

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.

Contact: Guillermo Zaragoza.
Alba Ruiz-Aguirre.

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

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

Objectives: 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 2025: CIEMAT unit has participated in the development of energy supply and management model for DEMO 3, which will be installed at CIEMAT-PSA in 2026, as well as the development of the system control strategy, data infrastructure and optimization methods for that DEMO. CIEMAT also participated in the M30 consortium meeting held in Cetraro (Italy) in June 2025. Finally, CIEMAT participated in the school with the course " Water & renewables. Coupling with renewable energy" and in the first online workshop titled “From Seawater to Freshwater: Innovative Paths to Sustainable Desalination” with the talk “Implementation of sustainable prototypes”.

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

Participants: FCC Aqualia SA, CIEMAT, University of 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 m^3 of freshwater and recovering 140 tonnes of minerals, with replication planned at 18 additional plants.

Achievement in 2025: CIEMAT contributed to defining and sequencing the stages of an integrated seawater treatment process, including desalination, brine concentration, and recovery of valuable compounds. A comprehensive process scheme was developed, detailing the operational order of each unit and their interdependencies, energy demand, and operating conditions. All stages were characterized by defining inlet and outlet streams, including flow rates, composition, salinity, and key physicochemical parameters, allowing consistent mass and energy balances and evaluation of overall performance. Scaling projections were performed under different operational scenarios to assess precipitation and fouling risks in the MD system. These analyses were based on the Langelier Saturation Index (LSI), solubility products (Ksp), and saturation quotients (Qs), supporting the election of operating conditions to minimize scaling. An experimental campaign was conducted in the MD unit at La Caleta Desalination Plant (Adeje, Tenerife) to concentrate the monovalent stream from nanofiltration. Semi-batch and batch modes were compared at 80 °C (hot side), 24-29 °C (cold side), 1,100 L/h, and 43-47 g/L initial salinity. While STEC and total water recovery were similar, semi-batch produced more permeate but required longer to reach CF = 3. CIEMAT also participated in M6 and M12 consortium meetings.

Integración de sistemas de desalación en plantas termosolares de torre central y reutilización de salmuera para producción de macroalgas (SOLDESALBIO)

Participants: CIEMAT, University of Almería, EU-SOLARIS, ENSI.

Contact: Patricia Palenzuela Ardila.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento).

Background: Water scarcity affects over one-third of the global population, while 80 % of wastewater is untreated. The water sector is energy-intensive, consuming ~4 % of global electricity. Integrating renewable-powered desalination with macroalgae cultivation can reuse nutrient-rich brine, reduce environmental impacts, and simultaneously address interconnected energy, water, and food security challenges.

Objectives: The main objective of the project is to advance the Energy-Water-Food nexus by evaluating an innovative scheme that integrates renewable energy technologies with desalination systems and macroalgae production. The goal of this novel system is to achieve zero carbon emissions in the combined production of freshwater, energy, and macroalgal biomass. By reusing brine from desalination as a nutrient source for macroalgae cultivation, the project seeks to enhance resource efficiency, minimize environmental impact, and contribute to a circular economy.

Achievement in 2025: A simulation tool has been developed for a cogeneration system that integrates a reverse osmosis plant (3 m^3/h nominal feed water flow rate), a compressed air energy storage (CAES) system, a compressor, a macroalgae plant and a PV plant. All the models have been integrated to simulate their behaviour (see Figure 30): the RO operates with an electric pump driven by PV during the day and with a pneumatic pump fed by air from the CAES after sunset. The compressed air from the CAES is also discharged to a solar micro-turbine that has not been included in the system model. Likewise, the brine leaving the RO is used for macroalgae production that also uses PV for recirculation pumping. This simulation tool has been used to perform annual simulations to evaluate the performance of the systems either using only solar energy or with grid support.

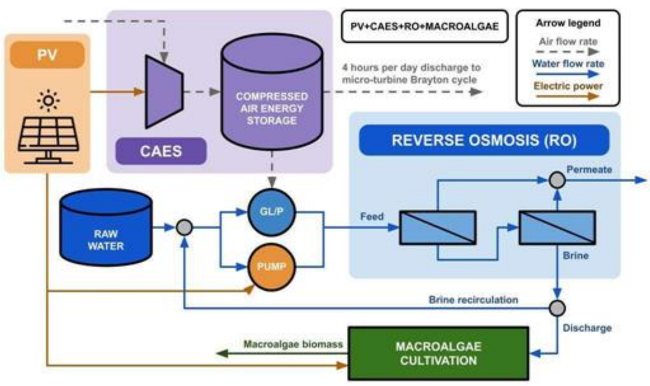

Figure 30. Scheme of the cogeneration system that integrates PV, RO, CAES and macroalgae cultivation

Integración de la destilación por membranas en la producción de hidrógeno verde para mejorar su sostenibilidad (HYDROMEM)

Participants: CIEMAT, University of Málaga, NCSR Demokritos.

Contact: Alba Ruiz-Aguirre.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento).

Background: Membrane distillation (MD) and electrolysis technologies face several limitations: MD systems usually require an external heat source to operate, while electrolysis units depend on external cooling systems to manage heat. Additionally, electrolysis often relies on a continuous natural water supply. Integrating these technologies can overcome these drawbacks by providing the necessary heat internally, eliminating the need for external cooling, and allowing an independent operation of natural water sources.

Objectives: HYDROMEM aims to demonstrate a pilot-scale solution integrating MD to supply high-purity water for renewable hydrogen production, enhance efficiency by using electrolysis waste heat, and evaluate the feasibility of thermally coupling MD with electrolysis to desalinate seawater and produce freshwater sustainably

Achievement in 2025: A preliminary study models the integration of a PEM-type electrolyser under two different scenarios, which differ in the type of MD module considered. In Scenario 1, a spiral-wound V-AGMD module configuration was modelled, while in Scenario 2, the module has a VMEMD configuration. In both cases, the integration proves technically feasible, with the available waste heat being sufficient to supply 18 and 12 modules, respectively. The modules were arranged in two parallel rows, each equipped with its own heat exchanger. Regarding water production, in both scenarios the required flow rate to meet the electrolyser demand (78 L/h) was achieved, and an additional surplus of water was generated, which could be used for other purposes. Moreover, the quality of permeate has been preliminary evaluated in a MD lab scale for two different membranes, one of PTFE and the other PE, under different operation conditions in terms of temperature, flow rates and configuration (AGMD and V-AGMD). For all cases, a conductivity below 2 µS/cm and 5 µS/cm was achieved for the AGMD and V-AGMD configurations respectively.

Red de Investigación en Ciencia y Tecnología de Membranas para el Tratamiento de Aguas (MEMBRANET).

Participants: UPM, CIEMAT, UPC, University of Zaragoza, University of Las Palmas de Gran Canaria, University of Cantabria, UPV, Universitat de Girona, UdG-LEQUIA, Instituto de Ciencia y Tecnología de Polímeros - CSIC, IMDEA-Agua.

Contact: Alba Ruiz-Aguirre.

Funding agency: Agencia Estatal de Investigación.

Background: The increasing global demand for sustainable water treatment, resource recovery, and energy-efficient separation processes has highlighted the importance of membrane-based technologies as key tools for addressing environmental and industrial challenges. These technologies play a crucial role in desalination, wastewater treatment, and resource recovery, contributing to more sustainable water management worldwide.

Objectives: The MEMBRANET National Network aims to coordinate collaboration among 12 research groups in membrane science and technology for water treatment. The network promotes technological exchange and supports knowledge transfer to industry, contributing to environmental protection by reducing effluent pollution and salinity while encouraging desalination and wastewater reuse to address water scarcity.

Achievement in 2025: CIEMAT contributed information on membrane distillation for water treatment to the network's website and monitoring reports, participated in the first international symposium on functionalized membranes with a special session dedicated to MEMBRANET, and took part in the Workshop on Modeling, Simulation, Optimization, and Control Engineering applied to water treatment organized within the network.

Destilación solar por membranas para la valorización de salmueras residuales (MEMBRINE)

Participants: CIEMAT.

Contact: Juan Antonio Andrés Mañas.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento).

Background: The inappropriate discharge of industrial brines into the sea or inland water bodies destroys aquifers and ecosystems. Apart from water, these residual brines can be valorised because high-value mineral species can also be recovered. However, brines must be concentrated and operations to do that consume high amounts of energy.

Objectives: Implementation of an optimized commercial-scale V-AGMD operation powered by solar thermal energy for brine concentration. The MEMBRINE project aims to develop, validate, and optimize the techno-economic aspects of a commercial-scale, solar-powered membrane distillation operation for brine concentration, contributing to achieving Zero Liquid Discharge. Specifically, the project will determine the most energy-efficient operating strategy with recirculation, and the optimal size of the solar energy input system.

Achievement in 2025: Commercial membrane distillation modules with different internal designs have been characterized, and the most thermally efficient for brine concentration has been determined. A techno-economic evaluation of the treatment of real residual brine from a reverse osmosis unit in a demonstration-scale membrane distillation plant with 10 modules has also been carried out. This plant is placed in an agricultural facility at the research centre IFAPA, close to the University of Almería. For this assessment, solar heat and heat from a boiler were used, in which biomass is recycled to generate the CO_2 that is supplied to an annexed experimental greenhouse, as well as the permeate produced.

SOLAR-Driven GREEN Ammonia Production from Agricultural Wastewater (Sun4Green).

Participants: UAB, CIEMAT.

Contact: Sixto Malato.
Alba Ruiz-Aguirre.

Funding agency: Universidad Autónoma de Barcelona (Proof of Concept).

Background: Global agriculture faces increasing pressure to meet food demand while minimizing environmental impact. Traditional urea production and fertilization methods rely on fossil-fuel-based processes and chemical reagents, contributing to greenhouse gas emissions, nitrate pollution, and high energy consumption. Innovative strategies are needed to produce fertilizers sustainably, directly at the point of use, and with minimal environmental footprint.

Objectives: To develop a portable photochemical reactor capable of converting nitrates, present in agricultural soils into ammonia directly in the field.

Achievement in 2025: Design and installation at CIEMAT-PSA facilities of a portable photochemical reactor capable of treating approximately 20 L of wastewater to convert nitrates into ammonia directly in the field.

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

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

Contact: Samira Nahim
Isabel Oller.

Funding agency: European Commission (H2020-LC-GD- 2020-1)

Background: Green transition is at the forefront of political and societal ambitions for more sustainable economies, industries, and societies. The means to reach green transition usually consider Renewable Energy Technologies as the key towards CO2 emission reduction and decarbonisation of the electricity grid. However, sustainable uptake of RETs can only be ensured through the effective implication of stakeholders all along the value chain and throughout the development of tailored technologies. In this context, the ENERGICA project focuses on a wider scope of activities than strictly technical, providing sustainable technologies.

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

Achievements in 2025: During this year, the assessment of the multi-step cascade reactor (MSCR) of 5 L and 0.5 m2 of surface, described in previous reports, has continued in CIEMAT's facilities to determine the capability of the technology to treat a wide variety of chemical and biological targets in urban wastewater. The capability to treat urban wastewater for agricultural reuse as the intended use was tested by assessing its capability to inactivate E. coli, somatic coliphages (SOMCPH) as viral indicator (Figure 31), and spores of sulphite-reducing clostridia as a surrogate for protozoan cysts according to the Regulation (EU) 2020/741 of the European Parliament on minimum requirements for water reuse. Additionally, the capability to reduce the emergent and highly concerning antibiotic resistance genes (ARGs) was also assessed. Finally, the capability of the proposed photocatalytic reactor to be used as a potential quaternary treatment was also evaluated by the removal of organic microcontaminants.

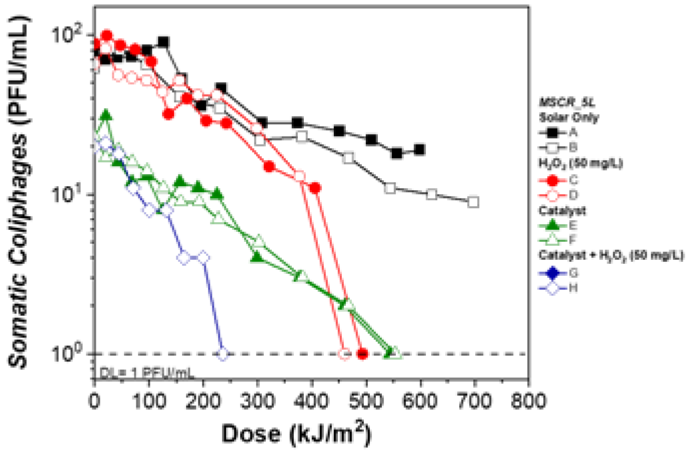

Figure 31. SOMCPH inactivation in UWW by the ENERGICA MSCR of 5L by different solar processes.

