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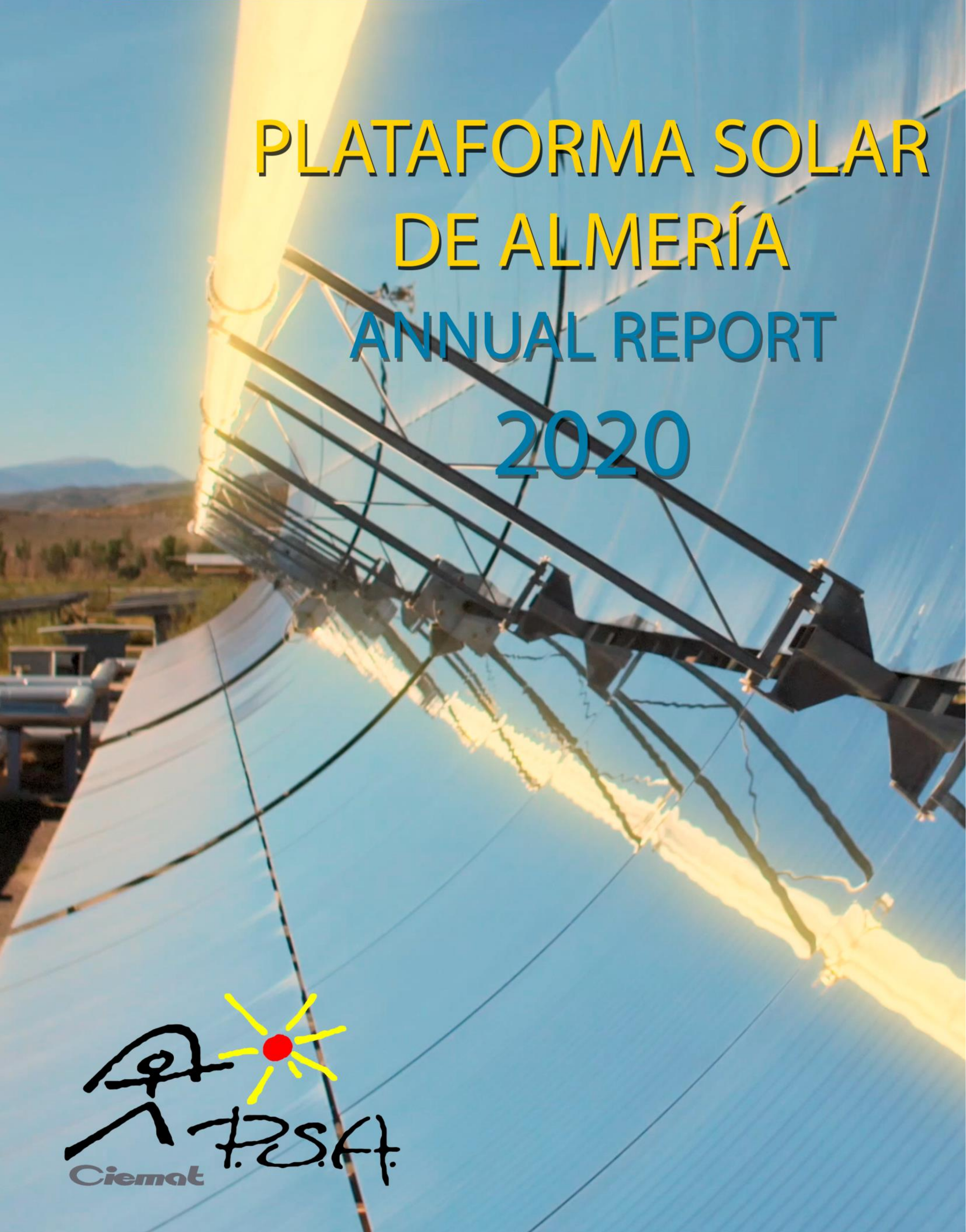

PLATAFORMA SOLAR DE ALMERÍA

ANNUAL REPORT 2020

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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.

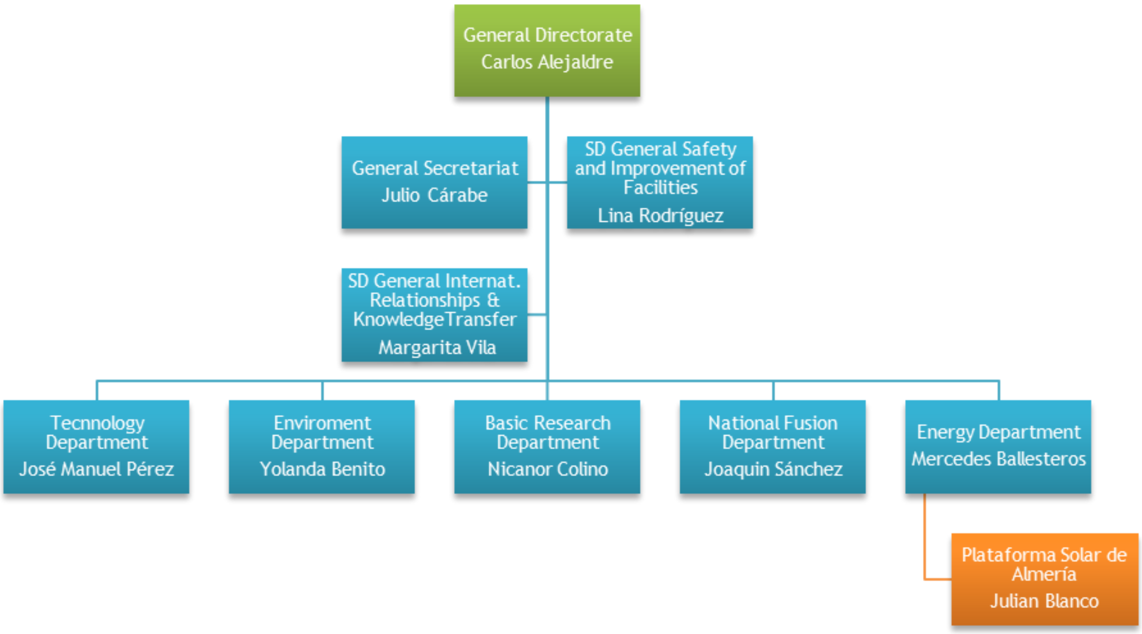


Figure 1. Integration of the PSA in the CIEMAT organization.

The following goals inspire its research activities:

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

Until 2020, research activity at the Plataforma Solar de Almería has been structured around four R&D Units under a Technical Coordinator, plus a strong unit to manage and also coordinate all facilities and laboratories, namely the PSA Management Unit. In addition to the different horizontal services (IT ser-vices, 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.

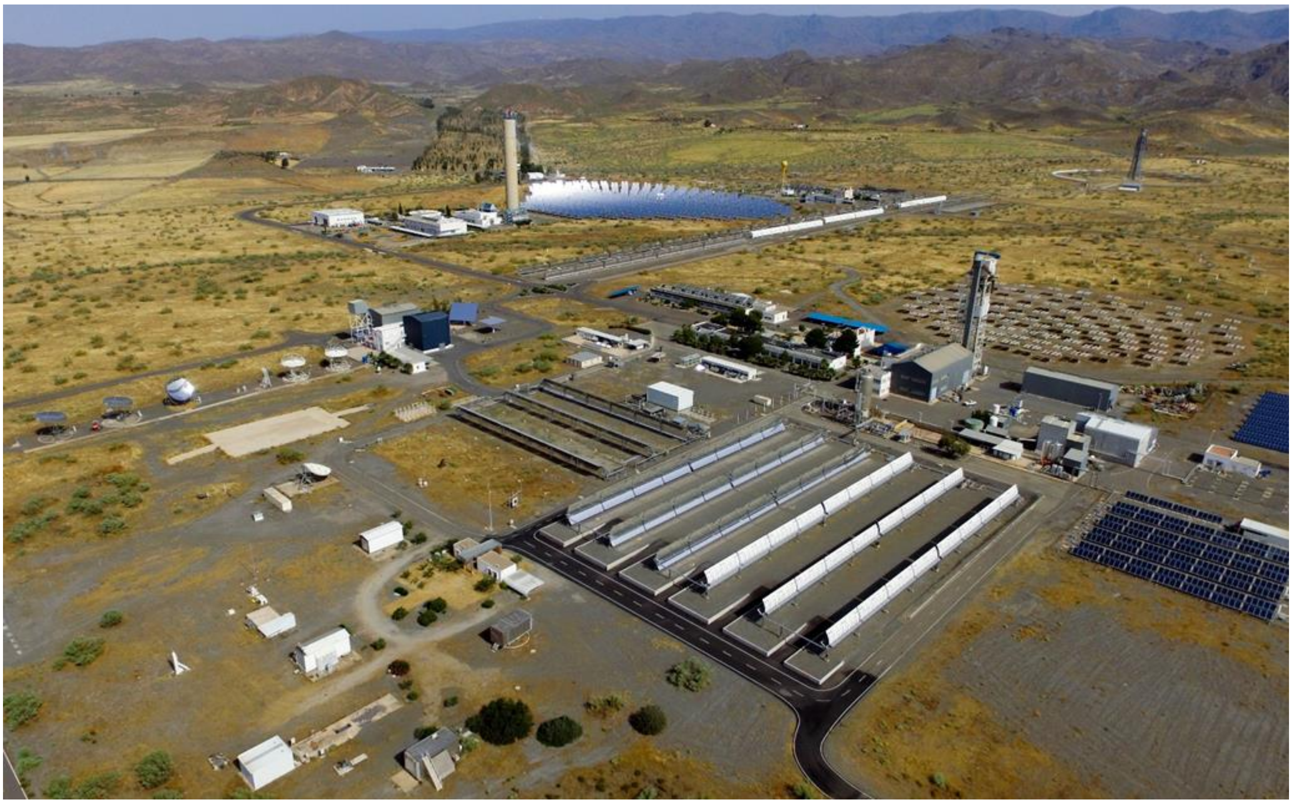


Figure 2. Aerial view of the PSA.

The four R&D Units are as follows:

- Solar Concentrating Systems. This unit develops and studies components for solar fields, complete systems, and applications of concentrated solar thermal energy technologies, for electricity generation and industrial process heat.
- Solar Desalination. Its objective is to develop brackish water and seawater solar desalination.
- Solar Treatment of Water. Exploring the chemical possibilities of solar energy, especially its potential for water decontamination and disinfection.
- Thermal Storage & Solar Fuels. The objective of this Unit is providing solutions to concentrating solar thermal systems to become a dispatchable technology, by thermal storage systems and/or Hydrogen production by thermochemical processes.

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 four 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. It is also the Director's Office that channels demands to the different general support units located at CIEMAT's main offices in Madrid.

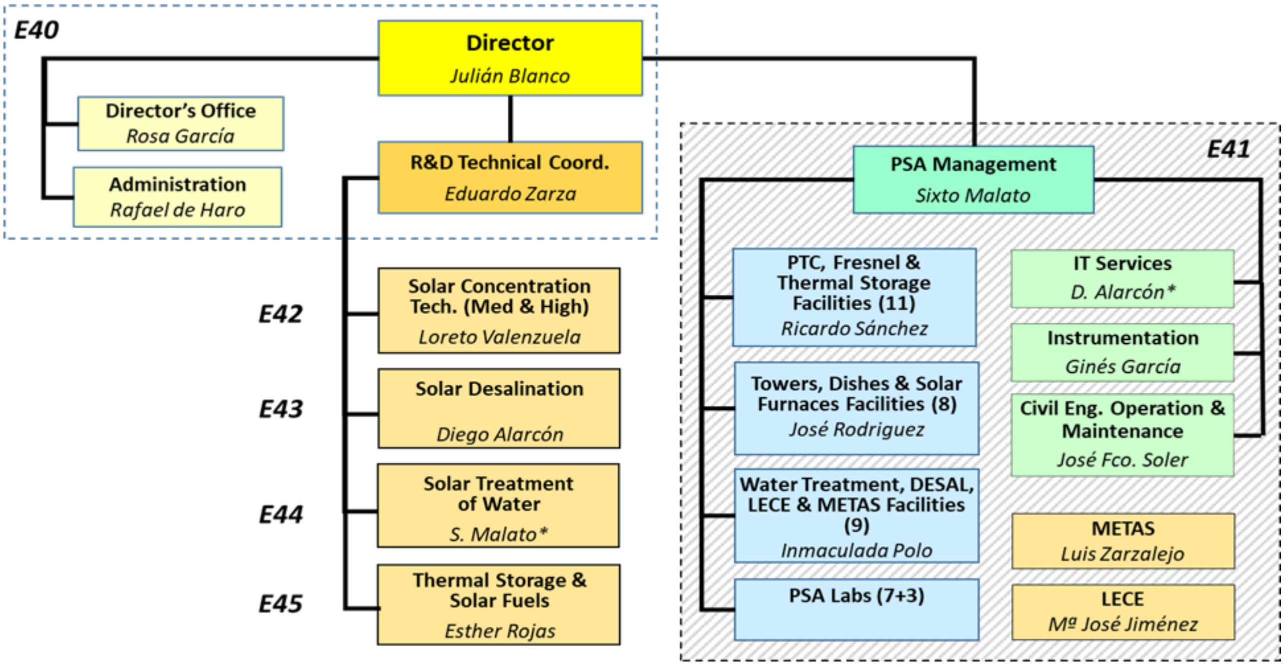


Figure 3. Internal organizational structure of PSA in 2020.

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 134 persons that as of December 2020 made up the permanent staff lending its services to the Plataforma Solar de Almería. In addition to this staff, there is a significant flow of personnel in the form of visiting researchers, fellowships and grants handled by the Office of the Director. Of the 122 people who work daily for the PSA, 65 are CIEMAT personnel, 13 of whom are located in the main offices in Madrid.

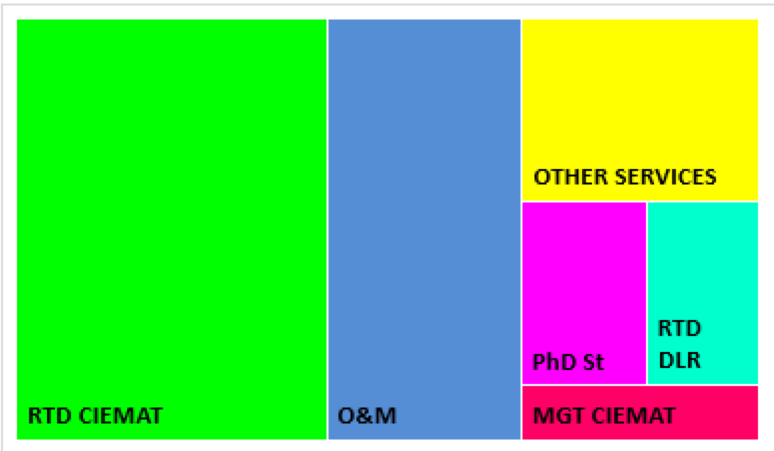


Figure 4. Distribution of permanent personnel at the PSA as of December 2020.

In addition, the 8 persons 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 are made up of a no less important group given the centre's characteristics. These are the personnel working for service contractors in operation, maintenance and cleaning in the various different facilities. Of these 32 persons, 15 work in operation, 13 in maintenance and 4 in cleaning. The auxiliary services contract is made up of 5 administrative personnel and secretaries, 7 IT technicians for user services, and another 5 persons from the security contract, what makes a total of 17 per-sons.

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

The PSA operating budget in 2020 totals 3.1M Euros (not including R&D personnel or new infrastructure).

Figure 5. PSA staff in 2020.

2 Facilities and Infrastructure

2.1 Parabolic Trough Systems

2.1.1 The DISS experimental plant

This test facility was erected and put into operation in 1998 for experimenting with direct generation of high-pressure-high temperature (100 bar/400°C) steam in parabolic-trough collector absorber tubes. It was the first 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 6 and Figure 7) consists of two subsystems, the solar field of parabolic-trough collectors and the balance of plant (BOP). In the solar field, feed water is preheated, evaporated and converted into superheated steam at a maximum pressure of 100 bar and maximum temperature of 400°C as it circulates through the absorber tubes of a 700-m-long row of parabolic-trough collectors with a total solar collecting surface of 3,838 m^2. The system can produce a nominal superheated steam flow rate of 1 kg/s. In the balance of plant, this superheated steam is condensed, processed and reused as feed water for the solar field (closed loop operation).

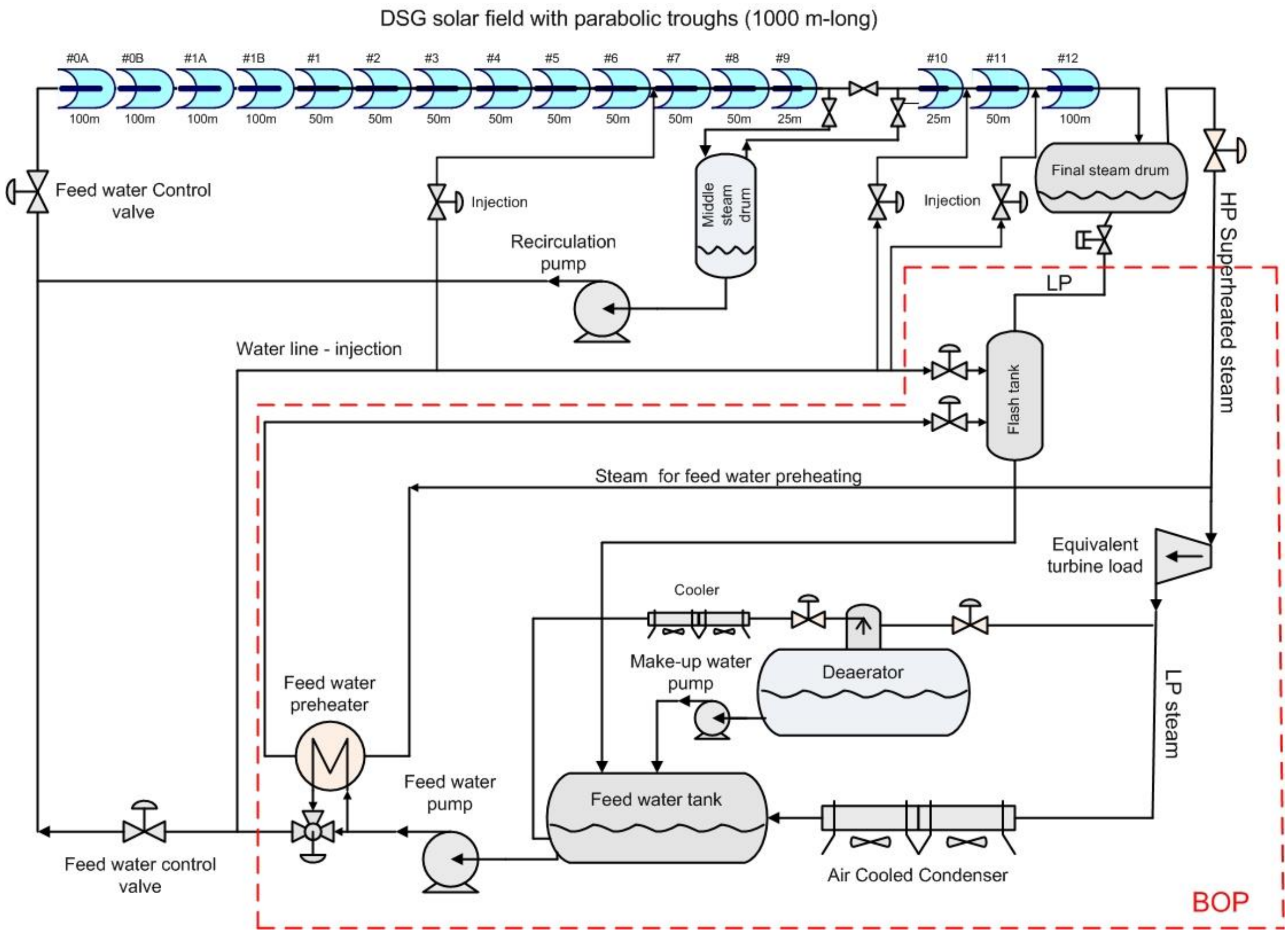


Figure 6. Simplified flow diagram of the PSA DISS loop.

In 2012, within the DUKE Project, three additional parabolic-trough collectors were installed in the solar field and all the absorber tubes were replaced by new ones, to increase up to 500°C the temperature of the superheated steam produced, enabling to generate direct steam at 100 bar and 500°C.

Facility operation is highly flexible and can work from exceptionally low pressures 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 in 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 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 7. 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 holes, water-steam separators, specific instrumentation, etc.).
- Study and development of control schemes for solar fields with DSG.
- Study and optimization of the operating procedures that must be implemented in this type of solar field.
- Thermo-hydraulic study of two-phase of water/steam in horizontal tubes with non-homogeneous heat flux.

2.1.2 The HTF Test Loop

The HTF test loop was erected in 1997 and it is an ideal facility for evaluating parabolic-trough collector components under real solar energy operating conditions. The facility is appropriately instrumented for qualifying 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 flex-hoses for connecting parabolic-trough collectors in the solar fields.
- Solar tracking systems.

The facility consists of a closed thermal-oil circuit connected to three solar collectors of 75-m long connected in parallel, being able to operate only one at a time (see simplified diagram of the facility in Figure 8). The east-west rotating axis of the solar collectors increases the number of hours per year in which the angle of incidence of the 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.

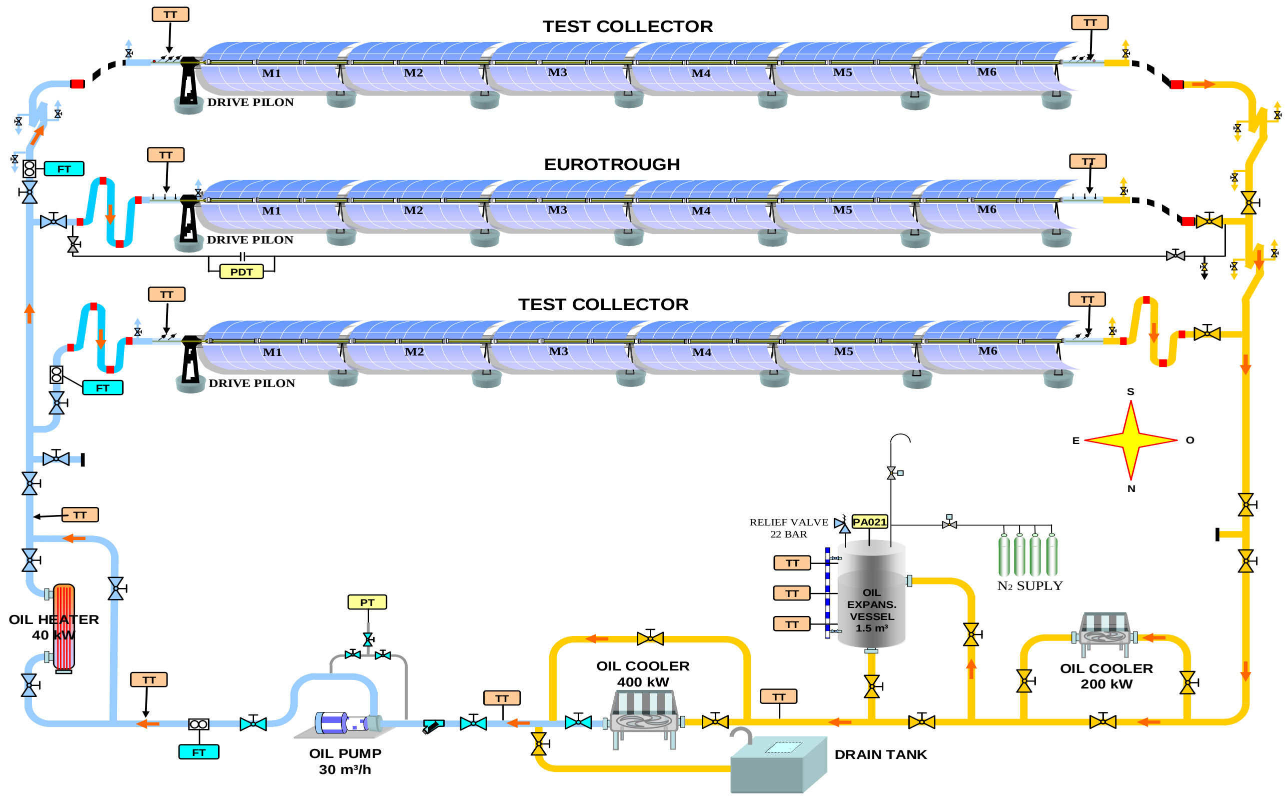


Figure 8. Diagram of the HTF test Loop located at the PSA.

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

- 1-m^3-capacity oil expansion tank, with automatic nitrogen inertisation.
- Oil circuit sump tank.

- Mechanical-draft oil cooler, with air speed control and 400-kW maximum cooling.
- Centrifugal oil pump, with a flow rate of up to 8.3 litres per second.
- Two 40-kW electric oil heaters.

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 in 1998. This collector is now used to evaluate and qualify new designs of receiver tubes, reflectors and other components for parabolic-trough collectors.

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

2.1.3 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 E-W orientation complete parabolic trough collectors with a maximum unit length of 180 m. 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 oriented 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 m^3, a gas-fired oil heater with a thermal power of 250 kW, 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 circuit associated to the North and South fields are composed of:

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

Each oil circuit is also provided with an oil draining tank big enough to receive all the oil existing in the circuit, a complete set of instrumentation to monitor oil mass flow, pressures and temperatures, as well as 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

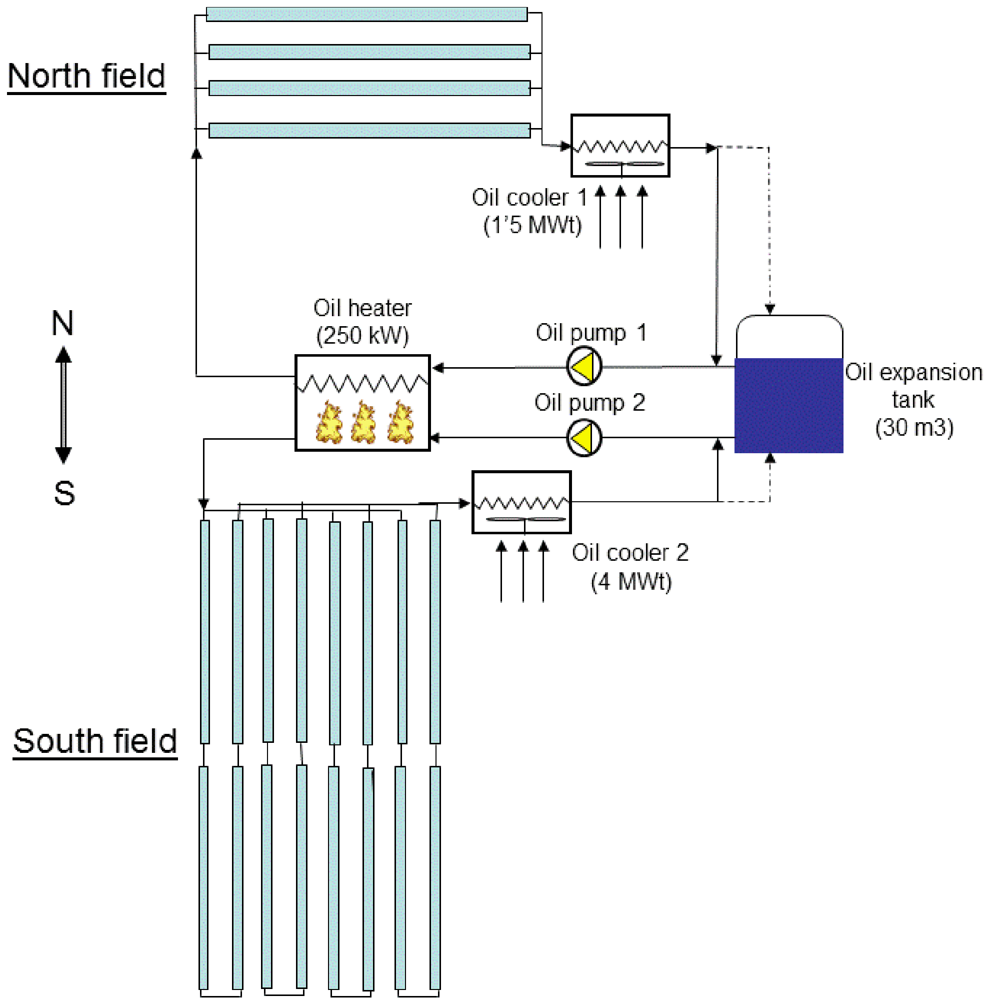


Figure 9. Simplified scheme of the PTTL facility

2.1.4 PROMETEO: Test facility for checking new components and heat transfer fluids for large-parabolic troughs

An experimental closed loop is installed at the North-East area of the PSA. It was designed and erected by the company *Iberdrola Ingeniería y Sistemas* in 2010 starting the test campaign along the following year. The pilot plant was transferred to CIEMAT to be used as testing loop.

The East-West oriented test loop 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.

The collector modules are connected to the balance of plant (BOP) in parallel or in series configuration using the ad hoc set valve. 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 inlet of the collector. 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.

Figure 10. View of the PROMETEO test facility.

2.1.5 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 thermocline 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 11. 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 ≥0.95, and the peak optical efficiency is 77.5%. The receiver tubes used in this solar field were delivered by Archimede Solar Energy (Italy) 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. This is the reason why 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.

2.1.6 Innovative Fluids Test Loop (pressurized gases) in parabolic-trough collectors

The purpose of this experimental facility is to study the use of pressurized gases as heat transfer fluid in parabolic-trough collectors, evaluating their behaviour under a diversity of real operating conditions.

The experimental test loop (see Figure 12) 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.

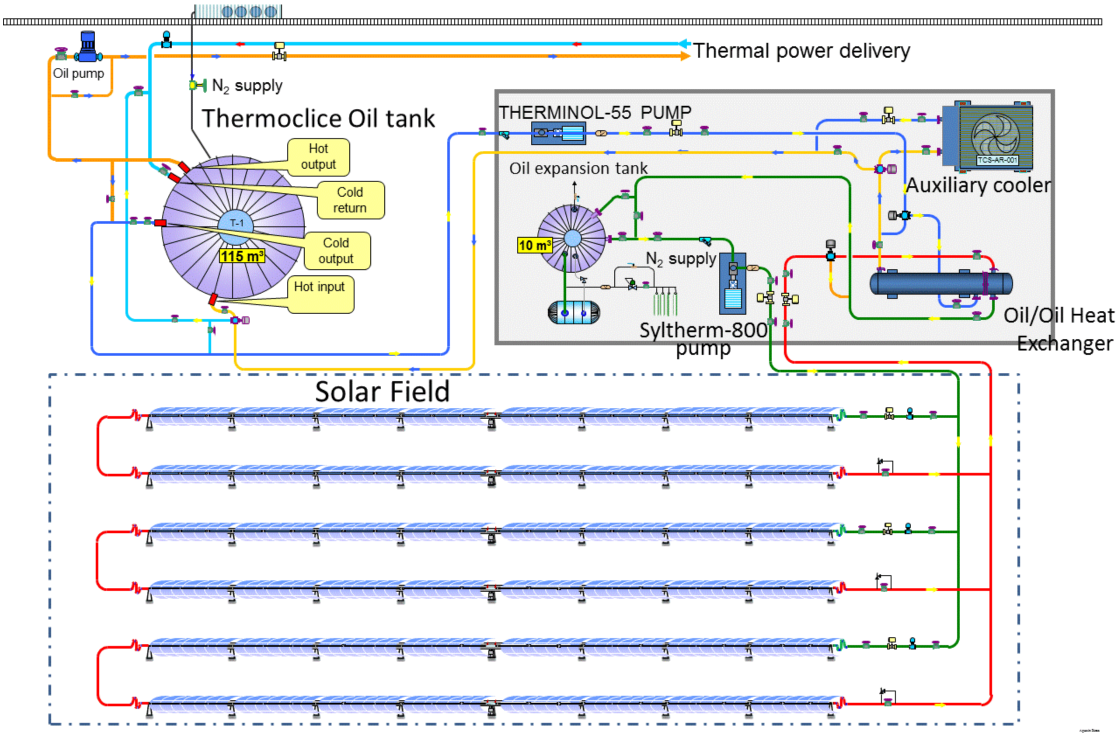


Figure 11. Diagram of the TCP-100 2.3 MWth parabolic-trough facility

The IFL facility was originally designed to work at pressures and temperatures of up to 100 bar and 400°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 are connected in series.
- A 400-kW air-cooler able to dissipate the thermal energy in the fluid delivered by the collectors. It has two 4-kW motorized fans.

Figure 12. View of the IFL experimental facility (with parabolic troughs) using compressed gas as heat transfer fluid.

- A blower driven by a 15-kW motor which 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 for filling the main test loop with the gas used as heat transfer fluid.

Since testing at 400°C was successfully completed at the end of 2009, this facility was then upgraded to achieve temperatures of up to 515°C and it was connected to a two-tank molten-salt thermal storage system to test their joint capacity for collecting and storing solar thermal energy with a view to making use of them in dispatchable high-performance thermal cycles. This increase in test loop design conditions to 100 bar and 515°C made the implementation of different improvements necessary (conventional absorber tubes in one of the two collectors were replaced with advanced high-temperature tubes, stainless steel pipes were installed for the high temperature zone and changes were made in the control system).

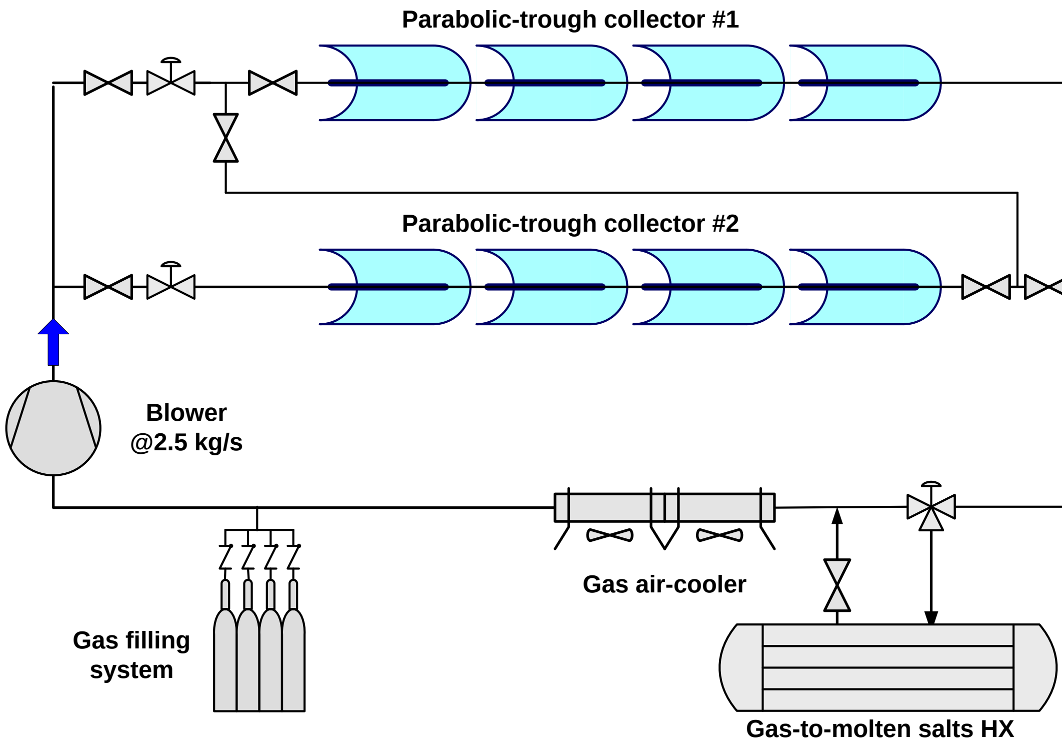


Figure 13. Simplified system diagram of the IFL experimental facility located at the PSA.

