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MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

ANNUAL REPORT 2016

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ALMERÍA


PLATAFORMA SOLAR
DE ALMERÍA
TABERNAS
ALMERÍA

Annual Report 2016

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1. General Presentation

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

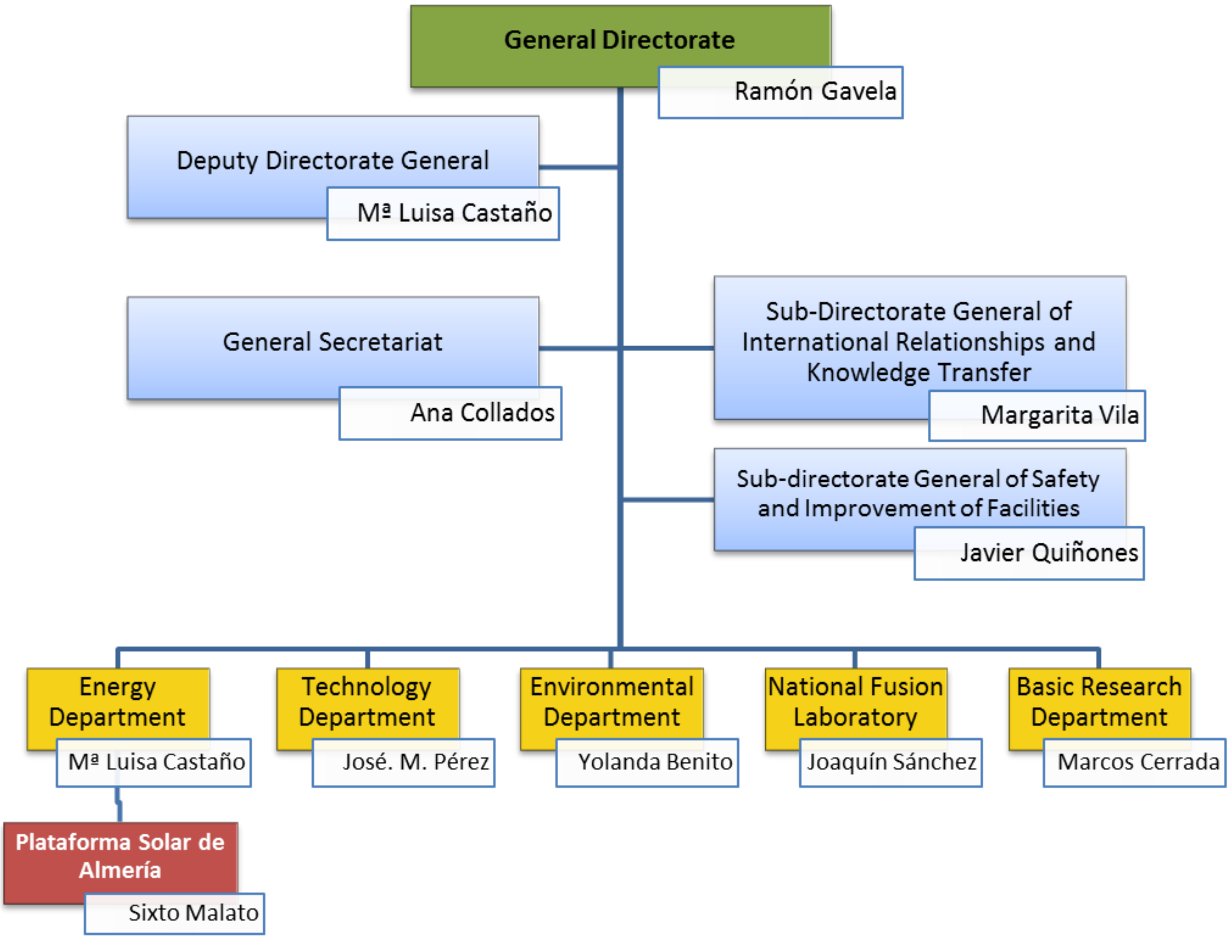


Figure 1. Integration of the PSA in the CIEMAT organization.