Solar catalysis for a renewable energy future (SOLFUTURE)

Participants: IMDEA-Energía, Instituto de Ciencia de Materiales de Madrid-CSIC, ICIQ, CIEMAT, APRIA Systems S.L., CEPSA.

Contact: Sixto Malato.

Funding agency: Agencia Estatal de Investigación (Ayudas a Proyectos de I+D+i en líneas estratégicas en colaboración público-privada).

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 2025: The activities of the PSA-CIEMAT group within SOLFuture have been primarily based on producing solar fuels and chemicals from natural resources and waste using solar photoreactors (informed in 2024) and, additionally, solar collector designing for this application. The development of gas-phase photocatalytic reactions at medium temperatures (150-250 °C) requires the design of a solar concentrator prototype that exhibits an optimal balance between photon transfer and thermal efficiency. The linear Fresnel collector has been chosen as the best option for applications requiring process heat without subsequent connection to a power cycle for electricity production. The design options favour a thermal collector plus a photocatalytic collector. In the thermal section, a linear Fresnel collector with thin glass reflectors and a vacuum tube is proposed. In the photocatalytic section, to reduce heat loss, a Fresnel collector with a transparent glass tubular receiver is also recommended. The reflectors in this section should be made of aluminium. Option 1: Direct coupling; the gas circulates both inside the absorber tube of the thermal section and inside the absorber tube of the photocatalytic section. Option 2: Indirect coupling; pressurized water or silicone-based thermal oil is used in the thermal section for heat exchange with the photocatalytic section (Figure 32).

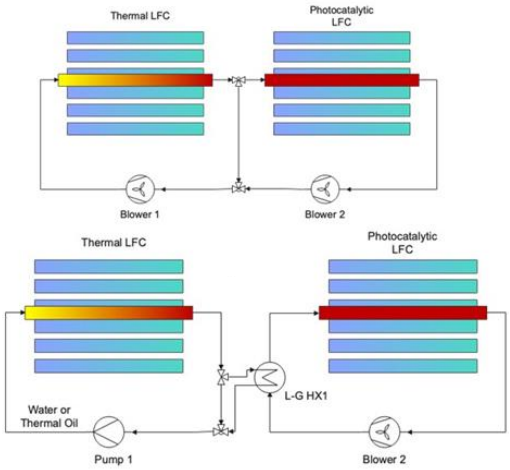

Figure 32. Options of design of a thermal collector plus a photocatalytic collector for H_2 production.

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

Participants: UPV, Universidad Rey Juan Carlos, CIEMAT.

Contact: Sixto Malato.
Isabel Oller.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento).

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 2025: To achieve the project objectives, it has been necessary to monitor the removal of contaminants, the inactivation of antibiotic-resistant bacteria (ARBs), and the effect on antibiotic resistance genes (ARGs). The project has also explored aspects such as the reuse and valorisation of wastewater, including the production of H_2 using organic contaminants as a sacrificial agent. The strategy to achieve these objectives has been designed focusing on different aspects. These include the evaluation, treatment, and valorisation of reclaimed urban wastewater for use in hydroponics, testing secondary and tertiary effluents from several wastewater treatment plants (WWTPs) using different photo-assisted AOPs (achieving simultaneous bacterial inactivation and contaminant removal). A similar strategy has been followed for the treatment of aquaculture wastewater, enabling its reuse in hydroponics (Figure 33). Among the photocatalytic products (PCPs) used, high-performance materials with adsorbent properties, zero-valent iron, and circumneutral pH photo-Fenton stand out, among others; many of them illuminated by solar energy. This has been complemented by experimentation in photocatalysis for hydrogen production, using these effluents as a sacrificial agent. To achieve these objectives, laboratory-scale and pilot-plant experimentation has been combined using the most comprehensive analytical techniques and bioassays.

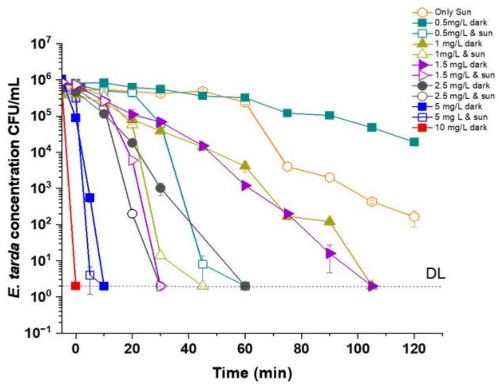

Figure 33. Chlorine treatment under solar irradiation of simulated aquaculture effluent, containing *E. tarda*, in a laboratory scale photoreactor.

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

Participants: IMDEA Energy, ALBA-CELLS, Instituto de Ciencia de Materiales de Madrid -CSIC, Univesity of Girona, Instituto de Química Física "Rocasolano"- CSIC, CIEMAT, Instituto de Ciencia de Materiales de Sevilla -CSIC, UPM, Universidad Rey Juan Carlos.

Contact: Sixto Malato.
Diego-César Alarcón-Padilla.

Funding agency: Agencia Estatal de Investigación (Proyectos Orientados A La Transición Ecológica y a La Transición Digital)

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: The design and construction of a solar photoelectrochemical device to develop chemical reactions has been carried out at PSA, including two different levels of radiation density and strict temperature control for a double illuminated reactor allowing the use of orientation strategies of the collectors according to the target radiation levels. However, this design was not completed, and the design of a new, simplified reactor based on CPC collectors with a larger diameter than the existing ones was assessed. Assembly was done at PSA with the integration of the different components (Figure 34). Systematic campaigns have been developed to quantify the reactor's performance under different experimental conditions. Three different catalysts ($Cu/TiO_2/SrTiO_3$, CuO-NiO-TiO_2 and TiO2/NiO) have been tested.

Figure 34. Final prototype CPC photoreactor constructed in SolarChem 5.0 project.

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.

Funding agency: Agencia Estatal de Investigación (Proyectos Orientados A La Transición Ecológica y a La Transición Digital)

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 2025: This project has successfully finished on May 31st, 2025. Along its implementation, different quaternary treatments based on UVC, and solar radiation combined with hydrogen peroxide, peroxomonosulfate, peracetic acid and ozonation, were tested and compared with some of the conventional treatments already installed in different urban wastewater treatment plants. A focus on the generation of disinfection byproducts as well as bacteria and genes resistant to antibiotics were tackled. Based on the generated data from those experiments, CIMNE (a partner of the project) developed predictive models based on Machine Learning tools with three main objectives, the prediction of the degradation and inactivation of contaminants, the envisage of formation of disinfection byproducts and the creation of a decision support tool (Figure 35).

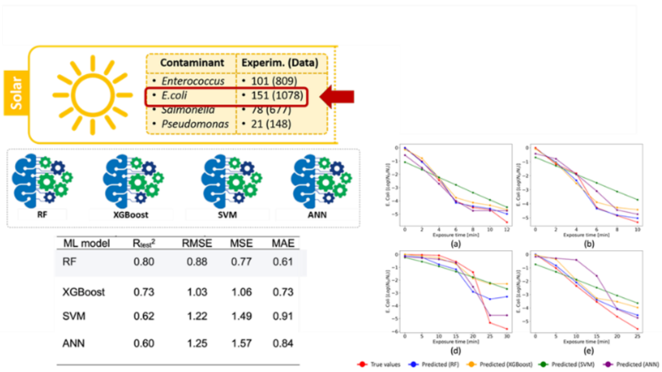

Figure 35. Machine Learning Models developed by using CIEMAT´s experimental data for the inactivation of E. coli by the application of solar quaternary treatments with the addition of chlorine, H_2O_2, peroxomonosulfate, etc.

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, Council of the Province of 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 begun in December 2022.

Achievements in 2025: To expand the data set needed to generate predictive models, four water sampling campaigns (monitoring every three months) were carried out in 2025 throughout the Province of Almeria in the 3 representative regeneration and drinking treatment plants selected based on the results obtained during 2024. Using the data generated during the overall project, a multivariate correlation analysis was carried out in order to identify the physical-chemical parameters with the greatest predictive power over the output variables (DBPs, disinfection by-products). Subsequently, machine learning architectures were implemented to optimize the convergence of the predictions (Chlorate prediction, Figure 36).

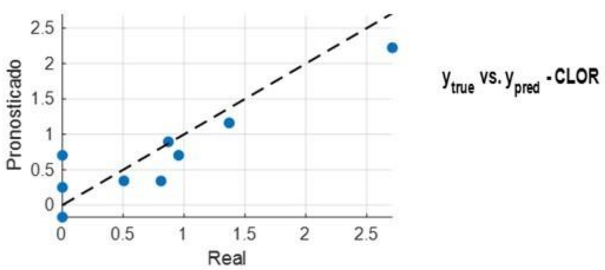

Figure 36. Chlorate generation prediction in drinking water treatment plants by the numerical model developed in the project.

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: University of Almería, CIEMAT.

Contact: Isabel Oller.

Funding agency: Agencia Estatal de Investigación (Proyectos de Generación de Conocimiento)

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/sulphate-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 2025: Two coordination meetings have been performed, on February 17th and December 12th, 2025. In addition, a short-term training school was organized by CIESOL (University of Almería) and CIEMAT (PSA) as part of the training and diffusion activities scheduled in the project description of work. The training school took place on December 10th, 2025, in the facilities of CIESOL focusing on analytical chemistry advanced tools, and on December 11th, 2025, in the facilities of the Solar Treatments of Water Unit facilities at PSA, on microbiological analytical tools and solar quaternary treatments. 23 people attended the short-term training school coming from different countries, not only Spain (Portugal, Romania, United Kingdom, Brazil, etc). As the main objective of ANDROMEDA project is the combination of reduction and oxidation processes for the elimination of organic persistent contaminants at low concentrations, new photoreactors must be designed and constructed for testing supported materials in anoxic conditions. In this sense, Figure 37 shows one of the CPC photoreactors that has been adapted for the introduction of supported materials in the tube and for working in anoxic conditions thanks to nitrogen bubbling inside the borosilicate tubes. In addition, different new photocatalysts obtained from wastes from agriculture and based on zero valent iron have also been tested for the elimination of persistent organic and mobile microcontaminants from different water matrices.

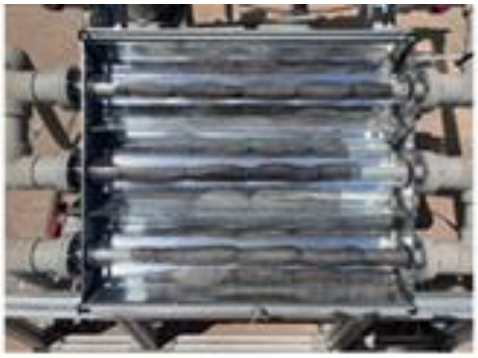


Figure 37. New solar photoreactor for testing supported photocatalysts to test both oxidation and reduction capacities. Left: CPC photoreactor with the supported zero valent iron in a mesh inserted in the tube thanks to the polypropylene support used. Right: one tube.

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

Participants: UAB, IMB-CNM-CSIC, Univ. Antwerpen, IMRCP UMR-CNR, Univ. Pisa, Arkyne tech., CIEMAT, Iowa State.

Contact: Sixto Malato.
Alba Ruiz-Aguirre.

Funding agency: European Commission (HORIZON-EIC-2022-PATHFINDERCHALLENGES-01).