2.1.7 NEP: The facility for Polygeneration Applications

Polygeneration is an integral process for the purpose of obtaining three or more products from one or more natural resources. In the case of solar energy, it makes use of the thermal energy from a solar field for several simultaneous applications, such as generating electricity, desalting water for drinking water supply and the rest for domestic hot water (DHW).

The purpose of this facility is the preliminary study of the behaviour of a parabolic trough solar field of small concentration ratio, the determination of its feasibility as a heat source in polygeneration schemes, in particular in CSP+D requiring temperatures around 200°C. The collector selected was the Polytrough 1200 prototype 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 efficiency over 55% in the range of 120-220°C (for 1000 W/m^2 of direct normal irradiance).

The field is configured with eight collectors placed in 4 parallel rows, with 2 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 making use of the thermal energy for polygeneration can be evaluated.

Currently, the solar field is also being used to generate steam for driving the double-effect absorption heat pump coupled to the PSA MED plant.

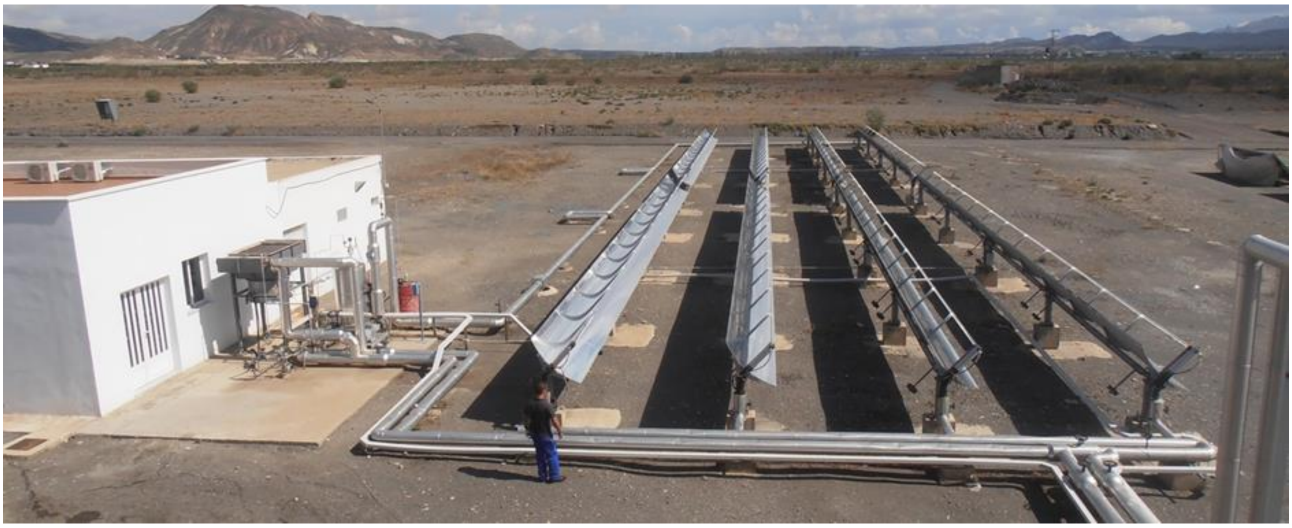


Figure 14. NEP PolyTrough 1200 solar field.

2.2 Installations associated with Parabolic Trough Systems

2.2.1 KONTAS: Rotary test bench for parabolic trough systems

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

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

The 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 is connected to a heating and 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 uncertainties of the density. The heating and cooling unit dissipates the energy the hot 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 inlet of the collector. 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.

Figure 15. Side view of KONTAS test bench and the heating/cooling unit (right side).

2.2.2 Accelerated full lifecycle tests of rotation and expansion performing assemblies (REPAs) for parabolic troughs systems

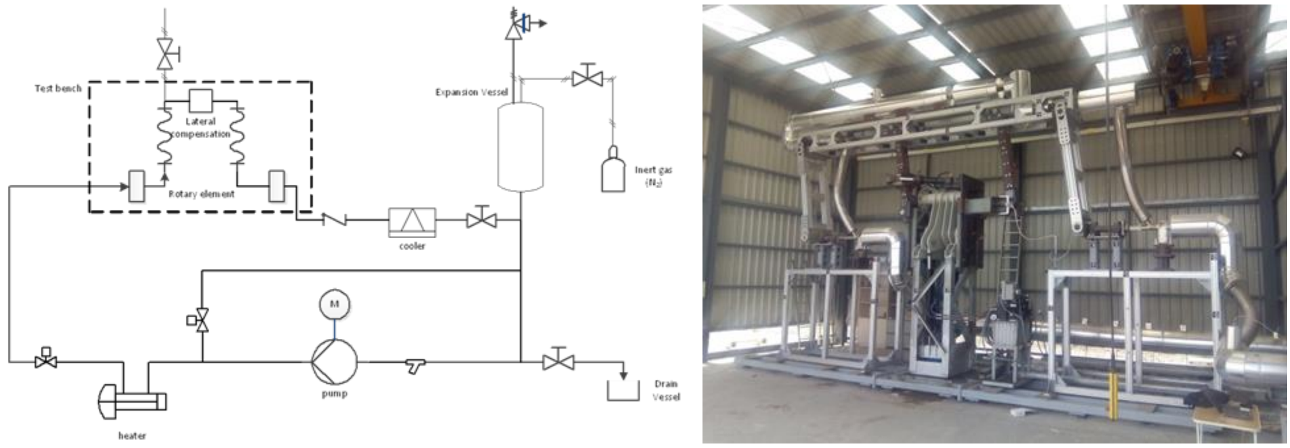
The REPA test facility is the result of merging CIEMAT activities in Task 14.4 of the European project SFERA-II (finished in 2017) and DLR activities within the national German project StaMeP. The facility is now used by CIEMAT and DLR in the framework of a joint collaboration.

The test bench is divided into two functional sections, the so-called kinematics unit, to hold and move the pieces REPAs to be tested, and the balance of plant unit for supplying the conditioned heat transfer fluid (see Figure 16.a).

The balance of plant unit is composed of a variable speed HTF pump which circulates the HTF through a pipe with an adapted collar-type electrical heater before passing through the REPA to be tested, 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 the volume difference caused by the density variation of the working fluid when its temperature changes.

The kinematics unit (see Figure 16.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.
- Rotating angle is 205° and stow position in 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.



(a) (b)

Figure 16. Schematic diagram of the REPA test loop at PSA (a) and north view of the test facility with two flex-hoses mounted for testing (b).

2.3 Central Receiver Systems

The PSA has two exceptional facilities for the testing and validation of central receiver 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.

2.3.1 The 6 MWth CESA-1 Plant

The CESA-1 plant (see Figure 17) 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 17. 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 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 measure of solar extinction is available on-line in the control room of the CESA-1 facility at PSA, facilitating the daily operation tasks (Figure 18). 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.

Currently there is an airborne particle counter in operation whose measurement is of interest for studies of solar extinction, soiling and evaluation of volumetric receivers.

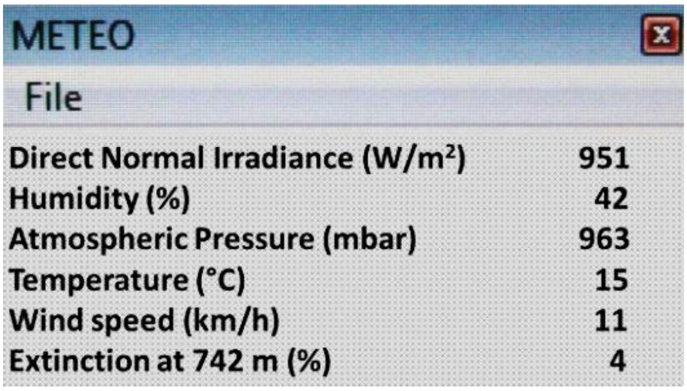


Figure 18. On-line measurement of the solar extinction in the control room of CESA-1 facility at PSA.

2.3.2 The SSPS-CRS 2.5 MWth facility

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

Figure 19. Aerial view of the experimental SSPS-CRS facility.

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

The original SSPS-CRS heliostat field was improved several years ago with the conversion of all its heliostats into completely autonomous units powered by photovoltaic energy, with centralized control communicated by radio using a concept developed and patented by PSA researchers (Figure 20). 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 20. An autonomous heliostat in the SSPS-CRS field.

The nominal average reflectivity value of the field is actually 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, one direct and the other indirect. 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.

2.3.3 AORA Solar Tower facility

At the end of 2019, a new tower facility has been 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 of 16 m^2 reflecting surface each 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 21. General view of the AORA solar tower facility.

2.4 Parabolic DISH Systems

2.4.1 Accelerated ageing test bed and materials durability

This installation consists of 3 parabolic dish units model DISTAL-II with 50 kW total thermal power 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: materials tests, air-cooled volumetric receivers tests (metal or ceramic), tests of small-size receivers prototypes with or without heat transfer fluid, etc.

The three parabolic dishes DISTAL-II (Figure 22) 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 existing at PSA, which is described in the laboratories section of this document (section 3.3).

Figure 22. View of a parabolic-dish DISTAL- II with the original Stirling engine.

Figure 23. Accelerated aging tests of steel samples at a parabolic-dish DISTAL- II

2.4.2 EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected (Figure 24), 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.

2.5 Installation of Solar Furnaces

2.5.1 SF-60 Solar Furnace

The SF60 consists basically in a 120 m^2 flat heliostat that reflects the solar beam onto a 100 m^2 parabolic concentrator which in turn concentrates the incoming rays on the focus of the parabola, where the tested specimens are placed. The incoming light is regulated by a louvered shutter placed between the heliostat and the concentrator. Finally, a test table movable on three axes is used to place the specimens in the focus.

Figure 24. Front and back views of the EURODISH.

In this furnace, 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 only heliostat associated with the SF-60 consists of 120 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 25 and Figure 26 show the heliostat installed in this solar furnace and a detail of the back side of the facet, respectively.

Figure 25. HT120 heliostat in tracking.

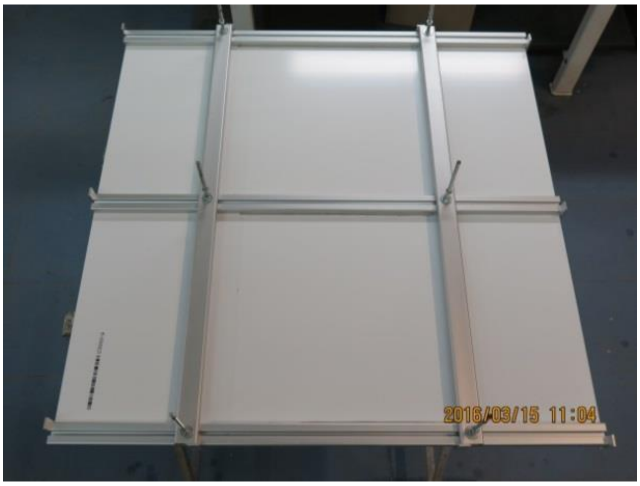


Figure 26. Back side of facet.

The parabolic concentrator is the main feature of this solar furnace. It is made of spherically curved facets distributed along five radii with different curvatures depending on their distance from the focus. It concentrates the incident sunlight from the heliostat, multiplying the radiant energy in the focus.

The shutter (attenuator), see Figure 27, 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.

Figure 27.Shutter of the PSA SF-60 Solar Furnace.

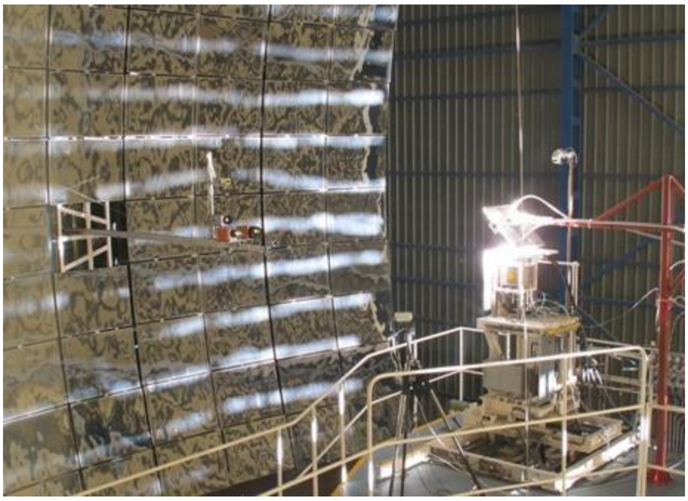


Figure 28. Interior view of the PSA SF-60 Solar Furnace in operation.

The combination of all the components described lead to the flux density distribution in the focus which 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, 300 W/cm^2, total power, 69 kW, and focal diameter, 26 cm.

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

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

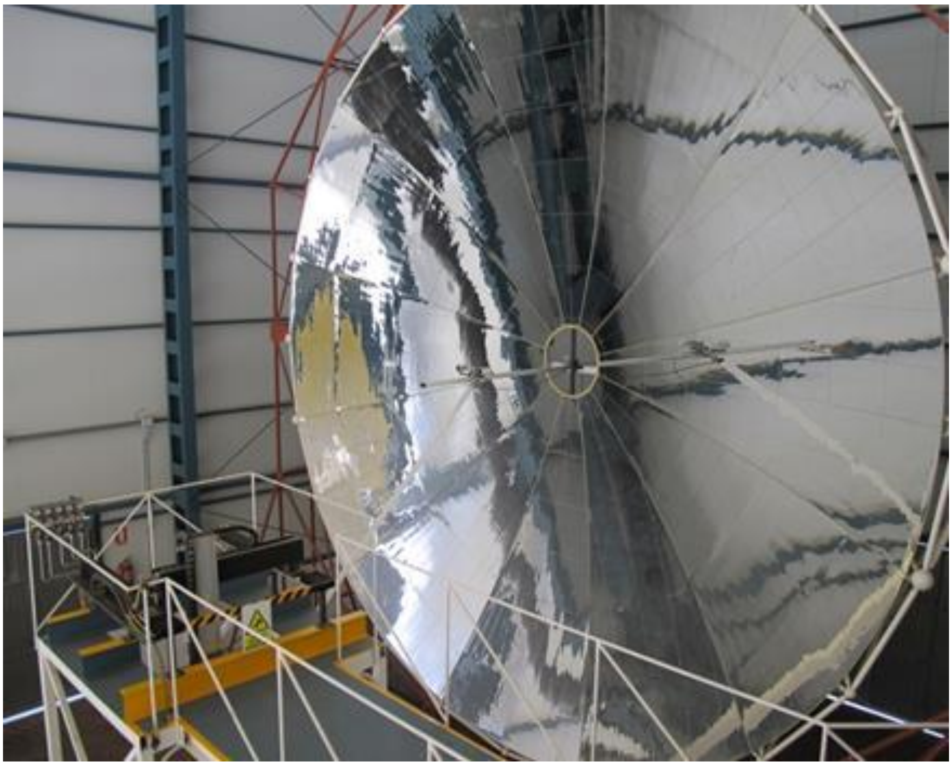


Figure 29. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

2.5.3 SF-5 Solar Furnace

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

It is called SF5 (Solar Furnace 5), by its 5-kW power-, reaches concentrations above 7,000 suns, its focus diameter is 2.5 cm, and is mainly devoted to heat treatment of materials at high temperature, 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.

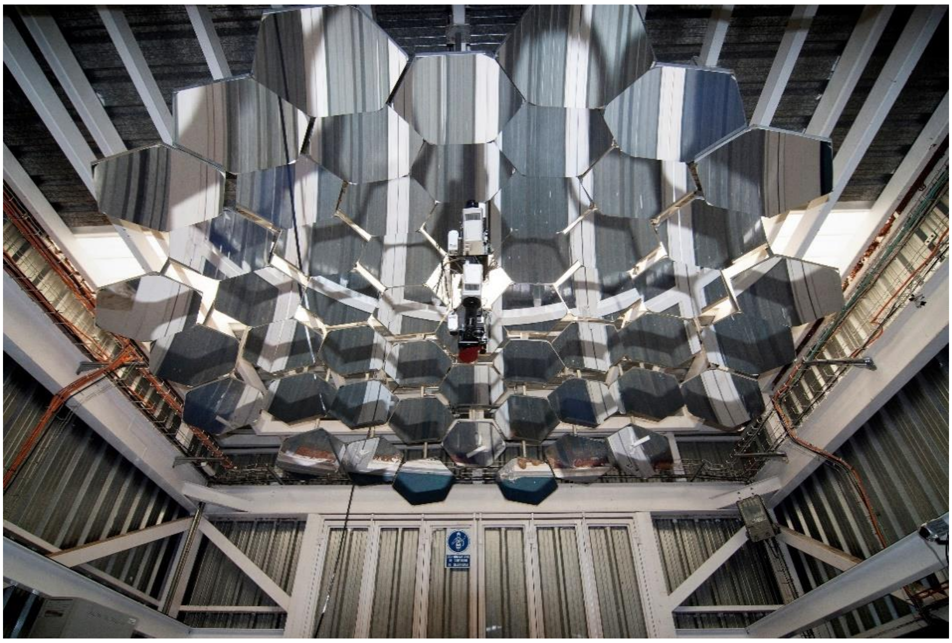


Figure 30. Concentrator of the SF-5 Furnace.

2.6 Thermal Storage Systems

2.6.1 Molten Salt Test Loop for Thermal Energy Systems

This facility is composed of, on one hand, an outdoor test loop, which is a replica of a commercial thermal energy storage system with 40 t of nitrate molten salts and a two-tank configuration, and, on the other hand, an indoor test bench, named BES-II.

The outdoor loop of MOSA is the largest facility worldwide similar to a commercial two-tank molten salt storage system on a reduced scale, so everything related to this type of systems can be tested in this facility in a relevant and extrapolated scale. Some applications of this facility are:

- Checking of components (pumps, flowmeters, etc.) for their use in a liquid molten salt medium.
- Optimization of procedures in normal operation for a two-tank system configuration.
- Optimization of procedures in risk situations for a two-tank system configuration. Designing recovery procedures.
- Validation of models and simulation approaches for molten salt thermal systems.
- Characterization of heat exchangers for molten salt/oil.
- Characterization of thermocline tanks.

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

Figure 31. Molten Salt (MOSA) outdoor test loop.

BES-II, an indoor installation at the PSA, is especially designed for the testing of valves, pressure transmitters and other small molten salts components under 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 32. 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.

2.6.2 Atmospheric Air Packed Bed Test Bench

This facility is an insulated storage tank of around 0.1 m^3 where different packed bed configurations and materials can be tested using atmospheric air as heat transfer fluid. Provided with a maximum electric power of 15 kW, a charge process with air up to 900°C is possible. Thermocouples along its length and at different radial positions give an accurate map of temperature of the packed bed.

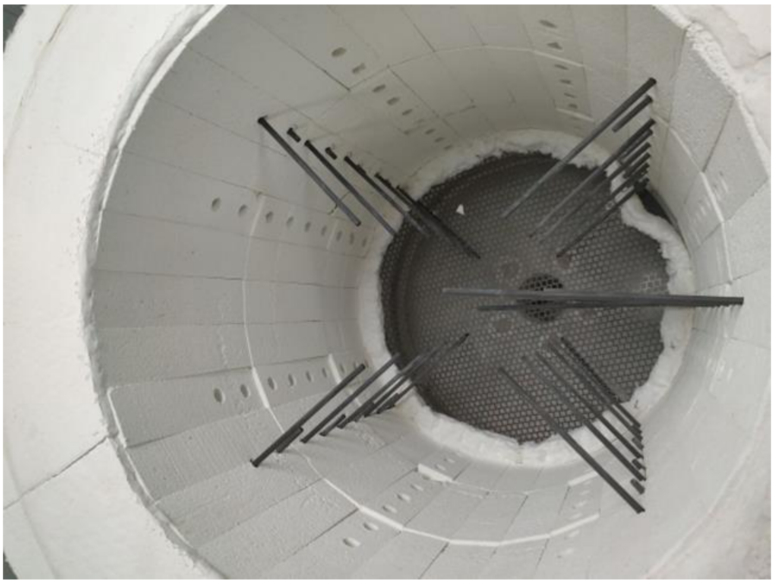


Figure 33. Picture taken from the top of the tank, showing its internal room and thermocouples at different lengths and radial positions.

Figure 34. Researcher adjusting some items from the upper top of the tank.

2.7 Experimental Solar Desalination Installations

2.7.1 Multi-Effect Distillation Facilities

2.7.1.1 Solar Multi-Effect Distillation Facility

This facility is composed of the following subsystems:

- A 14-stage multi-effect distillation (MED) plant
- A field of stationary large-size flat plate solar collectors
- A water-based solar thermal storage system
- A double effect (LiBr-H_2O) absorption heat pump
- A fire-tube gas boiler

The multi-effect distillation unit is made up of 14 stages or effects, arranged vertically with direct seawater supply to the first effect (forward feed configuration). At a nominal 8 m^3/h feedwater flow rate, the distillate production is 3 m^3/h, and the thermal consumption of the plant is 190 kW_{th}, with a performance ratio (number of kg of distillate produced per 2,326 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 the solar collectors and energy collected is 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.

(b)

(a) (c)

Figure 35. 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 (c).

The solar field (AQUASOL-II) is composed of 60 stationary flat plate solar collectors (Wagner LBM 10HTF) with a total aperture area of 606 m^2 and is connected with a thermal storage system (40 m^3) through a heat exchanger.

The double effect (LiBr-H_2O) absorption heat pump 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.

2.7.1.2 Test-Bed for Solar Thermal Desalination Applications

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

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

Figure 36. The 606-m^2 large-aperture flat plate solar collector field (AQUASOL-II).

It consists of 4 loops with 14 large-aperture flat plate collectors each (two rows connected in series per loop with 7 collectors in parallel per row), and one additional smaller loop with 4 collectors connected in parallel, all of them titled 35° south orientation. Each row has its own filling/emptying system consisting of two water deposits, from which the heat transfer fluid is pumped to the collectors at the beginning of the operation and where all the water volume in the collectors is spilt either at the end of the operation or when a temperature limit is reached (above 100°C). The solar field has flow control valves that allow having an equal distributed flow rate without further regulation. Besides, the facility has an air cooler that allows the entire energy dissipation from the solar field, which is useful for efficiency tests at different temperature levels. The five loops of collectors are connected with a thermal storage system through a heat exchanger. The thermal storage system consists of two connected water tanks for a total storage capacity of 40 m^3. This volume allows sufficient operational autonomy for the fossil backup system to reach nominal operating conditions in the desalination plant.

The flexibility of the solar field allows the operation of each loop independently, through their own valves and pumping system. Each loop is connected to an individual heat exchanger that offers the possibility of coupling it with any low-temperature thermal desalination system for testing purposes.

2.7.2 CSP+D test facilities

2.7.2.1 CSP+D Test Bed: Integration of MED Thermal Desalination & Solar Thermal Power Plants

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

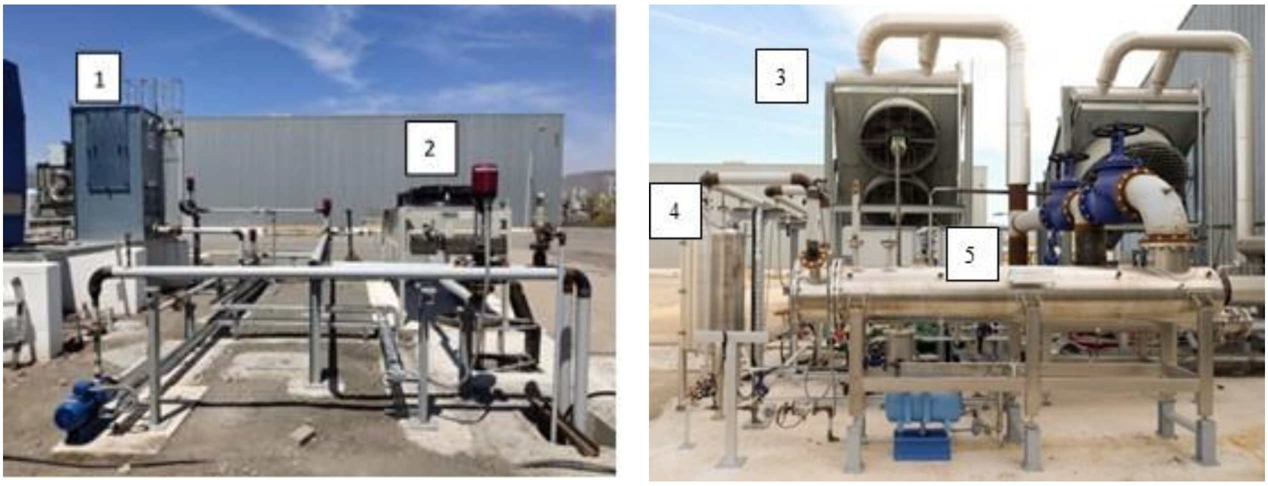
(a) (b)

Figure 37. View of the outside of the CSP+D test bed building with the air coolers (a) and partial view of the interior of the CSP+D test bench (b).

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

2.7.2.2 Hybrid-cooling pilot plant

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



(a) (b)

Figure 38. General view of the hybrid-cooling test bed: (a) Cooling circuit: wet cooling tower (1) and air-cooled heat exchanger (2). (b) Exchange circuit: air-cooled condenser (3), condensate tank (4) and surface condenser (5).

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

2.7.3 Membrane Desalination Test Facilities

The installation is designed for evaluating solar thermal desalination 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

1500 litres acting as heat buffers for thermal regulation and storage; they also have a distribution system which 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.

(a)

(b)

Figure 39. Internal (a) and external (b) 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 together 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 modules that have been evaluated or are under evaluation is:

1) Plate and frame air-gap (AG) MD commercial modules from Scarab (total membrane area 2.8 m^2).
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).
3) Spiral-wound PGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
4) Two spiral-wound AGMD modules from Aquastill with membrane areas of 7 m^2 and 24 m^2 each.
5) WTS-40A and WTS-40B units from Aquaver, based on multi-effect vacuum membrane distillation technology using modules fabricated by Memsys (5.76 m^2 and 6.4 m^2 total membrane area respectively).
6) Three spiral-wound modules from Aquastill operating in vacuum-enhanced air-gap configuration with membrane areas of 7.24 and 26 m^2 respectively.

2.7.3.1 Pilot Plant for Studying Combinations of Forward Osmosis and Reverse Osmosis

The plant has three different units (Figure 40) that can be coupled in different ways between them: (i) forward osmosis; (ii) reverse osmosis; (iii) microfiltration. The forward osmosis (FO) unit uses a 4" spiral-wound Cellulose Triacetate (CTA) membrane with eleven membrane leaves of 1.5 m^2 surface each, supplied by HTI. The nominal flow rate is 3.6 m^3/h. The reverse osmosis (RO) unit has four vessels that can be connected in series or parallel, each of which hosting 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. The unit is designed so that SWRO, BWRO or NF membranes can be used. Finally, there is an MF unit with 3 m^3/h nominal flow rate. The installation is completely monitored with pressure sensors, conductivity- and flow-meters, and 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.

2.7.3.2 Closed-loop seawater feed system for desalination testing.

The system is composed of three storage tanks connected in series containing a total volume of 300 m^3 of real seawater (Figure 41). The containers are connected to a hydraulic 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.

Figure 40. Test bed for FO-RO combination research.

Figure 41. Containers filled with real seawater for desalination tests in closed-loop.

2.8 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.

- Solar simulators.
- UVC-pilot plant.
- Ozonation pilot plant.
- Nanofiltration pilot plant.
- Pilot plant for photocatalytic production of hydrogen based on solar energy.
- Wet Air oxidation pilot plant.
- Electro-oxidation pilot plant
- Solar UVA monitoring equipment
- Pilot plants for biological treatment.
- Experimental culture camera.

Solar CPC pilot plants

Since 1994 several CPC pilot plants have been installed at PSA facilities (Figure 42). 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 aluminum mirror with Compound Parabolic Collector (CPC) shape to optimize solar photons collection in the photo-reactor tube. The modules are place on a platform titled 37° from the horizontal to maximize the global solar collection of photons through the year. In addition, the pilot plants are equipped with added systems for different purposes, for example: 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.

Table 1. Summarize of CPC pilot plants at PSA facilities.

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	- 50L ozonation system - Biological water treatment system - Monitoring (pH, T, ORP, O_2, flow rate, H_2O_2, O_3), control (pH, T, flow rate)
2007 (SOLEX)	3.08(x2)	40/22	Flow	32	- Twin prototypes - Plexiglass screen - Monitoring dissolved O_2 and temperature - Specially developed for photo-Fenton applications
2008 (FIT)	4.5	60/45	Flow	50	- Monitoring (pH, T, O_2, 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, O_2, flow rate) and control (T (20-55°C), O_2, flow rate) - -Sedimentation tank
2011 (HIDRO-CPC)	2.1	25/14.24	Flow	32	- -Coupled with H_2 generation pilot plant
2011 (CPC25)	1	25/11.25	Flow	50	
2013 (ELECTROX)	2	40/25	Flow	50	- Coupled with electro-photo-Fenton plant

Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added systems/Characteristics
2013 (NOVO75)	2	74/68.2	Flow	75	- Monitoring (pH, T, O_2, flow rate) and control (T, O_2, 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, O_2, flow rate) and control (T, O_2, flow rate) - - Automatic control system for filling the system accordingly to incident energy - - Solar panel for water heating

(a)

(b)

Figure 42. View of several CPC photo-reactors for purification of water. a) CPC facilities I, b) CPC facilities II.

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

A 2 m^2 CPC collector (Figure 43) with 10 borosilicate glass tubes (50 mm diameter), illuminated volume of 22 L and a total volume of 75 L is connected to four electrocells 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 shape (CPC and U mirror type) has been installed at PSA (Figure 44). 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 photoreactors. 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 which permits to increase water temperature prior to fill in the photoreactors.

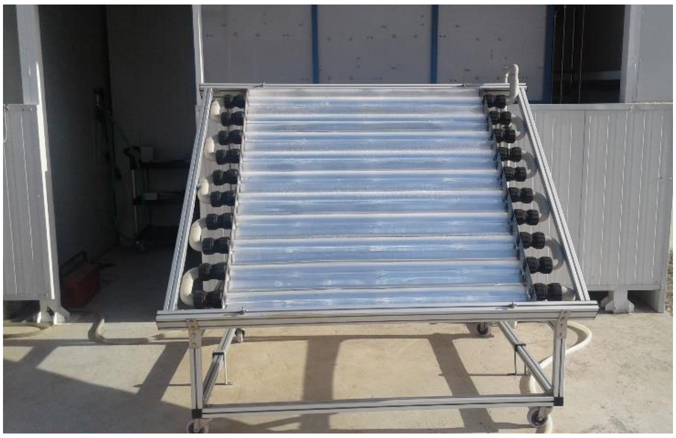


Figure 43. View of 2 m^2-CPC coupled to Electro-Fenton pilot plant (ELECTROX).

Figure 44. View of new CPC and U-type photoreactors (NOVA 75 V 1.0).

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 wavelength limitation to 290 nm simulating external solar radiation. Temperature can be also modified and controlled in both systems by a cooling system (SUNCOOL).

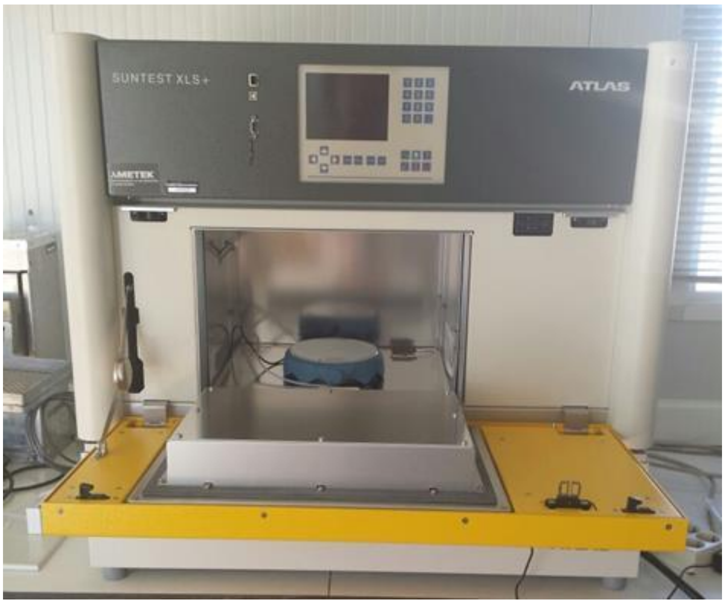


Figure 45. Solar simulator SUNTEST XLS+.

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; (iii) dissolved ozone sensor.

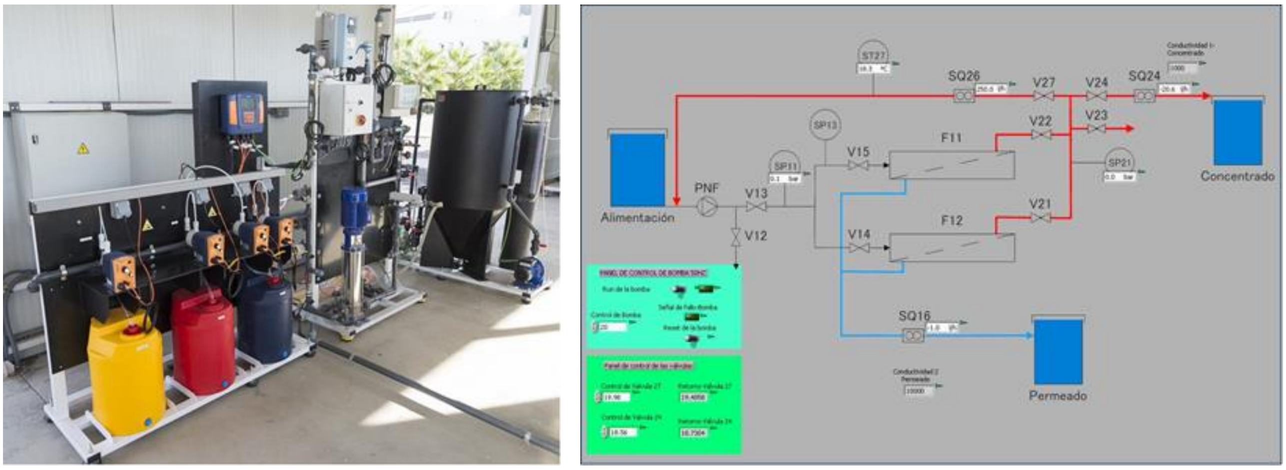
In 2020, the ozonation pilot plant has been improved with the main objective of increasing the gas-liquid mass transfer of the system. The contact column reactor increased its volume from 20 to 300 L (Figure 46.a) and a pressurized system with a total volume of 110 L that allows working in a batch-flow mode (Figure 46.b) or in micro-nano-bubbles ozone sparging mode (venturi pump, Figure 46.c) have been installed. This ozonation system works in batch mode allowing its combination with other technologies such as, CPC photoreactors, photocatalyts and the UV pilot plant.