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 technological innovations contributing to increased market acceptance of solar thermal technologies.
- Promote North-South technological cooperation, especially in the Mediterranean Area.
- Assist industry in identifying solar thermal market opportunities.

Figure 2. Aerial view of the Plataforma Solar de Almeria.

Since 2012, research activity at the Plataforma Solar de Almeria has been structured around three R&D Units:

- Solar Concentrating Systems. This unit is devoted to promote and contribute to the development of solar concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes.
- Solar Desalination. Its objective is new scientific and technological knowledge development in the field of brackish and sea water solar desalination.
- Water Solar Treatment. Exploring the chemical possibilities of solar energy, especially its potential for water detoxification and disinfection.

Supporting the R&D Units mentioned above are the management services offered by the Administration Department and the Office of the Director, the technical services, which includes maintenance, operation and civil engineering services and are grouped together in the Infrastructure Management Unit, the IT services and the Instrumentation services. These units are largely self-sufficient in the execution of their budget, planning, scientific goals and technical resource management. Nevertheless, the three R&D units share many PSA resources, services and infrastructures, so they stay in fluid communication with all the above services units, the Administration Department and the Office of the Director. For its part, the Office of the Director must also ensure that the supporting capacities, infrastructures and human resources are efficiently distributed. It is also the Office of the Director that channels demands to the various general support units located at the CIEMAT’s main offices in Madrid.

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 137 people that as of December 2016 made up the permanent staff lending its services to the Plataforma Solar de Almeria. 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 127 people who work daily for the PSA, 61 are CIEMAT personnel, of whom 13 are located in the main offices in Madrid.

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 people, 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 people from the security contract, making a total of 17 people.

In addition, the 10 people who make up the DLR permanent delegation as a consequence of their current commitments to the Spanish-German Agreement also make an important contribution.

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

Figure 3. Management staff grouped at PSA. a) Office of the Director, b) Administrative department, c) Instrumentation Services unit, d) IT Services unit.

(a)

(b)

(c)

Figure 4. Technical services staff grouped at PSA. a) Operation unit, b) Cleaning and Maintenance unit, c) Infrastructure Management unit.

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

The PSA expense budget has an upward trend, in large part due to higher income, both from European Commission project funding, and from the National Plan for RD&I, although the most important factor was the increase in revenues from research contracted by business.

The PSA operating budget in 2016 totals 3.7 M Euros (not including R&D personnel or new infrastructure).

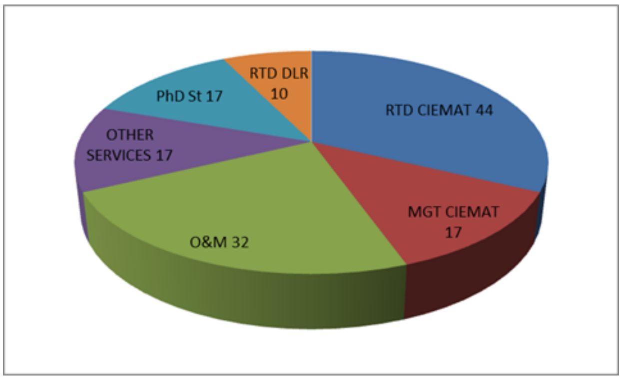


Figure 5. Distribution of permanent personnel at the PSA as of December 2016.

New Administrative procedures and accounting rules imposed to PSA in January 2016

The new administrative rules and accounting procedures imposed by the Spanish Government to PSA in January 2016 have been a significant barrier to develop in an efficient way the R+D activities and projects which PSA is involved in, thus introducing significant delays in many of the activities planned by PSA to be carried out in 2016. The new administrative environment imposed to PSA has even made impossible the payment of our yearly fee to international entities like the International Solar Energy Society (ISES) and SolarPACES.