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 2025: The design of a small-scale, 6-L laboratory solar photoreactor based on a CPC system was completed. Photocatalytic nitrate conversion could be performed under anoxic conditions, requiring continuous bubbling of an inert gas. The photocatalytic reduction of NO_3^- using TiO_2-P25 with CuO and NiO cocatalysts, was studied at both laboratory and pilot scales at Iowa State University and the PSA, respectively. At lab scale, the influence of wavelength, nitrate concentration, light exposure time, and type of sacrificial agent was assessed for both ammonia and urea production. At the pilot scale, the effects of the water matrix and sacrificial agent concentration were evaluated in terms of ammonium production and hydrogen formation. This latter, a byproduct not included in the CONFETI project objectives but relevant due to its impact on nitrate reduction efficiency. At pilot scale, the photocatalytic reduction of nitrate using TiO_2-P25:CuO and TiO_2-P25:NiO with glycerol as a reducing agent was highly efficient in demineralized water but showed reduced performance in more complex matrices due to competing ions and organic matter. Nitrate conversion followed the order DW > WeW-1 > WeW-2. TiO_2-P25:CuO achieved higher conversion rates and better NH_4^+ selectivity than TiO_2-P25:NiO. Specifically, in WeW-1 at 0.075 M of glycerol, the value of NH_4^+ production was 92.4 % and 78.4 % for TiO2-P25:CuO and TiO2-P25:NiO, respectively, and 87 % of selectivity in both cases (Figure 38).

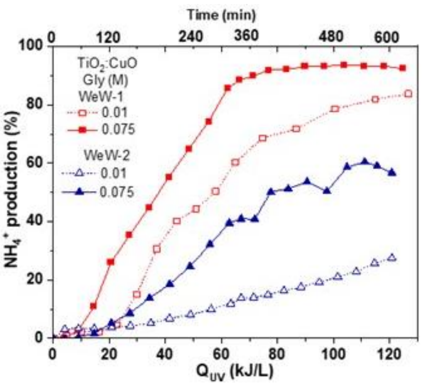

Figure 38. Pilot scale production of NH^{4+} in the presence of two different glycerol concentrations (0.01 M and 0.075M) with TiO_2:CuO in WeW-1 and WeW-2 under natural solar radiation and anoxic conditions.

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

Participants: University of Oslo, 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 2025: Two coordination meetings have been carried out: one in Aachen in June 2025 and the second one in Thessaloniki in November 2025. In addition, the review meeting with the project officer took place online on June 23rd, 2025. The photoreactor designed by the Solar Treatments of Wastewater Unit at PSA, has been tested for the autotrophic growing of different genetically modified C. necator strains for the production of isobutanol and the generation of 3-methyl-1 butanol as subproduct. The applied gas flow rate has been 12.5 mL/min with a distribution of H_2:CO_2:O_2 of 8:1:1, that is 10 mL/min of H2, 1.25 mL/min of CO_2 and 1.25 mL/min of O_2.The influence of the presence of two reported substrates, 2 % of fructose and the mixture of 2 % of fructose and 1 % pyruvate, on the isobutanol production has been studied maintaining the same operating conditions. CIESOL-University of Almería has developed a methodology for detection and quantification of isobutanol in gas chromatography-mass spectrometry (limit of quantification, LOQ: 50 µg/L), having entered as associated partner of REFINE project with initial date of October 2025. In the case of the experiments performed with minimal media added fructose 2 % and 1 % pyruvate, isobutanol could not be quantified since the detected values were below the LOQ. The production of isobutanol during the experiment performed with minimal media and fructose 2 %, gave the highest production after 48 h of assay (Figure 39).

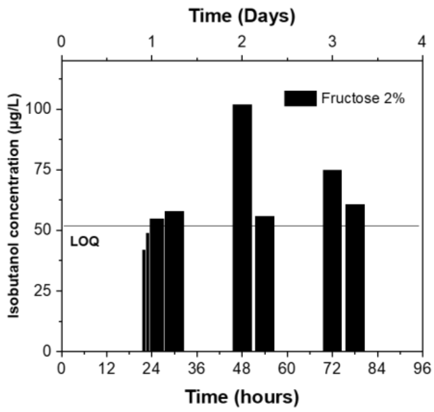

Figure 39. Isobutanol production in the experiments in which *C. necator* has been grown with minimal media and 2 % of fructose alone.

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, Universita Degli Studi del Piemonte Orientale Amedeo Avogadro, Aalborg University, Clermont Auvergne INP, CIEMAT, Panepistimio Ioanninon, UPV, Alma Mater Studioum – Universita Di Bologna, ULTRAAQUA A.S, INERIS, Institutt for Energiteknikk.

Contact: Isabel Oller.
Sixto Malato.

Funding agency: European Commission (HORIZON-MSCA-2022-DN-01-01).

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 to produce 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 centres, 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 2025: Two coordination meetings with associated workshop and summer school have been carried out at the University of Aalborg in September 2025 and at the University of Ioannina in April 2025, respectively. IN2AQUAS is a Marie Curie project focused on the training of 15 doctorate candidates that must obtain two PhD labels from two different universities within the project consortia. As part of the training and activities of the doctorate candidates they have to spend eleven months in secondments. In 2025 the Solar Treatments of Wastewater Unit at PSA hosted two doctorate candidates throughout six and four months, which determined the optimum conditions for urban wastewater treatment by using peroxomonosulfate and sodium hypochlorite evaluating their efficiency in the elimination of target and non-target microcontaminants. The second one applied a battery of toxicity assays to three different solar based photochemical treatments with persulfate and peroxomonosulfate for the elimination of four antibiotics. In addition, one of the doctorate candidates from the Solar Treatments of Wastewater Unit at PSA went on secondment to the University of Torino in June 2025 and the other started the assessment of the efficiency of a solar water treatment based on the use of agricultural commercial substances as a potential environmentally sustainable solution that increases the circularity of the water-energy-food nexus. A new associated partner has been included in the project after an amendment process; this is VIVA Materials Consulting, located in Seville (Spain) and with the main objective of developing new NF and UF membranes using recycled materials as support for water reuse and recovery of valuable products from the food sector.

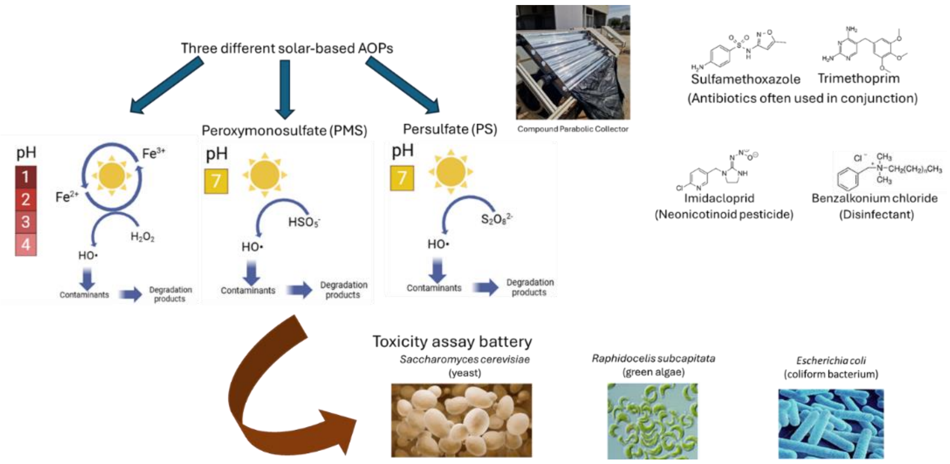

Figure 40. Solar based photochemical experiments with oxidants carried out along one of the secondment periods for the elimination of antibiotics and the assessment of related toxicity.

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

Participants: LNEG, MG sustainable engineering AB, Imperial College Of Science Technology And Medicine, Fraunhofer, Universita Di Bologna, Hogskolan I Gavle, Solarus Renewables AB, IST-ID, CIEMAT, Belgium Volt.

Contact: Sixto Malato.
Ilaria Berruti

Funding agency: European Commission (HORIZON-CL5-2024-D3-01-10).

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 H2, 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 2025: Hydrogen production will result from the remediation of industrial wastewater using solar power and low cost nanostructured TiO_2-based photocatalysts. Comprehensive guidelines on the use of industrial wastewater (IWW) as a source of sacrificial agents (SAs) for solar-driven photocatalytic hydrogen production has been done, evaluating the dual potential of this approach to simultaneously generate renewable hydrogen and treat wastewater, aligning with circular economy and EU decarbonisation goals. These guidelines have identified critical parameters influencing the viability of this method, such as organic content (COD, BOD), pH, dissolved oxygen, turbidity, light-scattering compounds, and the presence of inhibitory inorganic ions. Studies suggest that moderate to high concentrations of organic pollutants, when carefully managed, can enhance photocatalytic hydrogen production efficiency. Excessive concentration of SA may hinder light penetration and catalyst activity, while insufficient SA levels would dramatically reduce reaction kinetics. Thus, optimization of this parameter through careful characterisation of SA concentration in SA and eventual dilution with other IWW streams is essential. Finally, these guidelines present a step-by-step decision-making framework for evaluating the suitability of using IWW streams as sources of sacrificial agents in photocatalytic hydrogen production. Based on these results, the candidate IWW can be classified as likely, likely but subject to pre-treatment or testing, unlikely or unsuitable. The flowchart (Figure 41) ensures a systematic first approach to identifying promising aqueous waste streams for sustainable hydrogen production and IWW pollutant remediation.

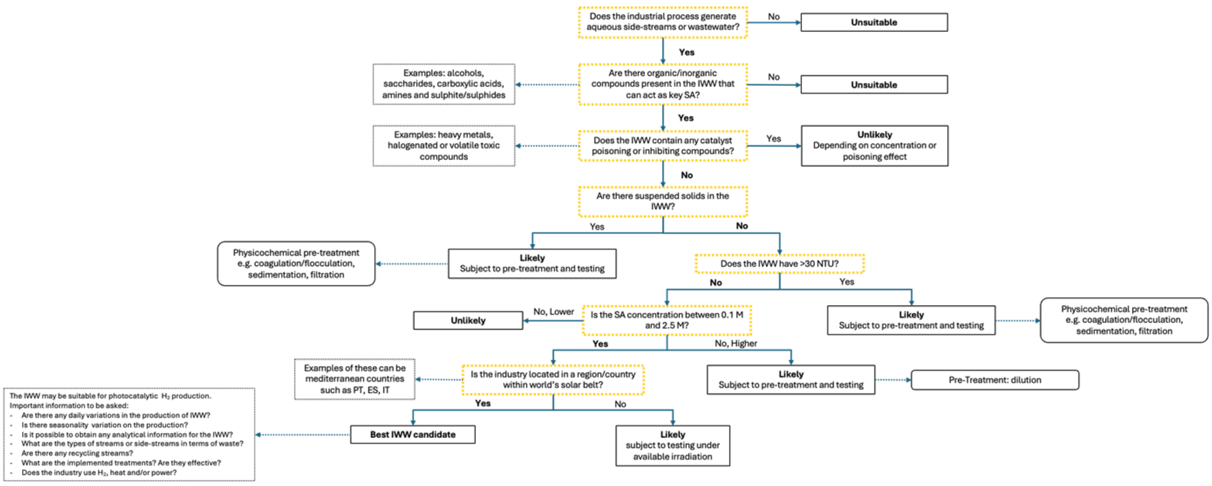

Figure 41. Decision tree on the most favourable industrial wastewater candidates for hydrogen production.

Identificación, cuantificación y eliminación de contaminantes emergentes en cuencas hidrográficas (AQUACARE)

Participants: University of Cádiz, University of Porto, Université de Perpignan Via Domitia Scteur Sciences et Technologies Biocapteurs, Fundación Aitiip, Agencia de Medio Ambiente y Agua de Andalucía Dirección de Gestión del Agua y Calidad Ambiental, CMPEAE, Instituto Portugués do Mar e da Atmosfera, Centre National de la Recherche Scientifique, CIEMAT.

Contact: Isabel Oller.

Funding agency: INTERREG SUDOE.

Background: Urban wastewater is a major source of river pollution. Until now, the Urban Wastewater Treatment Directive did not regulate discharges of micropollutants, such as pharmaceuticals, cosmetics, and microplastics. These residues are found in all our water bodies and are harmful to the environment and human health. Rivers in the SUDOE region, given their vulnerability to climate change, must be protected from these pollutants. The new Urban Wastewater Treatment Directive, which will lead to cleaner rivers and lakes across Europe, includes the control of micropollutants and mandates the application o

Additional treatment to urban wastewater to remove these micropollutants. It also urges Member States to compile a list of areas that pose a risk to health or the environment due to the presence of micropollutants and to systematically monitor them. The proliferation of micropollutants and their treatment remains a challenge, making this project crucial for integrating the Directive into the various SUDOE regions and ensuring their alignment with its provisions.