(a) (b) (c)

Figure 46. Pictures of the improved parts of the ozonation pilot plant: a) New 200L contact column reactor; b) Pressurized tank; c) Venturi pump for micro-nano-bubbles generation.

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



(a) (b)

Figure 47. a) Nanofiltration pilot plant; b) New labview interface for control and automatic operation of the pilot plant.

UVC-H2O2 pilot plant

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 48).

Photocatalytic generation of hydrogen pilot plant

The pilot plant for photocatalytic hydrogen generation is composed by a closed stainless-steel tank of 22 L connected to a CPC photo-reactor for the simultaneous removal of organic contaminants from aqueous solutions and hydrogen generation (Figure 49). The tank is fitted with gas and liquid inlet and outlet and a sampling port. Two parallel mass flow controllers are used to control the desired N_2 gas flow into the reactor headspace during the removal of O_2 to achieve the reduction conditions as well as to drag the hydrogen produced. A centrifugal pump (PanWorld NH-100PX) with a flow rate of 20 $L \cdot min^{-1}$ is used to recirculate the aqueous slurry from the tank to the tubes of the CPC. The photo-reactor is composed of 16 Pyrex glass tubes (inner diameter 28.5 mm, outer diameter 32 mm, irradiated length 1,401 mm) mounted on a fixed platform tilted 37° (local latitude). The total area and volume irradiated is 2.10 m^2 and 14.25 L, respectively.

Figure 48. UVC pilot plant installed at PSA facilities.

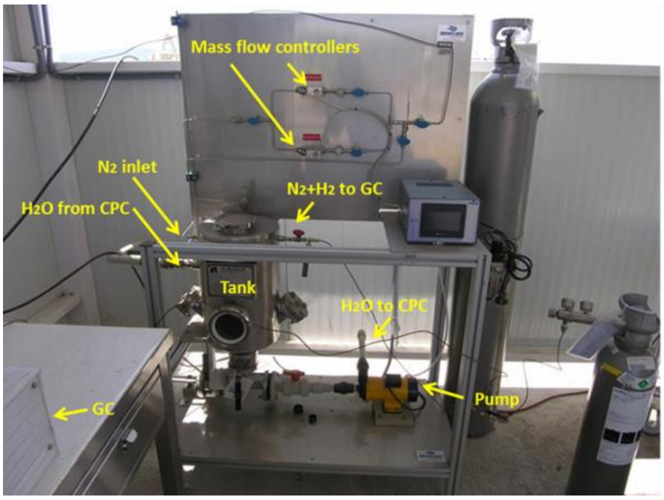


Figure 49. Solar pilot plant for photocatalytic generation of hydrogen.

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 50). 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.

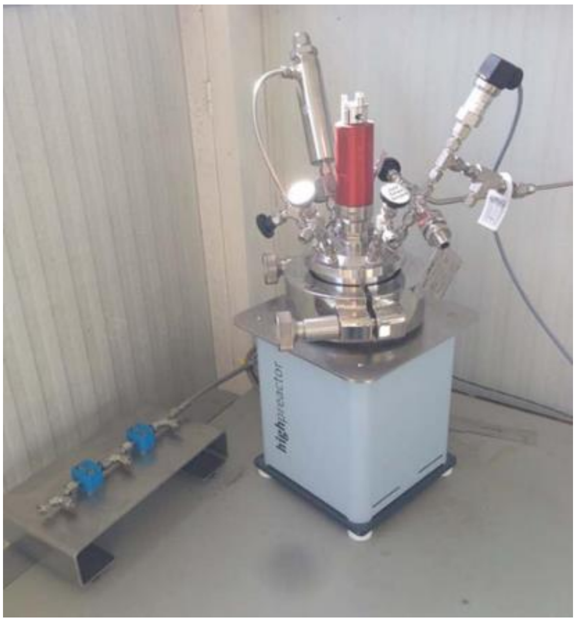
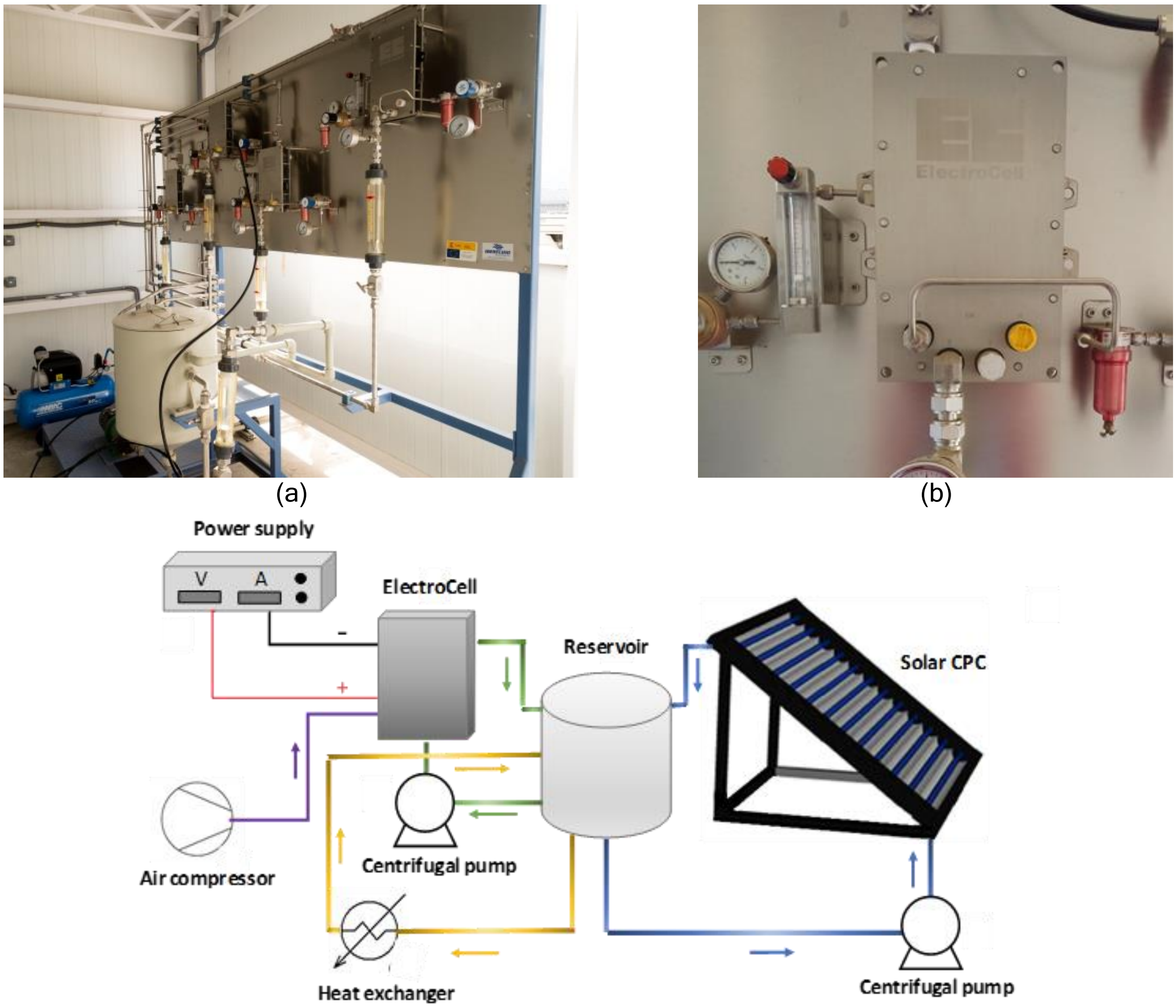


Figure 50. Wet Air Oxidation Pilot plant.

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 51).



(c)

Figure 51. a) Electro-oxidation pilot plant; b) Electrochemical cell of the solar-assisted electrooxidation pilot plant; and c) Schematic diagram of the solar-assisted electrooxidation pilot plant.

Solar UVA monitoring equipment

UV and global solar radiation data monitoring and storage system is composed by different pyranometers (Figure 52), including global solar radiation in the range of 310-2,800 nm (Kipp and Zonen CMP-6 with sensitivity 5-20 $V \cdot W^{-1} \cdot m^{-2}$, max. value: 2000 $W \cdot m^{-2}$), and the global UVA radiation in the range of 300-400 nm (Kipp and Zonen CUV-5 with sensitivity 1 $Mv \cdot W^{-1} \cdot m^{-2}$, max. value: 100 $W \cdot m^{-2}$). Besides this, a spectral photometer with double channel was installed to monitor the solar spectral irradiance at the location of the solar tests. This equipment (AVANTES) has UVA sensors and filters to measure in the whole spectral range of 200 – 1,100 nm.

(a) (b) (c)

Figure 52. CUV-5 radiometer (a). View of all solar UV radiometers (horizontal (b) and inclined (c) setup) used in the Solar Treatment of Water Unit).

Biological pilot plant

A biological pilot plant with a double depuration system (Figure 53) 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.

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 (Qmax = 1.1 m^3/h, T = 80°C) area available. An internal coil thermostated by a chiller (Qmax = 15.5 L/min, 2,750 W, range = -10 - 40°C) is incorporated in 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 as a control to be able to work during 48 H. 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 (Qmax = 20 L/h, Pmax = 3 bar, PP), pH controller and a pH sensor (Range: 0 - 14, Pmax: 3 bar, T = -5 - 70°C). Finally, the system has a 25 L jacketed borosilicate crystallizer with a stirrer inside (range: 0/30 - 1,000 rpm, P: 60 W, material: PTFE) with a pump (flowmeter range: 90 - 900 L/h). The temperature control is carried out by a control system formed by a chiller (Qmax = 15.5 L/min, 2,750 W, range = -10 - 40°C) and an external Pt100 temperature sensor (Figure 54).

Figure 53. Biological pilot plant installed at PSA facilities.

Figure 54. 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 55). 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.

Figure 55. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

2.9 Optical characterization and solar reflector durability analysis facility - OPAC

The PSA optical characterization and solar reflector durability analysis facility, which is the result of a joint collaborative project between CIEMAT and DLR, has the necessary equipment to completely characterize the materials used as reflectors in solar concentrating systems. This laboratory allows the evaluation of characteristic optical parameters of solar reflectors and their possible deterioration. The following equipment is available in the laboratory of optical characterization of solar reflectors (see Figure 56.a):

- Three portable specular reflectometers, Devices and Services Model 15R-USB, for measuring specular reflectance at 660 nm at 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 460, 550, 650 and 720 nm and at different aperture angles (2.3, 3.5, 7.5, 12.5 and 23 mrad).

- Reflectometer prototype for measuring specular reflectance in a 5 cm diameter with spatial resolution of 10 pixel/mm, which measures at various wavelengths and aperture angles (model SR^2, designed and patented by DLR).
- Perkin Elmer Lambda 1050 spectrophotometer, with 150-mm integrating sphere and specular reflectance accessory with 0 to 68° incidence angles (URA).
- Nikon D3 camera and 90 cm Cubalite kit for photos of specular surfaces without parasitic reflections.
- Zeiss Axio microscope model CSM 700 (with magnifications of 5, 10, 20, 50 and 100) for finding the profiles and roughness of highly reflective surfaces.
- Hitachi S3400 electronic scan microscope (SEM) with EDX analysis.
- Parstat 4000 impedance system to analyse the corrosion of reflector materials.
- General Purpose Optical bench as accessory for the Perkin Elmer Lambda 1050 spectrophotometer with advanced features for mounting optical devices for the development of new measurement instruments.
- Attension Theta 200 Basic tensiometer for static and dynamic contact angle assessment, which is a key parameter to study the performance of the anti-soiling coatings applied to solar reflectors and receiver tubes.

The solar reflector durability analysis laboratory is designed for accelerated ageing tests of these materials with the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime (see Figure 56.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:

- ATLAS SC340MH weathering chamber for temperature (from -40°C to +120°C), humidity (from 10% to 90%), solar radiation (from 280 to 3000 nm) and rainfall of 340L.
- Vötsch VSC450 salt spray chamber with temperatures from 10°C to 50°C (450 L).
- Erichsen 608/1000L salt spray chamber with temperatures from 10°C to 50°C.
- Two ATLAS UV-Test radiation chambers where UV light (with a peak at 340 nm), condensation and temperature can be applied. One of the chambers also includes rain simulation.
- Hönle UVA Cube Ultraviolet radiation chamber.
- KÖHLER HK300M acid rain chamber, 300 L and temperatures up to 70°C and humidity up to 100%, to apply the Kesternich test.
- SC100 heatable water bath, to perform the Machu test, according to the Qualitest guideline.
- Vöstch VCC3 0034 weathering chamber to test the material resistance against corrosive gasses (335 L, see Figure 56.b).
- Ineltec CKEST 300 test chamber for humidity and condensation testing with temperatures up to 70°C (300 L).
- Memmert HCP108 weathering chamber to apply humidity (20-95%) and temperature (20-90°C) with humidity and 20-160°C without humidity).
- Two Nabertherm LT 24/12 and LT 40/12 Muffle Furnaces.
- Control Técnica/ITS GmbH sandstorm chamber with wind speeds up to 30 m/s and dust concentrations up to 2.5 g/m^3.
- Erichsen 494 cleaning abrasion device to test the degradation due to the cleaning brushes, with several cleaning accessories.
- Taber 5750 linear abraser to check the materials resistance against the abrasion.

- Lumakin A-29 cross-cut tester to analyse the possible detachment of the paint layers.
- Several devices for thermal cycles specially designed at the PSA.

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

(a) (b)

Figure 56. OPAC solar reflector optical characterization lab (a) and durability analysis lab (b)

2.10 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:

1) 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.

2) 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.

3) CETeB Test cell: This is a new 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.

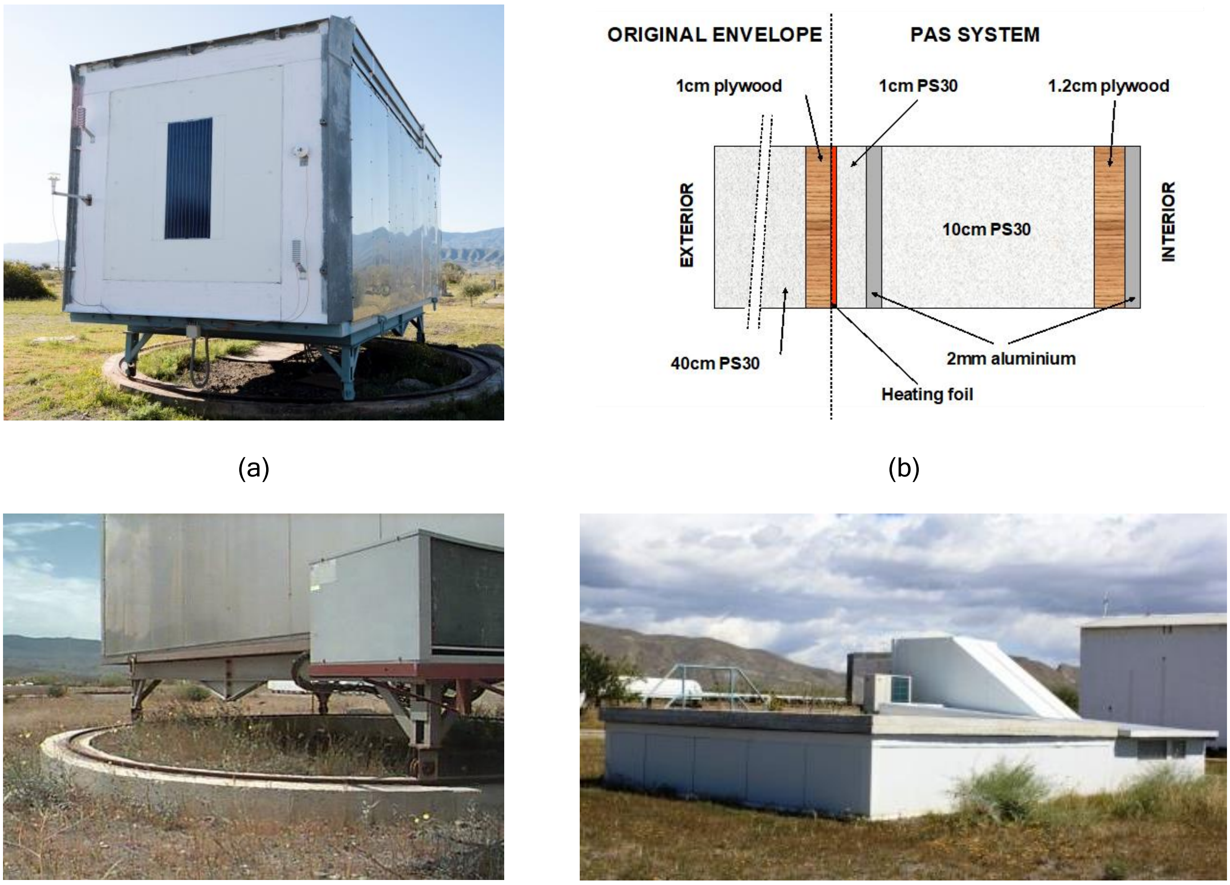


Figure 57. (a) CIEMAT's PASLINK test cell carrying out a thermal test of a PV module, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

4) 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.

5) 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.

6) 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 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 m2 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.

Figure 58. (a) Reference single-zone building, (b)ARFRISOL Building Prototype in use, (c) Solar Chimney. Configuration including Phase Change Material tiles, (d) Ventilated façade tested in a Test Cell. Different configurations with light and dark external face.

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.

3 Laboratories

3.1 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 most of it incident on 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).

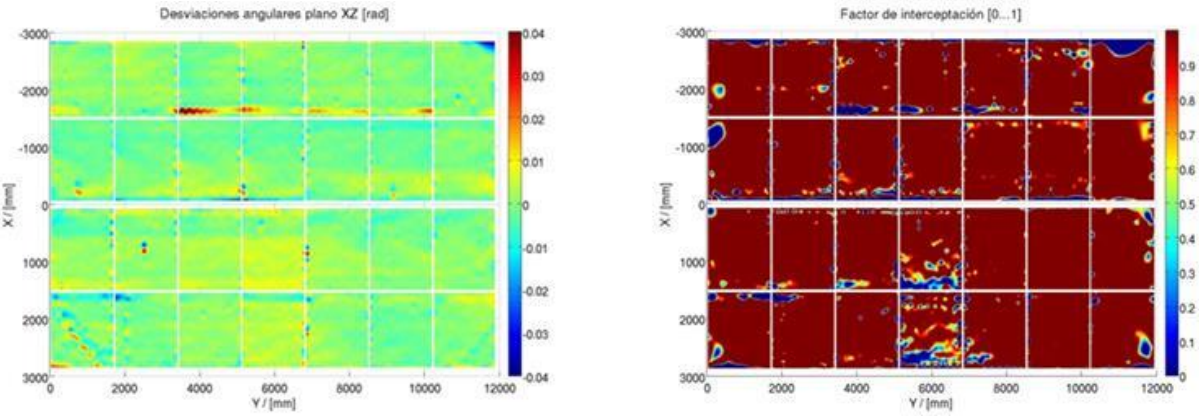
The equipment allocated to this activity at PSA is composed of:

- 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 has been 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).



(a) (b)

Figure 59. Angular deviations (a) and intercept factor (b) of a parabolic-trough collector module analysed by photogrammetry.

3.2 Radiometry laboratory – RadLab

The activity line devoted to Radiometry came up of the need to verify measurement 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 60. View of the PSA Radiometry equipment.

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

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

- The MIKRON 330 black body is a cylindrical cavity which can provide any temperature from 300°C to 1700°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 61. IR sensor calibration using a black body.

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

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

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

- The Metallography Room
- The Microscopy Room
- The Thermogravimetry Room
- The Thermal Cycling Room
- The Electronic microscope Room

The laboratory equipment located in these rooms is listed below.

3.3.1 Metallography Room

- 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 y 1.25 mm and 710, 630, 425, 315, 250, 160, 150, 90, 53 y 32 µm)
- Digital Camera with reproduction table

Figure 62. View of the Metallography Room in the Solar Furnaces building

3.3.2 Microscopy 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.
- 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

3.3.3 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 pure Hydrogen atmosphere up to 1,750°C
- Tests under pure Oxygen atmosphere
- Tests under H2O steam with other gases simultaneously.
- Tests under corrosive atmosphere up to 1,000°C
- CEM System (Controled evaporator mixer system) for steam supply.
- Fixed Gas Detector: Dräger Polytron SE Ex, with a control system Regard 1.

(a) (b)

Figure 63. View of a) the Microscopy Room, and b) the thermogravimetric balance inside of its Room.

3.3.4 Thermal Cycling Room

It includes the instrumentation necessary for thermal cycling:

- two muffle furnaces,
- a high-temperature kilns,
- a weathering chamber,
- an air-cooled volumetric receiver test loop and associated instrumentation,
- optical and electronic microscopes,

3.3.5 Electronic microscope Room

The indoor devices located in the four rooms described above are complemented by an electronic microscope installed in its own room, which is shared by the Solar Treatment of Water Unit and the Solar Concentrating System units. For further details see section 0.

3.4 Receivers testing and characterization for concentrating solar thermal systems - SRTLab

This activity line comprises both linear tube-type receivers and volumetric air receivers. The equipment associated to linear receivers is located at PSA and the two main test devices are: a) a test bench called HEATREC (see Figure 64.a), for measuring heat loss of single receiver tubes under indoor laboratory conditions, and b) an outdoor test bench called RESOL (see Figure 64.b), for measuring optical efficiency of single receiver tubes under natural solar radiation. Heat loss measurements can be done under vacuum conditions to avoid convection outside the glass tube, thus obtaining a more uniform temperature along the receiver section and looking for the heat loss by radiation. In addition, is possible to determine heat loss at different vacuum levels in the space between the metallic absorber tube and the glass envelope.

(a) (b)

Figure 64. View of the HEATREC test chamber to measure heat losses in solar receiver tubes (a) and RESOL test bench to measure receiver's optical efficiency (b).

The emissivity of the selective coating can be then inferred from these measures. The optical efficiency test is done by 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 an 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.

HEATREC device lets to characterize heat losses of receiver tubes with inner diameter greater than 62 mm and tube length lower than 4.5 m. Measurements can be performed for absorber 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 4,060 mm-long and with absorber tube diameter of 70 mm.

Besides HEATREC and RESOL, the activity line devoted to linear receivers is equipped with tools and devices for proper manipulation and monitoring of receiver tubes.

3.5 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 for anti-reflective treatments for glass covers 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 evaluate 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 devoted to testing and characterization of solar reflectors.

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

- Perkin Elmer LAMBDA 950 Spectrophotometer (Figure 65.a).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 65.b)
- *Portable Optosol absorber characterization equipment*: This equipment measures solar absorptance and thermal emittance of selective absorbers at 70°C, both on flat substrates and absorber tubes. The device for measuring absorptance has an integrating sphere with two detectors. For measuring emissivity, it has a semi-cylindrical tunnel which emits infrared radiation at 70°C.
- LEICA DM4 M optical microscopy with image acquisition system and software for image analysis (Figure 65.c).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 65.d).
- BROOKFIELD LVDV-I+ Viscometer.
- BRUKER DektakXT stylus profilometer with optical camera and software for surface analysis (Figure 65.e).
- KSV CAM200 goniometer for measuring contact angles (Figure 65.f).
- Kilns. There are three kilns for thermal treatment:
  - 120x100x300 mm kiln with a maximal temperature of 1,200°C.
  - Controlled atmosphere kiln with a maximal temperature of 800°C.
  - 500x400x600 mm forced convection kiln with a maximal temperature of 550°C.

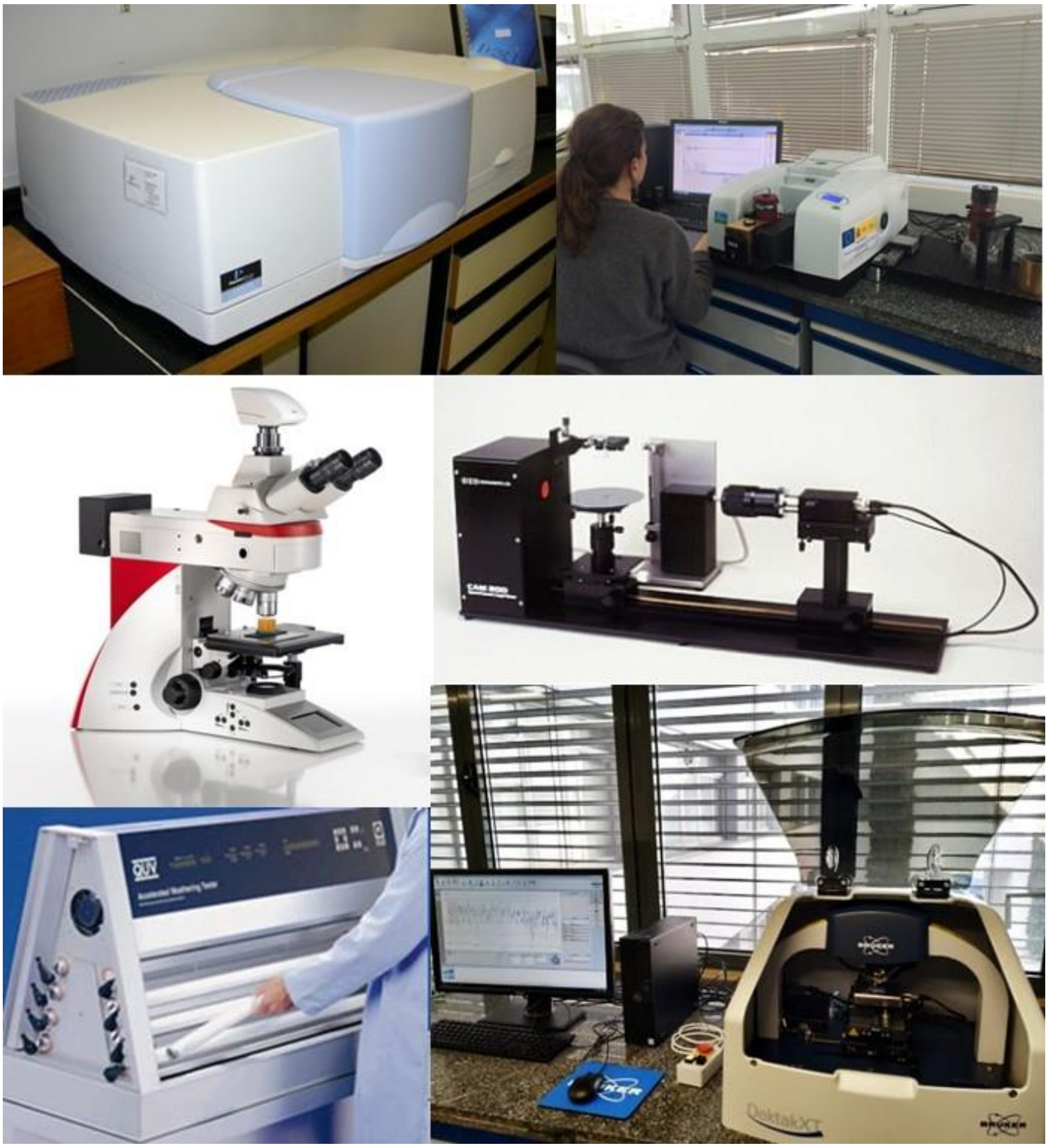


Figure 65. Advanced optical coatings laboratories equipment.

3.6 Porous media laboratory for solar concentrating systems - POMELAB

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

1) Thermal characterization of volumetric absorbers.

Its main component is a test bench designed for the thermal test of new volumetric absorbers and configurations and its ageing in steady and dynamic conditions. The main components installed in this test bench (Figure 66) are:

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

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

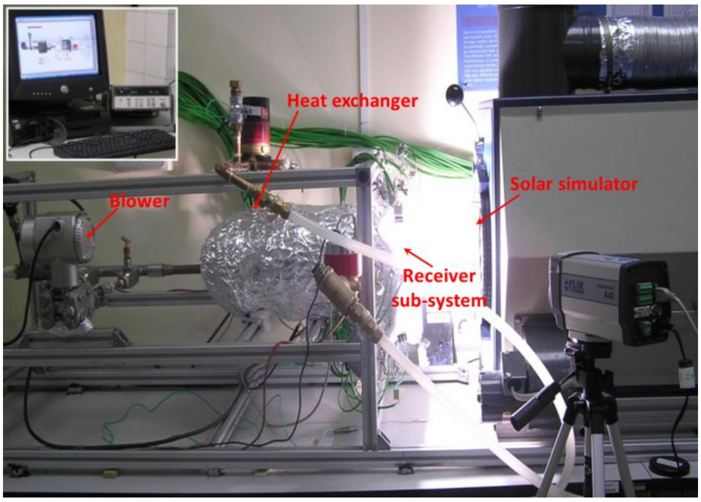


Figure 66. Test bench for volumetric receiver testing.

2) Measurement of the pressure drop up to 300°C.

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

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

- Sodeca Blower with velocity control
- Hastinik ball valve of 1 ½".
- Airflow anemometer
- Nabertherm heating resistor
- Honeywell pressure difference-meter

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

Figure 67. Test bench for pressure difference measurement with configuration up to 300°C.

3.7 Laboratory for the Assessment of Thermal Storage Materials - TESLab

This laboratory is intended to study the feasibility of materials as storage media at a preindustrial scale. Focussing on the performance of phase change materials (PCM) for latent storage the following instruments are available:

- HDR: Small furnace under ambient air atmosphere with an accurate control of heating/cooling rates, sample temperature monitoring; allows PCM melting/freezing cycles up to 500°C and subsequent cycles, or cycles with stand-by periods. Sample size: 10-20 g.
- SUBMA: Small closed device inside a furnace, for 30-40 g sample sizes. It allows tests under inert atmosphere (N_2, Ar), controlling furnace temperature and gas flow, sample temperature monitoring. PCM melting/freezing cycles up to 500°C, subsequent cycles as well as cycles with stand-by periods can be performed.
- AgH: Furnace under ambient air atmosphere and with an accurate control of heating and cooling. It allows PCM melting/freezing cycles up to 350°C, subsequent cycles, and cycles with stand-by periods for 10-20 g sample sizes.

Figure 68. Working using the HDR device

3.8 PSA Desalination Laboratory

3.8.1 Bench-Scale Unit for Testing Membrane Distillation applications in Air-Gap, Permeate-Gap and Direct Contact Configurations

The installation consists of a test-bed with a small plate and frame module (**¡Error! No se encuentra el origen de la referencia.**) that can be used for evaluating direct-contact, air-gap or permeate-gap membrane distillation. The module is made of polypropylene and designed so that the membrane can be replaced very easily. The module has 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. The effective membrane surface is 250 cm^2.

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 69. Bench-scale unit for testing membranes on isobaric MD.

3.8.2 Bench-Scale Unit for Flat Sheet Membrane Distillation Testing

The facility is a high precision laboratory grade research equipment (Figure 70) designed for testing fundamental and feasibility test trials on membrane distillation. It possesses the following unique features that are essential for representative and scalable results:

1) Cell format with representative flow distribution. The cell size is sufficient for flow distribution and regime to be applicable to full-scale MD technology.

2) Adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VMD, VAGMD).

3) Temperature precision of 0.5°C.

4) Driving force temperature difference controllable.

5) Fully automated control system and large range of possible parameter settings by touch screen PLC.

6) Practical A4 format for membrane and condenser foil materials.

Figure 70. Bench-scale unit for testing MD with flat-sheet membranes.

3.8.3 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 71). 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 cell. 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.

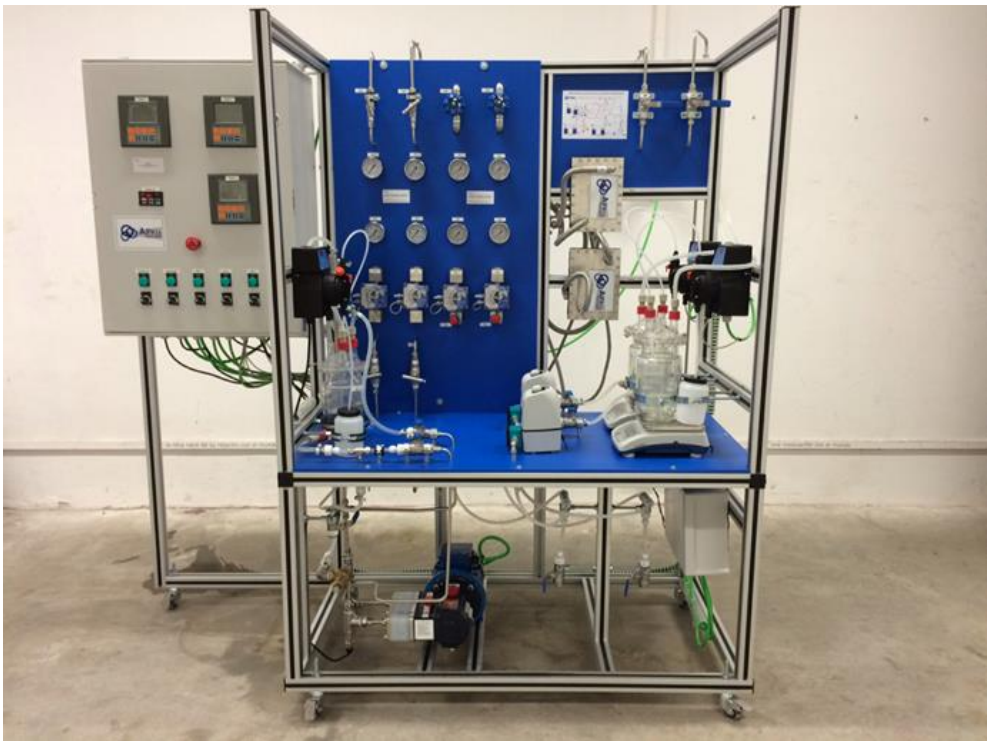


Figure 71. Bench-scale unit for testing FO and PRO.

3.9 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

3.9.1 General laboratory

The main laboratory is 94 m^2 (Figure 72). It is equipped with four large work benches, two gas extraction hoods, a heater, a kiln, ultrasonic bath, three centrifuges, two UV/visible spectrometers, a fluorometer, a vacuum distillation system, ultrapure water system, pH gauge, turbidimeter and conductivity-meter, and precision-scale table. 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 72. General view of the new PSA Water Technologies Lab.

3.9.2 Chromatography laboratory

This laboratory (Figure 73.b) is equipped with three high performance liquid chromatographs with diode array detector (HPLC-DAD and two UPLC-DAD) with quaternary pumps and automatic injection; an Automatic Solid Phase Extraction (ASPEC) which permits working with low concentration of pollutants (Figure 73.c) and two ion chromatographs (Figure 73.a): one configured for isocratic analysis of amines and cations (Metrohm 850 Professional IC), and another for gradient analysis of anions and carboxylic acids (Metrohm 872 Extension Module 1 and 2) with conductivity detectors (Methrom 850 Professional IC detector). Two total organic carbon (TOC) analysers by catalytic combustion at 670°C and total nitrogen (TN) analyser with autosampler are also available. In addition, an AB SCIEX TripleTOF 5600+ was acquired to detect and identify non-targeted or unknown contaminants present in wastewater or generated (transformation products) during the water treatments: Triple TOF by a DuoSpray Source combining Turbo Ion Spray and APCI (Atmospheric Pressure Chemical Ionization) modes. Besides, the system includes metabolomics statistical package to analyse multiple samples from multiple experiments and identified possible chemical and biological markers (Figure 73.d).

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

Figure 73. a) Metrohm Ion chromatograph System. b) General view of the chromatography lab at PSA facilities. c) Agilent Ultra-fast UPLC-DAD analyzer. d) SCIEX TripleTOF 5600+ equipment.