The new administrative procedures have greatly extended the duration of the procedures to purchase goods, equipment and to hire manpower for new projects. The new accounting rules, among other problems, block the funds transferred to PSA for multi-year projects, so that those funds received before the last quarter of the year have to be spent within the same year, even when the funds received are advanced payments to cover PSA activities during several years. Only those funds received in the last quarter of the year may be used the following year.

Since this new administrative and accounting rules, which are incompatible with the nature of an international entity like PSA, are a great barrier to continue with the active participation of PSA in international and multi-year projects, the situation will become very critical if they are not urgently modified by the Spanish Government to provide PSA with an administrative environment compatible with our requirements as an European Large Scientific Installation and a Spanish Singular Science and Technology Infrastructure (ICTS).

Local and national authorities have been informed by PSA about this unbelievable and senseless situation in which PSA has been constrained by the Spanish public Administration. However, at the time of writing this report the situation has not been modified by the Spanish public Administration.

2. Facilities and Infrastructure

2.1 Experimental Installations and Laboratories Existing at PSA for Solar Thermal Concentrating Systems

2.1.1 PSA Experimental facilities for solar thermal concentrating systems

At present, the main test facilities available at the PSA related to solar thermal concentrating systems are (see Figure 6):

- CESA-1 and SSPS-CRS central receiver systems, 6 and 2.5-MWth respectively.
- DISS 2.5-MWth test loop, an excellent experimental system for two-phase flow and direct steam generation for electricity production research with parabolic-trough collectors in different working conditions, up to 500ºC and 100bar.
- The FRESDEMO “linear Fresnel” technology loop.
- An Innovative-Fluids Test Loop, named IFL
- TCP-100 2.3-MWth parabolic-trough collector field with associated 115-m^3 thermal oil storage system
- The Parabolic Trough Test Loop (PTTL) facility
- A parabolic-trough collector test facility with thermal oil (the so-called HTF Test loop) for qualification of components and complete collectors.
- 4-unit dish/Stirling facility, named DISTAL, and 2 EuroDish units.
- A group of 3 solar furnaces, two of them with horizontal axis (60 kW_{th} and 40 kW_{th}) and a third one with vertical axis (5 kW_{th}).
- A test stand for evaluation and qualification of small parabolic trough collectors, named CAPSOL.
- A molten salt test loop for thermal energy systems, named MOSA