Objectives: The overall objective of AQUACARE is to protect and conserve water resources, strengthening resilience against emerging micropollutants. The implementation of this project would provide the administrations and companies in these regions with strategic resources to address the proliferation of emerging pollutants in rivers and their consequent deterioration. It will provide a common methodology for the identification, analysis, and reduction of micropollutants; a strategic reference plan for the sustainable management of these discharges and for reducing the input of micropollutants into river basins; valuable information on unreported sources of pollution and the presence of these pollutants in river basins; as well as solutions and best practices for stakeholders, including public participation and awareness-raising.

Achievements in 2025: This project started in July 2025 and the kick off meeting took place virtually on July 8th, 2025. The coordinator is the University of Cádiz with partners from France and Portugal (SUDOE region). One coordination meeting has taken place in person in September 2025 in Cádiz, hosted by the University of Cádiz. In this project the Solar Treatments of Water Research Unit at PSA is leading activity A 1.4., related with the evaluation of the most appropriate and feasible technologies to reduce contaminants present in water bodies and activity A 1.5., with the objective of the identification and prioritize treatment solutions to be tested at demonstration level. Till the moment, only the sampling points on different water bodies along Spain, Portugal and France have been defined. Common protocols on microcontaminants and microplastics, as well as common procedures for taking samples for toxicity assays are being discussed and elaborated.

Research towards simplified models for smart buildings (MOD4SMART)

Participants: GEOTER, GAPTEK, CARTIF, CIEMAT.

Contacts: María José Jiménez.

Funding agency: Agencia Estatal de Investigación (Proyectos de I+D+i en Líneas Estratégicas colaboración público-privada.

Background: The use of industrialised construction is growingly becoming inserted in the marked solving functional problems. This issue demands the addressment of energy performance focusing on the specific characteristics of this construction and its elements. Experimental assessment of prefabricated panels to determine its actual energy performance is relevant in this context.

Objectives: Application of smart technologies to improve the energy and operational performance of the buildings focussing on industrialised construction, and carrying out research and development on simplified models to be integrated in building smart systems that would enable their response to the energy flows, maximizing the energy efficiency and the sustainability

Achievements in 2025: Test and energy performance assessment of several prefabricated panels have been conducted at at the LECE Laboratory. These tests have been carried out in order to obtain the thermal and solar transmitances (U and g) of the tested panels. Six panels have been installed in the so called CESPA III test cell in order to characterise the panels themselves. An additional panel has been installed in the PASLINK tests cell in order to characterise the frame of the panel that performs as a thermal bridge. The tested panels are installed in the test cell replacing part of the envelope of the test cell by the panel or set of panels that have been tested. Once the panels have been placed the sensors and measurement devices required to carry out the tests have been installed.

The required parameters, U and g, have been obtained applying the dynamic integrated method for spreads of 10 %, 3 % and 1 %. It is remarkable that the obtained g value was not negligible even though the panels are opaque. The applied method has been enhanced incorporating the capability to determine the required length of the test campaign as function of the admissible spread of the required parameters.

Figure 42. Tested panels installed in the CESPA III and PASLINK Test Cells where they were tested. (left) Identification of the panels tested at CESPA III Test Cell, (centre) sensors installed in the indoor surface of the panels and Test Cell, (right) panel installed in PASLINK Test Cell and sensors measuring climate variables.

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 affiliated European Research Centres. EU-SOLARIS intends to be the reference in the CSP/STE research infrastructures domain 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 links 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, Portugal and Spain (statutory seat), with national funds. Greece participates currently as Observer. Portugal has recently joined after a two-year period as Observer.

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:

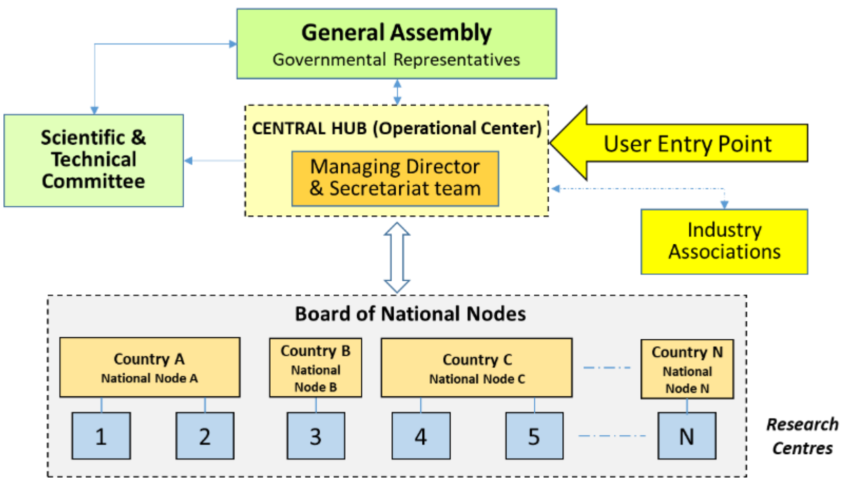

Figure 43. Governance framework of EU-SOLARIS ERIC

One of the funding sources of EU-SOLARIS ERIC is its participation in Horizon Europe-funded projects, most of them under the ‘Research Infrastructures’ Work Programme.

Currently, the project SOLARIZE (Bringing EU-SOLARIS to its Zenith, #101131982) is particularly relevant for the consortium. SOLARIZE is coordinated by EU-SOLARIS ERIC and supports a set of measures and activities aimed at ensuring the long-term sustainability of the ERIC, including:

- An early-stage researchers’ mobility programme
- Organisation of the annual Doctoral Colloquium and Summer School
- Presentation of the Annual Awards for the best doctoral thesis in CST and for the most relevant research infrastructure in this field
- Development of a joint e-infrastructure

Regarding the delivery of access services, EU-SOLARIS is also a beneficiary of the Horizon Europe project RISEnergy (#101131793). Within this framework, it offers transnational access to seven affiliated entities in the field of CST: IMDEA (ES), DLR (DE), CNRS (FR), CENER (ES), University of Évora (PT), LNEG (PT), and the Cyprus Institute (CY).

Figure 44. Presentation of the Annual Awards 2025 at the Doctoral Colloquium event.

Among the most relevant activities carried out within SOLARIZE in 2025 is the organisation of the ‘Doctoral Colloquium 2025’, held in Almería.

SOLARIZE will run until the end of 2027, and a number of activities aimed at enhancing the cohesion of the CST R&D community are already planned. More information about the programme is available on the project website.

Contact: Diego Martínez Plaza

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 thirty 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, Piamonte Orientale (Italy), Politecnica delle Marche (Italy), Foggia (Italy), Udine (Italy), RCSI (Ireland), West Attica (Greece), Coimbra (Portugal), Aguascalientes (Mexico), IES Los Angeles, IES Argar, IES Alhamilla. 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 2nd colloquium took place from June 2nd to 4th and was hosted by CIEMAT-PSA. 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 2025.

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 2025)

MEDITERRANEAN RESEARCHERS' NIGHT (2024 AND 2025 EDITIONS), MEDNIGHT

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

Contact: Lidia Roca

Funding agency: European Commission (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

Contact: Lidia Roca

Funding agency: FECYT.

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.

SOL-PRÉNDETE 2: DIDÁCTICA Y DIVULGACIÓN DE LA ENERGÍA SOLAR TÉRMICA DE CONCENTRACIÓN

Participants: CIEMAT

Contact: Lidia Roca

Funding agency: FECYT.

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

Scientific outreach activities focused on solar thermal technologies can serve as a stimulus from early educational stages through university level, engaging students and the general public in science and research innovation.

Objectives: This project aims to showcase the facilities and research activities carried out at PSA to society at large, and to school and pre-university students in particular. It promotes a hands-on, engaging learning approach designed to convey both practical and theoretical knowledge through a live experience that enhances scientific culture and fosters students' interest in scientific and research careers. Specifically, the project focuses on three thematic areas: solar thermal energy (electricity and/or heat production), water and energy, and control engineering in solar thermal energy systems.

Outreach activities

- European Research Night 2025: 7 researchers from PSA participated in the most important outreach activity in Spain. We covered research lines related to solar concentrating systems and water, using models and games to engage visitors. This activity was performed at the same time in Almería and Madrid.

Figure 45. PSA staff during European Research Night 2025 in Almería.

- CIEMAT at your school: during 2025, a total of 16 activities were performed in different schools of Almería and Madrid.
- International Day of Women and Girls in Science: Women from PSA-CIEMAT participated in different activities: 1) presentations at secondary schools about water and solar energy, 2) "Girls in control", an online STEM initiative to explain control engineering

in an entertaining way organized by the Comité Español de Automática, 3) workshop on solar water treatment and 4) MEDNIGHT Tales at school.

- XIV 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 Isabel Cristina Espinoza Pavón was classified for the final stage.
- ‘Pint of science kids’. Gema San Vicente participated in Madrid’s edition of this event with the workshop ‘Fabrikar patatas fritas solares’.
- ‘Ciclo de seminarios científicos del Instituto de Micro y Nanotechnología -CSIC (IMN-CSIC)’. Gema San Vicente participated with “Development of optical coatings for concentrated solar thermal technologies”.
- Participation in Aemener Fair (Madrid).

Figure 46. PSA stand at XIV FERIA madridesciencia.

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 47 and Figure 48) consists of two subsystems, the solar field of parabolic-trough collectors and the balance of plant (BOP). In the solar field, with the upgrade implemented in 2012, feed water is preheated, evaporated and converted into superheated steam at a maximum pressure of 100 bar and maximum temperature of 500 °C as it circulates through the absorber tubes of a 1000-m -long row of parabolic-trough collectors with a total solar collecting surface of 5,400 m^2. The system can produce a nominal superheated steam flow rate of 1 kg/s. In the BOP, this superheated steam is condensed, processed and reused as feed water for the solar field (closed-loop operation).

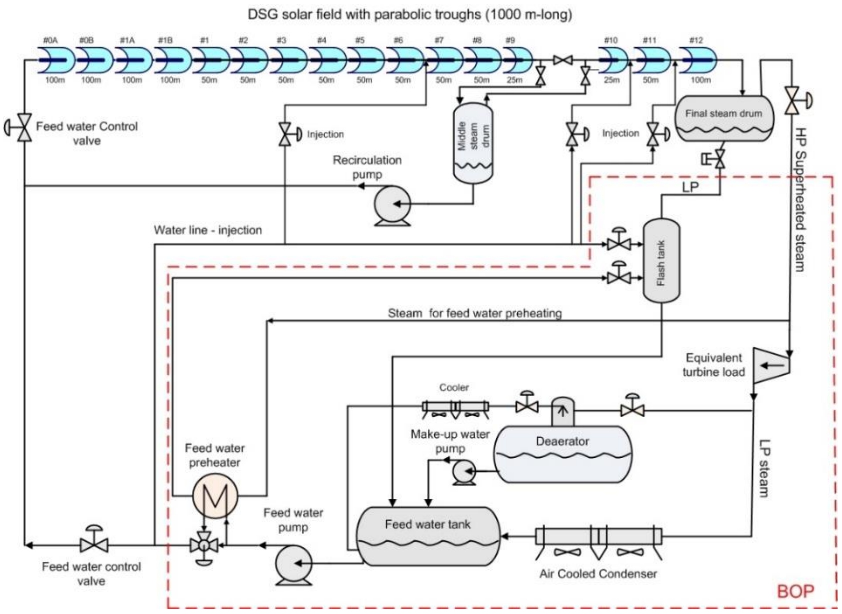

Figure 47. Simplified flow diagram of the PSA DISS loop.

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

Figure 48. 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 49). 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.