3.9.3 Microbiology laboratory

47-m^2 microbiology laboratory with biosafety level 2 (Figure 74) is equipped with five microbiological laminar flow (class-II) cabins, two autoclaves, three incubators, a fluorescence and phase contrast combination optical microscope with a digital camera incorporated. Besides, automatic grow media preparer and plaque filler and a filtration ramp with six positions are available.

Figure 74. 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 spectrophotometer NanoDrop 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 storage in a reproducible way without any risk of cross contamination between samples.

3.9.4 Microscopy laboratory

The microscopy laboratory is a 11 m² room (Figure 75.a) in which a Scanning Electron Microscope (SEM) is installed. Besides, the microscopy laboratory also has environmental secondary electron detector (ESED). For the preparation of microbiological samples and catalysts to be analysed in the SEM, the system is complemented with a metal coater and critical point dryer. In this room it is also located two optical microscopes: i) a fluorescence and phase contrast combination optical microscope and, ii) a FISH microscope (Leyca) with fluorescence module to develop the FISH (Fluorescent in situ hybridation) technique for visualization of DNA hibrydation with specific probes in live cells used for monitoring of key microorganisms within a heterogeneous population (Figure 75.b).

(a) (b)

Figure 75. a) SEM (Scanning Electron Microscope). b) Optical microscope for FISH technique.

In addition, the system is completed by a station for photographic documentation, consisted in 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.

3.10 PSA radiometric net

The PSA has had a meteorological station since 1988, primarily for measuring integral solar radiation (global, direct and diffuse radiation), but also for other generic meteorological variables (temperature, wind speed and direction, relative humidity and atmospheric pressure, accumulated precipitation, etc.). The old station was completely remodelled in 2005 following the strictest requirements of quality and precision in the measurement of solar radiation according to the Baseline Surface Radiation Network guidelines. This station is called METAS station since 2012 (Figure 76).

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

- Measurement of the terrestrial radiation balance. Incoming and outgoing shortwave and long-wave radiation is measured at 30 m
- Solar radiation component characterization: (global, direct and diffuse)
- UV and PAR spectral bands
- Vertical wind profile: wind speed and direction at 2, 10 and 30 m
- Vertical temperature and humidity profile at 2 and 10 m
- Miscellaneous weather information: rain gauge, barometer and psychrometer

Figure 76. 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 pyreheliometers (absolute cavity radiometer PMOD PMO6-CC) and a total of 19 field pyreheliometers has been installed close to METAS; on the other hand 3 calibration benches with capacity to carry 20 pyranometers each one have been placed at 50 meters of METAS (Figure 77). These facilities are operated in collaboration with the Instrumentation Unit.

Figure 77. Calibration facilities.

Since the beginning of 2018 there are seven new radiometric stations fully operational all around the PSA area. These stations are equipped with first-class pyranometers and pyrheliometers, 2-axis solar trackers and have data acquisition systems Campbell CR1000 (METAS has a CR3000).

Figure 78. PSA radiometric stations.

4 Solar Concentrating Systems Unit

4.1 Introduction

The aim of the activities carried out by the Solar Concentrating Systems Unit (USCS) is to promote and develop concentrating solar thermal (CST) systems for both power generation and industrial process heat, whether for medium/high temperatures or high photon fluxes. This PSA Unit that is composed by two R&D Groups:

- Medium Concentration (MC) Group
- High Concentration (HC) Group

The MC group mainly works in the development of line-focus solar collector technology (parabolic troughs and linear Fresnel systems) and the HC group is focused on the development of point-focus technology, for solar tower systems, parabolic dishes or even the development and application of solar furnaces. Regardless of whether each group has its activities focused on a type of concentrating solar thermal technology, there are cross-cutting activities, common to both groups, related to the development and evaluation of optical concentrators (support/sun-tracking structures, reflectors), development of optical coatings for solar components (absorber, glass covers), durability analysis, etc. These horizontal activities have been carried out by the USCS staff in the framework of research project of the Unit but also in projects involving other research units of the Plataforma Solar de Almería.

Even with the difficult circumstances we have experienced this year, a great effort also continued to dissemination activities, through virtual participation in international conferences, workshops, seminars and Master courses to promote the knowledge about concentrating solar thermal energy technologies and their applications.

The year 2020 has been a challenging one for this R&D Unit not only because of the global situation due to the COVID pandemic, but in particular because of the reorganization of activities and groups promoted by the current PSA Management that becomes operational in 2021 and brings to an end a period of joint work under the umbrella of the PSA R&D unit “Solar Concentrating Systems”.

4.2 Medium Concentration Group

4.2.1 Introduction

The Medium Concentration group has continued its activities in the field of development, testing, and evaluation of components for line-focus solar collectors (SOLTERMIN and INSHIP projects and bilateral contracts with Spanish companies), development of new techniques and measurement capabilities (SFERA-III project), testing of a new silicone fluid for parabolic troughs (SIMON project), modeling and simulation of power plants with parabolic-troughs for heat generation (INSHIP project) and analysis of integration with other renewable energy sources for power generation (POSYTYF project), water saving technologies for power plants (SOLWARIS project), testing of functional materials (RAISELIFE project), and contributing to the development of standards and guidelines for the testing and evaluation of components for solar thermal power plants (Standardization activities, but also through Soiling and SHTF-Guideline projects financed by SolarPACES). The collaboration with the industry (manufacturing of components or operation of existing solar power plants) within the framework of partnership agreements or technical services continued this year.

Finally, in January of this year 2020 our colleague Javier León Alonso retired after more than 35 years of work at PSA (Figure 79). Javier has worked on practically all concentrating solar power technologies, having been a key figure in PSA's R&D team and the engineer responsible of O&M for line-focus solar test facilities for a large period of his career.

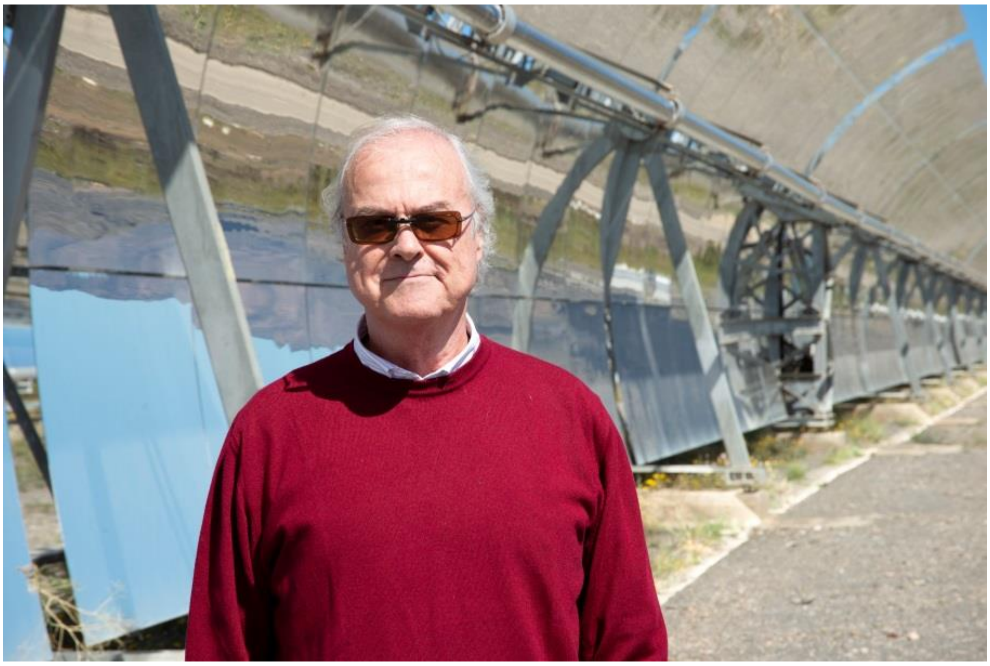


Figure 79. Medium Concentration Group staff: Javier León at the DISS test facility.

4.2.2 List of projects the group has been involved in

- Soluciones termosolares para integración en procesos industriales, SOLTERMIN
- Solar facilities for the European Resarch Area - SFERA-III
- Components and materials' performance for advanced solar supercritical CO2 power plants, COMPASsCO2.
- Silicone fluid maintenance and operation, SIMON
- Integrating National Research Agendas on Solar Heat for Industrial Processes, INSHIP
- POwering SYstem flexibiliTY in the Future through Renewable Energy Sources, POSYTYF
- Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology, RAISELIFE
- Solving water issues for CSP plants, SOLWARIS
- Silicone Based HTF in Parabolic Trough Applications – Preparation of a Guideline, Si-HTF Guideline

4.4 High Concentration Group.

4.4.1 Introduction

In 2020, as in previous years, the activities of the high concentration solar group (GACS) have been focused on the firm commitment to volumetric receiver technology (CAPTURE and NEXTOWER projects), with the aim of increasing the operating temperature of the central receiver systems beyond 600°C (which currently represents the commercial limit) with the idea of coupling these systems, not only to more efficient thermodynamic cycles (steam or gas), but also to thermal processes that require this high temperature range. In addition, as a consequence of this increase in temperature, research into materials that solve the problems associated with operation at high temperatures, in addition to implementing novel thermal storage, through the use of liquid metals (Pb and Pb-Bi).

At the same time, due to the wide experience the group has on heliostats design and testing, we have developed new heliostats concepts (SOLTERMIN) as well as the assessment of heliostat prototypes for different companies (Sophia, Photon, Solarblue). Without overlooking the development of measurement and characterisation methodologies for point focus technology and its components (SFERA-III).

In this year, the group just started a new project (COMPASsCO2) focused on materials development for next generation of supercritical CO_2 solar tower systems.

Finally, the experience acquired during these last years in the measurement of atmospheric attenuation has allowed us to open ways of collaboration with third countries and to commercially developed a system for atmospheric attenuation on commercial solar power plants with the collaboration of BCB; that will allow to a better characterization of both, the site and the operational procedures of the systems.

4.4.2 List of projects the group has been involved in

- Competitive Solar Power Towers, CAPTURE
- Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems, NEXTOWER
- *Fortalecimiento de la calidad de sistemas solares industriales de torre mediante la medida de parámetros y estimación de la atenuación atmosférica con enfoque a entornos climáticos desérticos*, 17BPE3-83761
- Solar extinction measurement system commercialization – Ref. 8510/2018
- PV plant with thermal cogeneration, SOLARBLUE
- Sophia and Photon heliostat prototypes
- *Soluciones termosolares para integración en procesos industriales*, SOLTERMIN
- Solar facilities for the European Resarch Area - SFERA-III
- Components and materials' performance for advanced solar supercritical CO_2 power plants, COMPASsCO2.

5 Thermal Storage and Solar Fuels Unit

5.1 Introduction

The Thermal Storage and Solar Fuels Unit (ATYCOS in its Spanish acronym) was formally launched in 2018 due to a reorganization of the former Concentrating Solar Systems Unit lead by Dr E. Zarza. People of this former unit have been joined in ATYCOS to help turning concentrating solar thermal systems into a dispatchable technology by two R&D approaches: designing improved thermal energy storage systems and by producing hydrogen with thermochemical processes.

During 2020, ATYCOS researchers have been actively working in international, national and regional funded projects, listed in the following paragraph. Apart from those, several technical services have been provided to companies, mainly dealing with testing and characterization of components and equipment for molten salt loops.

Through its experts, the Thermal Storage and Solar Fuels Unit participates actively in several scientific networks (Energy Storage JP of EERA, Task II and III of SolarPACES TCP of the IEA, task 58/33 SHC/ECES TCPs, Spanish association for Hydrogen -AeH2-) and national (AENOR-GT3) and international (IEC- CTN 206/SC 117/GT 03 and ASME-PCT52) standardization committees.

The activities on thermal storage deal with all aspects involved in the development, verification and optimization of efficient Thermal Energy Storage Systems (TESS) by:

- Proposing new storage media and characterizing some of their properties.
- Testing components for molten salt loops (valves, pressure gauges, vertical pumps, heat tracing, etc.).
- Designing new heat storage concepts with known storage media considering both the specific application and the thermal energy source.
- Testing novel modules for energy storage, both sensible and latent, even in real solar conditions.
- Modelling the behaviour of TESS, with own and commercial programs.
- Optimizing the operation strategies of TESS in order to obtain a maximum advantage of the stored energy.

On the other hand, the strategic task of the Group of Solar Hydrogen and solarisation of industrial processes addresses the demonstration, scale-up, of solar-driven thermochemical processes for the production of fuels (e.g. hydrogen, syngas) and industrial processes (e.g. cement, metallurgy, etc), by exploiting their know-how to develop suitable solar reactors and components and qualification of reactor materials to transfer the results to larger scales close to industrial size. A recent approach is to use thermochemical processes in the Moon and Mars to produce vital resources in the Moon and Mars in the space.

The lines of activity are concentrated in the following fields:

- Development of hybrid solar/fossil endothermic and thermochemical cycles processes for hydrogen production with concentrated solar energy.
- Technological feasibility of the use of solar thermal energy as the energy supply in high temperature industrial processes.
- Characterization of materials and components for solar reactors under extreme conditions

5.2 List of projects the unit has been involved in

- Small-Scale Solar Thermal Combined Cycle, POLYPHEM
- Solar facilities for the European Research Area - Third Phase, SFERA-III
- Concentrated solar power in the transport sector and in heat and power production, ACES2030
- Energy storage solutions based on conCRETE, E-CRETE
- Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond, HYDROSOL-BEYOND
- A Lunar CHEMical In-Situ recource utilization Test plant. ALCHEMIST Phase A, ALPHA

6 Solar Desalination Unit

6.1 Introduction

The Solar Desalination Unit (UDeS in its Spanish acronym) has the objective of new scientific and technological knowledge development in the field of desalination and thermal separation processes powered by solar energy.

Main current research lines are the following:

- Large-capacity thermal processes with special emphasis in multi-effect distillation (LT-MED, TVC-MED, ABS-MED)
- Small-capacity thermal processes with special emphasis in membrane distillation (MD) and forward osmosis (FO)
- Co-generation of electricity and desalinated water (CSP+D)
- Salinity-gradient power generation: reverse electrodialysis (RED) and pressure-retarded osmosis (PRO)
- Thermal-driven separation processes for brine concentration and industrial wastewater treatment
- Dynamic modelling, process optimization and advanced control strategies in solar desalination processes.

During 2020, the Unit has continued its relevant R&D activities within the framework of national and international projects. Most notable is the participation in two new H2020 projects with a strong participation of the industry sector: WATER MINING and INNOTHERM. In particular, the first one involves the creation of a Living Lab at PSA, involving a Community of Practice on solar desalination with zero liquid discharge and the production of high-quality salts and water suitable for agriculture. A couple of new facilities have been incorporated into the portfolio of its experimental facilities, a novel MD pilot plant and a system to operate with real seawater in the desalination experiments.

The international relevance of the activities carried out in the Unit is clearly supported by the following positions currently held:

- Member of the European Desalination Society (EDS) Board of Directors (2016-2020)
- Coordination of the Renewable Energy and Desalination Working Group of the Platform Water Europe.
- Coordination of the Renewable Energy Desalination Action Group of the European Innovation Partnership on Water of the European Commission.
- Operating Agent of SolarPACES (Solar Power and Chemical Energy Systems) Task VI (Solar Energy and Water Processes and Applications).

6.2 List of projects the unit has been involved in

- Solving water issues for CSP plants, SOLWARIS
- Bio-Mimetic and Phyto-Technologies designed for low-cost purification and recycling of water, INDIA-H2O

- Promoting Energy-Water Nexus resource efficiency through Renewable Energy and Energy Efficiency, EERES4WATER
- Next generation water-smart management systems: large scale demonstrations for a circular economy and society, WATER-MINING
- Intelligent water treatment technologies for water preservation combined with simultaneous energy production and material recovery in energy intensive industries, INTELWATT
- Soluciones termosolares para integración en procesos industriales, SOLTERMIN
- Solar facilities for the European Research Area - Third Phase, SFERA-III
- Solar Twining to Create Solar Research Twins, SOLARTWINS
- Integrating National Research Agendas on Solar Heat for Industrial Processes, INSHIP

7 Solar Treatment of Water Unit

7.1 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 25 years of research activity. The Unit was pioneer in Spain and keeps a consolidated national leadership. The Unit has participated in more than 25 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 techniques for the evaluation of such processes. Formal collaborations in the academic sector include dozens of public institutions in the EU, South America 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 the School. Presently, 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 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 2020 edition has been adapted to on-line platform mode within a series of specific webinars (>70 on-line attendants) and co-organised by Solar Treatment of Water Unit.

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

- Solar photocatalytic and photochemical processes as tertiary treatment for the removal of pollutants of emerging concern and microorganisms, related with, ECOSAFEFARMING (ERA-NET, WATER JPI), AQUACYCLE (CBC ENI MED), PANIWATER (H2020-India) and NAVIA projects and AQUALITY Marie Skłodowska-Curie Action.
- Solar photochemical processes for the remediation of industrial wastewaters, related with UMA SOLAR (Network) and CALYPSOL project.
- Integration of Advanced Oxidation Processes with other water treatment technologies (NF/UF; Ozone, Bioprocesses, etc.), related with AQUALITY Marie Skłodowska-Curie Action and CALYPSOL project.
- Evaluating photocatalytic efficiency of new materials under solar light in pilot reactors, related with ECOSAFEFARMING (ERA-NET, WATER JPI), UMA SOLAR (Network), RATOCAT (ERA-NET), CALYPSOL and NAVIA projects.
- Photocatalytic and photochemical processes for water disinfection in different scenarios related with WATERSPOUTT project and ALICE Marie Skłodowska-Curie Action.
- Pilot solar photo-reactors for production of hydrogen and other photo-fuels, related with RATOCAT (ERA-NET) project.

7.2 List of projects the unit has been involved in

- Network: Iberoamerican Solar Water Treatment Network (UMA SOLAR)
- Water Sustainable Point of use Treatment Technologies, WATERSPOUTT
- Accelerate Innovation in Urban Wastewater Management for Climate Change, ALICE
- Interdisciplinar cross-sectoral approach to effectively address the removal of contaminants of emerging concern from water, AQUALITY
- Development and testing of a novel photocatalytic system for efficient cogeneration of clean water and hydrogen for ecosafe agriculture, ECOSAFEFARMING
- Rational design of highly effective photocatalysts with atomic-level control, RATOCAT
- Photo-irradiationand Adsorption based Novel Innovations for Water-treatment, PANIWATER
- Advanced and hybridized technologies addressing recalcitrant pollutants, micropollutants, reusing and revalorization in different wastewater, including technological and economical approaches. (CALYPSOL)
- Towards increasing the sustainable treatment and reuse of wastewater in the Mediterranean Region, AQUACYCLE
- Urban wastewater reclamation by Novel mAterials and adVanced solar technologies: assessment of new treatment quAlity Indicators, NAVIA

8 Projects

Standardization activities at Spanish and international level, Technical Committees *IEC/TC117* and *AEN/CT206-SC117*

Participants: ABENGOA, AENOR, AICIA, CENER, CIEMAT, PROTERMOSOLAR, SCHOTT Solar, SENER, TECNALIA, TEKNIKER; DLR, Fraunhofer, CEA, ENE, IEECAS, LNEG

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Funding agency: CIEMAT

Background: Since Concentrating Solar Thermal (CST) systems are a relatively young technology, the CST sector is still experiencing a lack of standards. This lack of standards is a barrier for the development of the technology and the evaluation and qualification of components.

Objectives: The scope of the international committee IEC/TC-117 implemented within the umbrella of the International Electrotechnical Commission, and the sub-committee AEN/CTN-206-SC117 implemented within the Spanish AENOR standardization body is the development of standards for the Solar Thermal Electricity (STE) sector by putting together the experience of R+D centres, Industries, Engineering companies, components manufacturers and promoters.

Achievements in 2020: PSA units of Concentrating Solar Systems (CSS) and Thermal Storage Systems (TSS) have participated in standardization activities at both international and national levels in 2020. This contribution has been made under the umbrella of the international standardization committee IEC/TC-117 and the Spanish sub-committee AEN/CTN206/SC117.

At Spanish level, the PSA CSS unit has coordinated and participated in the elaboration of the new standard UNE-206017:2020 "Sensores específicos para la evaluación global de centrales termosolares" ("Specific sensors for global evaluation of solar thermal power plants") issued in November 2020. This PSA unit has also coordinated and participated in the working group elaborating a new UNE standards for "*Criterios de diseño, instalación y verificación de las prestaciones de las juntas cinemáticas en las centrales termosolares con tecnología de captadores cilindroparabólicos"*, ("Design, installation and qualification criteria for rotation and expansion assemblies in solar thermal power plants with parabolic trough collectors"), while the TSS unit has participated in the working group related to a new standard for "*Sistemas de almacenamiento térmico para centrales termosolares de torre*".

At international level, the PSA CSS unit has undertaken the Secretariat of the technical committee IEC/TC-117 in 2020 and it has also participated in the following IEC/TC117 project teams:

- PT 62862-3-1 "Solar thermal electric plants – Part 3-1: General requirements for the design of parabolic trough solar thermal electric plants".
- PT 62862-4-1 "Solar thermal electric plants – Part 4-1: General requirements for the design of solar tower plants".
- PT 62862-5-2 ED1 "General requirements and test methods for large-size linear Fresnel collectors", which will be issued in 2021.
- IEC TS 62862-3-3 "General requirements and test methods for solar receivers", issued in February 2020.

The PSA CSS unit has also participated in the preparation of four proposals for new standards, which were submitted to IEC/TC-117 in November 2020:

- Silicone-based heat transfer fluids for the use in line focusing CSP Applications.
- Performance Test Code for CSP-PTC Plants
- Accelerated Aging Tests of Silvered-Glass Reflectors for Concentrating Solar Technologies.
- Laboratory Reflectance Measurement of Concentrating Solar Thermal Reflectors.

The PSA TSS unit has participated in the elaboration of the final draft of the IEC standard 62862-2-1 30 "*Thermal energy storage systems - Characterization of active, sensible systems for direct and indirect configurations*".

Implementation of the Initiative for Global Leadership in Solar Thermal Electricity, HORIZON-STE

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

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Funding agency: European Commission, H2020-LC-SC3-2018-Joint-Actions-2

Background: Coordination and support action to provide support to the realisation of the Implementation Plans of the SET-Plan for CSP. The project proposes solutions and pathways for overcoming the essential shortcomings of the current national strategies related to CSP/STE that are: a) for the industry: the legal framework conditions for the procurement of manageable RES; and b) for the R&I sector: entering in working relations with national funding agencies with the objective of increasing the public funding to support the development of the R&I projects already prioritized by the European CSP/STE stakeholders according to their expected impact on the sector. These projects were integrated into the Implementation Plan (IP) of SET-Plan.

Objectives: Assessment of the conditions required for replicating in European countries the commercial cost levels (< 10€ cents/kWh) that already achieved by the industry on CSP/STE world markets (financial conditions, type of auctions, the contribution of innovations delivered by R&I) and paving the way for the implementation of FOAK (*First Of A Kind)* projects as one of the objectives of the Initiative and its Implementation Plan. A final objective is the active promotion for the introduction of CSP/STE into energy strategy policies at European or national levels.

Achievements in 2020: PSA has mainly contributed to work packages (WP) 1 and 3 of HORIZON-STE in 2020. Within WP1, PSA has been responsible for deliverables D1.3 "*Analysis results of the 12 CSP R&I Activities resulting from the Implementation Plan of the SET Plan*" and D1.4 "*Report on options for financing instruments and scheme*s", both issued in May 2020. Due to the confidential nature of D1.3, only D1.4 is available at the official web site of the project.

The progress in the 12 high priority R&I activities defined in the Implementation Plan (IP) for the CSP/STE SET Plan were analysed by PSA in collaboration with the other partners and the results were included in D1.3. The main conclusion from this analysis is that stakeholders have many innovative ideas for technology improvements and cost reduction of solar thermal electricity. However, the modest budget so far devoted by the countries committed with the IP of CSP/STE SET Plan and the European Commission for the development of these innovations is the main barrier to achieve the objectives defined in the IP. D1.4 includes an overview of the funding sources available at European or national level in Belgium, Cyprus, France, Germany, Greece, Italy, Portugal, Spain and Turkey for the activities defined in the IP for the SET plan of CSP/STE.

In WP3, PSA has coordinated and participated in the preparation of the *"Input Paper for the Clean Energy Transition Strategic Research and Innovation Agenda (SRIA)" with the focus on the Thematic Cluster 1: Renewable Technologies – Concentrated Solar Power. This document presents the current status of the CST technology, the ongoing research is described and expected development and challenges are discussed.*

Solar Twining to Create Solar Research Twins, SolarTwins

Participants: METU, CIEMAT, DLR

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

Background: Concentrating Solar Thermal (CST) Technologies offer promising solutions to many societal challenges that lead to a sustainable and low-carbon energy future. Currently, Europe is a global leader in CST technologies, but this leading position is increasingly being challenged by large investments by other countries. SolarTwins is designed to respond to this challenge to European Technological Leadership by Twinning PSA and DLR's Institute for Solar Research to the CST research laboratory at the Center for Solar Energy Research and Applications (METU-GÜNAM-ODAK) of the Middle East Technical University (METU) at Ankara (Turkey). SOLAR TWINS started in January 2020 with a duration of 3 years.

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

Achievements in 2020: PSA researchers participated in the kick-off meeting held at METU's facilities at Ankara (Turkey) the last week of February 2020, visiting METU's CST infrastructures and other facilities that could be used in joint research lines between PSA and METU-GÜNAM. Four presentations were made by PSA researchers at the $ODAK_{2023}$ event organized by METU as part of the project kick-off activities to raise awareness of CST among Key Turkish Stakeholders and build support for CST among Turkish Ministries and Funding Agencies. After the meetings with METU's researchers and the visit to METU's facilities at the Ankara campus in February 2020, a SWOT analysis of METU concerning CST technologies and their applications was performed by PSA in collaboration with DLR.

Five joint research lines between PSA and METU's researchers were defined in 2020 within the topics: 1) Micropollutant removal from refinery and/or petrochemical wastewaters, 2) Metal recovery from seawater, 3) Membrane distillation with hollow fiber membranes, 4) Studying the treatment of disinfectants, 4) Turkey's EU-SOLARIS ERIC membership, and 5) Social aspects of CSP/STE contribution to sustainable energy transitions. Due to the Covid-19 pandemic, planned stays of METU´s researchers at PSA in 2020 had to be postponed, as well as the Summer School planned for September 2020 at Ankara with lectures given by PSA and DLR researchers.

Figure 80. SolarTwins kick-off meeting at METU.

Figure 81. SolarTwins team and invited speakers at the ODAK2023 event organized by METU.

An on-line Seminar Series was organized by METU in collaboration with PSA and DLR at the end of 2020 to compensate for the lower on-site collaboration due to the COVID-19 pandemic situation. PSA conducted the first seminar on December 18th, 2020, with the title "*An introduction to Concentrating Solar Thermal (CST) Technologies and Applications*".

Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology, RAISELIFE

Participants: DLR, Brightsource, Fraunhofer, CIEMAT, MASCIR, Dechema, CNRS, Universidad Complutense de Madrid, INTA, Corning, Laterizi Gambetolla (Soltigua), Vallourec.

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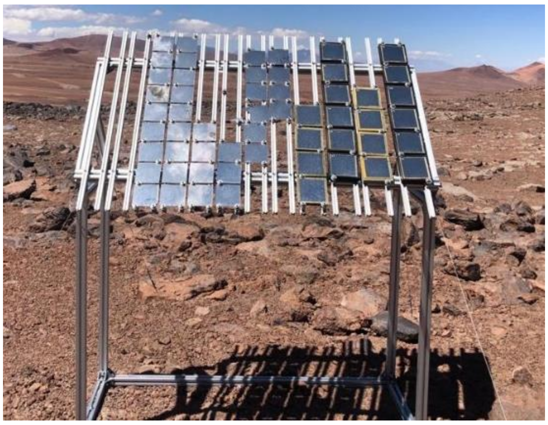
Funding agency: European Commission, EU-H2020-NMP-16-2015.

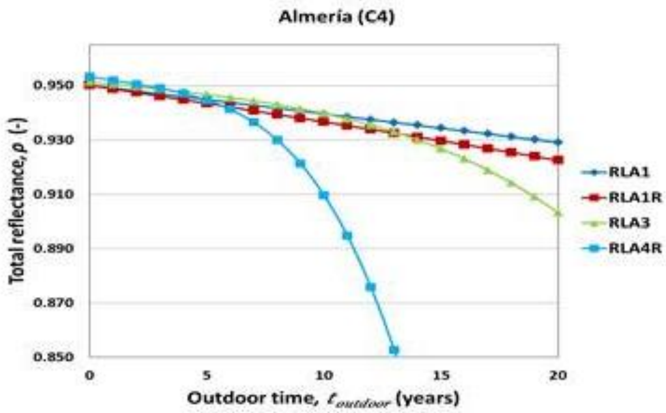
Background: The materials of concentrating solar thermal technologies are exposed to harsh outdoor conditions and are targeted to maintain their initial properties. Therefore, one crucial aspect is to improve the practical understanding of long-term in-service degradation on the performance of the functional material and its impact on the overall performance of the technology components and systems.

Objectives: It focuses on extending the in-service lifetime of five key materials for concentrated solar power technologies: 1) protective and anti-soiling coatings of primary reflectors, 2) high-reflective surfaces for heliostats, 3) high-temperature secondary reflectors, 4) receiver coatings for solar towers and line-focus collectors, 5) corrosion resistant high-temperature metals and coatings for steam and molten salts.

Achievements in 2020: During the last 3 months of the project, all CIEMAT's activities were finished. With respect to Work Package 1 (developed in cooperation with DLR) the last samples of each of the 17 primary reflector materials exposed in 11 worldwide sites were collected and analysed in the laboratory (Figure 82a). The comparison of the main degradation mechanisms observed in the outdoor tests with the results obtained in the accelerated aging allowed deriving two specific correlations to predict the lifetime of the materials studied. One correlation focuses on the erosion happened in the desert sites, which was adequately reproduced in a sandstorm chamber, while the other one addresses the corrosion occurred in the coastal sites, which was properly reproduced in the copper acetic salt spray test (Figure 82b). Both correlations, together with a simple procedure for material durability ranking, led to the publication of a reflector testing guideline. Several anti-soiling coatings were evaluated positively, and promising future candidate materials were identified. In addition, ultra-thin glass mirrors in combination with composite backing material were analysed for the development of novel light weight heliostats. Regarding Work Package 2, the secondary reflector developed by Fraunhofer ISE was used to develop a lifetime prediction model based on a constant temperature test (to simulate the operating conditions), a temperature cyclic test (to simulate thermal shocks due to plant start-up and shutdown, as well as cloudy events) and a damp-heat test (to reproduce the degradation connected to high humidity that could take place overnight). The protocol was validated at the solar furnace SF-60 at the PSA, where the real operating conditions were achieved. As for WP6, CIEMAT carried out a compilation of all the dissemination and communication activities that had been carried out throughout the project and prepared the corresponding report for the Commission. In addition, CIEMAT was responsible for updating the report on the exploitation of the results, taking into account all the changes that had occurred during the course of the project, and was also responsible for publishing the series of catalogues of best practices that were developed as a result of the research carried out in the project. Finally, all activities within the rest of the tasks where CIEMAT participated in this project were ended and all deliverables and reports were finalised.



(a)



(b)

Figure 82. Test bench exposed outdoor in Chajnantor, Chile (a) and example of reflectance estimation obtained with the lifetime prediction model, for Almería site (b).

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

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

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

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

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

Achievements in 2020: CIEMAT successfully coordinated the the 2nd General Assembly and 3rd Management Board meeting held at ENEA's premises in Cassacia (Rome), from 11 to 13 February 2020. Also, this year, CIEMAT coordinated the evaluation of the proposals submitted for the second call for proposals for access to the installations offered in the SFERA-III project, a very successful call for proposals in which a total of 62 proposals were received.

Figure 83. Photo of the participants in the 2nd General Assembly and 3rd Management Board meeting held at ENEA.

CIEMAT coordinates WP6 which is entitled Development of Test Procedures for Materials and Components of Thermal Storage Systems. Closely linked to the ACES2030 regional programme, the results obtained in 2020 of the degradation of some phase change materials (PCMs) by two approaches (TGA and heating in a furnace), and which imply different sample sizes, induce to sentence that it is necessary to work with these two approaches in order to determine the degradation kinetics of these PCMs in real operating conditions and therefore predict their long-term behaviour (Task 6.2). Discussions on the test procedures for prototype testing keep on as well as on the definition of KPIs from experimental results (Task 6.3). In collaboration with the Thermal Storage Working Group of SolarPACES Task III, which is coordinated by ATYCOS experts, a characterization methodology has been proposed for valves and pressure transducers for molten salt loops (Task 6.4).

CIEMAT activity within Task 7.1 (WP7) has been focused on the definition of best procedures for exegetic analysis of MED processes. In addition, as Task 7.2 leader, in parallel with other participants, has been working on the preliminary testing of polymeric materials for MED tube bundles. Particularly, CIEMAT is working on the establishment of the technical specifications for a new experimental facility (MED) using polymeric-based heat exchangers for MED process. Parallel to the work performed on the MED process, CIEMAT, together with the other partners, is also conducting work towards the development of procedures for Membrane Distillation (MD) and Forward Osmosis (FO) membranes testing. For the achievement of this goal, the assessment of new MD modules assisted by vacuum is being examined. In the frame of Task 7.3, CIEMAT has proposed tentative guidelines towards the performance evaluation standardization of DWT pilot plants (solar membrane distillation, nanofiltration, multi-effect desalination, CPC NOVO75). Special attention has been given to the definition of control loops and instrumentation in order to achieve the best procedures defined within Task 7.1 for the case of solar applications. Within Task 7.4 CIEMAT has been working on the development of in-house simulation software mainly related with the performance assessment of solar thermal cogeneration plants (CSP+D) coupled to MED and RO processes. Large optimization operations for thermoeconomic studies have required the development of simplified correlation models for MED plants to be able to run several thousands of yearly simulations within such optimization operations. Regarding membrane distillation, empirical correlations for GOR have been proposed for the new technology of multi-envelope spiral-wound air gap membrane distillation modules in conventional configurations.

IN WP8, CIEMAT has been involved in activities in tasks 8.2 and 8.3. Specifically, in Task 8.2, Tests procedures to assess the performance of materials for solar fuel production, CIEMAT has taken part in the creation of a database to guide the efforts of this task to standardise the techniques and procedures for monitoring and evaluating some key performance indicators of reactors. With standard benchmarking techniques, the resulting data can be used to determine correlation between reactor design, operating parameters and performance. In Task 8.3, Dynamic Control and Automation of Solar Fuel Reactors, CIEMAT has been working on developing advanced model-based algorithms to control solar fuel systems under solar transients. Based on H_2 production results obtained with a 100-kW cavity reactor concept at different operating conditions, the work performed has been focussed on the development of “refined” kinetic models, taking into account experimental findings. These “refined” kinetic parameters will then be employed to simulate the hydrogen production in the reactor under different operation strategies and identify the effects of crucial operating parameters.

CIEMAT also participates in WP10 Sensor calibrations and techniques for accurate determination of performance parameters of prototypes installed in research infrastructures, where our contribution has consisted in the development of a device for the measurement of forces and moments on the joints of parabolic trough collectors. Patent procedures have been initiated for this device. Furthermore, CIEMAT has participated in the development of a protocol to perform a round robin for measuring thermal losses in parabolic trough collector receiver tubes between the test benches of the entities participating in this activity of the project.