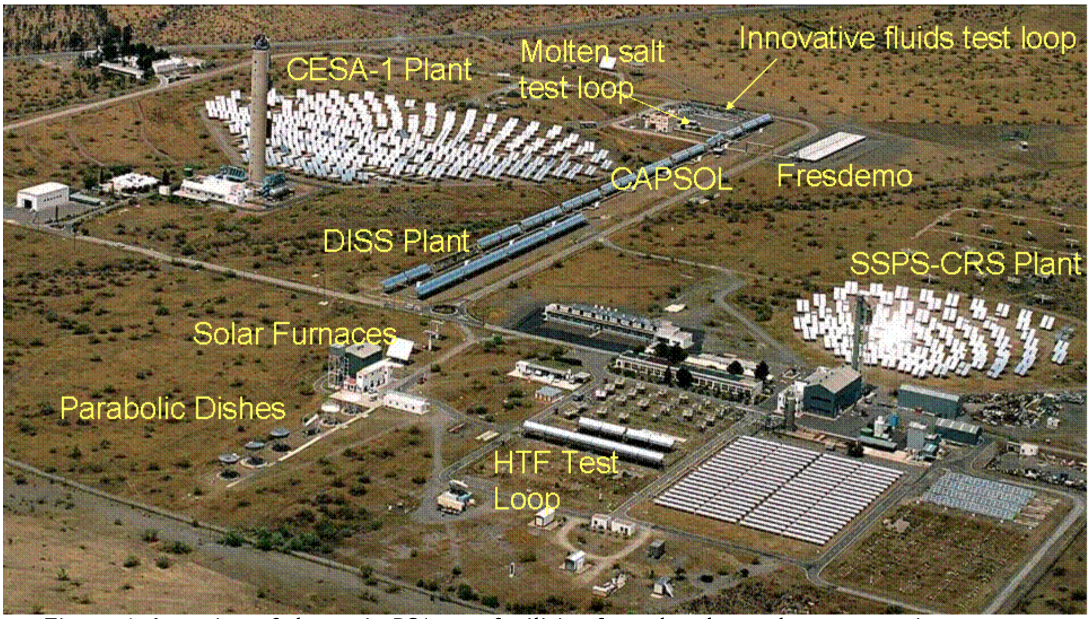


Figure 6. Location of the main PSA test facilities for solar thermal concentrating systems.

These experimental installations and other with less importance are described in detail in next sections, grouped by the type of technology used (Central receiver systems, Line-focus collectors and Parabolic Dishes), having a special section for the Solar Furnaces for very high concentration and/or temperature tests.

2.1.1.1 Central Receiver Facilities: CESA-1 and CRS

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.

The 6 MWth CESA-1 Plant

The CESA-1 plant 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 7. The CESA-I facility seen from the North.

Direct solar radiation is collected by the facility's 330 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. In spite of 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 MWth 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.

The SSPS-CRS 2.5 MWth facility

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

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

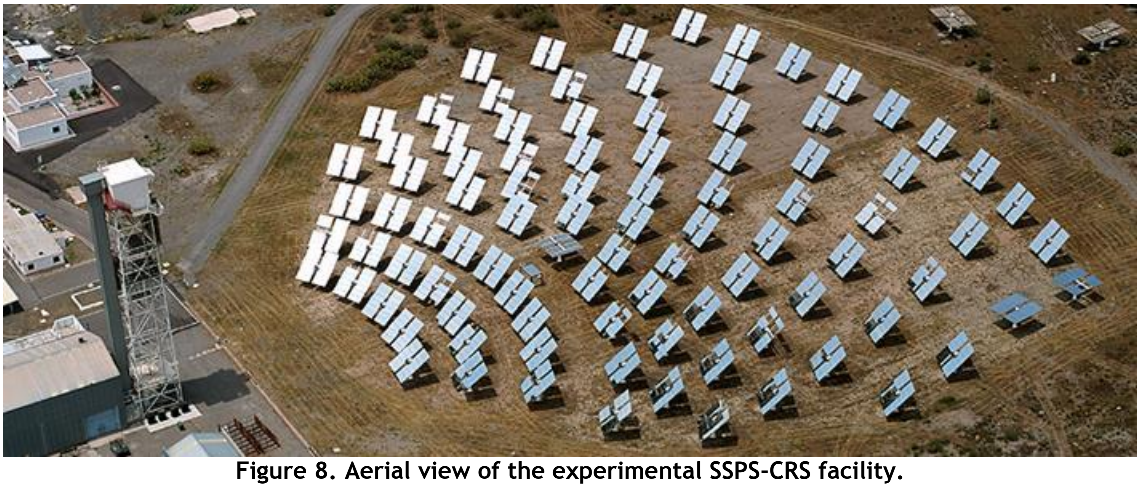


Figure 8. Aerial view of the experimental SSPS-CRS facility.


Figure 9. An autonomous heliostat in the SSPS-CRS field.

The original SSPS-CRS heliostat field was improved several years ago with the conversion of all of 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. This first autonomous heliostat field, which does not require the use of channels or cabling, was made possible by financial assistance from the Spanish Ministry of Science and Technology's PROFIT program.

The nominal average reflectivity value of the field is 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 MWth 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 (29dm^3/s, 8bar), pure nitrogen supplied by two batteries of 23 standard-bottles (50dm^3/225bar) each, steam generators with capacity of 20 and 60kg/h of steam, cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from a 8m^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.