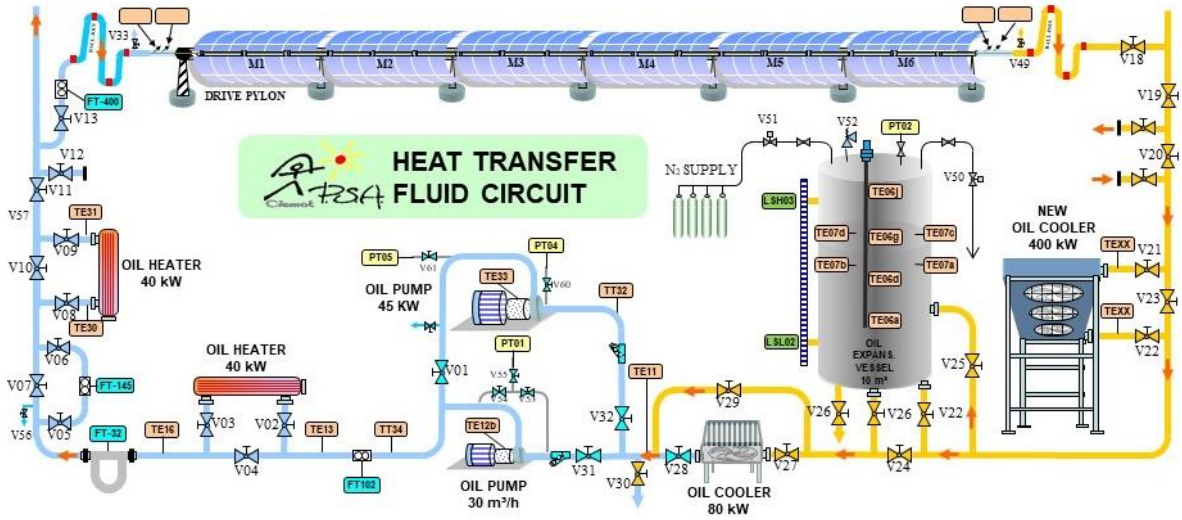

Figure 49. Diagram of the HTF test Loop located at the PSA.

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

- 10-m3-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.

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 m3, 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 m3/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 m3/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).

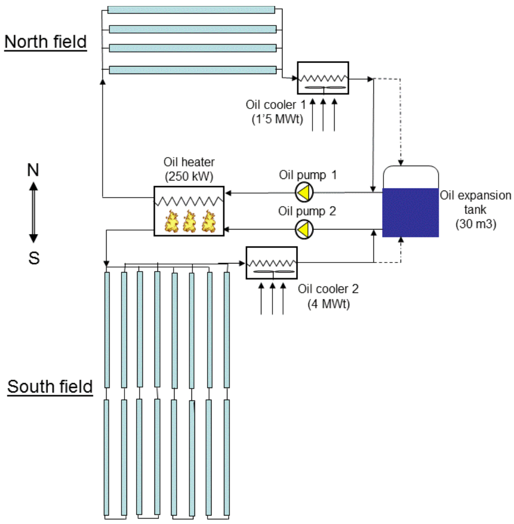

Figure 50. Simplified scheme of the PTTL facility.

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.

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

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 51. 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 52. 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.

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.

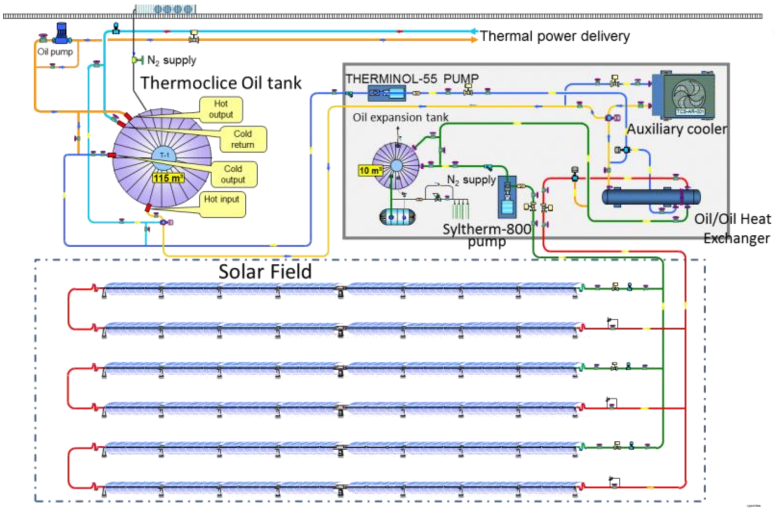

Figure 52. Diagram of the TCP-100 2.3 MW_{th} parabolic-trough facility

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 53) 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 53. 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.

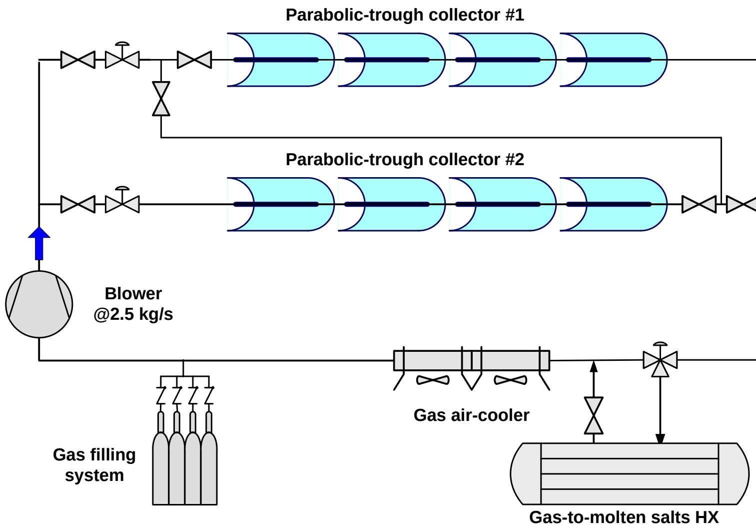

Figure 54. Simplified system diagram of the IFL experimental facility located at the PSA

THE FACILITY FOR POLYGENERATION APPLICATIONS (NEP)

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

Figure 55. NEP PolyTrough 1,200 solar field.

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

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

ROTARY TEST BENCH FOR PARABOLIC TROUGH SYSTEMS (KONTAS)

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 56. 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.

ACCELERATED FULL LIFECYCLE TESTS OF ROTATION AND EXPANSION PERFORMING ASSEMBLIES (REPAS) 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 57.a).

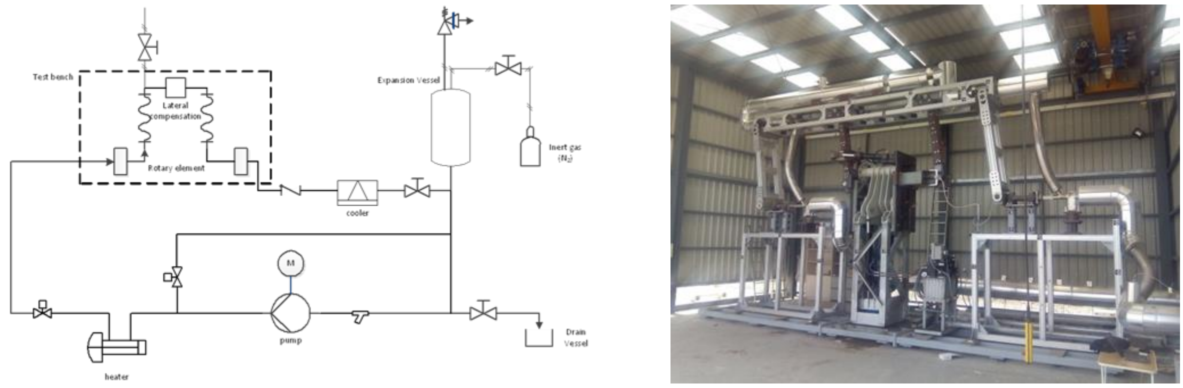

Figure 57. Schematic diagram of the REPA test loop at PSA (left) and north view of the test facility with two flex-hoses mounted for testing (right).

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 57.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.

SMALL-SIZED LFC PRESSURISED WATER TEST LOOP - LAVEC

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 tkWth, 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 58 shows the simplified scheme of LAVEC with a solar collector connected to the system for qualification/evaluation, while Figure 59 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.

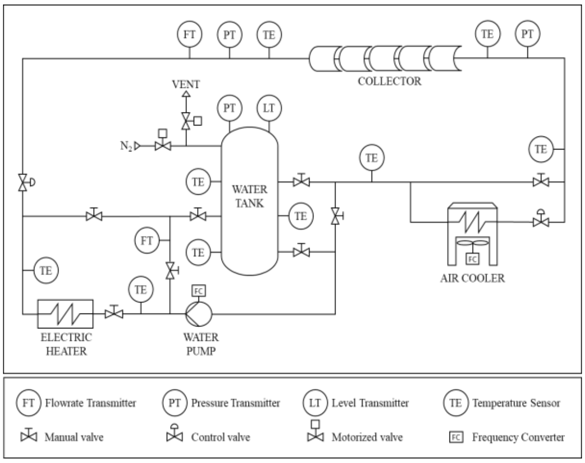

Figure 58. Simplified scheme of the LAVEC facility.

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

Figure 59. 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 60) 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 60. 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 61). 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.

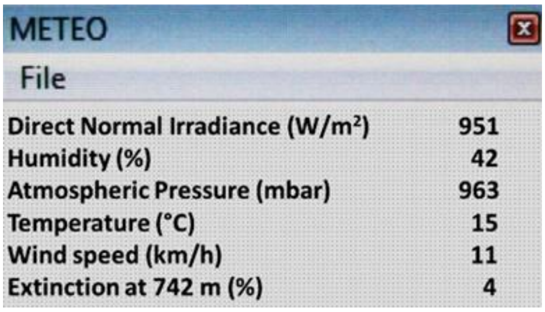

Figure 61. On-line measurement of the solar extinction in the control room of CESA-1 facility at PSA.

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.

Figure 62. Aerial view of the experimental SSPS-CRS facility.

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 63). 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 63. An autonomous heliostat in the SSPS-CRS field.

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.

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

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

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

AORA Solar Tower facility

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

Figure 64. 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.
- In 2024 the facility was upgraded with an electric heater, which allows the molten salt to be heated up to 500 °C. The heater is expected to be powered with electricity from a PV solar field, enabling future power to heat (P2H) studies.

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.

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 65. MOSA outdoor test loop

Figure 66. 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.

ATMOSPHERIC AIR PACKED BED TEST BENCH (ALTAYR)

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

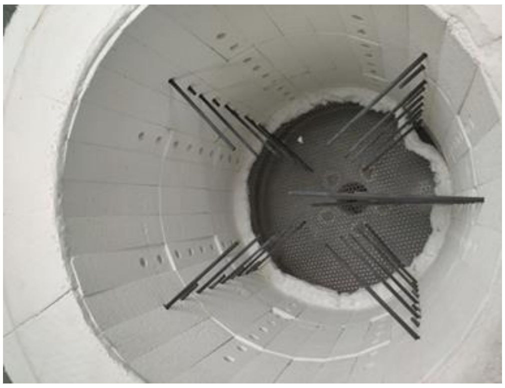

Figure 67. Picture taken from the top of the tank, showing its internal room and thermocouples at different lengths and radial positions.

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.

Following the relocation and assembly of the Altayr facility, all instrumentation was verified and the SCADA system was upgraded during 2025. Upon completion of the commissioning phase, experimental tests were conducted to validate the correct operation of all subsystems and to perform the characterization of the storage tank.

Figure 68. Altayr facility at PSA

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 69) were erected at PSA in 1996 and 1997, using the stretched membrane technology. These parabolic dishes have a diameter of 8.5 m, and the thermal energy delivered in the focus is 50 kW_{th}. The focal distance is 4.1 m, and the maximum concentration is 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 16,000 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.

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

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

EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected (Figure 71), discarding the stretched-membrane technology and applying a moulded composite-material system. These parabolic dishes can be used to test new prototypes of Stirling engines, or to perform any other test requiring a focus with 50 kW_{th} maximum and a maximum concentration of 16,000 suns at the focus. The tracking system is azimuth-elevation.

Figure 71. Front and back views of the EURODISH.