The main achievement in WP11 has been the signature of the subcontract with the specialized company that will perform the detailed design of the most suitable e-infrastructure to link the European R+D centres devoted to CST technologies. This subcontract was signed in October 2020 and TECNATON - the company awarded with this contract - started the activities with an analysis of limitations and requirements imposed by the software/hardware currently used by CIEMAT, CNRS, DLR and ENEA in the facilities chosen to be part of this e-infrastructure at the beginning.

Integrating National Research Agendas on Solar Heat for Industrial Processes, INSHIP

Participants: FRAUNHOFER, AEE-INTEC, CIEMAT, DLR, CNRS, ENEA, ETHZ, CEA, CYI, LNEG, CTAER, CNR, CENER, TECNALIA, UEVORA, IMDEA, CRANFIELD, IK4-TEKNIKER, UNIPA, IST-ID, FBK, CRES, METU, EERA AISBL, UNINA, UNIFI, US, CIC Energigune.

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Funding agency: European Commission, H2020-LCE-2016-ERA.

Background: Process heat is recognized as the application with the highest potential among solar heating and cooling applications. Solar Heat for Industrial Processes (SHIP) still presents a modest share of about 0.3% of total installed solar thermal capacity. As of today's, technology development stage is quite restricted to low-temperature applications, so INSHIP is focusing on CSP/STE technologies to widen the scope of industrial applications to a temperature range between 80-1500°C. INSHIP project corresponds to a new funding scheme (European Common Research and Innovation Agenda-ECRIA) designed by the European Commission as the next step beyond the current Integrated Research Agendas (IRP) and specifically targeting EERA JPs.

Objectives: INSHIP is a framework engaging major European research institutes with recognized activities on SHIP, into an integrated to achieve the coordination objectives of more effective and intense cooperation between EU research institutions; alignment of different SHIP related national research and funding programs, avoiding overlaps and duplications and identifying gaps; acceleration of knowledge transfer to the European industry while developing coordinated R&D TRLs 2-5 activities with the ambition of progressing SHIP beyond the state-of-the-art.

Achievements in 2020: In addition, to coordinate WP6 (Integrated SHIP research infrastructures) and WP8 (Advanced Networking Activities), in the framework of WP2, CIEMAT has contributed to the deliverable D2.5 ("Control tools and methods for SHIP") which includes solutions for flat-plate collectors to i) guarantee reliability and efficiency (a fault detection tool), ii) deal with multiple pumping flow rates (multivariable control strategy) and iii) improve the operation by reducing the start-up stage (optimal real-time predictive control methodology). In WP3 (Technology and applications to medium temperature, 150 - 400°C) CIEMAT has provided two deliverables: deliverable D3.8 titled "Reference design of solar steam integration layout for a food/beverage industry", which includes the design, dimensioning and the corresponding techno-economic study of direct solar steam generation system using parabolic troughs to supply steam in an almond factory that was selected as representative industry of the food sector with heat demand in the form of saturated steam at temperature over 150°C (this report is linked to the Tasks 3.1 and 3.2), and deliverable D3.9 titled "Mirror degradation characterization under industrial conditions", which contains all the information related to the demonstrator accomplished by CIEMAT in Task 3.3, in order to characterize solar mirrors degradation in industrial environments. This demonstrator is formed by 5 mirror test benches installed in representative sites with corrosivity levels from C2 to CX (according to ISO 9223, ISO 9226).Furthermore CIEMAT have contributed to the deliverable D3.10 titled "Compact optical designs", coordinated by University of Evora, which presents and overview of the existing solutions and the progress of four different solar collector systems more compact and easier to integrate in building envelopes, developed with the support of INSHIP and other in-kind projects. CIEMAT contribution has been focused on the development of an innovative linear Fresnel collector that can be integrated into pitched roofs of warehouses. In WP4 (Technology and applications to high temperature SHIP, 400 – 1,500°C) CIEMAT has completed the following tasks: In the subtask 4.2.4 (Study of thermal performance of a solar receiver at different operational conditions) CIEMAT has prepared and submitted the deliverable D2 Results of operation of the 100-kW plant with same boundary conditions than a lime production, which includes an evaluation of a solar thermal reactor that operates at temperatures near 1,000°C. This study also analysed which control strategy can allow the receiver to restore the initial conditions more efficiently. Annual simulations of the receiver performance were carried out using software for centralized applications (solar tower). In the task 4.4.4 (Development of a concentrator system providing a vertical beam for solar chemical reactors without need of active cooling) CIEMAT has prepared and submitted the deliverable D2 Small scale prototype designed. Final report and interim reports on the results of the research activity. This document includes a ray tracing performed on the concentrator system geometry to investigate possible slight deviations from the theoretical shape. Furthermore, additional work was carried out to improve the solar flux in the focal plane in terms of homogeneity, distribution, and/or other criteria. A remote collaboration with UEVORA was carried out in an adaption of a secondary mirror for an existing heliostat field of the Plataforma Solar de Almería.

POwering SYstem flexibiliTY in the Future through Renewable Energy Sources, POSYTYF

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

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Funding agency: European Commission, EU - H2020 - LC-SC3-RES-16-2019

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

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

Achievements in 2020: This project started in June 2020 and so far, the work of CIEMAT in WP1 has involved advising on the development of realistic scenarios of solar thermal energy generation, based on statistics. Definition of typical scenarios has been done, as previous step to run large scale system simulations. The first results have been included in "*D1.1 Definition and specification of Dynamic Virtual Power Plant (DVPP) scenarios*", which will be finished at the beginning of 2021. In WP2, CIEMAT is participating in the development of models of concentrated solar thermal power plants for grid integration studies including:

- Development of a simplified model of Solar Thermal Electricity (STE) plants in MATLAB that can be easily integrated with power generation models.
- Validation of the simplified STE model against detailed models of STE plants (already developed by CIEMAT in TRNSYS environment) will be performed, in order to guarantee, at a reasonable extent, reliable results from the simplified tool.

Finally, in WP5 CIEMAT is collaborating on the generation of data sets (renewable production) of solar thermal power plants, for the operation and management of virtual power plants.

SMALL-SIZED PTCS PRESSURIZED WATER TEST LOOP - LAVEC

Participants: CIEMAT

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Funding agency: Ministry of Science and Innovation within the Special State Fund for Dynamization of Economy and Employment, co-financed by Programa Operativo FEDER Plurirregional de España (POPE) 2014-2020.

Background: The use of solar energy for the supply of thermal energy to industrial processes is a market which growth expectations are high. However, there is a lack of test facilities suitable for qualification and evaluation of line-focus solar collectors design for this type of solar energy application. The lack of this type of facility is a barrier for the commercial development of these solar thermal systems.

Objectives: Taking into consideration the current lack of experimental facilities for evaluation and qualification of small line-focus solar collectors, it has been decided to design and build a new PSA test loop facility, suitable for the testing of medium temperature (100 – 250°C) solar thermal collectors. Any type of line-focus tracking solar collector can be tested, based in pressurized water as heat transfer fluid. The design of this facility is based on the previous project CAPSOL (already out of work), that was used for testing prototypes of small-sized PTCs using pressurized hot water up to 220°C. Additionally, the facility will fulfil the current standards for solar thermal collectors testing: ASTM E905-87:2013, SRCC 600 2014-17:2015 and ISO 9806:2017.

Achievements in 2020: The basic and detailed engineering of the facility (see the figure below) were finished: P&ID, piping flexibility and temperature expansion studies, and facility requirements. The main features adopted for the design of the LAVEC facility are the following:

- Heat transfer fluid: pressurized 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.
- Material used for the hydraulic circuit: stainless steel.
- Field length: up to 40 m, in both orientations: East-West and North-South.
- Cooling system capacity: up to 150 kWt, 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).

The technical specifications of the main equipment (water pump, expansion tank, electric heater and air cooler) have been prepared and the main equipment was purchased and received at PSA. Likewise, the project instrumentation and hand valves have also been specified, purchased and received at PSA. The draft of the layout and isometric drawings of the facility has begun, as well as the assembly specification. A paper based on the facility design "*A New Facility for Testing Line-Focus Concentrating Solar Collectors for Process Heat Applications*" was presented at ISES Eurosun2020 – 13th International Conference on Solar Energy for Buildings and Industry Virtual Conference, 01 – 04 September 2020.

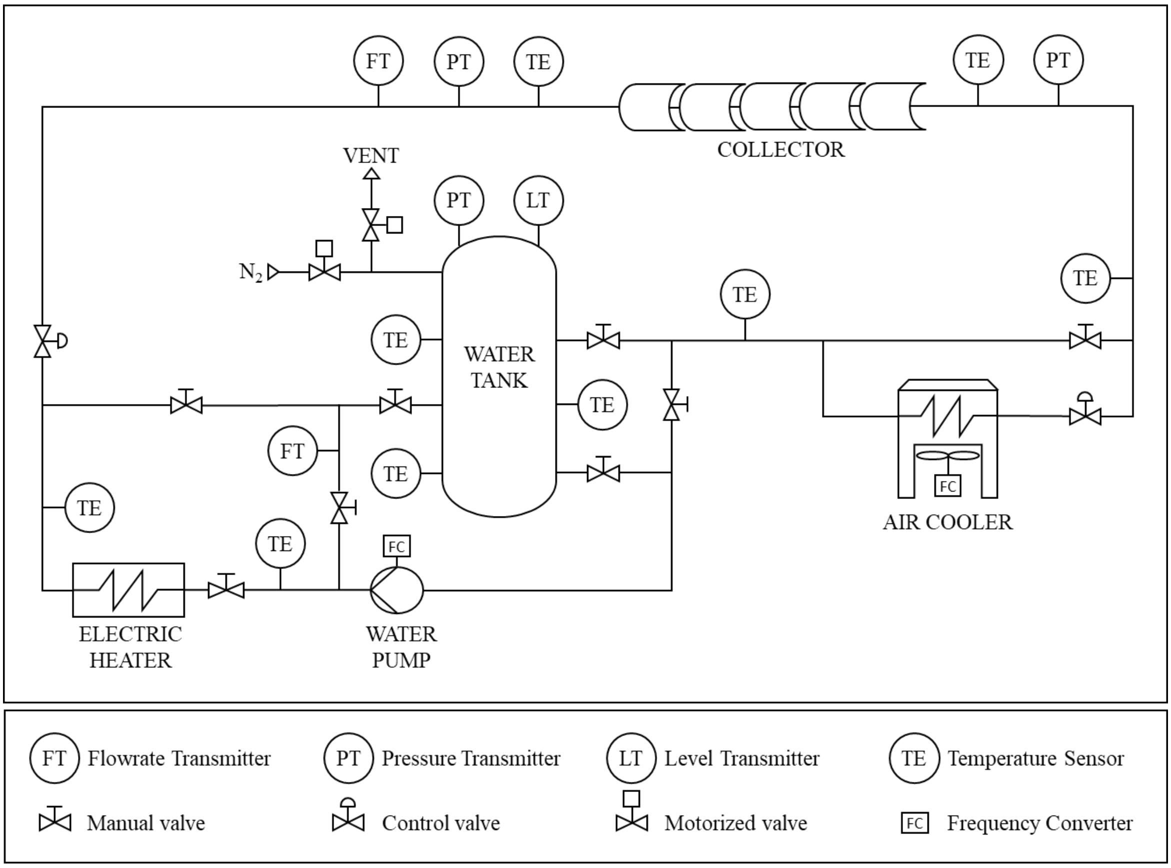

Figure 84. Simplified scheme of the LAVEC facility.

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

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

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

Background: The development of systems that can reach higher temperatures than those currently applied on commercial solar power plants (390°C of thermo-oil and 560°C of molten salt) allow the connection of solar energy into highly efficient and/or innovative systems such as high-temperature thermodynamic cycles (as Brayton cycles) and chemical or high-temperature processes as those related to solar fuels, materials processing and/or production or synthesis of chemicals. Among the media currently investigated to allow temperatures of 1000°C or more in high-temperature solar receivers the use of solid particles have the advantage that they can be also directly used as the thermal energy storage media.

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

Achievements in 2020: CIEMAT has already contributed this year with a literature review to identify the process parameters of the sCO2 Brayton cycle to be driven by solar energy for a sensitivity simulation study to define the target design pressure, temperature and flow rates of the sCO2 cycle, as part of Deliverable 1.1 submitted in January 2021. CIEMAT is also contributing by depositing coatings on particles to develop more efficient particles for the receiver in terms of solar radiation absorption. The first step has been to define the type of particles to be used and their relevant parameters to be considered. The methodology for testing and characterising them has been established.

The Materials for Energy Interest Division-DMXE of CIEMAT Technology Department also participates in the project studying innovative alloys as the heat exchanger structural material and has contributed to define the material to be tested and the selection criteria recorded in the Deliverable 1.3 to be submitted in January 2021.

Soluciones termosolares para integración en procesos industriales, SOLTERMIN

Participants: CIEMAT

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Funding agency: MINECO -Retos Investigación 2017: Proyectos I+D+i (Ref. ENE2017-83973-R) (Jan 2018 – Dec 2021)

Background: Commercial deployment of concentrating solar thermal (CST) technologies has grown significantly, with about 5 GWe of installed capacity worldwide for electricity generation. However, the commercial use of concentrated solar thermal energy is still very limited, despite the fact that more than 66% of total energy consumption in the industrial sector is dedicated to industrial heat processes.

Objectives: The project SOLTERMIN is developed by the Solar Concentrating Systems Unit and the Desalination Unit of the PSA. The project aims to advance in the development of new components and solutions to facilitate the integration of concentrated solar thermal technologies as thermal energy provider in industrial processes, with the following objectives:

- Development of a linear Fresnel solar collector for its integration in industries, including the development of a light-weight and optimized primary concentrator design to reduce optical losses and the development of an absorber coating valid up to 400°C and stable in air.
- Research on solar components for tower systems devoted to industrial process applications, including innovative and optimized heliostat designs and volumetric air receivers.
- Study of the durability and reliability of solar reflectors installed in industrial environments.
- Integration of linear Fresnel solar systems in different industrial processes: a) from a food and drink industry; and b) multi-effect distillation (MED) plant with steam ejectors. And integration of a solar tower system coupled to a Brayton cycle and a MED plant.

Achievements in 2020: The design of a multi-tube receiver for the first prototype of an innovative linear Fresnel collector has continued this year. After completing the construction of the support structure and primary concentrator, including the mirror facets that were manufactured at PSA in 2019, the evaluation of preliminary tests of the concentrated heat flux achieved in the showed concentrated heat fluxes up to 8.7 kW/m^2, which is in agreement to simulation results. The development of a selective coating stable in air for medium temperature applications has been completed (absorptance > 0.95 and emittance@350°C<0.10); the durability of the coating has been also checked since it was completed the testing in a muffle for 15 months and no degradation of the optical properties was observed. A new selective coating for high temperature (700°C) applications has been developed with a solar absorptance of 0.95 and a thermal emittance at 700°C of 0.20. Thermal stability after 2 months at 700°C has not been affected. A parametrical analysis on the influence of the axial-varied porosity for wire mesh volumetric receivers has been performed using six different commercial woven wire cloths. Finally, simulation models have been developed in TRNSYS to analyse the performance of LFC-solar fields integrated in two industrial processes (from the dairy and beverage industries), including the sizing of the solar field and the storage system and the definition of operation strategies.

Another achievement in 2020 has been the development of a preliminary model of the Brayton Cycle in Phyton (turbine, compressor, combustor, gas turbine and heat exchanger) considering some data from the solar tower AORA Solar. This model will be integrated with the model of the solar field (heliostat solar field) to perform annual simulations of the CSP plant when coupled with the MED-TVC unit. For the annual simulations, this unit has developed a code that allows discharging the online data from PVGis of solar radiation, temperature and wind velocity of a TMY, given the geographical parameters of a certain location. Finally, CIEMAT has developed a preliminary model of a steam generator (to be driven by a Fresnel solar field that has to be modelled) and has obtained a parametric equation from a simulation model of a MED-TVC unit previously developed by the unit. Both models have been integrated for simulation.

Silicone Based HTF in Parabolic Trough Applications – Preparation of a Guideline, Si-HTF Guideline

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

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Funding agency: SolarPACES (International Energy Agency).

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

Objectives: The project aims at forming an international expert work group with the assignment to elaborate an experienced-based guideline for the admission of silicone based HTF (SHTF) in PTC applications. The guideline shall be the basis for future international standardization activities in the same field. The project has a duration of 18 months and comprises three main phases: Data compilation, Admission procedure comparison and Guideline document.

Achievements in 2020: The project started in April 2019 with the activities and data compilation planned in WP1, i.e., the formation of the expert work group; a detailed summary of the qualification procedure executed for silicon heat transfer fluids (HTFs); and the compilation of standards and other existing documents applicable to the use of HTFs in solar thermal systems. Since CIEMAT had previous experience in the preparation of standards for solar power plants, in particular in the elaboration of UNE 206015:2018, it was the responsible leading a compilation of main physical and chemical properties relevant for HTFs in hydraulic heating systems, and standards and test methods available to measure or quantify these properties.

Within the framework of WP2 and in collaboration with DLR, Wacker Chemie AG, IEECAS and TSK Flagsol, CIEMAT contributed to the elaboration of a detailed comparison of testing procedures available in ASTM, ISO, DIN, UNE and GB standards, and in defining which test methods are relevant for silicone based HTFs and which are not, due to the physical-chemical properties of this type of fluids compared to others as diphenyl oxide/biphenyl mixtures that are extensively used in existing PTC solar power plants.

Finally, the main activity carried out in 2020 has been the elaboration and finalisation of the guideline document (WP3). It is published and available for free download in the SolarPACES webpage. This guideline and the formation of the expert work group are the basis for a new project submitted to SolarPACES in 2020 with the aim of preparing an official IEC Standard on silicon HTFs. The project proposal is approved and will start into execution in 2021.

Soiling measurement of solar reflectors

Participants:CIEMAT, DLR, ENEA, Fraunhofer ISE, University of Zaragoza, NREL, TSK, Abengoa and Rioglass.

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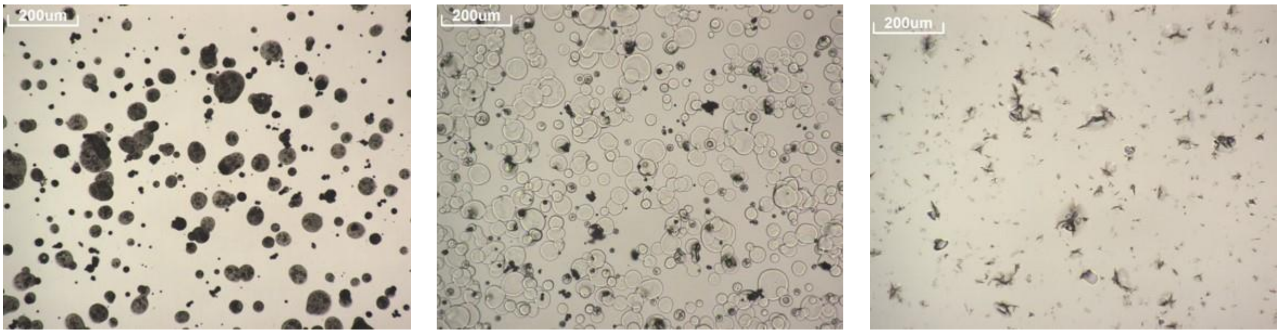
Funding agency: SolarPACES (International Energy Agency).

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

Objectives: The main goal is a new 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 2020: During 2020, significant advances were achieved within WP1, which is focused on the study of the field portable reflectometers. A deep analysis of the main features of the marketed reflectometers was performed, using information from the manufacturers' documentation, researchers' knowledge, and plant operators' experience. Also, the main practical difficulties faced by plant operators during the field measurements and the list of desired features for the ideal instrument were addressed. In addition, data collected on previous experiments performed to compare field portable reflectometers are being analysed.

With respect to WP2, which is devoted to obtaining correlations between portable and advanced lab instruments, the first activity performed was the preparation of a number of coupons with well-defined opacities that simulate the optical behaviour of naturally soiled reflectors. To achieve this goal, several different methods were applied to silvered-glass reflector samples (see Figure 85), such as spraying black paint, spraying hairspray, introducing the samples in a sand blast chamber, fixing particles with hairspray and enclosing particles between a glass sheet and the reflector. After a deep comparison of the different coupons, it was decided that the samples produced with the sand blast chamber are the best ones to reproduce the naturally soiled samples. During next year, the coupons will be measured both with portable and laboratory equipment by different institutions to estimate conversion functions that will permit to derive more representative reflectance values from the data acquired with field instruments.



(a) (b) (c)

Figure 85. Microscopic view of sprayed black paint (a), sprayed hairspray (b) and sand blasted (c) samples.

Solving Water Issues for CSP Plants, SOLWARIS

Participants: TSK (Coordinator), CEA, DLR, CIEMAT, Cranfield University, Fundación Tekniker, Rioglass Solar, Ingeniería para el Desarrollo Tecnológico, FENIKS, Barcelona Supercomputing Center, BrightSource Industries (Israel) Ltd, AMIRES.

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Funding agency: European Commission, EU-H2020-LCE-11-2017.

Background: Water consumption is a major issue for the commercial deployment of CSP/STE plants in desertic areas. Several technical innovations for water saving have been identified and some of them are already under development in the H2020 WASCOP project. SOLWARIS is somehow the continuation of the work initiated in WASCOP.

Objectives: The main objective of SOLWARIS is the testing and validation in a real commercial environment of important innovations for water saving in CSP/STE plants. These innovations include: antisoiling coatings for mirrors and receiver tubes, advanced cleaning systems, water recovery systems for the BOP and cooling tower effluents, cooling thermal energy storage and a plant O&M optimizer including soiling rate forecast.

Achievements in 2020: CIEMAT researchers participated in the M18 review meeting held at Brussels on 29th January 2020. Two presentations were made by CIEMAT researchers, one to present the advances achieved in WP6 and another one to present the advances in WP5.

In WP1, CIEMAT has cooperated with Cranfield University in the preparation of the activities to assess the community acceptability and livelihood impact of CSP plants (Task 1.2), focused on the Spanish

Case study. In WP3, CIEMAT has carried out a study of a hydrophobic anti-soiling coating on the glass tubes of RIOGLASS receivers (subtask 3.4.3). In addition, CIEMAT has studied the effect of the coating on the optical properties, the abrasion resistance and the durability under condensation conditions in CIEMAT laboratory by tests in samples of commercial tubes. The results showed that the coating was stable under the conditions tested and variations in abrasion behaviour were observed by the anti-soiling treatment. CIEMAT has also participated in the assessment of the durability of the anti-soiling coating for reflectors developed by IK4-TEKNIKER and RIOGLASS (subtask 3.4.2), by testing coated samples under accelerated aging conditions. Finally, the accelerated "edge-kicking" tests performed to the brush used in the dry-cleaning technology developed by BRIGHTSOURCE for heliostats were concluded (Task 3.3). The loss of cleaning efficiency noticed with the aged brushed might be compensated by increasing the number of passes.

In WP5, CIEMAT has been collaborating with the companies TSK and INDETEC in the manufacturing of the Water Recovery System with the Multi-Effect Evaporation (MEE) technology that will be installed at the CSP plant La Africana (Córdoba, Spain) for water recovery purposes. In addition, CIEMAT has collaborated in the definition of the technical specifications of the intermediate equipment and instruments required for the integration of the MEE unit into the CSP plant. CIEMAT has also collaborated with DLR and INDETEC in the design of the operation at partial load of the MEE plant for an O&M optimizer that DLR is developing within the Project. The main work of CIEMAT in this WP has been the development of a model of the MEE plant in Modelica and its validation in the design point with data provided by INDETEC, obtaining a good agreement between the results from the model and the design ones. All this activity has been reported in the deliverable D5.3 submitted in October 2020. Finally, CIEMAT has also participated in the definition of the control loops for optimization of the process. All process variables have been already defined, as well as the optimization criteria. Also, the developed model has been upgraded for optimization purposes.

Figure 86. Photo of the participants in the 18 monthly review meeting held at Brussels.

Silicone fluid maintenance and operation, SIMON

Participants: DLR (coordinator), CIEMAT, Wacker Chemie AG, TSK Flagsol Engineering GmbH, Senior Flexonics GmbH, TÜV NORD SysTec GmbH & Co. KG, Innogy SE, Rioglass Solar, S.A. Flucon Fluid Control GmbH, Ruhrpumpen GmbH

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Funding agencies: Solar-ERA.NET Transnational Call CSP 4.3 2016; MINECO – *Retos 2017 Acciones de programación Conjunta Internacional* (Ref. PCIN-2017-009) (Oct 2017-Mar 2020); German Federal Ministry of Economy and Energy and German Federal Ministry of Innovations, Science and Research (Jan 2018-Apr 2020).

Background: Silicone based heat transfer fluids (SHTF) have been used in the past as heat transfer fluids in medium scale installations such as PTC test loops e.g., at PSA (Spain), NREL (USA) and elsewhere (DOW, Syltherm 800®). SHTFs are pumpable below 0°C, environmental-friendly, low in hydrogen formation, almost odourless and very low in acute toxicity. Until now, such fluids are not used in large-scale commercial CSP power plants because available SHTFs are currently far more expensive than the widely used eutectic mixture of diphenyl oxide and biphenyl (DPO/BP). The development, testing and demonstration of reliability, performance, and competitiveness of new SHTFs are of great interest of the CSP sector.

Objectives: The SIMON (Silicone fluid maintenance and operation) project is close related to the SITEF project (2016 and 2017) and has the objective to accelerate the market introduction of two HELISOL® products: HELISOL®5A and HELISOL®XA with improved viscosity properties, and associated parabolic troughs solar field's components (REPAs and receiver tubes) at temperatures up to 450°C. Such operation temperatures are beyond state of the art in PTC power plants and increase the overall power plant efficiency. This innovate project is based on a German-Spanish cooperation making use of the so called PROMETEO and REPA test facilities located at PSA.

Achievements in 2020: The proof of concept of the heat transfer fluid HELISOL®XA, manufactured and supplied by Wacker Chemie AG and tested at the PROMETEO pilot plant, was successfully completed in July, when 480 hours of solar operation at 425°C were achieved. During the continuous testing of the HTF in this pilot plant, frequent hot vacuum sampling has been performed for checking the evolution and possible degradation with continuous operation. In parallel, at REPA test facility, activities developed consisted of commissioning and aging the same HTF at 450°C during 3,000 h. In this facility, frequent sampling of the HTF has been also done to compare the chemical and thermo-physical properties measured to the data from samples tested in the lab and obtained from PROMETEO facility. At REPA test facility, new REPAs from Senior Flexonics have been also tested in 2020.

The success on the execution of this SIMON project, in addition to the good performance of HELISOL®5A tested during previous SITEF project, has led to the international consortium's decision to promote new projects related to the use of silicon HTFs in parabolic trough collector applications, such as the German SING project, in which CIEMAT will continue to participate as an associate partner, and the CSP Eranet SI-CO project. Both projects will be implemented at PSA again and will start in 2021.

Figure 87. View of the PROMETEO test facility during operation for the SIMON project (Specific REPAs installed at the inlet/outlet of the parabolic troughs can be seen).

Competitive Solar Power Towers, CAPTURE

Participants: CENER (Coordinator), TEKNIKER, CIEMAT, FRAUNHÖFER-IKTS, BLUEBOX ENERGY LTD, CEA, FCT GMBH, SONCEBOZ SA, HAVER&BOECKER, TSK FLAGSOL, K-CONTROLS LTD, EDF, EUREC EESV.

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Funding agency: European Commission, H2020-LCE-2014-2015

Background: Volumetric atmospheric air receiver technology is a promising alternative to increase receiver efficiency of Solar Tower Power Plants. CIEMAT works on this technology since 1990 testing more than 15 different volumetric receiver prototypes in the las 20 years, being a strategic technology field of High Concentration Solar Group.

Objectives: The project global objective is to increase plant efficiencies and reduce levelized cost of electricity by developing all relevant components that allow implementing an innovative plant configuration consisting on a multi-tower decoupled advanced solar combined cycle approach that not only increases cycle efficiencies but also avoids frequent transients and inefficient partial loads, thus maximizing overall efficiency, reliability as well as dispatchability; all of which are important factors directly related to cost competitiveness on the power market.

Achievements in 2020: 2020 was the last year of the project and a complete test program has been carried out to evaluate both, individual components and the system as a whole. The installation consists of a 300 kW_{th} atmospheric volumetric receiver integrated with new design of SiC porous absorbers. The receiver is coupled to 2 regenerators whose mission is to act as a temperature exchange between hot atmospheric air and air at 10 bar pressure, to be expanded in an 80 kWe turbine. As summary, the system was operated up to the defined nominal conditions and the charging and discharging cycles of the regenerators were demonstrated.

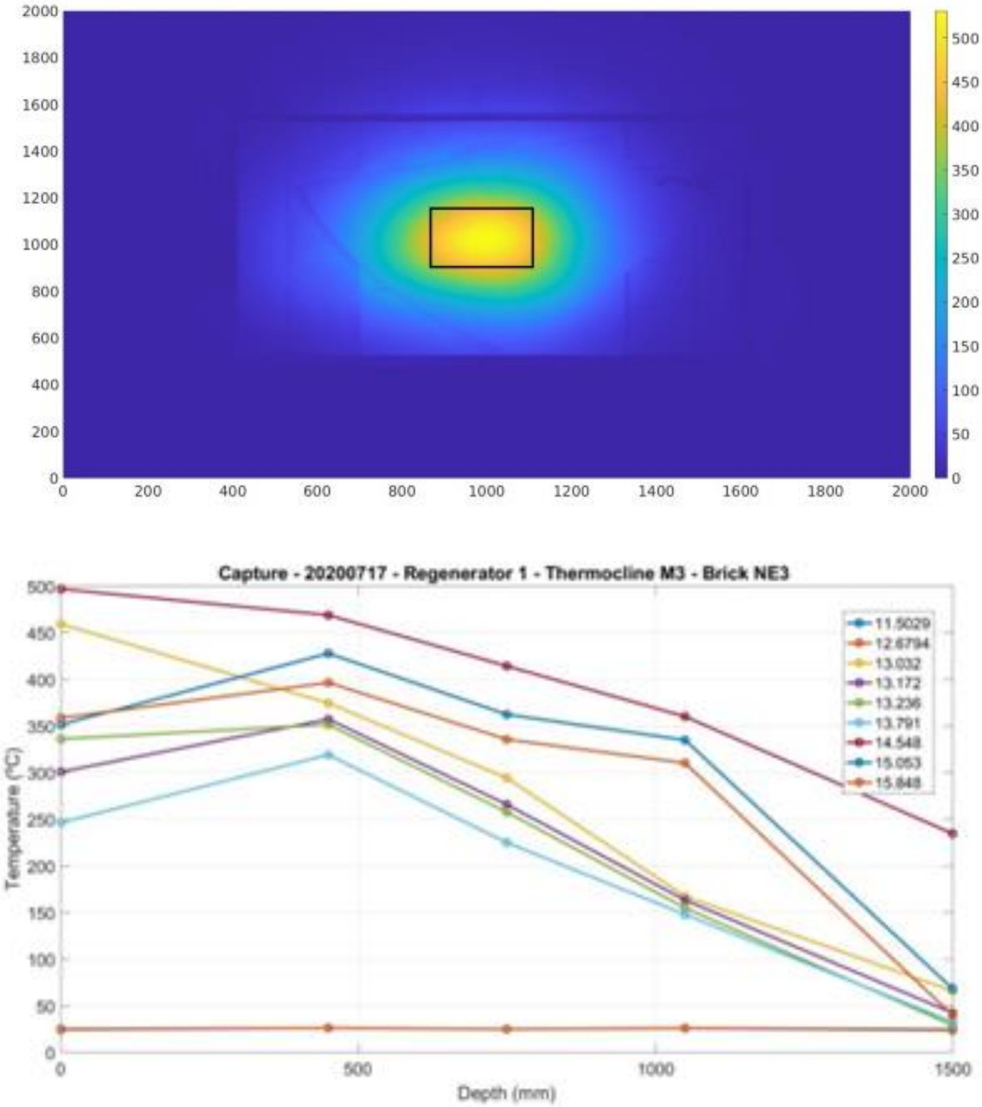

Figure 88. Pseudo coloured image for the CAPTURE receiver under operation (top) and thermocline temperatures inside regenerator #1 (bottom).

Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems, NEXTOWER

Participants: ENEA (coordinator), KTH, POLITO, CIEMAT, ICCRAM, UOXF, URM1, SANDVIK MT, BEWARRANT, CERTIMAC, R2M SOLUTIONS, LIQTECH, CALEF, SILTRONIX, GREEN CSP, ENGICER, UNE.

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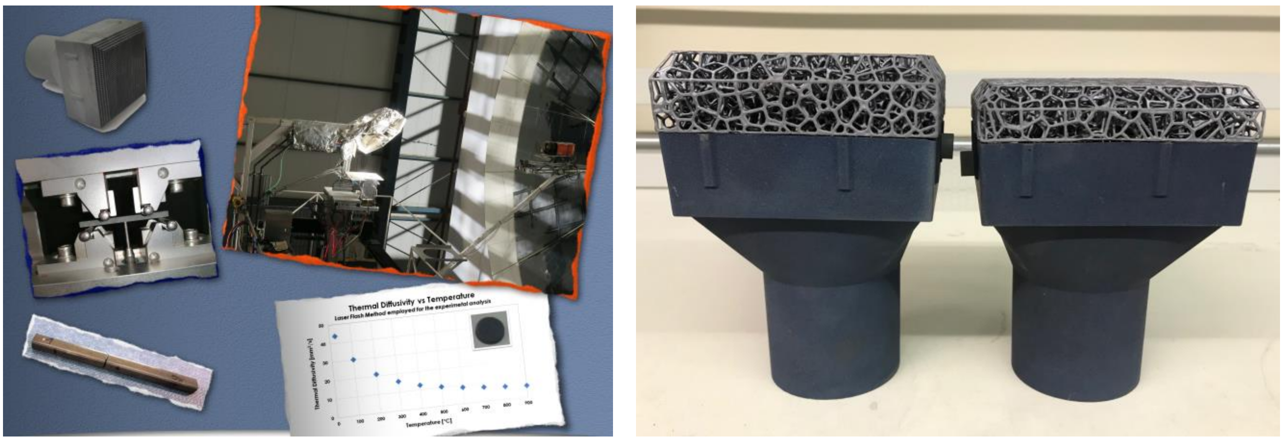
Funding agency: European Commission, H2020-NMBP-2016-2017. Grant Agreement no. 721045

Background: While volumetric air CSP towers are socially and technically appealing, for their great environmental sustainability and the potential for electrical and thermal power generation, their industrial exploitation has been significantly slowed down by the materials used for the core component (i.e., the high temperature solar receiver) which is affected by limitations in maximum working temperatures and in-service overall durability, mainly due to failure by thermal cycling.

Objectives: NEXTOWER project aims at demonstrating high-performance durable materials for the next generation of concentrated solar power (CSP) air-based tower systems, making them commercially competitive in the energy market beyond 2020. While CSP towers are socially and technically appealing for their great environmental sustainability and the potential for electrical and thermal power generation, their industrial exploitation has been significantly slowed down by the materials used for the core component (i.e., the high temperature solar receiver) which is affected by limitations in the maximum working temperatures and in-service overall durability, mainly due to failure by thermal cycling.