2.1.1.2 Linear Focusing Facilities: HTF, DISS, Innovative Fluids Test Loop, FRESDEMO, CAPSOL, KONTAS and Prometeo

At present, PSA has several linear-focusing solar collector facilities for both parabolic-trough and Linear Fresnel collectors. Many of these experimental installations, such as the innovative-fluids test loop or the DISS plant, are the only one of their kind in the World, and place the PSA in a privileged worldwide position for research and development of new parabolic-trough collector applications. The main characteristics of these facilities are briefly explained below.

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 several solar collectors of 75-m long connected in parallel (up to three collectors can be installed in parallel), being able to operate only one at a time. 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 5º. The thermal oil used in this facility (Syltherm 800®) has a maximum working temperature of 420°C and a freezing point of -40ºC.

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 and it 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.

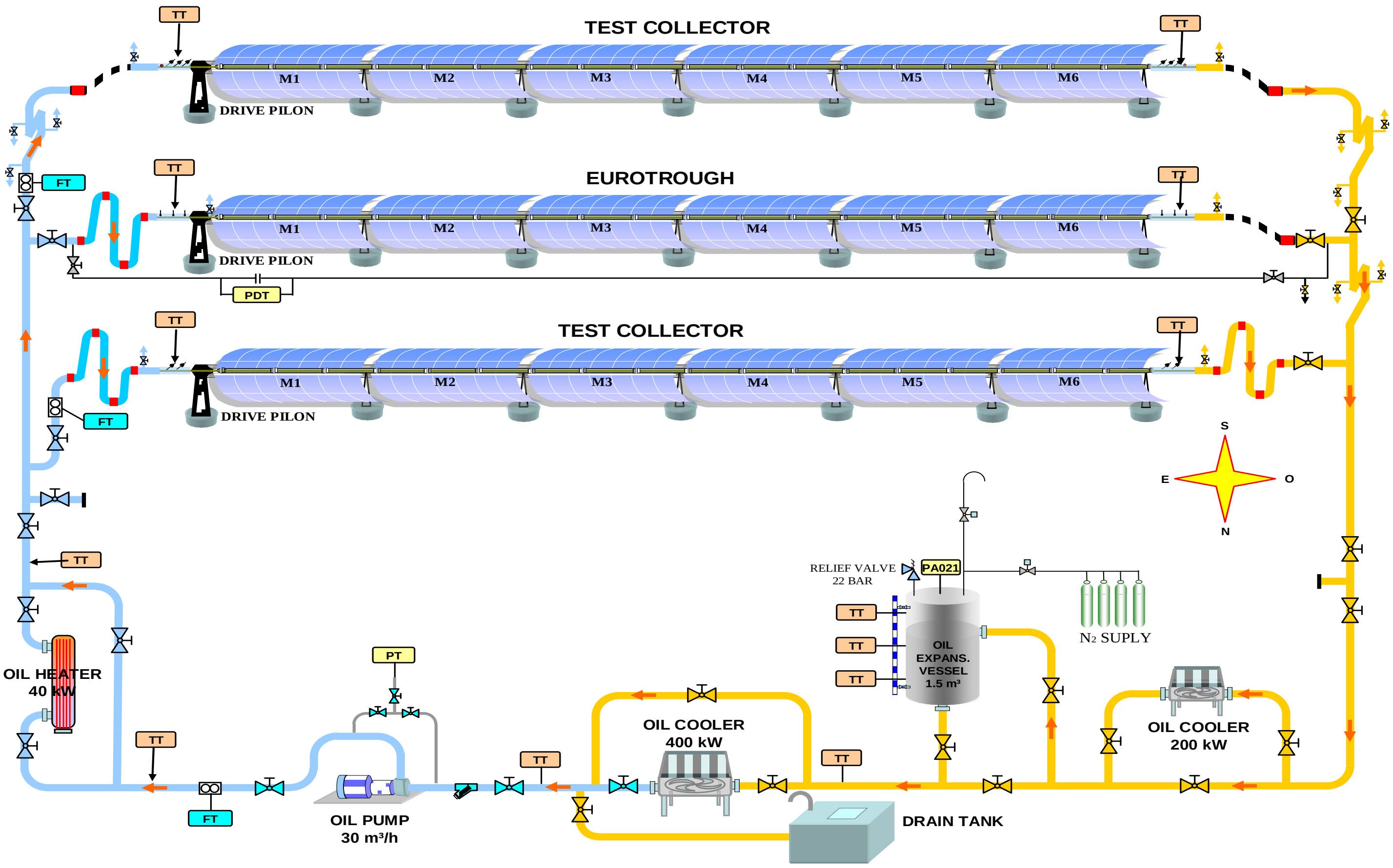


Figure 10. Diagram of the PSA "HTF test Loop".

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/400ºC) 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 11) 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 400ºC 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).

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 100bar and 500°C.

Facility operation is highly flexible and can work from very 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.