Solar Furnaces facility

SF-60 SOLAR FURNACE

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

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

Figure 72. HT120 heliostat in tracking

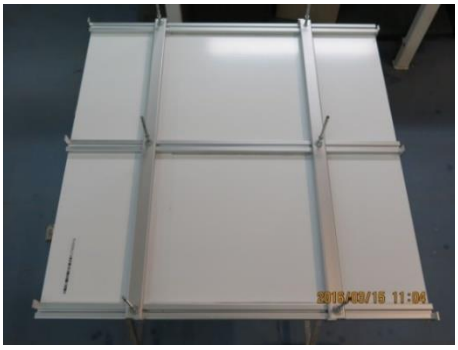

Figure 73. Back side of facet

The parabolic concentrator is the main component of solar furnace. Its function is to concentrate the sunlight reflected by the heliostat, multiplying the radiant energy in the focus. After thirty years in operation, the rectangular facets of the ancient Mc Donnell Douglas concentrator had deteriorated, showing optical defects and large surface undulation that affected its efficiency. That is why we 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.The new parabolic concentrator, called FAHEX 100 (Figure 74), is made of 463 facets grouped by their radius of curvature in three groups, depending on their distance from the focus. The facets with the smallest radius of curvature are located around the vertex of the parabola, followed by the facets with an intermediate radius of curvature, and finally, the facets with the largest radius of curvature are in the farthest part from the vertex of the concentrator.

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

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

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

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

SF-40 SOLAR FURNACE

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

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

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

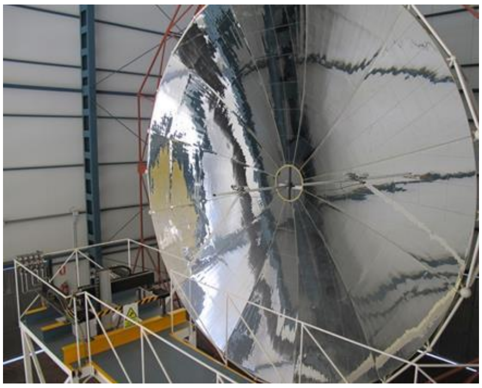

Figure 76. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

SF-5 SOLAR FURNACE

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

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

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

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.

Figure 77. Concentrator of the SF-5 Furnace.

Optical characterization and solar materials durability analysis facility (OPAC)

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 78.a):

- Three portable specular reflectometers, Devices and Services Model 15R-USB, for measuring specular reflectance at 15° incidence angle, 660 nm wavelength and different aperture angles (3.5, 7.5, 12.5 and 23 mrad).
- One portable specular reflectometer, Devices and Services model MWR, for measuring specular reflectance at 15° incidence angle, 460, 550, 650 and 720 nm wavelength and at different aperture angles (2.3, 3.5, 7.5, 12.5 and 23 mrad).
- One portable reflectometer, PSE model pFlex 2.1, for measuring specular reflectance at 8° incidence angle, 470, 525 and 625 nm wavelength, and 67 mrad aperture angle.

- One portable reflectometer, 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 M205 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 materials durability analysis laboratory is designed for accelerated ageing tests of these materials with the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime (see Figure 78.b). To do this, the environmental variables producing degradation of solar reflectors when they are exposed to outdoor conditions are applied in a controlled manner, both separately and in combination. The following equipment is available for these accelerated ageing tests:

- 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 78.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.

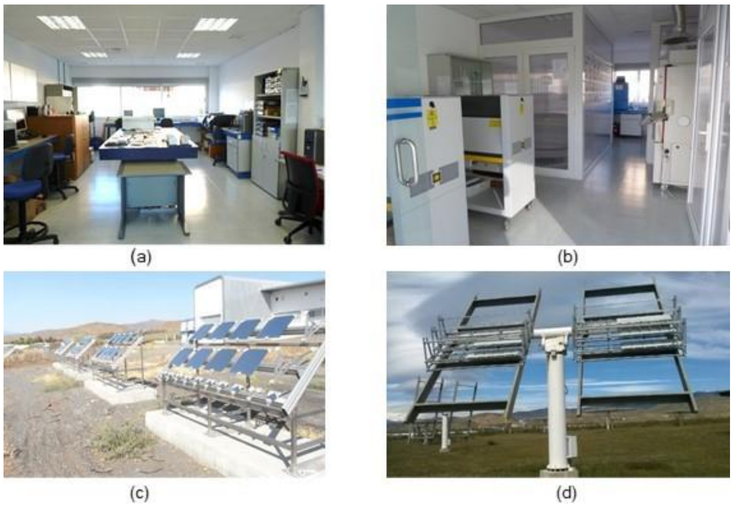

Figure 78. (a) Optical characterization lab, (b) durability analysis lab, (c) outdoor test bench and (d) outdoor accelerated aging test bench at OPAC facilities.

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 79. 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 wastewater 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.

FILM VACUUM MULTI-EFFECT DISTILLATION

The Film Vacuum Multi-Effect Distillation (FVMED) technology uses thin polymer films as heat transfer surfaces, enhancing corrosion resistance and improving thermal performance. The process operates under partial vacuum, allowing it to run at temperatures below 100 °C. The system consists of a flash chamber, four evaporation-condensation effects, and a final condenser. In addition, it includes two heat exchangers: one designed for integration with a solar thermal field and another connected to a cooling system.

Figure 80. The FVMED plant installed at CIEMAT-PSA.

MEMBRANE DISTILLATION TEST BED

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

Figure 81. Internal (Left) and external (right) 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 m^2 total membrane area respectively).
- Two units to evaluate spiral-wound modules from Aquastill operating in vacuum-enhanced air-gap configuration with membrane areas of 7.2, 24 and 26 m^2 respectively.

- A vacuum multi-effect membrane distillation (V-MEMD) unit with a 4-effect module with a total membrane area of 6.72 m^2.

Figure 82. 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 83). 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 83. 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 84). 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 84. 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 85. The PSA Cooling Facility. a) Wet Cooling tower and Air Cooled Heat Exchanger (Innovative Combined Cooling System); b) Steam generator connected to the Air Cooled Condenser and to the Surface Condenser; c) 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 plants 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 UV-transparent laboratory tubular reactor
- Cell culture bioreactor

SOLAR CPC PILOT PLANTS

Since 1994, several CPC pilot plants have been installed at PSA facilities (Figure 86). 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.

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 86) 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 (). 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.

Figure 86. View of several CPC photo-reactors for purification of water. water (up) CPC facilities I (down) CPC facilities II.

Figure 87. View of 2 m2-CPC coupled to Electro-Fenton pilot plant (ELECTROX).

Figure 88. View of new CPC and U-type photoreactors (NOVO 75 V 1.0).

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

Table 1. Summary of the CPC pilot plants available at PSA facilities.

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 89. Raceway Pond Reactor with capacities of: a) 15 L and 5 cm of liquid depth and b) 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).

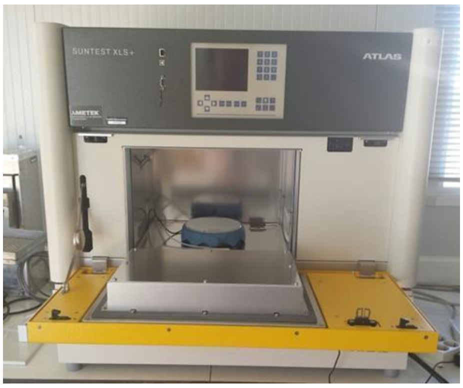

Figure 90. Solar simulator SUNTEST XLS+.

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 91.a).

Figure 91. UVC pilot plant installed at PSA facilities (left) and recent improvements (right).

The UVC pilot plant was improved (Figure 91.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 92) 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.

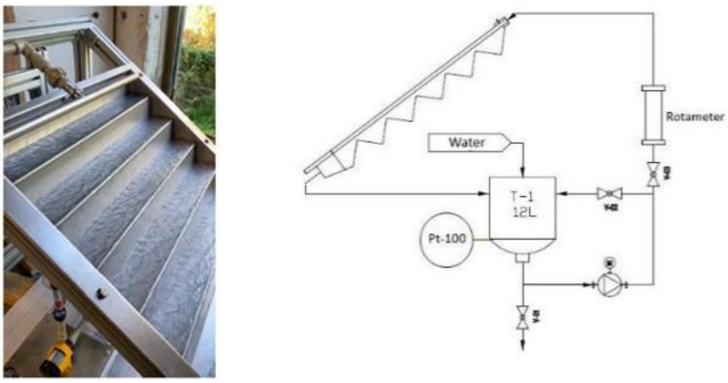

Figure 92. Solar waterfall reactor photography (left) and scheme (right).

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 93):

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

Figure 93. UV-LED lab system available at PSA facilities.

OZONATION PILOT PLANT

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

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 94.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 94.b and Figure 94. 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 94.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.

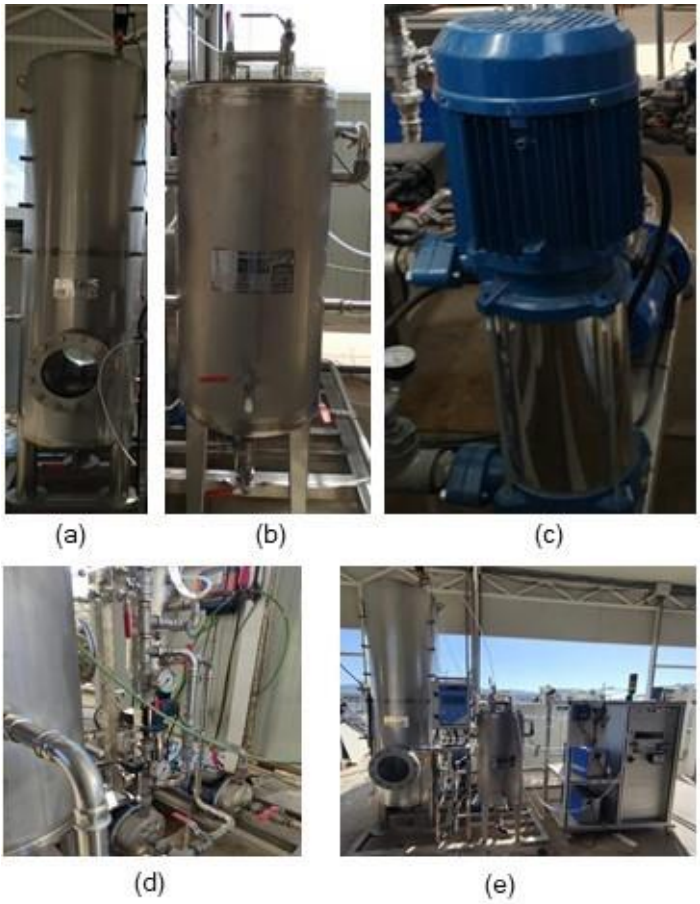

Figure 94. Pictures of the improved parts of the ozonation pilot plant a) New 580L contact column reactor; b) Pressurized tank; c) HP pump for nano-bubbles generation; d) Venturi for micro-bubbles injection and e) complete view of the new ozonation pilot plant.

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 95. 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 96.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 96.b) for controlling the required quality of the permeate flow generated as well as the concentrated stream.

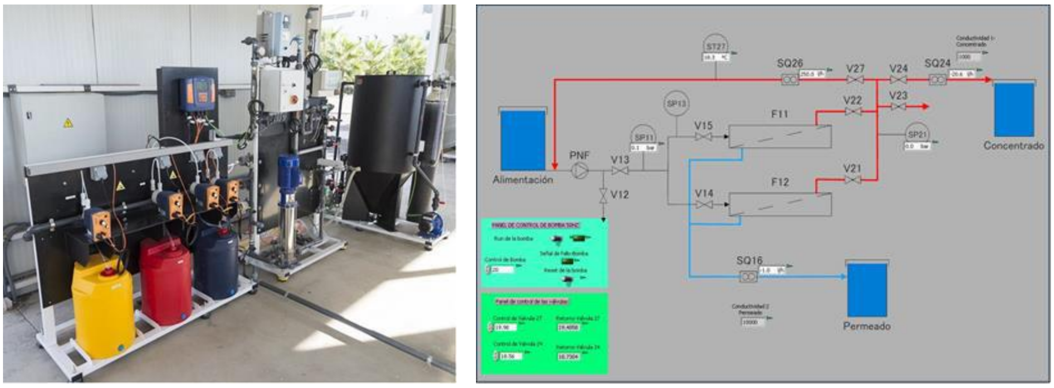

Figure 96. Nanofiltration pilot plant (left) and labview interface for control and automatic operation of the pilot plant (right).

PILOT PLANTS FOR THE PHOTOCATALYTIC PRODUCTION OF HYDROGEN

Two pilot plant reactors are available for carrying out reactions under anoxic conditions, specifically designed for photocatalytic hydrogen generation.