NEXTOWER responds by taking a comprehensive conceptual and manufacturing approach that starts by optimizing for durability the ceramic materials to achieve 20-25 years of maintenance-free service receiver components, while increasing their operating temperature for thermodynamic efficiency at the system level and possible unprecedented applications downstream, such as the direct interfacing with a Brayton cycle or the supply of zero-emission heat for industrial/chemical processing. The actual exploitation of the hotter air (up to 800°C) is then crucially tied to the development of a high-temperature thermal storage, here inspired by nuclear fission GEN-IV technology and based on liquid lead by means of new corrosion resistant steels.

Achievements in 2020: CIEMAT, together with other partners (particularly UNE), developed a procedure for accelerated cycling testing on SiC materials under concentrated solar radiation. This methodology was awarded with the CEN-CENELEC annual prize for the best European project related to international standard for the industry. At the same time, different geometries of absorber monoliths have been tested on the SF60 solar furnace to choose the better configuration for a final NEXTOWER whole volumetric receiver.



(a) (b)

Figure 89. Testing procedure for accelerated aging of SiC materials (a) and new volumetric geometries under test (b).

Fortalecimiento de la calidad de sistemas solares industriales de torre mediante la medida de parámetros y estimación de la atenuación atmosférica con enfoque a entornos climáticos desérticos, 17BPE3-83761

Participants: UA, PUC, UCh, Fraunhofer, PUC, CIEMAT, UAL, UHU

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Funding agency: Asociación Chilena De Energías Renovables (ACERA), Ministerio de Energía de Chile (MINEN), Corporación de Fomento de Chile (CORFO).

Background: Information about atmospheric attenuation of solar radiation between heliostats and receivers in Solar Tower Plants is necessary for their design, dimensioning and site selection. Said parameter also plays an important role in the operation of said plants, since it improves the estimation of the energy that reaches the receiver.

Objectives: Generation of the first map with estimated atmospheric attenuation values between heliostat and receiver for central receiver solar thermal tower power plants in the Atacama Desert in northern Chile.

Achievements in 2020: The project, which end in June, is currently in its final stage. So far it has resulted in the publication of 11 papers in first quartile scientific journals, as well as the presentation of 8 papers at international conferences and the organization of a forum on this topic at the Solar World Congress held in Santiago de Chile in 2019. Work is currently underway on the drafting of the project's final report. The results of the map indicate that the Atacama Desert is an ideal place for the installation of tower plants due to the operating conditions: maximum extinction values below 5% for 1 kilometre distance. To generate the map, the methodology developed at the PSA was applied and 30 years of satellite data of 9 atmospheric parameters corrected with terrestrial measurements were analysed for the entire Chilean territory. The results of the data analysis have not only been essential for the elaboration of the map but are proving to be revealing in studies of other areas such as, e.g., studies for photovoltaic technologies performance.

Figure 90. Weather station at the *Plataforma Solar del Desierto de Atacama* (PSDA) in Antofagasta (Chile). The station is equipped with a large variety of instruments ranging from atmospheric parameter measurements to solar resource measurements, including instrumentation for characterizing atmospheric aerosols and components, visibility sensors and size distribution of airborne particles.

PV plant with thermal cogeneration, SOLARBLUE

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

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

Funding agency: CDTI, FEDER - INNTERCONECTA 2018.

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

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

Achievements in 2020: 2020 has supposed the beginning of the project where the design of the heliostat and some preliminary tests have been performed. The validation of the design of selective filters, which started in a former project, has been finished as well as the validation of the commercial procedure for the manufactured of coated PV panels.

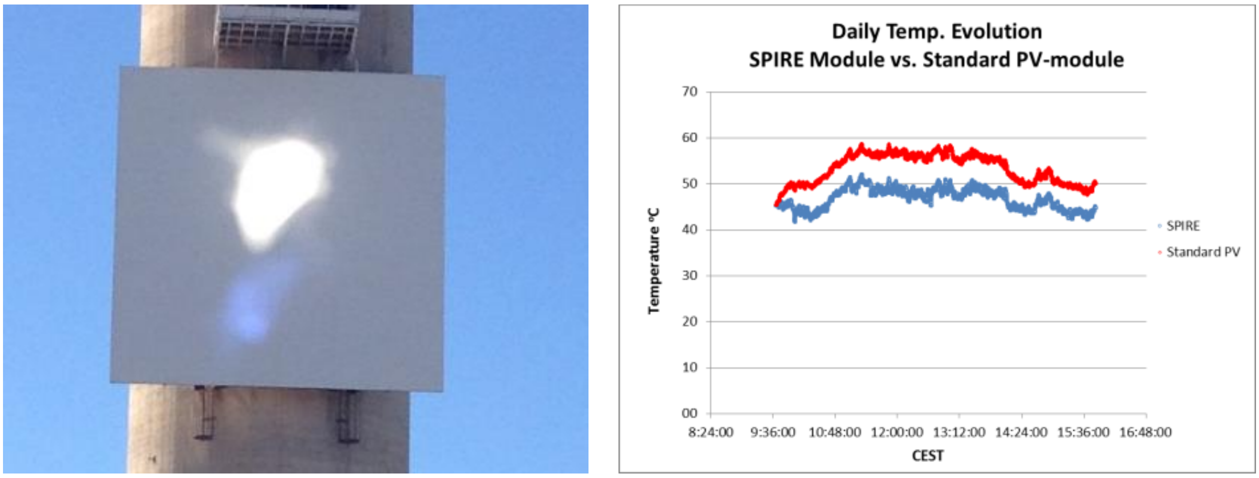

Figure 91. Comparison between SOLARBLUE coated and uncoated PV panels.

Sophia and Photon heliostat prototypes

Participants: TEWER (Coordinator), CIEMAT

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Funding agency: CDTI, FEDER Funds.

Background: Improving the efficiency of heliostats at the same time of a cost reduction of the fabrication and deployment of them is a way to foster the commercial growth of STE technology. CIEMAT works on the design and characterization of heliostats since 1990 and has developed a worldwide recognized methodology for the heliostats assessment in both optical and energetic faces. As a consequence of this work done in the last year, most of the heliostats prototypes commercially deployed worldwide have been tested on PSA facilities.

Objectives: The project global objective is to evaluate the behaviour of 2 different heliostats prototypes designed by TEWER with the aim of introduce a significant cost reduction on the solar field deployment for a commercial solar tower power plant. Both heliostats are small surface prototypes and include wireless strategies in both communication and power.

Achievements in 2020: The Sophia heliostat was installed in the heliostat test platform, tested and evaluated during 2018. The Photon heliostat have been installed during two different periods of 2020, firstly the pedestal (February), and later the reflective surface (September).

(a) (b)

Figure 92. Sophia heliostat (a) and Photon heliostat (b) at the heliostat test platform at PSA.

Small-Scale Solar Thermal Combined Cycle, POLYPHEM

Participants: CNRS (coordinator), CEA, CIEMAT, Arraela, Fraunhofer, Kaefer Isoliertechnik, Orcan, Euronovia, Aalborg CSP

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

Funding agency: European Commission, H2020-LCE-2016-2017

Background: With the objective of increasing the flexibility and improve the performance of small solar tower power plants, the concept of the project consists in implementing a combined cycle formed by a solarized micro gas-turbine and a Rankine organic cycle machine, with an integrated thermal storage device between the two cycles.

Objectives: The project will build a 60-kW prototype plant with a 2 MWh thermal storage unit and will validate this innovative power cycle in a relevant environment (TRL 5), assess its technical, economic and environmental performances and establish the guidelines for its commercial deployment.

Achievements in 2020: The main contribution of CIEMAT is on the thermal storage system (TSS). ATYCOS coordinates the WP for the design and simulation of the TSS. This TSS is a thermocline tank with filler. During 2020 a structured filler based on one of the concrete formulations developed during the project has been chosen. The shape and size of the bricks have been mainly defined by the possibilities commercially available. Comparison in terms of storage capacity of different solid bricks arrangements and hollow bricks has been performed. The final choice has also account for the easy of assembling the bricks in the tank as filler. The testing matrix and required instrumentation for the experiments to carry out in the MicroSol facility has been defined in collaboration with CNRS. These experiments have the objective of identifying, before erecting the POLYPHEM tank, any unexpected problem that may appear as well as of providing a set of experimental data to support a first validation of the modelling of the TES. The general P&D scheme of the POLYPHEM plant has been defined. Since not much time for testing will be available in the project to test the whole POLYPHEM tank, the critical tests have been identified in collaboration with the rest of the partners.

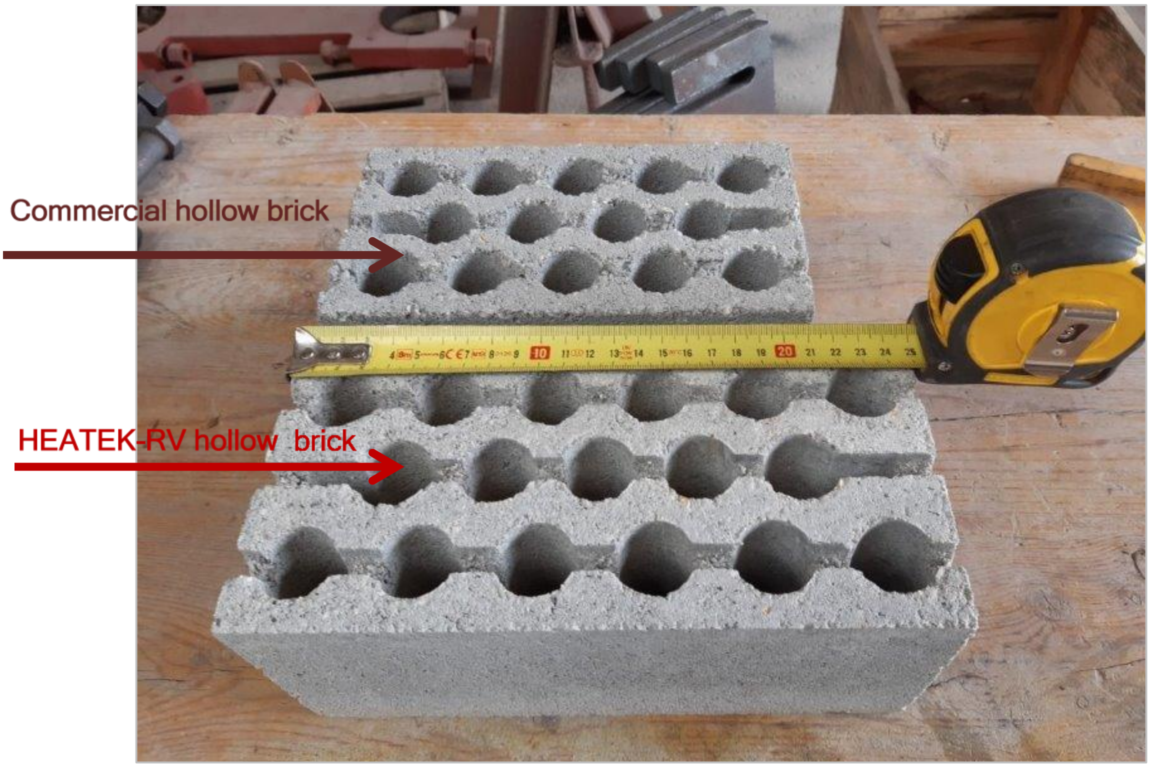

Figure 93. Comparison of geometry between a commercial hollowed brick and one using Heatek-RV®.

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

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

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

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

Background: Three main challenges covering aggressive penetration of CSP within end use energy mix by 2030: Renewable electricity where a new class of better CSP plants are required; Solar process heat where technologies and integration schemes are required; Solar fuels for transport, where materials, technologies and processes for the H_2 production and storage are required.

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

Achievements in 2020: In relation to CIEMAT Thermal Storage Group, two main activity lines can be distinguished: one focusses on defining the methodology to validate phase change materials as latent storage material and another one on packed bed thermal storage at high temperature with atmospheric air as heat transfer fluid.

In the first line, during 2020, the analysis of the thermogravimetric measurements (TGA) of some fatty acids has gone on. In addition, in order to obtain information on the thermal degradation of these acids in conditions as close as possible to those of operation, isothermal weight loss tests have been carried out for lauric acid using an oven and sample quantities between 1 g and 5 g. In general, it has been observed that the kinetic results obtained by both methods (TGA and furnace) differ considerably because they are greatly affected by the amount of sample used in the tests. Therefore, it is necessary to jointly analyse both types of results in order to determine the degradation kinetics of these PCMs in real operating conditions and therefore predict their long-term behaviour.

Figure 94. Photograph of the types of fillers used in the experimental tests carried out in the ALTAYR tank.

In the second line, new tests have been carried out in ALTAYR test bench using a new material, more resistant, both mechanically and thermally, and with greater storage capacity. It has been compared with the material used previously (Figure 95). The following two figures show both fillers and the comparison of their temperature-time curves for charging processes with the same operating conditions.

The contribution of the CIEMAT Solar Fuels Group to the present project is focused on the development of new materials for thermochemical cycles aimed at clean hydrogen production. The various materials being studied include ABO3-type perovskite materials that improve the redox characteristics of the materials most commonly used to date, such as Ni ferrites ($NiFe_2O_4$), as well as materials based on Cerium oxide (CeO_2) that allow the high activation temperatures for this material (1,400 – 1,600°C) to be reduced.

During 2020, tests were started with some perovskite-type materials. In general, to improve the performance of perovskite-type materials, the A and B positions are doped respectively by other elements A′ and B′ to form oxides of structure with the formula of $A_{1-x}A'_xByB'_{1-y}O_3$. The doping of A′ can mainly increase the oxygen vacancies and promote the electronic conductivity, and the doping of B can basically enhance the electrocatalytic activity. In this preliminary work, we mainly consider the effect of A-position doping on the performance of the oxygen evolution reaction, for that, we have prepared a series of perovskite oxides $La_{0.6}$ $Sr_{0.42}$ $Fe_{0.8}$ $Co_{0.2}O_3$, and $La_{0.2}$ Sr0.8 $Fe_{0.8}$ $Co_{0.2}O_3$ (Figure 96).

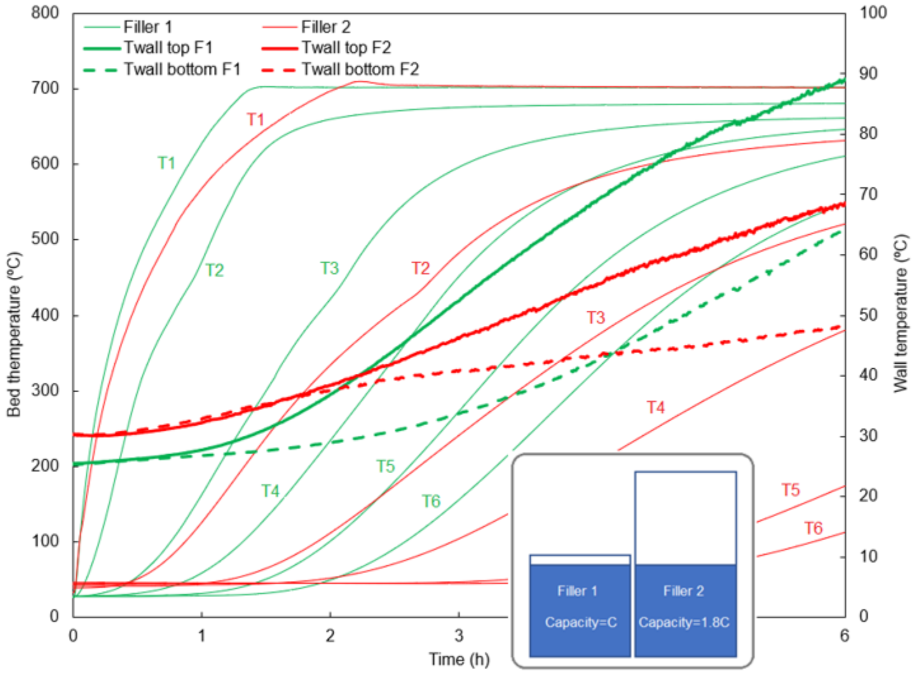

Figure 95. Thermocline curve evolution for a charge process at 700°C and 50 kg/h for the two considered fillers.

According to the results in Figure 96, the amount of Sr in the material has a considerable improvement in the amount of O_2 measured in the nitrogen stream leaving the reactor is observed. This result is of great importance for the synthesis of new materials, and it can lead to an increase of H_2 in the same proportion in the hydrolysis stage (around 30%).

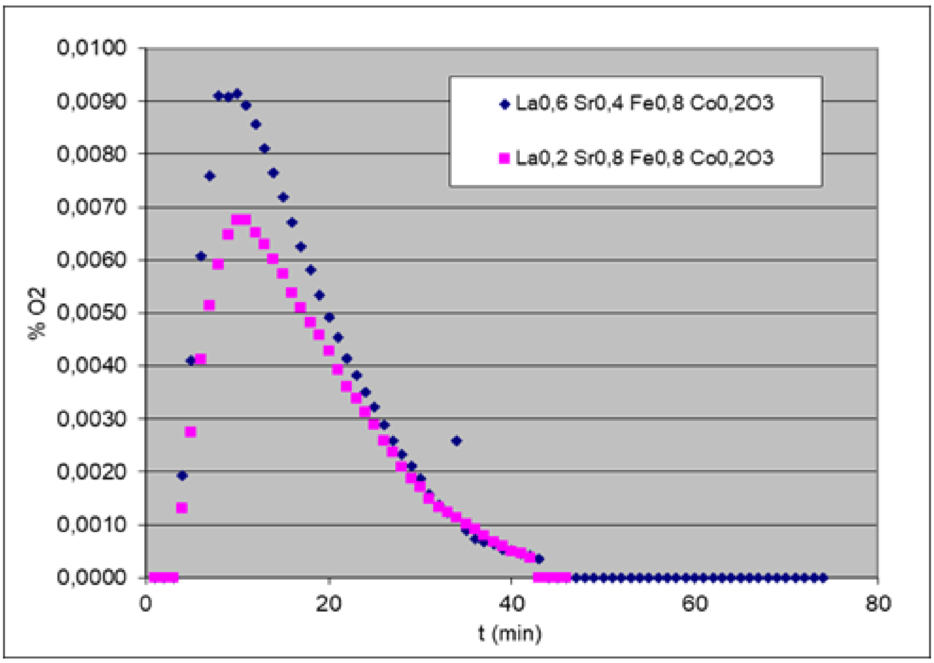

Figure 96. Evolution of O_2 in some of the synthetized materials obtained by doping different A-postions of the commercial sample.

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

Participants: APTL, DLR, Hygear ENGICER SA, SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA, COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, ABENGOA HIDROGENO SA, CIEMAT.

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

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

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

Objectives: The main objectives of the project are summarized above:

- Improvement of the stability, cyclability and performance of the redox materials and redox structures (1,000 cycles or 5,000 hours of operation),
- Design novel solutions for high temperature solid-solid and solid-gas heat recovery. Heat recovery rates substantially higher than 50% are requested to meet that target,
- Embed and validate smart solutions to minimize the consumption of auxiliaries like flushing gas. Target should be to reduce energy losses through such auxiliaries to less than 25% of the energy output,
- Design and development of intelligent systems and a smart process of control and automation, including predictive and self-learning tools, and
- Demonstration of long-term performance of materials and key components under realistic boundary conditions using existing solar test facilities is needed. (core components like the solar receiver in a scale of about 500 kW). Testing period of the hardware, minimum 6 months.

Achievements in 2020: During 2020, the pilot plant was commissioned to complete the testing campaign already committed. These testing campaigns were run during the second half of the first year of the project, within the months that are characterized of high in-solation, and also cover the first half of the second project-year. Trials were an essential step of the project to identify the operability of all existing hardware and software, limitations and bottlenecks of the existing configuration via exposure tests of adequate duration and to define the baseline operation of the plant prior to the upcoming modifications.

The receiver showed a short start-up time and a fast response to changes in operation, indicating the low thermal inertia, characteristic of volumetric receivers, as opposed to the cavity receivers previously evaluated. A range of 950 - 1,100°C could be maintained stable on the reactor for a long daily period of time (≈ 6 h).

Considering that the thermochemical process involved to face different operational conditions, the influence of process parameters was also analysed. Parametric tests included the variation of the cycle length, the variation of mass flow of steam and mode of operation, providing valuable information on the general thermal behaviour of the cavity. Final tests were focused to analyse the efficiency of the process by using not only isothermal but swing mode operation.

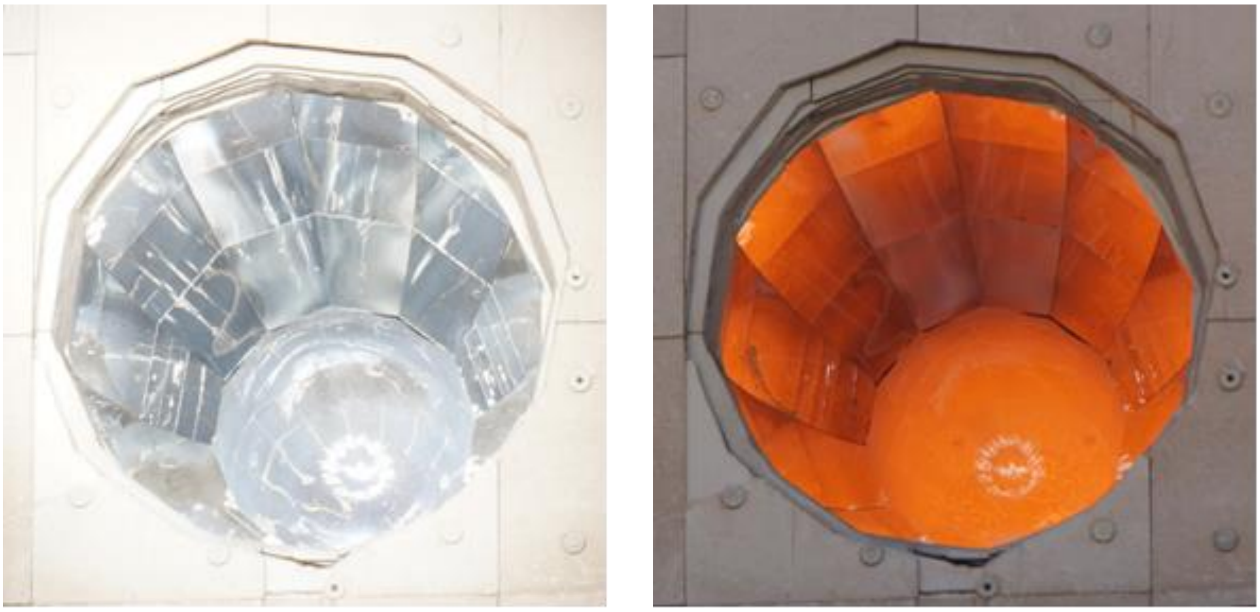

Figure 97. Hydrosol reactor at 1,100°C. (a) With concentrated solar radiation. (b) Immediately after the defocus; the orange glow of the thermal radiation is prominently visible. (In reality, the view on the left is extremely much brighter than the one on the right, but this cannot even remotely be reproduced in photographs.).

It can be stated that operating the module in a swing mode leads to higher hydro-gen production rates. Obviously, operating the cavity non-isothermally will lead to thermal stress and fatigue on the active and structural materials when compared to isothermal approach. A durability test inspection was implemented at the end of the tests although it is scheduled on the project a more in-depth study achieving at least 1,000 cycles.

A Lunar CHEMical In-Situ recource utilization Test plant. ALCHEMIST Phase A (ALPHA)

Participants: Space Applications Services (Belgium), CIEMAT (Spain), Airbus Defense and Space (Germany), SINTEF (Norway), Abengoa (Spain), Aavid Thermacore (UK), Technical University of Munich (Germany), Vrije Universiteit Amsterdam (Netherlands), Centre de Recherches Pétrographiques et Géochimiques (France), Centre Terre et Pierre (Belgium), CBK (Poland)

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Funding agency: European Space Agency, Contract ITT AO-9107

Background: Every three years, the ESA Council on Ministerial Level meets to decide about the European activities in space for the coming years. The latest meeting was end of November 2019 in Sevilla (Spain). The European Space Agency (ESA) planned to propose to the Council (among many others) a mission with the purpose of demonstrating In-Situ Resource Utilization (ISRU) on the Moon. ISRU means that *local* resources, especially minerals, are used to produce useful goods like air (oxygen), water, metals, construction materials, or rocket propellant. To prepare the proposal, ESA issued several ITTs (Invitations to Tender) to do detailed preparatory studies about the mission, divided into the segments transportation, communication, and payload, this project is among them. It is the follow-up project of the Alchemist-project (ESA-Contract ITT AO-9107) carried out in 2018.

In the years before, at the PSA, there was designed, built, and tested in the Oresol project a full-scale test plant able to reduce ilmenite (a common mineral on the Moon) with the help of hydrogen and concentrated solar power to produce water. The knowledge and practical experience gained in Oresol was the decisive advantage of PSA to be invited to participate in the ITT.

The project ALCHEMIST is the first ESA payload study that defines the high-level details of a lunar ISRU payload operating with the hydrogen reduction process.

Objectives: The principal goal of the phase was to define the hardware of a hydrogen reduction plant operating on the Moon. This included the sub-systems for excavation of the lunar sand (regolith), the pre-processing like sieving or enrichment, the processing of the regolith with hydrogen at 900°C, and the fluid management for the hydrogen supply, recirculation, and extraction and storage of the product water. Goal of the mission is to produce 100 g of water from lunar regolith.

Achievements in 2020: No tests have been carried out this year, so no results have been achieved.

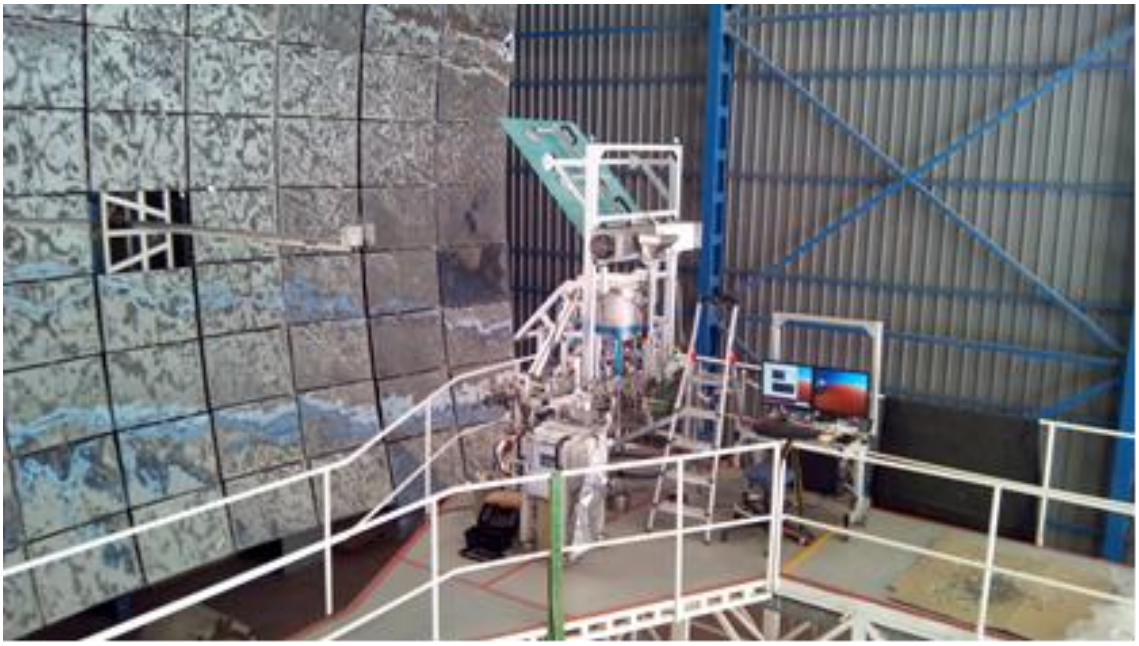

Figure 98. Oresol experiment on the test platform of the Solar Furnace SF60.

Resource recovery from industrial wastewater by cutting edge membrane technologies, REWACEM

Participants: FRAUNHOFER (coordinator), AEE INTEC, BFI, UNIPA, CIEMAT, DEUTSCHE EDELSTAHLWERKE, SOLARSPRING, AT&S, ELECTRONIQUEL, DEUKUM, AIZ, USTUTT, TECNOZINCO, PSE

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Funding agency: European Commission, H2020 Programme

Background: Production of metal goods brings, along with the generation of a multitude of different wastewater streams as the ones from cooling circuits and gas cleaning, rinsing water and diluted pickling acids from electroplating as well as washing water from casting of tools and automotive components. The high demand for water, often needed in demineralized quality for rinsing or washing purposes, is already a problem for production sites in the semi-arid regions of Southern Europe. Additionally, metal processing consumes plenty of different process fluids like acids, bases, and salts leading to contaminated wastewater streams, which need disposal, causing high costs and significant environmental impact in general.

Objectives: The main objective of REWACEM Project is the application and demonstration of innovative and efficient water treatment technologies with the effect of a significant reduction of water use, wastewater production, chemical consumption and energy use for the metal production, processing and coating industries. The proposed approach is an integrated system comprising between one and two cutting edge membrane technologies (Diffusion Dialysis (DD) and Membrane Distillation (MD)) which is highly suitable for adaptation to the manifold metal processing branches using low-grade waste heat and concentration gradients to provide energy-efficient wastewater treatment and liquid stream recovery.

Achievements in 2019: During this year, the activities of the REWACEM Project have concluded with the demonstration at pilot-scale of a plant combining diffusion dialysis, membrane distillation and reactive precipitation. This plant was installed in the factory of the company Electroníquel (Gijón, Spain) and recovery values for sulfuric acid (85-100%) and copper (85%) have been achieved, also obtaining high-quality permeates (50-60 µS/cm) from the residual water of the copper electroplating processes carried out in the aforementioned factory.

Bio-mimetic and phyto-technologies designed for low-cost purification and recycling of water, INDIA-H_2O

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

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

Background: INDIA-H20 will develop, design and demonstrate high-recovery, low-cost water treatment systems for saline groundwater and industrial wastewaters, focused on the arid state of Gujarat, with scarce surface water resources. Solutions will be demonstrated in small-scale rurally relevant low-cost systems, and a centre of excellence will be established in water treatment membrane technologies, design operation and monitoring.

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

Achievements in 2020: CIEMAT participated in the design of the forward osmosis (FO)-reverse osmosis (RO) system and the definition of the control needs, both for the rural brackish groundwater desalination application and for the industrial wastewater treatment application. As coordinators of WP4 (ICT Enabling Remote Monitoring, Control and Optimisation), CIEMAT also participated in the design and selection of online sensor solutions for the water treatment systems, and in the development of operation and control systems. In particular, a first evaluation of the optimal operation in the batch-RO system was performed based on the input-output model results provided by the University of Birmingham (responsible of the technology). Also, a Piping and Instrumentation Diagram (P&ID) was elaborated for the installation of the system at PDPU (location of the centre of excellence), as well as for the rural application (in the village of Lodhva), aiming at low-cost and easy control system. The development of software was followed closely checking the preliminary models of FO and RO. The models were defined and complemented with a solar energy collection model developed by CIEMAT. In addition, an analysis of the BRO-FO system operation at PDPU was performed based on steady state models provided by the partners.

Promoting energy-water nexus resource efficiency through renewable energy and energy efficiency, EERES4WATER

Participants: CTA (coordinator) (ES), US (ES), CIEMAT (ES), ITC (ES), UCC (IE), BRINERGY (ES), ENERAREA (PT), UEVORA (PT), RML (IE), CU (UK), ESPRIT (FR)

Contacts: Diego Alarcón, diego.alarcon@psa.es

Funding agency: European Commission, INTERREG Atlantic Area Programme

Background: According to the priorities established in the Research and Innovation Strategies for Smart Specialization (RIS3), sustainable solutions to technological advancement of the energy and water sectors with regard for regional specific features are required, from industrialized to rural. Technological solutions should be adapted to different scenarios commonly exist in the Atlantic Area, specially to coastal areas and islands.

Objectives: EERES4WATER will enhance the institutional, technical and social framework to promote the direct use of renewable energy sources and energy efficiency in the water cycle by influencing related policies and introducing new processes and technologies. Main goal is to provide Atlantic Area stakeholders with the tools and instruments needed to overcome the Energy-Water nexus challenges and increase its utilization.

Achievements in 2020: The main activity during 2020 has been focused on the development of two case studies where the techno-economic feasibility of autonomous solar desalination concepts in the Canary Islands at small and large scale has been evaluated. Regarding the small scale, the implementation of small multi-effect distillation (MED) plants powered by solar energy, both thermal and photovoltaic, has been evaluated to cover both energy needs of the distillation plant. The results have shown that the high investment cost of the MED plant is a handicap for its selection compared to other alternatives such as the combination of photovoltaic and reverse osmosis (RO). As for large capacity systems, the CSP+PV+RO combination has been shown to be an alternative that can offer more competitive costs than conventional desalination when considering the real costs of generation on the islands. Capacity factors above 90% have been obtained thanks to the thermal storage systems of the CSP plant, which offer an alternative with less environmental impact than the PV-RO plants due to the low capacity factor of the latter. On the other hand, work has continued to support the University of Seville and ITC in terms of updating the performance obtained with the latest developments in membrane distillation pilot plants.

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

Participants: TU DELFT (coordinator), SEALEAU, KWR, EURECAT, NTUA, SELIS, CIEMAT, DECHEMA, BRUNEL, UNIABDN, WaterEurope, HEXION, UNIPA, WETSUS, UAB, JIN, ACSA, ICCS, RHDHV, KVT, LARNACA, NEMO, ACCIONA, USC, JIIS, ADA, REVOLVE, ENoLL, WEI, LENNTECH, TITANSALT, ECSITE, SOFINTER, VSI, THERMOSSOL, NOURYON, FLOATING FARM, MADISI

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

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

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

Achievements in 2020: The project started in September. CIEMAT worked on preparing the implementation of Case Study 2 and the detailed concept: to demonstrate a seawater desalination scheme with zero liquid discharge powered by solar thermal energy that can be more sustainable than the current technologies of reverse osmosis connected to the grid, especially if the goal is to produce water for irrigation. To achieve this, the improvement in the efficiency of a multi-effect distillation plant will be evaluated after a pre-treatment of seawater with nanofiltration, which will allow the plant to operate at a higher temperature and with a higher concentration factor. The brine produced will be crystallized to produce high purity sodium chloride, and the distilled water will be remineralized with the brine from the nanofiltration (richer in divalent ions) to be used for irrigation water. The concept includes the use of solar thermal energy as the main source of energy. The principles of value-sensitive design will be used in the implementation, developing a Community of Practice to engage stakeholders. Also, a Living Lab will be created at PSA.

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

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

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

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

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

Objectives: CIEMAT participates in case study 2 in Castellgali (Barcelona), where a pilot plant will be built which will consist of an integrated reverse electrodialysis (RED) system and membrane distillation powered by solar energy to valorise a collector of brine from mining activities, with the aim of producing electrical energy and deionized water.

Achievements in 2020: The project started in October, and the preliminary definitions were made for the laboratory tests necessary for the development of Case Study 2, in particular, the membranes and modules to be evaluated at PSA.

Network: Iberoamerican Solar Water Treatment Network (UMA SOLAR)

Participants: CIESOL-UAL, CIEMAT y SERC Chile

Contacts: Sixto Malato, sixto.malato@psa.es
Isabel Oller, isabel.oller@psa.es

Funding agency: FONDECYT *Fondo Nacional de Desarrollo Científico y Tecnológico de Chile, Programa de Cooperación Internacional*.