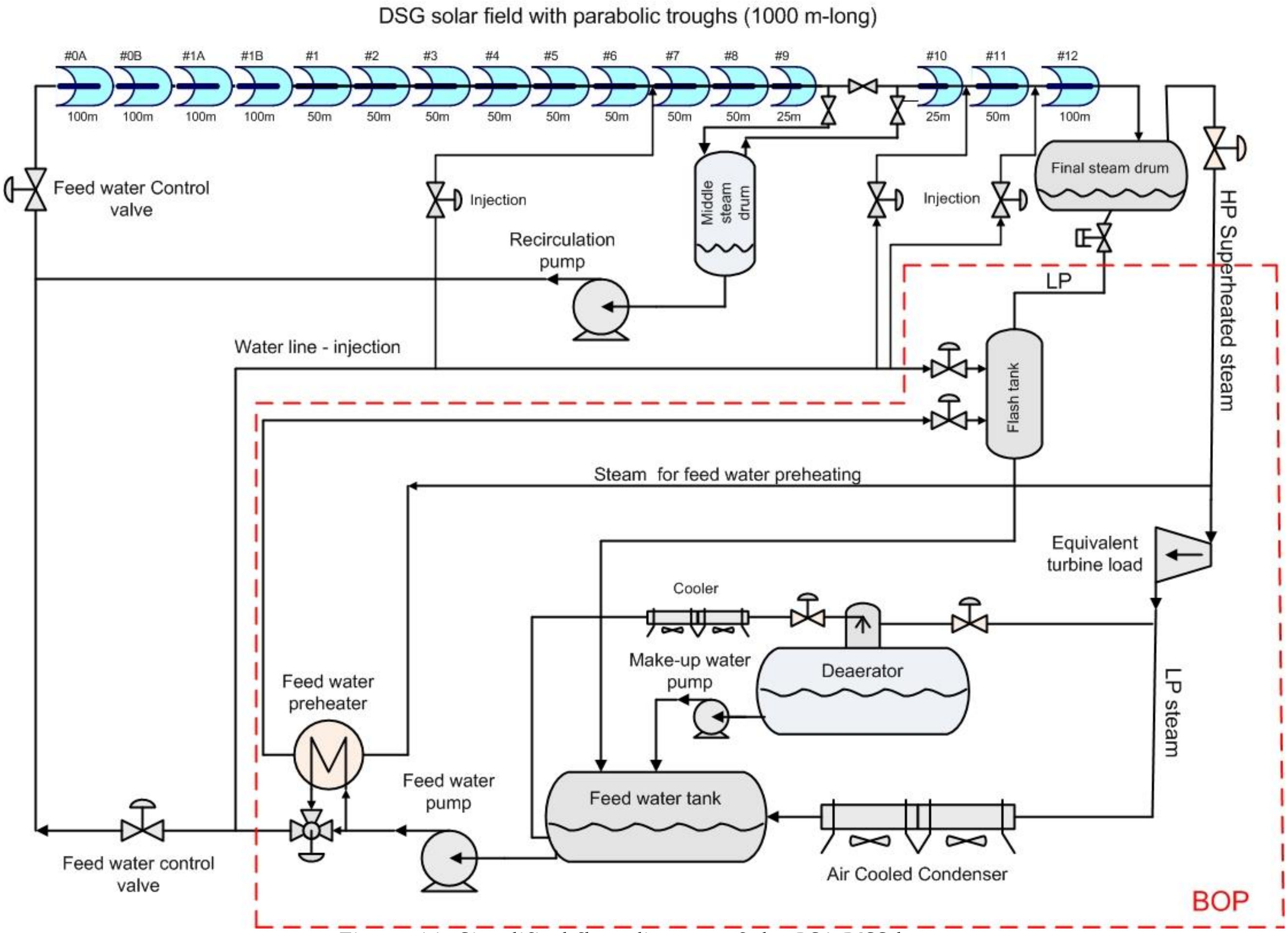


Figure 11. Simplified flow diagram of the PSA DISS loop.

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 flexholes, 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.

Figure 12. View of the DISS plant solar field in operation.

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 is located north of the DISS experimental plant control building, which houses the equipment necessary for its control and data acquisition.

Figure 13. View of the IFL experimental facility (with parabolic-troughs) using compressed gas as heat transfer fluid.