25-L Pilot plant consists of:

- Compound parabolic concentrator (CPC) solar reactor: composed by 16 borosilicate glass tubes, 32 mm in outer diameter and 1530 mm in length, connected in series and positioned at the focal point of the CPC solar anodized aluminium mirror. The photoreactor is mounted on a fixed platform tilted at 37° (corresponding to the latitude of the PSA-CIEMAT facility). The total and the irradiated volume are approximately 25 and 14 L, respectively, with a total irradiated area of 2.1 m² (Figure 97).

- 10 L closed stainless-steel tank: fitted with gas and liquid inlet and outlet, a sampling port and headspace volume of 7 L.
- Gas phase circulation system: two mass flow controllers (operating range 0.4-20 mL/min and 20-500 mL/min; BRONKHORST HI-TEC) are used to control the nitrogen gas flow, which is employed to remove oxygen from the system as well as to eject the hydrogen produced from the system and carry it to the MicroGC analyser that uses Ar as gas carrier (Micro-GC 490, Agilent).
- Liquid recirculation system: composed by a pump (PanWorld NH-100PX, flow rate: 30 mL/min) that allows the recirculation from the tank, through the CPC and its return.

Figure 97. Photoreactor installed at PSA-CIEMAT facility composed by: (left) Stainless steel tank, mass flow controller and gas cromatograph and (right) Compound parabolic collector (CPC).

6-L Pilot plant consists of:

- Compound parabolic concentrator (CPC) solar reactor: composed by 2 borosilicate glass tubes, (50 mm in outer diameter and 1100 mm in length), connected in series and positioned at the focal point of the CPC solar anodized aluminium mirror. The photoreactor is mounted on an adjustable platform, whose angle can be modified to optimize solar radiation capture. The total and irradiated volume are approximately 6 and 3 L, respectively, with a total irradiated area of 0.29 m².
- 4.4 L closed stainless-steel tank: fitted with gas and liquid inlet and outlet, a sampling port and headspace volume of 2.8 L.
- Gas phase circulation system: two controllers (BRONKHORST HI-TEC, two ranges: 10-500 mL/min and 2-100 mL/min) are used to control the nitrogen gas flow for the removal of oxygen from the system and for driving the hydrogen produced from the system to the MicroGC analyser that use Ar as gas carrier (Micro-GC 990, Agilent). The gas line also includes a dedicated branch for calibrating the equipment.
- Liquid recirculation system: composed by a pump (PanWorld NH-100PX, flow rate: 20 mL/min) that allows the recirculation from the tank, through the CPC and its return.
- 15 L sedimentation tank: to facilitate recovery and reuse of the photocatalyst.

WET AIR OXIDATION PILOT PLANT

A pilot plant was designed and installed in 2016 as a harsh pre-treatment to reduce the complexity of industrial effluents and reaction time of a subsequent solar advanced oxidation process (AOPs) (Figure 98). 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.

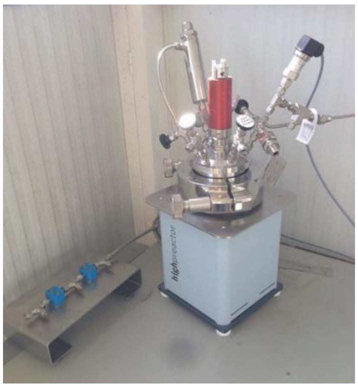

Figure 98. Wet Air Oxidation Pilot plant.

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 99).

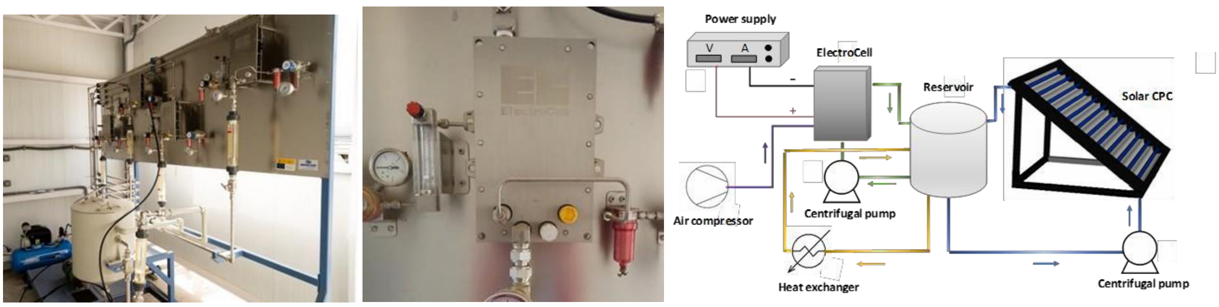

Figure 99. Electro-oxidation pilot plant (left); Electrochemical cell of the solar-assisted electrooxidation pilot plant (centre) and schematic diagram of the solar-assisted electrooxidation pilot plant (right).

SOLAR UVA MONITORING EQUIPMENT

UV and global solar radiation data monitoring and storage system is composed by different pyranometers (Figure 100), 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: 2,000 $W\cdot m^{-2}$), 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 - 1,100 nm.

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

Figure 100. CUV-5 radiometer (left). View of all solar UV radiometers, horizontal (centre) and inclined (right) setup used in the Solar Treatment of Water Unit.

PILOT PLANT FOR PHYSICOCHEMICAL PRE-TREATMENT OF WASTEWATERS

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

PILOT PLANTS FOR BIOLOGICAL TREATMENT

A biological pilot plant with a double depuration system (Figure 101) 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 101. 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 102).

Figure 102. 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 103). 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} =2,200 $m^3 \cdot h^{-1}$).

Figure 103. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

SOLAR UV-TRANSPARENT TUBULAR REACTOR

The solar UV-transparent tubular reactor (Figure 104) has been provided by APRIA Systems S.L. and consists of a tubular tube with an illuminate surface of 0.05 m^2 (75 mm diameter and 216 mm height). This reactor allows working with maximum 1 L of water under oxidant and reducing conditions.

Figure 104. UV-transparent laboratory tubular reactor available at PSA facilities.

Figure 105. Cell culture bioreactor at WATLAB laboratory facilities.

CELL CULTURE BIOREACTOR

A jacketed cell culture bioreactor system (Figure 105) with a total volume of 3 L (minimum working volume of 0.5 L). For precise temperature control it is sealed by a single piece 316L stainless steel headplate equipped with 18 ports which offers flexibility to use different accessories depending on the process (air inlets/outlets, probe holders, sampling tubes, baffles, etc). It includes an overhead agitator (20 to 800 RPM), which drives three 6-blade Rushton impellers (46 mm) to ensure homogeneous distribution of nutrients, gases, and cells. To maximize mixing efficiency and prevent vortex formation, the system is equipped with three internal baffles. For gases delivery, 3 units of L-type gas spargers featuring a 15-micron porous sintered metal tip ensuring fine bubbles and an optimal air aeration and gas transfer.

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

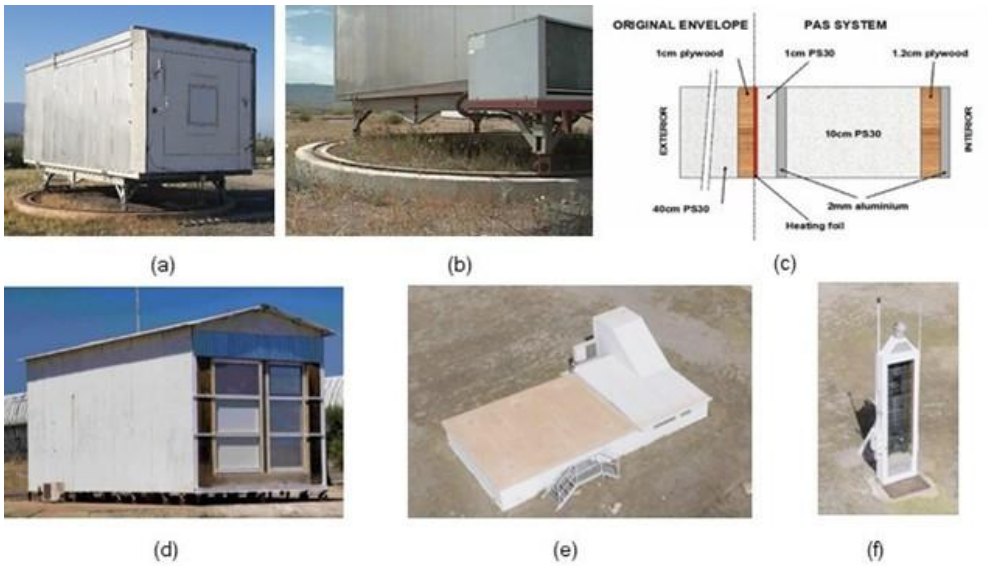

Figure 106. (a) Prefabricated industrialised modules being tested at the PASLINK Test Cell, (b) Detail of the rotating device, (c) Schematic drawing of the PAS system, (d) Set of prefabricated industrialised modules being tested at a CESPA Test Cell, (e) Exterior of the CETeB Test cell, (f) Solar Chimney.

Figure 107. (a) ARFRISOL Building Prototype in use, (b) 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 108.a), for measuring heat loss of single receiver tubes under indoor laboratory conditions, and b) an outdoor test bench called RESOL (see Figure 108.b), 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 108. 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).

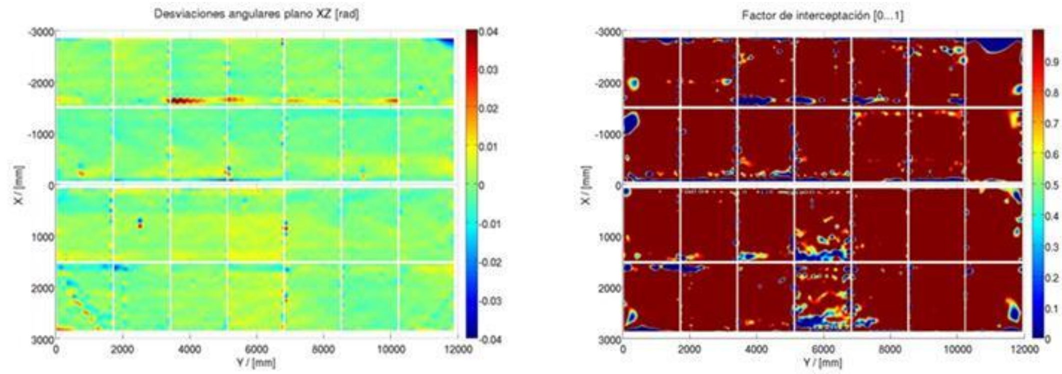

Figure 109. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry.

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 110. 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 1000 °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 111. IR sensor calibration using a black body.

Laboratory of Thermal Energy Storage (TESLAB)

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 (Figure 112. right), for condensing the evolved gases. It allows performing consecutive thermal cycles up to 500 °C and isothermal stand-by periods. Sample temperature can be monitored, and sample mass can be in the range of 1-10 g.

Figure 112. HDR.

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

Figure 113. SUBMA.

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

Figure 114. 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.

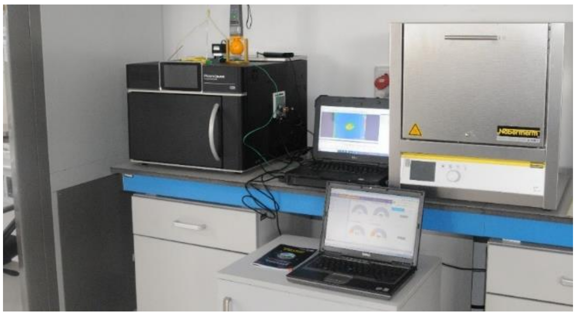

Figure 115. Microwave experimentation set up.

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

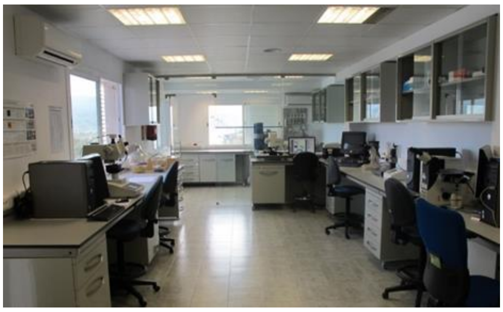


Figure 117. View of the Microscopy Room (left) and the thermogravimetric balance inside of its room (right).