Background: FONDAP, a program run by the National Commission for Science and Technology Research in Chile, promotes the development of scientific research centres of excellence. These centres leave a strong impact, working within priority areas and “responding to extremely important and relevant problems for the country” and “forming and consolidating research teams.” The development and widespread adoption of small-scale solar solutions in both, rural and urban communities will play an important role in the future as energy supply solutions of the country and a driver of productive applications. In this context, the SERC Chile RL1 (Solar Water Treatment), which is the research group coordinating this network, will develop its major effort in that focus. Therefore, consolidation/extension of a robust scientific community with a strong national/international cooperation network is a key factor.

Objectives: The network will foster collaboration among the research centres involved in UMA SOLAR, through the joint work of researchers, generating joint publications, presenting joint results in seminars and conferences, including PhD theses within the framework of the project and disseminating to the community the results achieved. Three main R&D collaborations are envisaged: solar treatment of water at pilot plant scale, new photocatalysis (materials) and solar mining.

Achievements in 2020: Considering that UMA SOLAR is a Network its planned activities have been delayed due to the Pandemic. However, Alejandro Cabrera Reina, PhD (Universidad de Santiago de Chile), responsible of this Network in Chile, has been able to successfully finalize his stay at PSA till December 2020.

Water Sustainable Point of use Treatment Technologies, WATERSPOUTT

Participants: CIEMAT; Universidad Rey Juan Carlos; University of Strathclyde; University of Malawi; Ecole Polytechnique Federale de Lausanne, National University of Ireland Maynooth, Makerere University; Stellenbosch University; Ecosystem Environmental Services S.A.; Mekelle University; Buckinghamshire New University; Helioz GMBH; Dublin City University; Stichting IHE Delft; Universidad de Santiago de Compostela; Royal College of Surgeons in Ireland (coordinator).

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

Funding agency: European Commission, H2020-WATER-2014-2015/H2020-WATER-2015-two-stage.

Background: Solar water disinfection (SODIS) is a household water treatment that uses direct sunlight to inactivate pathogens in water using 2-L PET bottles. It is widely accepted in developing countries, but some limitations still affecting the efficiency of this process such as the volume of water to be treated per batch (bottle).

Objectives: The main objective is to increase the user uptake of SODIS by designing and piloting three novel solar based technologies (Solar rainwater reactors, Solar jerrycans and Solar-ceramic filtration) providing larger volumes (≥20 L) of treated water per day. CIEMAT objective is to develop, construct and test reactors based on SODIS for disinfection of harvested rainwater providing 125 litres/day of treated water.

Achievements in 2020: The project has finalized in June 2020, and the last 6 months of project execution has been marked by the sanitary emergency situation of COVID-19. Therefore, during this period, CIEMAT researchers have been conducted mainly dissemination activities and management actions related with the project. Nevertheless, a numbers of great achievements have been reached by CIEMAT along the entire project execution, highlighting briefly the following: (i) Development and testing of large solar photo-reactors for rainwater disinfection (150 L/day) made of PMMA (polymethylmethacrylate) material and V-trough mirror, which demonstrated a very good performance both under controlled conditions at PSA facilities (Figure 99) and field conditions (Uganda and South Africa locations). (ii) Assessment of transparent and low-cost plastic containers (alternative to 1.5 L-PET (polyethylene terephthalate) bottles) for solar water disinfection, including 25 L-Jerrycan (made of PET material) and 20 L-buckets (made of PP-Polypropylene material). (iii) Collaboration on the development of empirical mathematical models as predictive tool of the inactivation behaviour of E. coli and MS2 coliphage by solar water disinfection under different weather conditions and solar technologies. (iv) Assessment of several strategies to improve the treatment efficiency, including use of very low concentration of chemicals (H_2O_2) and oxygen sparkling in the water. (v) Analysis of the long-life span of the plastic materials used in all the technologies developed in the project, i.e., PMMA, PET and PP (Figure 99).

The role of CIEMAT in this project has been crucial on the development and testing of the technologies proposed in the project for solar water disinfection. Our participation in WATERSPOUTT project has contributed positively on the visibility of CIEMAT as international research centre for development of solar water disinfection technologies, reaching good, active and fruitful collaboration with the rest of the partners involved in the project. In addition, the main impact expected from the WATERSPOUTT project results obtained lies on the knowledge transfers of the capability of using solar light for treating contaminated drinking water in low-income areas by the application of innovative technological approaches/solutions adapted to local conditions. For more details visit the website.

(a) (b)

Figure 99. a) Solar PMMA photo-reactors (140 L) at PSA facilities. b) Natural aging test performed at PSA facilities. View of different types of material being exposure directly to natural sunlight.

__Accelerate Innovation in Urban Wastewater Management for Climate Change, ALICE__

Participants: University of Ulster, Nothern Ireland Water Ltd., The Queen´s University of Belfast, Dublin City University, Dioenergy Ltd., Asociación BC3 Basque Centre for Climate Change, CIEMAT, GDW ESAMUR, Universita Degli Studi di Macerata, REINN Srl., Aset spa., University of Cyprus, Militos Symvouleutiki A.E.

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Isabel Oller, isabel.oller@psa.es

Funding agency: European Commission, H2020 - Marie Skłodowska-Curie Action (RISE) (GA 734560)

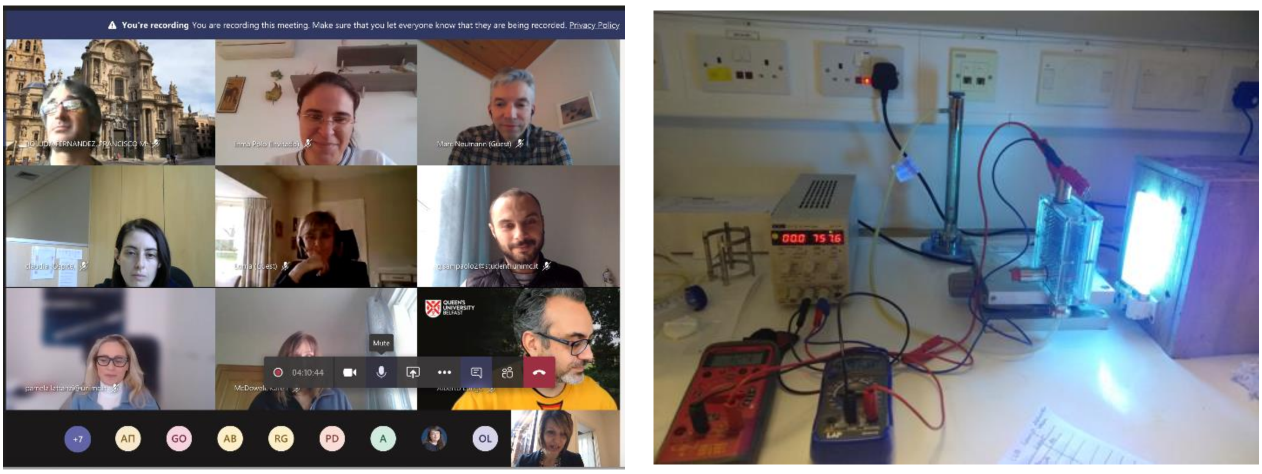
Background: The coming decades are likely to see some geographical areas experiencing a higher risk of flooding and other areas exposed to higher risks of droughts. More green and grey infrastructures, implementing increased effluent treatment including cooling and a greater recycling and reuse will pose a challenge in terms of financial sustainability of wastewater facilities.

Objectives: Accelerate innovation in urban wastewater management to address the future challenges arising from climate change. The project will identify solutions and seek to remove barriers for their implementation. The aim will be achieved through secondments and the transfer of knowledge, creating an effective interdisciplinary and inter-sectoral cooperation among the partners involved.

Achievements in 2020: In this year, where ALICE project has finalized last December 2020, inter-change of staff between the involved partners has been strongly affected and even not allowed due to COVID-19 pandemic situation. Therefore, main dissemination and sharing knowledge activities have been done through the organization of a series of workshops and a final conference on Nov-Dec. 2020 via on-line platforms. Discussions and knowledge exchange on this last conference about "How to improve the resilience of the wastewater sector to address the challenges of climate change?" were delivered, and particularly CIEMAT presented findings and knowledge on the specific topic related with 'Reuse of reclaimed wastewater: assessment of chemical and biological cross-contamination and phytotoxicity on crops' (Figure 100).

The main achievements reached by CIEMAT in the Alice project could be summarized as follows: (i) As regards on the innovative technologies to enhance the water reuse, CIEMAT, UU and NI Water have been involved on the discussion, development and testing of a new technology based on photo-electrocatalysis as potential alternative process for urban wastewater purification (Figure 100), (ii) Successful knowledge exchange related with advanced chemical, process engineering (including solar systems), microbiological, and toxicological aspects associated with the treated urban wastewater practices in Northern Ireland, Murcia Region and Italy, and (iii), successful knowledge exchange on the fate/behaviour of contaminants of emerging concern and the pathways of their transport from the disposal sites to the environment.

The main socio-economic impacts of ALICE project deals with the increasing of knowledge generated during the execution of the project as well as its transfer to scientific and stakeholder's community. It can highlight the impact of the research and diffusion regarding the availability of successful technical solutions (innovative and solar-based technologies) for a potential future implementation on WW infrastructures, promoting the safety reuse of reclaimed WW for agriculture according to the new approved EU regulation (2020/741). Besides, the findings related with the capability of reducing cross-contamination of crops irrigated with reclaimed WW by those innovative solutions, could bring great opportunities to move European society to a Green-World, mitigating the climate change and enhancing the urban circular economy. For more details visit the website.



(a) (b)

Figure 100. a) Alice Final Conference – Online, 4 December 2020. b) Laboratory scale set-up for photo-electrocatalysis (PEC) experiments at Ulster University facilities.

Interdisciplinar cross-sectoral approach to effectively address the removal of contaminants of emerging concern from water, AQUALITY

Participants: Universita Degli Studi di Torino, Universita Degli Studi del Piemonte Orientale Amedeo Avogadro, CNRS, Ecole Polytechnique, Karadeniz Teknik Universitesi, LIQTECH International A/S, Societá Metropolitana Axque Torino S.p.A., CIEMAT, Panepistimio Ioanninon, Universidad Politecnica de Valencia.

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

Funding agency: European Commission, H2020- Marie Skłodowska-Curie Action (ITN) (GA 765860)

Background: The complex challenges of the production of safe and clean water requires different levels of action, which include the synthesis of green materials, the development of enhanced water treatment technologies, the implementation of effective legal tools against water pollution and the correct management of the present water treatment facilities.

Objectives: AQUAlity is a multidisciplinary, interdisciplinary and cross-sectoral European Training Network aiming to generate and promote 15 highly skilled scientists with the potential to face the present and future challenges concerning the protection of water resources from Contaminants of Emerging Concern and to develop innovative purification technologies more effective than conventional adsorption and biological treatments.

Achievements in 2020: Two online project meetings have taken place virtually, both organized by the coordinators (University of Torino, Italy), and containing the update on the different technical and administrative and diffusion WPs. Technical WPs' update sessions contained 15 minutes presentation of each one of ESR´s work carried out along the last 6 months of their PhD. First project meeting was in April and the second one in September/October 2020. Solar Treatment of Water unit includes its research activities mainly in WP3 (Enhanced photochemical methods for the removal of CECs and pathogens in water and wastewater), in which the ESR Ilaria Berruti is performing her PhD, and in WP4 (Innovative hybrid NF/AOPs for CECs abatement), in which the ESR Dennis Deemter is performing his PhD. One of the last objectives achieved by Dennis Deemter have been related with the study of the recovery capacity of NF membranes on ammonium concentration normally contained in the effluent of municipal wastewater treatment plant effluents. In Figure 101 (a) a summary of the concentration of NH_4^+ present in the permeate stream under different experimental conditions but at pH 9 is shown. In the frame of WP3, Ilaria Berruti has studied, among other issues, the effect of different parameters on peroxomonosulfate efficiency on microcontaminants degradation and pathogens inactivation under the dark as well as the evaluation of the reactive species involved in the process in the presence of sunlight. In Figure 101 (b) reactive species present along perosomonosulfate treatment combined with solar energy is shown for the degradation of Sulfamethoxazole. For more details visit the website.

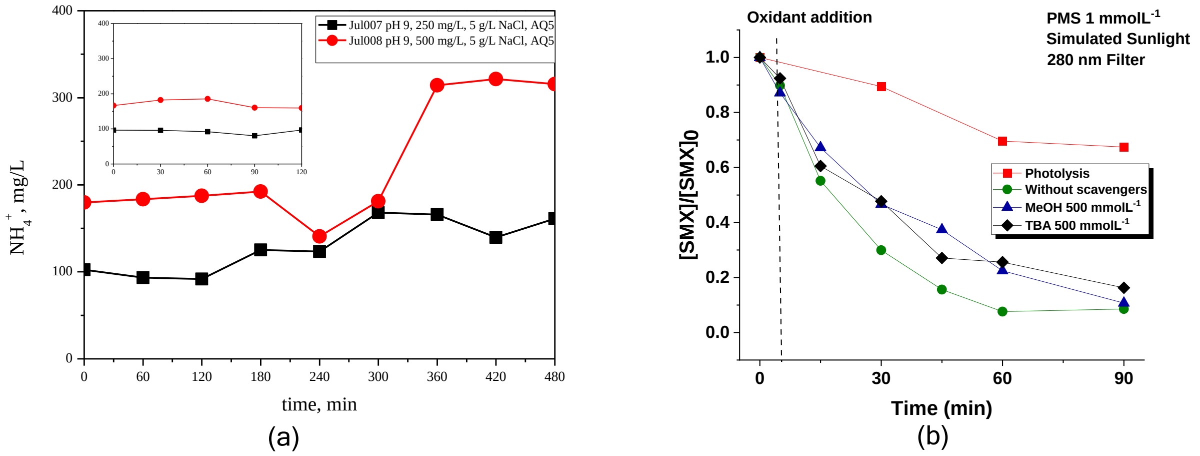


Figure 101. (a) NH_4^+ concentration in the permeate stream, at pH 9. Starting concentrations of 100 µg/L MCs, 5 g/L NaCl, 250 mg/L NH_4^+ (black) and 500 mg/L NH_4^+ (red). The inset shows the results without 5 g/L NaCl. (b) Reactive species involved in the peroxomonsulfate degradation of the microcontaminant sulfamethoxazole in combination with sunlight.

Development and testing of a novel photocatalytic system for efficient cogeneration of clean water and hydrogen for ecosafe agriculture, ECOSAFEFARMING

Participants: Istanbul University (Coord.), MIR Arastirma ve Gelistirme A.S. (Turkey), BUT - Brandenburg University of Technology (Germany), University of Ontario Institute of Technology (Canada), CIEMAT.

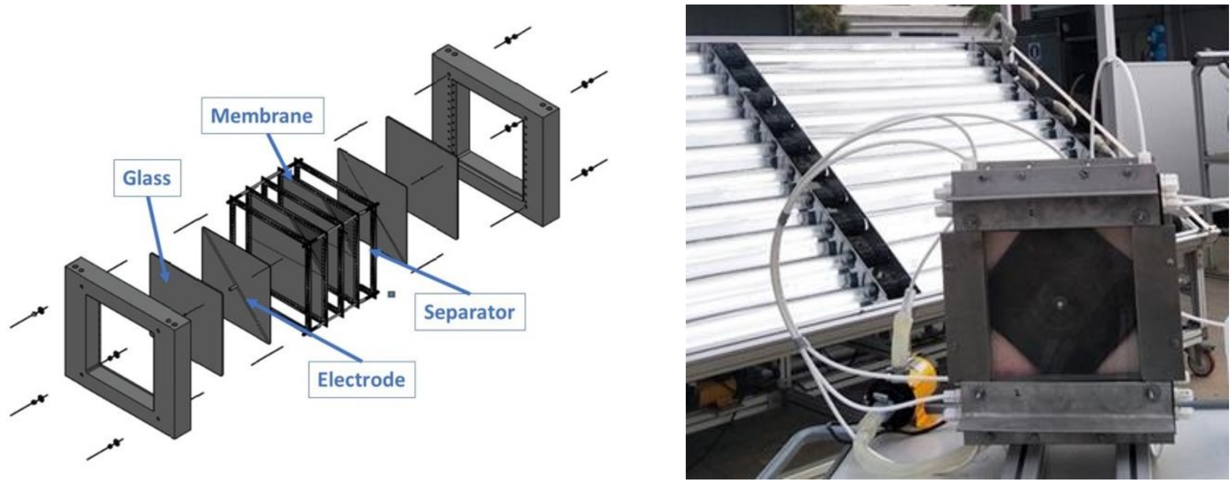
Contacts: Sixto Malato, sixto.malato@psa.es

Funding agency: WATER JPI 2016, ERAN-NET COFUND WATEWORKS 2015 and Spanish Ministry of Economy and Competitiveness (Reference PCIN-2017-131).

Background: There has recently been increasing interest in urban wastewater (UWW) utilization for agricultural and hydrogen production as it agrees with the six main pillars of sustainable energy systems: (i) better efficiency; (ii) better cost effectiveness; (iii) better resources use; (iv) better design and analysis; (v) better energy security; and (vi) better environment.

Objectives: The general aim of ECOSAFEFARMING is to develop and implement a novel and energy efficient tertiary treatment technology enabling reuse of UWW for safe agricultural irrigation. CIEMAT specific objectives are: Assessment of the performance of the lab-scale photocatalytic electrodialysis (PCED) reactor driven by sunlight for UWW purification, assessment of the optimized and scaled-up PCED and H2-PCED reactors, experimental assessment of treated UWW for irrigation of raw eaten crops in an experimental greenhouse, quantitative Microbial Risk Assessment and techno-economic analysis of experimental data.

Achievements in 2020: PCED was constructed and assembled at PSA (Figure 102) jointly with power supply, voltage-current applied potential and measurements and pump to control the inlet and outlet flow rates of both the anode and cathode. The components of the PCED were received at PSA in January 2020, and immediately after that, the system was assembled following the instructions of the provider of the reactor (Istanbul University, Ecosafefarming partner). Once the reactor was assembled, its performance was tested. Nevertheless, the results obtained showed non-significant conductivity variations in the electrode solution along treatment time and an increase in the conductivity value of the inter-membrane solution only in the first 5 min of the essay. To check if this hypothesis was correct, an additional experiment was performed. In this case, a dye (fuchsin acid, $C_{20}H_{17}N_3Na_2O_9S_3$) which turn the solution magenta were added to the inter-membrane solution (concentrate). Immediately after added it, the permeate solution began to acquire a magenta colour and moreover, and due to the dye addition, it was even possible to visually observe how the solution of the concentrate diffused through both membranes and it was mixing with the permeate of both reactor sides. The results of this experiment confirmed a defect in the reactor design or construction that generates a leakage between the different reactor compartments and, consequently the subsequent mixing of the concentrate and the permeate solutions. Under these conditions it was not possible to go further with any testing of the reactor.



(a) (b)

Figure 102. (a) Design of PCED system including anode and cathode (electrodes) separated in two cells by an ion exchange membrane (membranes) with optically translucent windows (glass) to permit the irradiation of the photocathode. (b) PCED operating at PSA.

Rational design of highly effective photocatalysts with atomic-level control, RATOCAT

Participants: University College Cork (Tyndall National Institute-UCC, Ireland, Coordinator), Delft University of Technology (The Netherlands), Instituto de Ciencia de Materiales de Sevilla, CSIC (Spain), CIEMAT.

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

Funding agency: M-ERA.net H2020 through Spanish Ministerio de Economía y Competitividad (MINECO). Project PCIN-2017-131.

Background: RATOCAT project aims to develop improved photocatalyst materials along with the processes for their production through atomic-level control of structure and functionality. The target technology is the generation of hydrogen gas from water using solar energy, which is a crucial component of the global transition to renewable energy sources.

Objectives: (i) Absorption of the visible-light solar spectrum by tailoring surface-modified catalyst materials; (ii) Surface modification of catalyst powders with non-critical materials via a deposition process that is scalable to the manufacturing environment; (iii) Wastewater as the feedstock for hydrogen.

Achievements in 2020: Different CuO+TiO2 mixture, based on two commercial and well characterized CuO (CuO nanoparticles from Sigma Aldrich, average size of the CuO nanoparticles 50 nm) and TiO_2 photocatalyst (Degussa P25), has been used to produce hydrogen by solar light irradiation and in presence of different organic compounds. The tested system shown different hydrogen generation capacity and energy efficiency. Loss of suspended Cu has been detected by characterizing the sample obtained after 5 consecutive runs, a process that is in agreement with the deposition of the catalyst on the walls of the CPC reactor. Therefore, CuO remains on the CPC pyrex walls and continued doing its role as hydrogen production did not stop, However, at lower efficiency as higher was proportion of CuO in the mixture (Figure 103).

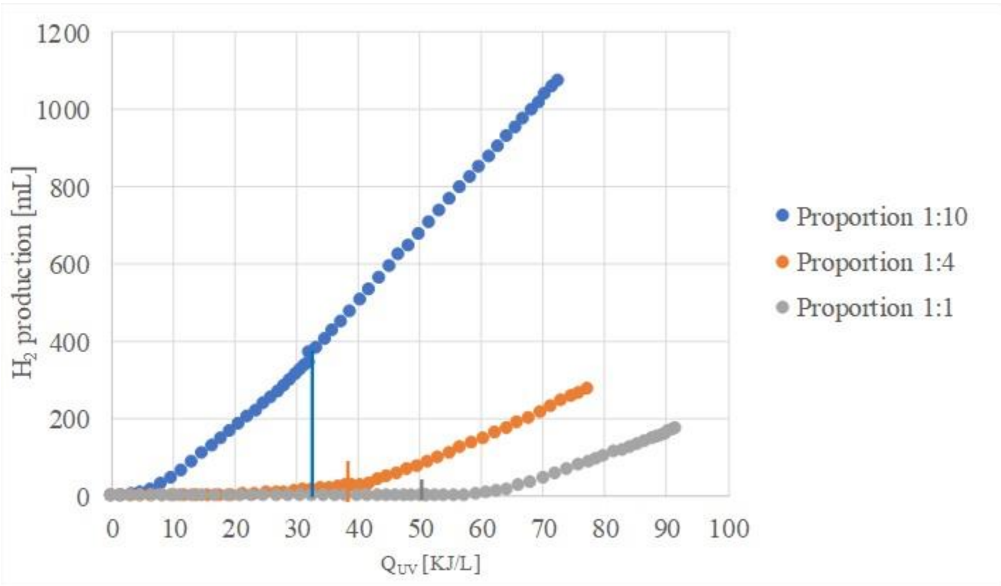


Figure 103. Production of H_2 at different CuO+TiO_2 ratios.

Photo-irradiationand Adsorption based Novel Innovations for Water-treatment, PANIWATER

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

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

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

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

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

Achievements in 2020: 1st General Assembly meeting of the PANIWATER project took place the 5th and 6th of March 2020 in Goa (India). The progress on WP2 (wastewater treatment) was presented by Isabel Oller (virtually) as the leader of the WP from the European side in coordination with the Indian part which showed the definitive places where the DEMO plants will be finally implemented. Associated to this project meeting, an International Conference on Photo-irradiation and Adsorption based Novel Innovations for Water treatment, was also celebrated in Goa (India) the 3rd and 4th of March 2020. Two works were presented in this conference in which an important participation of the members of the Solar Treatment of Water Research Unit was shown. The Review meeting of the project took place in November 2020 together with a Steering Committee. In Figure 104 a slide summarizing last experimentation carried out in the topic of solar photocatalytic processes is shown. One of the requirements done by the EC in the review meeting of PANIWATER project was to perform and Environmental and Health Risk Assessment to the field testing of the proposed technologies in the communities in India. An amendment process was also initiated and finalized along 2020 in which, among other modifications mainly in deliverables final dates, the University of Almería has been added to the consortium as a third party of CIEMAT with the objective of better focussing on the accurate identification and quantification of microcontaminants actually present in Indian wastewaters as well as their proper monitoring along the oxidation processes proposed. For more details visit the website.

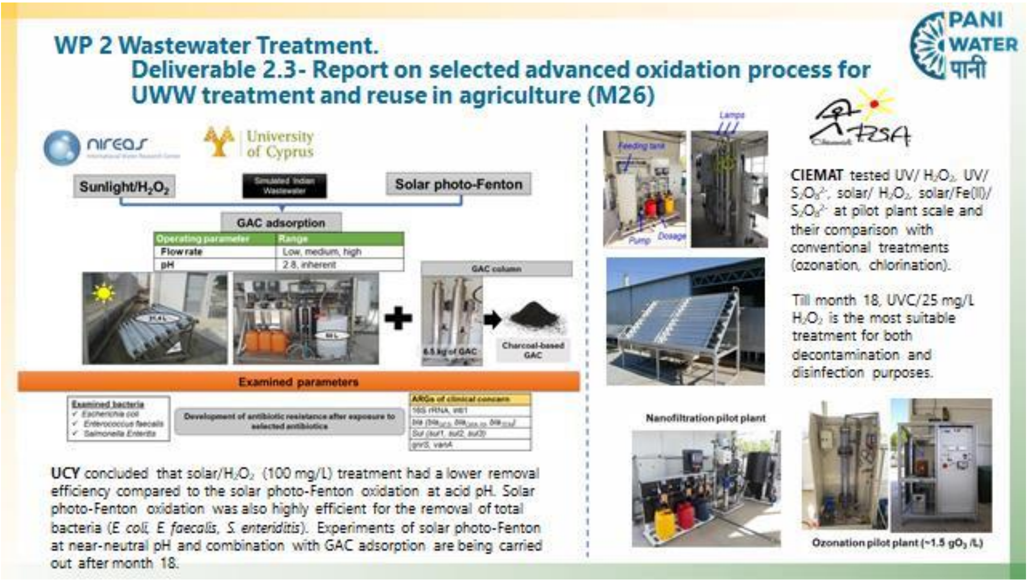


Figure 104. Summary of the experimentation carried out in the frame of WP2 by UCY and CIEMAT, focusing on solar and UVC oxidation treatments.

Advanced and hybridized technologies addressing recalcitrant pollutants, micropollutants, reusing and revalorization in different wastewater, including technological and economical approaches. (CALYPSOL)

Participants: UPV, URJC, CIEMAT.

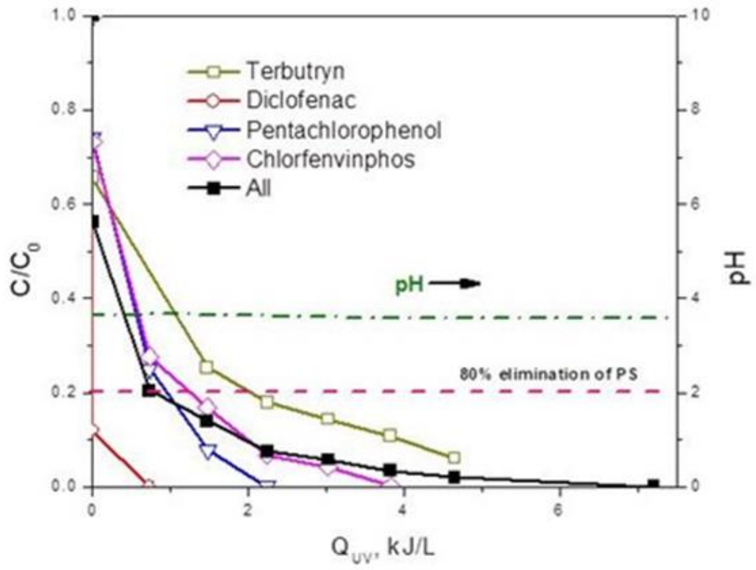
Contacts: Sixto Malato, sixto.malato@psa.es

Funding agency: Spanish Ministry of Science, Innovation and Universities (Reference RTI2018-097997-B-C32)

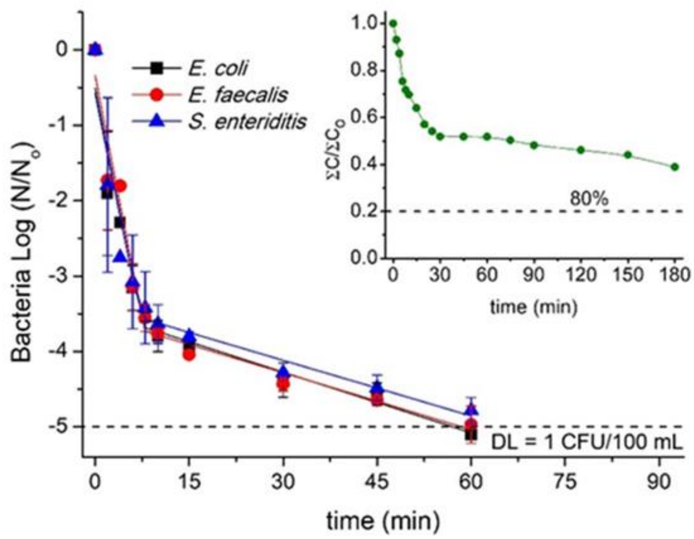
Background: The project tries to put together the know-how of in different areas of AOPs and wastewater decontamination to be a step forward to solve real problems of our society by the design of new strategies for the treatment of complex wastewaters, soil washing, or hydrogen generation adapted to southern/sunny countries, which can be, in turn, employed for other technological applications. The goals of the project are also thought to enhance the scientific and technological competitiveness of the Spanish productive system in the field of environmental remediation in connection with renewables source of energy.

Objectives: CALYPSOL will apply different reductive processes in order to obtain valuable by-products such as hydrogen, to investigate the oxidative capability of different Advanced Oxidation Processes for urban wastewater (secondary effluents) disinfection, the oxidative capability of photocatalytic processes with semiconductors and zero-valent iron (ZVI) materials, combination/integration of advanced technologies (AOPs and separation processes such as Membrane Distillation, NF, UF, etc.) for solid and wastewater treatment and resource recovery, disinfection and abatement of CECs in urban wastewater using solar or UVC based treatments in combination with primary (mainly solid separation) and secondary treatment (biotreatment). The final goal is to assess the technical feasibility of each process and the overall costs to compare with BATs available in northern Europe and propose alternatives for southern sunny countries.

Achievements in 2020: Many different advances were attained in the different WP of the project, some of them already 100% accomplished as "Assessment of chelating agents from natural wastewater and isolated from solid wastes (HLS) to enable photo-Fenton-like reactions at neutral pH" and, "UV/H2O2 and UV/Cl2 disinfection and treatment of CECs of different urban wastewater at lab and pilot scale". Olive mill wastewaters (OMW) have shown to be an interesting and innovative natural alternative to synthetic iron chelating agents in solar photo-Fenton processes at natural pH due to its high content of polyphenols, permitting valorisation of this residue that is typically found in sunny countries. It was demonstrated the oxidation of six CECs (acetaminophen, caffeine, carbamazepine, trimethoprim, sulfamethoxazole and diclofenac) in the presence of E. coli, E. faecalis and S. enteritidis in effluents from a municipal wastewater treatment plant using UVC/H2O2 on a pilot plant scale. Successful 4 log inactivation of bacteria and> 80% CEC degradation were achieved in less than 30 minutes.



(a)



(b)

Figure 105. a) Elimination of contaminants (at 40 µg·L-1 each) in SFW (pH 4) with Fe 0.1 mM and 50 mg·L-1 H2O2 using 1:1500 ratio OMW. b): Simultaneous bacterial inactivation and MCs degradation (inset) under UVC radiation in SMWWTP effluent as a function of treatment time.

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

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

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

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

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

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

Achievements in 2019: Second AQUACYCLE project meeting was held in Valletta (Malta) from the 3rd to the 5th of February 2020 under the Motto: "Changing the paradigm of wastewater reuse". It is important to recall that, in this project, CIEMAT leads work package 5 related to Operational demonstration and capacity building. 3rd project meeting took place 23rd and 24th of September 2020, virtually. After the 3rd meeting and following previous presentations and organization of workshops with stakeholders in Tunisia and Lebanon, the first workshop with stakeholders in Spain, focused on the APOC technology (based on the combination of anaerobic treatment with wetlands and photocatalytic processes under sunlight in raceway pond reactors for the elimination of microcontaminants and pathogens contained in urban wastewaters), was organized by CIEMAT and ESAMUR, via WebEx the 8th of October 2020. A great number of attendants to the workshop was attained (more than 70). In figure X the invitation and a screen capture taken along the workshop are shown. First justification period of this project was also presented and evaluated at the end of 2020. For more details visit the website.

Figure 106. First series of workshop of AQUACYCLE project. Workshop virtually organized by CIEMAT-PSA and ESAMUR the 8th of October 2020. The invitation and a screen image taken during the event.

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

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

Contact: Isabel Oller, isabel.oller@psa.es;
M. Inmaculada Polo, inmaculada.polo@psa.es

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

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

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

Achievements in 2020: The kick-off meeting of the project took place last 18th September 2020 in the University of Almeria (Almeria). During the meeting, different strategies of coordination and collaboration were discussed by the three partners involved in NAVIA project to successfully reach the tasks of the project. Among then, the key chemical and microbiological indicators to be tested as common parameters to assess the efficiency of all solar technologies proposed in the project were selected. Particularly, the following five chemical organic contaminants were selected: antibiotics (Trimethoprim and Sulfametoxazol), pesticides (Pentaclorofenol and pyrimethanil) and a solar filter (2-Hidroxi-4-Metoxi Benzofenona-5 Acido Sulfónico. Regarding microbial pathogens, the universal indicator *E. coli* as well as total coliforms will be monitored as main water quality parameters, but also coliphages (somatic coliphages (SOMCPH) and F-specific RNA bacteriophages (FRNA)) were selected as novel microbial indicators. Additionally, different antibiotic resistant genes (ARG) naturally occurring in UWW have been included with the objective of investigating their potential degradation by the proposed solar technologies, including *intI1* (class 1 integron), *qnrS* (Quinoline resistance), *sulI* (Sulfonamide resistance), *Tet(E)* (Tetracycline resistance), *blaTEM* (β-lactamase resistance).

Up to now, the activities carried out by CIEMAT have been focused on the development of the different laboratory procedures and methodologies required to the simultaneous analysis of all target indicators selected. All these analytical procedures will be applied during the assessment of the different solar technologies proposed in NAVIA for the treatment of UWW at different solar photoreactors at pilot plant scale (Figure 107).

Figure 107. Images of the solar photo-reactors used in NAVIA project for UWW reclamation at pilot plant scale, both located at CIEMAT facilities.

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

Participants: CIEMAT.

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

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

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

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

Achievements in 2020: The research conducted at the LECE Laboratory at PSA and also using stock data previously gathered here, delivered the following in 2020:

- Analysis of the feasibility to characterise the air renovation rate avoiding the intrusiveness of the traditional measurement techniques of the corresponding indicators in buildings (Energies 2020, 13(18), 4800). The viability to obtain the air renovation rate itself from measurements of the concentration of the metabolic CO_2, and the possibilities to express this rate as function of other climatic variables, were studied. N_2O tracer gas measurements have been taken as reference. Further research extending this analysis is incorporating Blower Door Tests (Figure 108).

- Considering the application of RC dynamic models for assessing thermal performance of buildings from in-situ tests, the following aspects relevant to this approach have been analysed (Energies 2020, 13(18), 4800): The effect of the solar radiation on the heat flux through the opaque walls versus the performance of the models including this effect, the optimum number of nodes required to represent the thermal systems, the assignment of inputs and outputs and the length of the test period. Additionally, several options modelling relevant effects using unmeasured variables were studied to evaluate the feasibility to reduce the cost and intrusiveness of the measurement devices required to obtain accurate results.