The IFL facility was originally designed to work at pressures and temperatures of up to 100 bar and 400ºC, 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.
- 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 400ºC was successfully completed at the end of 2009, this facility was then upgraded to achieve temperatures of up to 515ºC 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 515ºC 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).

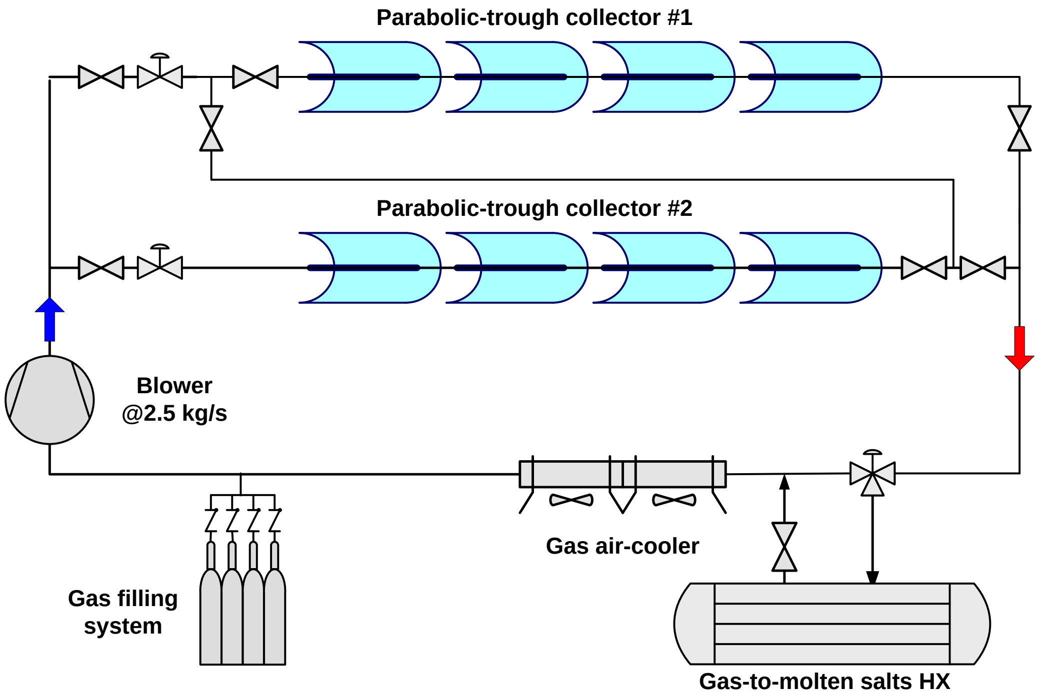


Figure 14. Simplified system diagram of the IFL experimental facility located at the PSA.