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 by SOC) and emissometer (ET100 by SOC) 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 118. 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 118).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 118).
- LEICA DM4 M optical microscopy with image acquisition system and software for image analysis (Figure 118).
- KSV CAM200 goniometer for measuring static contact angles (Figure 118).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 118).
- Rotational Viscometer SELECTA.
- BRUKER DektakXT stylus profilometer with optical camera and software for surface analysis (Figure 118).
- TABER linear abrader model 5750, equipped with different types of abrasive materials to measure the abrasion resistance of coatings and materials (Figure 118).
- 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 118).
- 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/cm2 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 119) 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 119. 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 120) 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) are 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, V-AGMD).
- Temperature precision of 0.05 °C.
- Driving force temperature difference controllable.
- Fully automated control system and large range of possible parameter settings by touch screen PLC.
- Lab-scale system to assess and quantify wetting, by using a transparent plate and frame cell with membrane area of 220 mm x 150 mm. With UV-A light and uranine, a harmless fluorescent substance added to the saline feed, the evolution of membrane wetting and permeate quality over time can be characterized and monitor for different commercial membranes, conditions, and operating modes (Figure 120).

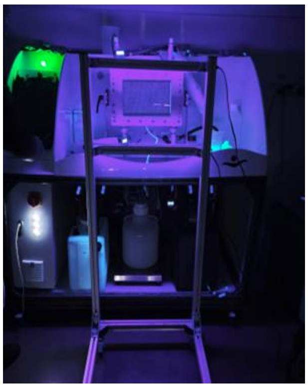

Figure 120. Bench-scale unit for testing MD with flat-sheet membranes (left), and UV-A arrangement for wetting characterization (right).

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 121). 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 121. 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 122). 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 122. General view of the new PSA Water Technologies Lab.

CHROMATOGRAPHY LABORATORY

This laboratory (Figure 123 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 123 C) and two ion chromatographs (Figure 123): 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 123 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 123 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 123. (a) Metrohm Ion Chromatographic System. (b) General view of the chromatography lab at PSA facilities. (c) Agilent Ultra-fast UPLC-DAD analyser. (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 124) 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 124. 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 125).

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 125. 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 has been called METAS station since 2012 (Figure 126).

The METAS station instruments are in the highest range of solar radiation measurement. All the radiation sensors are ventilated-heated and have a temperature measurement sensor. This equipment provides the best information on solar radiation and more general atmospheric variables and can be used for filtering input data and validating spectral models. They are used for:

- Measurement of the terrestrial radiation balance. Incoming and outgoing shortwave and long-wave radiation is measured at 30 m
- Solar radiation component characterization: (global, direct and diffuse)
- UV and PAR spectral bands

- Vertical wind profile: wind speed and direction at 2, 10 and 30 meters
- Vertical temperature and humidity profile at 2 and 10 meters
- Miscellaneous weather information: rain gauge, barometer and psychrometer

Figure 126. General view of METAS station.

Additionally, a set of complementary structures for the calibration of radiometers has been installed near to this meteorological station following the standardized international procedures (ISO-9059 and ISO-9846). On the one hand, a high-performance tracker with the possibility of carrying 2 reference pyrheliometers (absolute cavity radiometer PMOD PMO6-CC) and a total of 19 field pyrheliometers have been installed close to METAS; on the other hand, 3 calibration benches, with capacity to carry 20 pyranometers each one, have been placed 50 meters away from METAS (Figure 127). These facilities are operated in collaboration with the Instrumentation Unit.

Figure 127. Calibration facilities.

Since early 2018, there are seven new fully operational radiometric stations in the PSA area (Figure 128). All of these stations are equipped with first-class pyranometers and pyrheliometers, dual-axis solar trackers, and Campbell CR1000 data acquisition systems (METAS is equipped with a Campbell CR3000).

Figure 128. PSA radiometric stations.

15 Events

24th January 2025

Invited talk

Sixto Malato gave a talk in the XXI Scientific Conference of the University Materials Institute of Alicante, Spain.

4th Feb 2025

Visit

Visit to the PSA of the Department of Optics from the University of Granada.

19th February 2025

Invited talk

Sixto Malato gave a talk in the "Master Universitario en gestion Sostenible y Tecnología del Agua". In the Escuela Politécnica Superior. University of Alicante, Spain.

15th March-30th June 2025

Research Stay

Naia Barandica. Stay at National Institute of Chemistry (Slovenia), in the Laboratory for Coating Development.

1st April 2025

Course

Alba Ruiz Aguirre participated in the "Mares y Costas de Andalucía" course with the oral presentation "Desalación Sostenible: Integración de energías renovables para un futuro sin escasez de agua".

9th April 2025

Course

Samira Nahim-Granados gave an invited talk in the Training course on technologies and tools for the efficient reuse of wastewater in the University of Valencia, Spain.

9th April 2025

Course

Lidia Roca participated at the MEIoDIZER school with the course " Water & renewables. Coupling with renewable energy".

13th - 14th May 2025

Workshop

Second prize for Best Poster Presentation at the workshop "Smart Operation of Energy Storage Technologies in Future Energy Markets", held in Madrid in May 2025 to the work: Baigorri, J.; Kubikova, T.; du Toit, T.; Rodriguez-de-Arriba, P.; Romani, J.; Sanchez, D.; Ávila-Marín, A.L.; Zaversky, F.; Techno-economic Assessment of Hybrid Energy Storage: Integrating High-temperature Air-based CSP and CAES for Optimized Operation in Spain.

17th - 22nd May 2025

Invited expert

Antonio Ávila-Marín, member of the HelioCon Board of Advisors, carried out a one-week stay in Las Vegas (USA), fully funded by the HELIOCON project, to attend the workshop organized at the University of Las Vegas and to participate in the annual HELIOCON project meeting.

30th May 2025

Visit

Visit to the PSA of students of the Master's Degree in Energy 2024/25 of the Universidad Autónoma de Madrid

3th June 2025

Workshop

Naia Barandica acted as organizer and participant in the first edition of workshop NEXTGEN CIEMAT which took place in CIEMAT, Madrid.

4th June 2025

Award

Particia Palenzuela and Lidia Roca awarded by EU-SOLARIS, in the category “Outstanding contribution to the improvement of CST research infrastructures’ capabilities and services” for the contribution “Research Facility to Improve the Resources Management in Cooling for CSP Plants".

6th June 2025

Invited talk

Isabel Oller gave an invited talk titled “Wastewater recovery by alternative water treatment technologies in Industry” within the 2nd EUSOLARIS Doctoral Colloquium in Almería (Spain).

1st and 3rd July

Invited Talk

Antonio Ávila-Marín delivered 8 hours invited lectures on “New trends in Concentrated Solar Thermal Technologies” at Politecnico di Torino (Italy)

9th June 2025

Invited Professor

Antonio Ávila-Marín was invited as a Visiting Professor at the Politecnico di Torino (Italy) for a one-month research stay, carrying out postdoctoral research activities on microscale porous media simulation.

15th September 2025

Invited talk

Sixto Malato and Ilaria Berruti gave invited talks in the “International school on water reuse (ISWR) - 4th edition”. University of Torino, Italy.

18-19th September 2025

Workshop

Antonio Ávila-Marín and Daniel Sánchez-Señorán organized the “2nd International Workshop on Solar Towers Performance Enhancement & Cost Reduction”, held at CIEMAT - PSA on 18-19 September 2025, within the framework of the EU-SOLARIS funded project "Analyze Heliostat Field - Phase II: BCS as a calibration reference system".

9th Oct 2025

Visit

Visit to PSA for the start of the 2025-2026 Master's Program in Solar Energy at CIESOL-University of Almería.

12th -13th October 2025

Invited talk

Sixto Malato gave a talk in the "2nd Latin-America School on Environmental Applications of Advanced Oxidation Processes (AOPs)". NH Collection Monterrey, San Pedro, México

15th -17th October 2025

Invited talk

Sixto Malato gave a talk in the I Simposio InnoBio - Innovación y Ciencia en la Frontera del Conocimiento. "Experiencias en la creación y gestión de unidades de investigación: Grupos, Centros e Instituciones". Universidad Nacional de Colombia, Sede Manizales. Manizales, Colombia.

20th -21st October 2025

Invited talk

Sixto Malato and Isabel Oller gave invited talks in the "Escuela Colombiana de Procesos Avanzados de Oxidación", University of Medellín, Medellín, Colombia.

3rd November 2025

Round table

Isabel Oller was invited as expert for the Inaugural coffee break of the Andalusia Science Week at the University of Almería with the high school and secondary school students from Benhadux, in the University of Almería (Spain).

3rd-4th November 2025

Seminar and workshop

The URBAN MOME Network on URBAN MOME Network, Towards efficient URBAN environments through MOdelling, MEasurement, and control in the built environment, leaded by M.J. Jiménez and S. Soutullo, celebrated a dissemination Seminar followed by a workshop hosted and co-organised by IREC in Barcelona, Spain. 3-4 November 2025. The event had the participation of National and International experts in the topic. This Network is funded by Spanish National Research Agency, as thematic network ref. RED2022-134655-T.

5th November 2025

Expo

Alba Ruiz Aguirre participated at the Desalination Technology EXPO with an oral speaking invitation to discuss "Sustainable Desalination Living Lab: Innovation for Water Management in Semi-Arid Regions"

10-12th November

Workshop

Antonio Ávila-Marín participated as an invited speaker in the Workshop on Concentrated Solar Power (CSP) and High-Level Meetings between Mexican Energy Sector Institutions and SolarPACES, held in Mexico City (Mexico) on 10-12 November 2025, delivering the presentation “Heliostat Field Technology Review: Design & Operation Considerations.”

12th November 2025

Workshop

Alba Ruiz Aguirre was invited to the1st International Workshop on Photovoltaic Technologies and Desalination for Sustainable Development (IW PTDSD ´25) with the plenary talk “Solar Thermal-Assisted Concentration of RO Brines for Circular Desalination Systems”.

1st December 2025

Workshop

Alba Ruiz-Delgado and Isabel Oller were invited to give a talk in the 4th University-Business Conference “Professional Profile of the Chemical Engineer” in the University of Almería, Almería (Spain).

2nd Dec 2025

Visit

Visit to the PSA by students of the Engineering Degree in Energy 2024/25 of the University of Málaga.

4th December 2025

Webinar

Alba Ruiz Aguirre participated in the1st Public Webinar of MEIoDIZER project. From Seawater to Freshwater with the course “Implementation of Sustainable Prototypes”.

10th-11th December 2025

Training

Alba Hernández Zanoletty, Ilaria Berruti, Samira Nahim, Sixto Malato and Isabel Oller participated in the organization of the Short-term Training for Researchers and Technical Staff. “Technologies, analytical techniques and current issues on non-conventional wastewater treatment”, CIESOL-PSA (CIEMAT), Almería, Spain.

11th December 2025

Workshop

Alba Ruiz-Delgado gave a talk titled “The role of the sun in the redox photoreactions for the treatment and artificial photosynthesis” in the XIX Marathon of EEZA (CSIC). University of Almería (Spain).

15th December 2025

Online seminar

Alba Ruiz Aguirre participated in the Doctoral Program in Chemical Engineering, Energy and Process Engineering at the University of Cantabria with the course “Concentración de salmueras asistida por energía solar térmica para sistemas de desalación circulares”.

16 Publications

PhD Thesis

Alba Hernández Zanoletty. Innovative strategies based on natural and solar technologies for urban wastewater reclamation. Universidad de Almería, Escuela Internacional de Doctorado (EIDUAL). 29th May 2025. Supervisors: Isabel Oller Alberola and María Inmaculada Polo López.

Daniel Sánchez-Señoran. Thermo-fluid-dynamic analysis of wire mesh volumetric receivers: geometrical parameters and operating conditions. Universidad Rey Juan Carlos (URJC), 3rd June 2025. Supervisors: Antonio L. Avila Marin and Miguel Ángel Reyes Belmonte (URJC).

Isabel Requena. Batch operating solar membrane distillation systems for concentration of brines. Universidad de Almería. 29th May 2025. Supervisors: Guillermo Zaragoza and Juan Antonio Andrés Mañas.

SCI publications

Abad-Alcaraz V., Castilla M., Carballo J.A., Bonilla J., Domingo Álvarez J. Multimodal Deep Learning for Solar Radiation Forecasting. **Applied Energy**. 2025. 393, 126061. https://doi.org/10.1016/j.apenergy.2025.126061

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