Figure 108. Experiment set up corresponding to a Blower Door Test carried out at the Office Building Prototype at PSA.

9 Training and educational activities

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

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with an agreement with the University of Almeria (UAL) and with the own program to young researcher of CIEMAT.
- Management of miscellaneous educational cooperation agreements with other entities for sending students to the PSA (Universities of Almería, Murcia, Dalarna-Sweden, , Federal Sao Carlos-Brasil, Juarez Autónoma de Tabasco-México, Salerno-Italy, etc)

The normal training and education activities provided by the PSA were affected by the outbreak of the COVID19 pandemic in early 2020, which strongly modified many planned actions. Some of them have had to be postponed or have been carried out virtually.

The close and enduring collaboration between CIEMAT and the University of Almería has allowed us to carry out the third 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.

Related with the Educational Cooperation Agreement between CIEMAT and the University of DALARNA (Sweden), the "Solar Thermal Power" course was given by PSA researchers in the framework of the Master Programme in Solar Energy Engineering. With 5 credits, this course takes part during the 2nd cycle of this Master Programme organized by the European Solar Engineering School, ESES (University of Dalarna). The first part of the CSP training course was hold from the 8th to the 19th of June and consisted of the theory lessons, taught by two researchers from CIEMAT at Dalarna University (Börlange, Sweden), while during the second part of the CSP training course the students from this university visited the facilities from the 15th to the 16th of December. Due to COVID-19 pandemic, both parts were delivered virtually.

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

The 2nd Summer School and Doctoral Colloquium of SFERA-III were scheduled to take place in June 2020. However, due to the COVID-19 crisis, both activities were postponed.

In order to promote the higher education of young researchers in the environmental applications of AOPs, as well as to overcome national boundaries and bureaucracy barriers, a group of European scientists (Management Committee, MC) from different Universities and Research Institutes, with a strong and internationally recognized expertise in this field, founded (in June 2014) the “European PhD School on Advanced Oxidation Processes”. The PSA is one of the members of this school since its creation.

10 Events

16 January 2020

Lecture

Sixto Malato was invited as professor of Master in Water Technologies of the University of Alicante, Spain.

5-7 February 2020

Official Workshop

Javier Bonilla was invited to participate in the workshop "Solar thermal power plants in Spanish energy planning" organized by Genera (International Energy and Environment Fair) in Madrid (Spain), where he spoke about "A tool for optimising the electricity mix by applying artificial intelligence techniques".

3 March 2020

Workshop

Esther Rojas was invited as speaker in the seminar "Sustainable Energy Mix: breaking down prejudices" at the IES Guadarrama, Madrid (Spain), organized by CIEMAT as part of the series of science divulgation activities.

15 June 2020

Webinar

Guillermo Zaragoza was invited to give a seminar on "Membrane Distillation as an Alternative for Solar Desalination", in the framework of the International Desalination Association (IDA) Academy Webinar Series, Spring 2020: Renewable Energy & Advanced Water Treatment Solutions. Online.

14 October 2020

Workshop

Guillermo Zaragoza was invited to give a talk on "Renewable energy desalination in the WEF Nexus", in the event "Technology options for the Water-Energy-Food nexus" (part of the series: "Addressing the Water-Energy- Food (WEF) Nexus in the context of Climate Change and Sustainable Development") organized by EU-GCC Clean Energy Technology Network. Online.

2 October 2020

Lecture

Isabel Oller was invited to give a virtual lecture "A common vision for a Water-Smart Society WG: Contaminants of Emerging Concern" in the virtual event on Polluters of growing concerns: pharmaceutical in ground and drinking water, SMECONNECT.

14 October 2020

Workshop

Rocío Bayón was invited as speaker in the seminar "Thermal storage for electricity production", organized by CIEMAT, as part of the series of workshops on Renewable Energy Storage. Online.

5 November 2020

Round Table

Azahara Martínez, Ilaria Berruti and Melina Roccamante were invited to participate as speakers to the Round Table "Café Con Ciencia" within the title "Is there water for everything?” which took place virtually in Almería (Spain).

10 November 2020

Round Table

Guillermo Zaragoza was invited to participate as speaker in the Panel Discussion on Thermal Desalination by Membrane Distillation (one of the “International Colloquia on Thermal Innovations” series) organized by the Massachusetts Institute of Technology (MIT). Online.

11 November 2020

Lecture

Diego Alarcon was invited to give a lecture on “Desalación de Aguas mediante Energía Solar Térmica” on the II Curso Internacional de Transferencia de Conocimiento sobre la Energía Solar y Tratamiento Solar de Agua en la Macro Región Centro Sur Andina, organised by SERC Chile.

13 November 2020

Invited Lecture

Loreto Valenzuela was invited to give a lecture at the “VII Conference on career opportunities for Physicists” organized by the Physics Teaching Commission of the University of Granada (Spain) and with the title “Career opportunities in Public Research Organisations”.

18 November 2020

Lecture

Sixto Malato was invited to give a lecture on “Advanced oxidation technologies for disinfection and removal of contaminants of emerging concern” held at Diputación de Almería, Spain.

20 November 2020

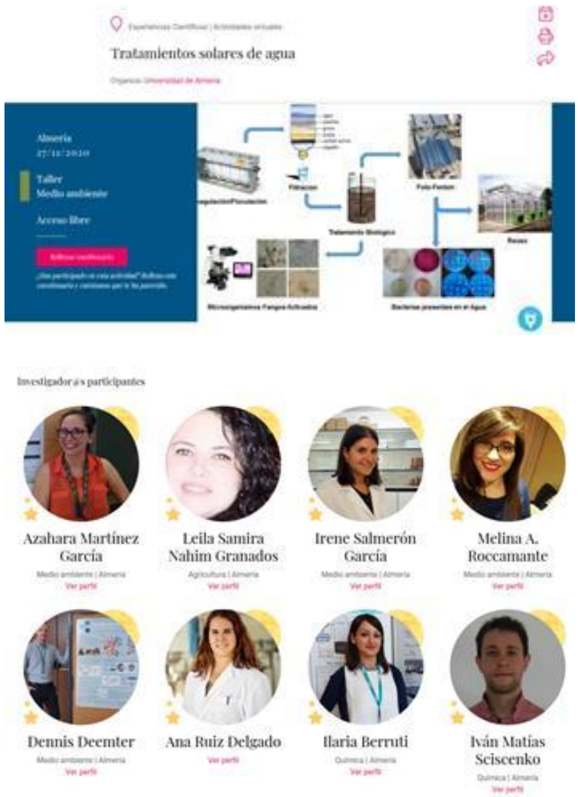
Lecture

Inmaculada Polo was invited to give a virtual lecture on “Incidence and removal of antibiotic resistant bacteria in wastewater” in the frame of the XII JORNADAS SOBRE LA UNIÓN EUROPEA. Online.

27 November 2020

Lecture

Alba Ruiz, Ana Ruiz, Samira Nahim, Irene Salmerón, Melina Roccamante, Azahara Martínez, Ilaria Berruti y Dennis Deemter participated in the European researchers’ night event with a video called “Solar treatments of water”. This event was organised by the University of Almería, Spain.



16 December 2020

Webinar

Isabel Oller was invited to give a webinar on "Toxicity tests: methods and relevance for water/wastewater treatment by AOPs" as part of the International PhD School on Advanced Oxidation Processes (IPS-AOP).

11 Publications

PhD Thesis

Andrés-Mañas, Juan Antonio (2020). Evaluation of the use of vacuum in advanced pilot-scale membrane distillation modules powered by solar energy for the desalination of seawater and brines. Universidad de Almería.

Fernández Reche, Jesús (2020). Contributions to the optical characterisation of heliostats and heliostat fields for central receiver systems. (Unpublished doctoral thesis). Universidad de Almería.

Gil Vergel, Juan Diego (2020). Hierarchical Control and Optimization Strategies Applied to Solar Membrane Distillation Facilities (Unpublished doctoral thesis). Universidad de Almería.

Nahim Granados, Leila Samira (2020). Assessment of solar-driven processes and ozonation for disinfection, decontamination and reuse of fresh-cut wastewater. Universidad de Almería.

Pulido Iparraguirre, Diego (2020). Development of a prototype medium-temperature linear Fresnel solar collector. (Unpublished doctoral thesis). Universidad de Almería.

Salmerón García, Irene (2020). Evaluation of electrochemical processes assisted by solar energy for water depuration. Universidad de Almería.

Dissertations

José Antonio Salinas García (2020). Diseño de las modificaciones necesarias para la implementación de un calentador de sales en la instalación de ensayos MOSA. Universidad de Almería.

Olof Eriksson (2020). Techno-Economic Analysis of Reverse Osmosis combined with CSP+PV in Kuwait. Dalarna University.

Álvaro Marín Silvestre (2020). Modelado y análisis tecno-económico de plantas termosolares de receptor central hibridadas con fotovoltaica para aplicaciones de cogeneración de electricidad y agua desalada. Centro de Investigación en Energía Solar UAL-CIEMAT

José Alfonso Romero Ramos (2020). Diseño y análisis tecno-económico de instalaciones 100% solar (térmica + fotovoltaica) para proceso de destilación térmica MED de baja temperatura. Centro de Investigación en Energía Solar UAL-CIEMAT.

Miguel Ángel Ruiz (2020). Diseño de un sistema solar de refrigeración y estudio de las necesidades de CO_2 en un invernadero cerrado. Centro de Investigación en Energía Solar UAL-CIEMAT.

Francisco Varela Vigo (2020). H_2 solar production using a solar themochemical cycles. Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT).

Solar Concentrating Systems Unit

SCI PUBLICATIONS

Ballestrín, J., Carra, E., Alonso-Montesinos, J., López, G., Polo, J., Marzo, A., Fernández-Reche, J., Barbero, J., Batlles, F.J. Modeling solar extinction using artificial neural networks. Application to solar tower plants. *Energy* 199 (2020), 117432. DOI: https://doi.org/10.1016/j.energy.2020.117432.

Barbero, J., Alonso-Montesinos, J., Ballestrín, J., Carra, M.E., Fernández-Reche, J. Atmospheric horizontal extinction determined with a single digital camera-based system in the scope of solar power tower plants. *Measurement* 149 (2020), 107025. DOI: https://doi.org/10.1016/j.measurement.2019.107025

Buendía-Martínez, F., Fernández-García, A., Sutter, F., Martínez-Arcos, L., Reche-Navarro, T., García-Segura, A., Valenzuela, L. Uncertainty study of reflectance measurements for concentrating solar reflectors. *IEEE Transactions on Instrumentation and Measurement* 69(9) (2020), 7218-7232. DOI: https://doi.org/10.1109/TIM.2020.2975387

Cantone, M., Cagnoli, M., Fernández-Reche, J., Savoldi, L. One-side heating test and modeling of tubular receivers equipped with turbulence promoters for solar tower applications. *Applied Energy* 277 (2020), 115159. DOI: https://doi.org/10.1016/j.apenergy.2020.115519

Carballo, J.A., Bonilla, J., Berenguel, M., Fernández-Reche, J., García, G. Solar tower mockup for the assessment of advanced control techniques. *Renewable Energy* 149 (2020), 682-690. DOI: https://doi.org/10.1016/j.renene.2019.12.075

Carra, E., Marzo, A., Ballestrín, J., Polo, J., Barbero, J., Alonso-Montesinos, J., Monterreal, R., Abreu, E.F., Fernández-Reche, J. Atmospheric extinction levels of solar radiation using aerossol optical thickness satellite data. Validation methodology with measurement system. *Renewable Energy* 149 (2020), 1120-1132. DOI: https://doi.org/10.1016/j.renene.2019.10.106

García-Segura, A., Fernández-García, A., Ariza, M.J., Sutter, F., Watermeyer, P., Schmüker, M., Valenzuela, L. Corrosion on silvered-glass solar reflectors exposed to accelerated aging tests with pollutant gases: A microscopic study. *Corrosion Science* 176 (2020), 108928. DOI: https://doi.org/10.1016/j.corsci.2020.108928

Gerraiche, D., Bougriou, C., Guerraiche, K., Valenzuela, L., Driss, Z. Experimental and numerical study of a solar collector using phase change material as heat storage. *Journal of Energy Storage* 27 (2020), 101133. DOI: https://doi.org/10.1016/j.est.2019.101133

Milosan, I., Florescu, M., Cristea, D., Voiculescu, I., Alin Pop, M., Cañadas, I., Rodríguez, J., Bogatu, C.A., Bedo, T. Evaluation of heat-treated AISI 316 stainless steel in solar furnaces to be used as possible implant material. *Materials* 13 (2020), 581. DOI: https://doi.org/10.3390/ma13030581

Novas, N., Fernández-García, A., Manzano-Agugliaro, F. A simplified method to avoid shadows at parabolic-trough solar collectors facilities. *Symmetry* 12 (2020), 278. DOI: https://doi.org/10.3390/sym12020278

Nouri, B., Noureldin, K., Shclichting, T., Wilbert, S., Hirsch, T., Schroedter, M., Kuhn, P., Kazantzidis, A., Zarzalejo, L.F., Blanc, P., Yasser, Z., Fernández-Reche, J., Pitz-Paal. Optimization of parabolictrough power plant operations in variable irradiance conditions using all sky imagers. *Solar Energy* 198 (2020), 434-453. DOI: https://doi.org/10.1016/j.solener.2020.01.045

Luca, M.A., Tierean, M.H., Pisu, T.M., Rodríguez, J., Croitoru, C., The influence of concentrated solar energy flux on the structure and properties of stainless steel brazed joints. *Journal of Thermal Analysis and Calorimetry* 141 (2020), 1291-1304. DOI: https://doi.org/10.1007/s10973-019-09113-8

Pereira, J.C., Rodríguez, J., Fernandes, J.C., Guerra, L. Homogeneous flux distribution in high-flux solar furnaces. *Energies* 13 (2020), 433. DOI: https://doi.org/10.3390/en13020433

Polo, J., Ballestrín, J., Carra, E. Assessment and improvement of modeling the atmospheric attenuation based on aerosol optical depth information with applicability to solar tower plants. *Energy* 208 (2020), 118399. DOI: https://doi.org/10.1016/j.energy.2020.118399.

Savoldi, L., Allio, A., Bonvento, A., Cantone, M., Fernández-Reche, J. Experimental and numerical investigation of a porous receiver equipped with Raschig Rings for CSP applications. *Solar Energy* 212 (2020), 309-325. DOI: https://doi.org/10.1016/j.solener.2020.11.006

Valenzuela, L., Setien, E., Zarza, E., Analysis of a failure mechanism in parabolic troughs receivers due to bellows cap overirradiation. *Engineering Failure Analysis* 111 (2020), 104491. DOI: https://doi.org/10.1016/j.engfailanal.2020.104491

Wiesinger, F., Sutter, F., Fernández-García, A., Wetter, J., Wolfertstetter, F., Hanrieder, N., Schmücker, M., Pitz-Paal, R. Sandstorm erosion on solar reflectors: Highly realistic modeling of artificial aging tests based on advanced site assessment. *Applied Energy* 268 (2020), 114925. https://doi.org/10.1016/j.apenergy.2020.114925

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Bourdon, D., Wolfertstetter, F., Fernández-García, A., Sansom, C., Azpitarte, I., Bouaddi, S., Perez, G., Maccari, A., van Nijnatten, P., Surquin, E., Perrotta, F. Saving water on concentrated solar power plants: The holistic approach of the WASCOP project. SolarPACES 2019. *AIP Conf. Proc.* 2303 (2020), 210002. DOI: https://doi.org/10.1063/5.0029639

Caron, S., Garrido, J., Setien, E., Harzallah, R., Noč, L., Jerman, I., Röger, M., Sutter, F. Forty shades of black: A benchmark of high temperture sprayable black coatings applied on Haynes 230. SolarPACES 2019. *AIP Conf. Proc.* 2303 (2020), 150007. DOI: https://doi.org/10.1063/5.0028773

Montecchi, M., Sutter, F., Fernández-García, A., Heimsath, A., Torres, F., Pelayo, C. Enhanced equivalent model algorithm for solar mirrors. SolarPACES 2019. *AIP Conf. Proc.* 2303 (2020), 100005. DOI: https://doi.org/10.1063/5.0028768

Mutuberria, A., Sánchez, M., Testani, C., Fernández-Reche, J., Rinaldi, A., Zarza, E. Challenges and handicaps on the design of an efficient beam-down system at an existing heliostat field layout. *2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe* (EEEIC / I&CPS Europe), Madrid, Spain, 2020, 4 pp, https://doi.org/10.1109/EEEIC/ICPSEurope49358.2020.9160816

Nouri, B., Noureldin, K., Schlichting, T., Wilbert, S., Hirsch, T., Schroedter-Homscheidt, M., Kuhn, P., Kazantzidis, A., Zarzalejo, L.F., Blanc, P., Yasser, Z., Fernández-Reche, J., Pitz-Paal, R. A way to increase parabolic trough plant yield roughly 2% using all sky imager derived DNI maps. SolarPACES 2019. *AIP Conf. Proc.* 2303 (2020), 110005. DOI: https://doi.org/10.1063/5.0028667

Rinaldi, A., Barieri, G., Vitale, D., Rizzo, E., Tincani, A., Di Piazza, I., Fernández-Reche, J., Ávila-Marín, A., Testani, C. Engineering challenges in high temperature liquid lead storage for concentrated solar power systems. ***2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe*** (EEEIC / I&CPS Europe), Madrid, Spain, 2020, 5 pp, https://doi.org/10.1109/EEEIC/ICPSEurope49358.2020.9160826

San Vicente, G., German, N., Maccari, A., Fernández-García, A., Morales, A. Soiling study on antireflective coated glass samples and antisoiling/antireflective coated glass samples. SolarPACES 2019. ***AIP Conf. Proc.*** 2303 (2020), 210005. DOI: https://doi.org/10.1063/5.0028594

Sutter, F., Reche-Navarro, T.J., San Vicente, G., Fernández-García, A. Durability of anti-reflective coatings for parabolic trough receivers. SolarPACES 2019. ***AIP Conf. Proc.*** 2303 (2020), 150015. DOI: https://doi.org/10.1063/5.0028751

Sutter, F., Fernández-García, A., Montecchi, M. Indirect method to determine near-normal sun-conic reflectance. SolarPACES 2019. ***AIP Conf. Proc.*** 2303 (2020), 100007. DOI: https://doi.org/10.1063/5.0028749

Wette, J., Sutter, F., Buendía-Martínez, F., Fernández-García, A. Effect of long term outdoor exposure on anti-soiling coatings for solar reflectors. ***AIP Conf. Proc.*** 2303 (2020), 150016. DOI: https://doi.org/10.1063/5.0028960

Wolfertstetter, F., Fonk, R., Prahl, C., Röger, M., Wilbert, S., Fernández-Reche, J. Airborne soiling measurements of entire solar fields with Qfly. SolarPACES 2019. ***AIP Conf. Proc.*** 2303 (2020), 100008. DOI: https://doi.org/10.1063/5.0028968

Wolfertstetter, F., Hanrieder, N., Bellmann, P., Ghennioul, A., Wette, J., Fernández-García, A. Parallel soiling measurements for 4 mirror samples during outdoor exposure with TraCS. SolarPACES 2019. ***AIP Conf. Proc.*** 2303 (2020), 100009. DOI: https://doi.org/10.1063/5.0028969

BOOKS

Manzano-Agugliaro, F. and Fernández-García, A. Eds. Surfaces and Interfaces for Renewable Energy. Ed. MDPI, Basel, Switzerland. 108 pages. February 2020. ISBN: 78-3-03928-129-9. DOI: https://doi.org/10.3390/books978-3-03928-129-9.

Valenzuela, L. Ed. Research on Solar Collector. Ed. MDPI, Basel, Switzerland. 212 pages. July 2020. ISBN 978-3-03936-422-0. DOI: https://doi.org/10.3390/books978-3-03936-422-0

PRESENTATIONS AT CONGRESSES

Oral presentations

Buendía-Martínez, F., Fernández-García, A., Wette, J., Sutter, F., Valenzuela, L. UV degradation of primary mirrors in outdoor exposure and accelerated aging. ***SolarPACES 2020***, September 29-October 2, 2020. Alburquerque, USA (Online).

Buendía-Martínez, F., Fernández-García, A., Sutter, F., Wetter, J., Valenzuela, L. Ensayos de envejecimiento acelerado de reflectores solares sometidos a radiación UV y corrosión. ***CIES 2020 – XVII Congresso Ibérico e XIII Congresso Ibero-americano de Energía Solar***, November 3-5, 2020. Lisboa, Portugal (Online).

Carra, E., Ballestrín, J., Fernández-Reche, J., Marzo, A., Polo, J., Barbero, J., Monterreal, R., Enrique, R., Alonso-Montesinos, J. Metodologías para la determinación de la extinción atmosférica de la radiación solar para distintos usos y casos de aplicación. ***CIES 2020 – XVII Congresso Ibérico e XIII Congresso Ibero-americano de Energía Solar***, November 3-5, 2020. Lisboa, Portugal (Online).

Casanova, M., Ballestrín, J., Monterreal, R., Fernández-Reche, J. Medida de alta irradiancia en receptores de plantas de torre. ***CIES 2020 – XVII Congresso Ibérico e XIII Congresso Ibero-americano de Energía Solar***, November 3-5, 2020. Lisboa, Portugal (Online).

Christodoulaki, R., Biencinto, M., González, L., Drosou, V., Valenzuela, L. Dimensioning Tool for the Balance of Plant of Solar Heat for Industrial Processes Systems. ***13th International Conference on Solar Energy for Buildings and Industry (EuroSun 2020)***, September 1-4, 2020. Athens, Greece (Online).

Dominguez-Lopez, L.M., Valenzuela, L., Zarza, E. A new facility for testing line-focusing concentrating solar collectors for process heat applications. ***13th International Conference on Solar Energy for Buildings and Industry (EuroSun 2020)***, September 1-4, 2020. Athens, Greece (Online).

Posters

Ahmed Chekh, B., Fernández-Reche J., Valenzuela, L., Pulido-Iparraguirre, D., Villasante, C. Compact system for fast on-line geometry characterization of facets for solar concentrators. ***SolarPACES 2020***, September 29-October 2, 2020. Alburquerque, USA. (Online).

Thermal Storage and Solar Fuels Unit

SCI PUBLICATIONS

C. Rathgeber, S. Hiebler, R. Bayón, L. F. Cabeza, G. Zsembinszki, G. Englmair, M. Dannemand, G. Diarce, O. Fellmann, R. Ravotti, D. Groulx, A. C. Kheirabadi, S. Gschwander, S. Höhlein, A.König-Haagen, N. Beaupere, L. Zalewski. Experimental Devices to Investigate the Long-Term Stability of Phase Change Materials under Application Conditions. ***Applied Sciences*** 10 (2020), 7968, https://doi.org/10.3390/app10227968

Vidal, A., Martinez, D. An ageing protocol for testing high temperature solar materials for thermochemical applications. ***Solar Energy Materials and Solar Cells*** 212 (2020), 110572A. https://doi.org/10.1016/j.solmat.2020.110572

Vidal, A., Gonzalez, A., Denk, T. A 100 kW cavity-receiver reactor with an integrated two-step thermochemical cycle: Thermal performance under solar transients. ***Renewable Energy*** 153 (2020), 270-279. https://doi.org/10.1016/j.renene.2020.01.146

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González-Pardo, A., Denk, T., Vidal, A. Lessons learnt during the construction and start-up of 3 cylindrical cavity-receivers facility integrated in a 750 kW solar tower plant for hydrogen production. ***AIP Conference Proceedings*** 2303 (2020), 170008. https://doi.org/10.1063/5.0029579

Bayón, R., Rojas, E. Prediction of thermocline zone development at the beginning of dynamic processes in single storage tanks with liquid media, ***AIP Conference Proceedings*** 2303, (2020) 190001. https://doi.org/10.1063/5.0028900

Nache Romo, C., Pérez García, M., Rodriguez-Garcia, M.M., Torres-Moreno, J.L. Techno-Economical Assessment of Molten Salts Thermal Energy Storage Options in a Central Receiver Solar Plant in Southern Spain, ***SWC/SHC 2019 Proceedings***, https://doi.org/10.18086/swc.2019.21.05

PRESENTATIONS AT CONGRESSES

Plenary, keynotes, and other Guest lectures

Rojas, E. Thermal and Thermochemical Energy Storage at SolarPACES. ***SolarPACES 2020***. September 29-October 2, 2020. Alburquerque, USA (Online).

Oral presentations

Alonso, E., Rojas, E., Bayón, R. Experimental and numerical study of an air solid thermocline thermal energy storage system operating at high temperature. ***SolarPACES 2020***. September 29-October 2, 2020. Alburquerque, USA (Online).

Alonso, E., Rojas, E., Bayón, R. Packed-bed thermocline testing facility with air as HTF for sensible thermal energy storage. ***13th International Conference on Solar Energy for Buildings and Industry (EuroSun 2020)***, September 1-4, 2020. Athens, Greece (Online).

Bayón, R., Bonanos, A., Rojas, E. Assessing the Long-Term Stability of Fatty Acids for Latent Heat Storage by Studying their Thermal Degradation Kinetics. *13th International Conference on Solar Energy for Buildings and Industry (EuroSun 2020)*, September 1-4, 2020. Athens, Greece (Online).

Posters

Rodríguez, M., Rojas, E. Caruncho, J. M. Thermal Storage Filler Material Distribution for the Polyphem Project. *SolarPACES 2020*. September 29-October 2, 2020. Alburquerque, USA (Online).

Vidal, A. Preliminary results of thermal testing campaign in a 750 kW thermochemical solar pilot plant: Hydrosol-Beyond project. *SolarPACES 2020*. September 29-October 2, 2020. Alburquerque, USA (Online).

Solar Desalination Unit

SCI PUBLICATIONS

Andrés-Mañas, J. A., Roca, L., Ruiz-Aguirre, A., Acién, F. G., Gil, J. D., Zaragoza, G. Application of solar energy to seawater desalination in a pilot system based on vacuum multi-effect membrane distillation. ***Applied Energy*** 258 (2020). https://doi.org/10.1016/j.apenergy.2019.114068

Andrés-Mañas, J. A., Ruiz-Aguirre, A., Acién, F. G., Zaragoza, G. Performance increase of membrane distillation pilot scale modules operating in vacuum-enhanced air-gap configuration. ***Desalination*** 475 (2020). https://doi.org/10.1016/j.desal.2019.114202

Asfand, F., Palenzuela, P., Roca, L., Caron, A., Lemarié, C.-A., Gillard, J., Turner, P., Patchigolla, K. Thermodynamic performance and water consumption of hybrid cooling system configurations for concentrated solar power plants. ***Sustainability*** 12(11) (2020). https://doi.org/10.3390/su12114739

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Gil, J. D., Mendes, P. R. C., Camponogara, E., Roca, L., Álvarez, J. D., Normey-Rico, J. E. A general optimal operating strategy for commercial membrane distillation facilities. ***Renewable Energy*** 156 (2020), 220-234. https://doi.org/10.1016/j.renene.2020.04.074

Gil, J. D., Roca, L., Berenguel, M. Modelling and automatic control in solar membrane distillation: Fundamentals and proposals for its technological development | Modelado y control automático en destilación por membranas solar: Fundamentos y propuestas para su desarrollo tecnológico. ***RIAI - Revista Iberoamericana de Automática e Informática Industrial*** 17(4) (2020), 329-343. https://doi.org/10.4995/riai.2020.13122

Gil, J. D., Roca, L., Zaragoza, G., Normey-Rico, J. E., Berenguel, M. Hierarchical control for the start-up procedure of solar thermal fields with direct storage. ***Control Engineering Practice*** 95 (2020). https://doi.org/10.1016/j.conengprac.2019.104254

J.I. Martínez-Costa, M.I. Maldonado Rubio, R. Leyva-Ramos. Degradation of Emerging Contaminants Diclofenac, Sulfamethoxazole, Trimethoprim and Carbamazepine by Bentonite and Vermiculite at a Pilot Solar Compound Parabolic Collector. Catalysis Today 341, 26-36, 2020. https://doi.org/10.1016/j.cattod.2018.07.021

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Pistocchi, A., Bleninger, T., Breyer, C., Caldera, U., Dorati, C., Ganora, D., Millán, M. M., Paton, C., Poullis, D., Herrero, F. S., Yuece, S., Zaragoza, G. Can seawater desalination be a win-win fix to our water cycle? *Water Research* 182 (2020). https://doi.org/10.1016/j.watres.2020.115906

Poblete, R., Cortes, E., Maldonado, M.I. Fenton and solar photo-Fenton processes in the depuration of wastewater resulting from production of grape juice. A factorial design. *Journal of Chemical Technology and Biotechnology*, 5(5) (2020), 1329-1336. https://doi.org/10.1002/jctb.6317

BOOKS CHAPTERS AND NOT SCI JOURNALS

Andrés-Mañas, J.A., Ruiz-Aguirre, A., and Zaragoza, G. Membrane Distillation Powered by Solar Thermal Energy: Pilot Projects. In: "Membrane Distillation Materials and Processes" (Series: Energy, Science and Technology); Eds Y.M. Lee, E. Drioli; Nova Science Publishers, New York; 2020. ISBN: 978-1-53617-448-9.

PRESENTATIONS AT CONGRESSES

Plenary, keynotes and other Guest lectures

Blanco, Julian; Bonilla, Javier; Zarza, Eduardo; Alarcón-Padilla, Diego-Cesar. Optimization of CSP Development in Spain using Inductive Projection Planning Tool based on Artificial Intelligence, *CSP4Climate 2020*, December 15,2020. The Cyprus Institute, Nicosia, Cyprus (online).

Zaragoza, G. Membrane Distillation as an Alternative for Solar Desalination. *CSP4Climate 2020*, December 17, 2020. The Cyprus Institute, Nicosia, Cyprus (Online).

Oral presentations

Blanco, Julian; Bonilla, Javier; Zarza, Eduardo; Alarcón-Padilla, Diego-Cesar. Optimización del desarrollo de la energía termosolar en España en el contexto de la transición energética. *XVII Congresso Ibérico e XIII Congresso Ibero-americano de Energía Solar (CIES)*, Lisboa, Portugal (online), 2020.

Bonilla, J., Crespo, L. Inductive Projection Planning: Putting CSP in the Picture*. SolarPACES 2020*, September 29-October 2, 2020. Alburquerque, USA (Online).

Gil, J. D., Roca, L., and Berenguel, M. Starting-up strategies for solar thermal fields attending to time and economic criteria: Application of hierarchical control. *21st IFAC World Congress*.

Palenzuela, P., Roca, L., Asfand, F., Patchigolla, K. Experimental Assessment of a Pilot Scale Hybrid Cooling System for Water Consumption Reduction in CSP Plants. *SolarPACES 2020*, September 29-October 2, 2020. Alburquerque, USA (Online).

Pataro, M. L., Americano da Costa, M. V., Roca, L., Guzmán Sanchez, J. L., and Berenguel, M. An economic D-RTO for thermal solar plant: analysis and simulations based on a feedback linearization control case. *XXIII Congress Brasileiro de Automática (CBA 2020)*.

<u>Posters</u>

R. Bartali et al. Decarbonization of industrial processes: technologies, applications and perspectives of low- temperature solar heat (80 - 150°C). *13th International Conference on Solar Energy for Buildings and Industry (EuroSun 2020)*, September 1-4, 2020. Athens, Greece (Online).

Solar Treatment of Water Unit

SCI PUBLICATIONS

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Malato S., Giménez J., Oller I., Agüera A, Sánchez Pérez J.A. Removal and Degradation of Pharmaceutically Active Compounds (PhACs) in Wastewaters by Solar Advanced Oxidation Processes. In: Removal and Degradation of Pharmaceutically Active Compounds in Wastewater Treatment. Eds.: Rodriguez-Mozaz; S., Blánquez Cano, P., Sarrà Adroguer, M., Springer Nature Switzerland AG, 2020. DOI: https://doi.org/10.1007/698_2020_688

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PRESENTATIONS AT CONGRESS

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Oller I. Solar Energy-Water Nexus for industrial wastewater recovery. *International conference on Nexus: Energy Water & (Bio)Industry – Technological solutions towards industrial resource efficiency*. 30th January 2020, Vienna (Austria).

Oller I., Polo-López M.I., Granados S.N., Malato S. Water-Energy-Food nexus in industrial and urban wastewater recovery. *PHOTOPUR Online-Symposium*. 9th -10th December 2020.

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Gómez-Couso H., Reboredo-Fernández A., Abeledo-Lameiro M.J., Polo-López M.I., Fernández-Ibáñez P., Ares-Mazás E.. Photocatalytic inactivation of the waterborne protozoan parasite Cryptosporidium parvum: heterogeneous photocatalysis with TiO_2 versus homogeneous photocatalysis with photo-Fenton. ***International Conference on Photo-irradiation and Adsorption based Novel Innovations for Water treatment, PANI-WATER***. Goa (India), 3rd-4th March 2020.

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Energy Efficiency in Building R&D Unit

SCIENTIFIC JOURNALS

Díaz-Hernández, H.P., Torres-Hernández, P.R., Aguilar-Castro, K.M., Macias-Melo; E.V., Jiménez, M.J. Data - Based RC Dynamic Modelling Incorporating Physical Criteria to Obtain the HLC of In-Use Buildings: Application to a Case Study. ***Energies*** 13 (2020), 313. DOI: 10.3390/en13020313

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Jiménez, M.J., Guzmán, J.D., Sánchez, M.N., Olmedo, R., Castaño, S., Heras, M.R. (In Spanish). "Laboratorio de ensayos Energéticos para Componentes de la Edificación (LECE) de la Unidad de I+D UiE3 del CIEMAT. Tipos de recintos, metodologías y casos de estudio". Chapter of: "Red de excelencia MONITOR. BIA2017-90912-REDT. Experiencias en España". ISBN: 978-84-122767-4-9. pp. 93-106.

Sánchez, M.N., Olmedo, R., Guzmán, J.D., Soutullo, S., Castellanos, A., Seco, O., Castaño, S., Bravo, D., Enríquez, R., Jiménez, M.J. (In Spanish) "Monitorización de Sistemas Constructivos, Edificios y Entornos Urbanos en la Unidad de I+D UiE3 del CIEMAT. Medida directa, indirecta e índices". Chapter of: "Red de excelencia MONITOR. BIA2017-90912-REDT. Experiencias en España". ISBN: 978-84-122767-4-9. pp. 23-36.

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PRESENTATIONS AT CONGRESS

Guest lectures

M.J. Jiménez. (In Spanish) "Experimental set-up and measurement of the Round Robin Test Box at Plataforma Solar de Almeria. Overview of available data and analysis topics". Presented at

“DYNASTEE WEBINARS 2020. Dynamic Calculation Methods for Building Energy Performance Assessment”. Organised by INIVE-DYNASTEE. 16th September 2020. On-line.

M.J. Jiménez, J.D. Guzmán, M.N. Sánchez, R. Olmedo, S. Castaño, M.R. Heras. (In Spanish) “Laboratorio de ensayos Energéticos para Componentes de la Edificación (LECE) de la Unidad de I+D UiE3 del CIEMAT. Tipos de recintos, metodologías y casos de estudio”. Presented at “2ª JORNADA de la RED DE EXCELENCIA MONITOR”. Organised by the “Instituto de ciencias de la construcción Eduardo Torroja” and the “Instituto Valenciano de la Edificación”. 20th November 2020. On-line.

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