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 oil.

The TCP-100 solar field is composed of six parabolic trough collectors, model TERMOPOWER, installed in three parallel loops, with two collectors in series within each loop. Each collector is composed of eight parabolic trough module 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 n, 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 Archimedes 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 400ºC. 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.

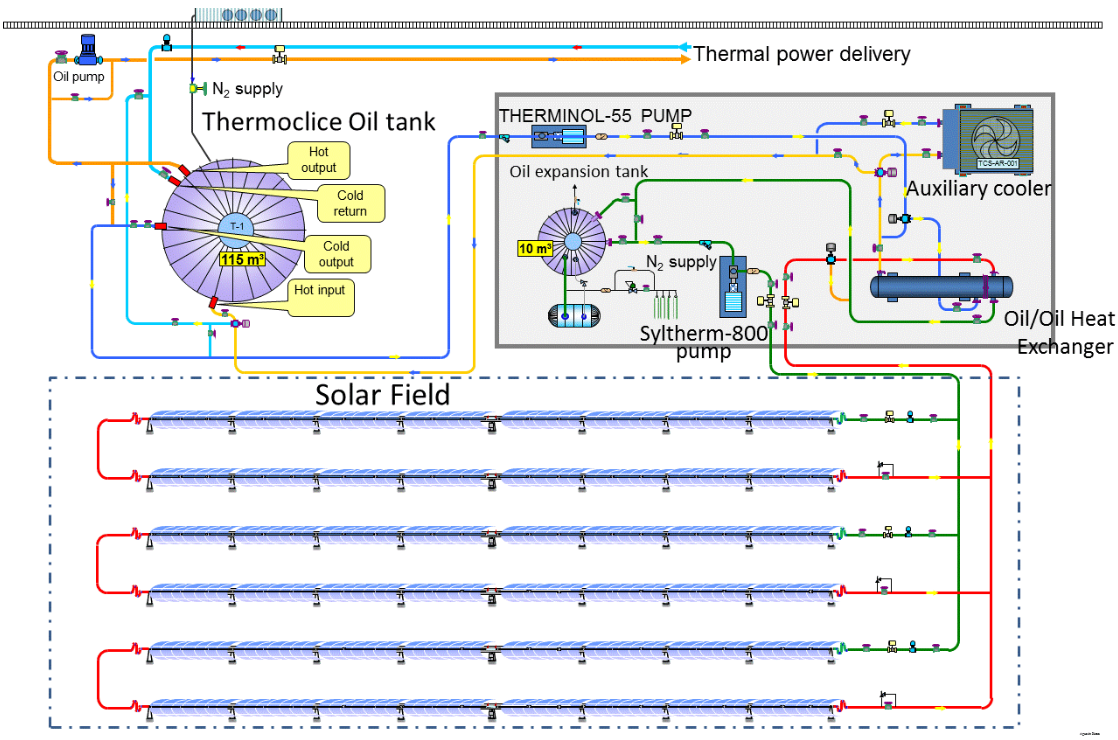


Figure 15. Diagram of the TCP-100 2.3-MWth parabolic-trough facility.

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.

The Parabolic Trough Test Loop (PTTL) facility

This large test facility is implemented in a 420mx180m plot of the PSA and it is composed of two solar fields:

- the North field is designed to install with a 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 30mx30m concrete platform between the two fields, and both circuits share: an oil expansion tank with a capacity of 30 m3, a gas-fired oil heater with a thermal power of 250 kW, 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 40ºC, 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

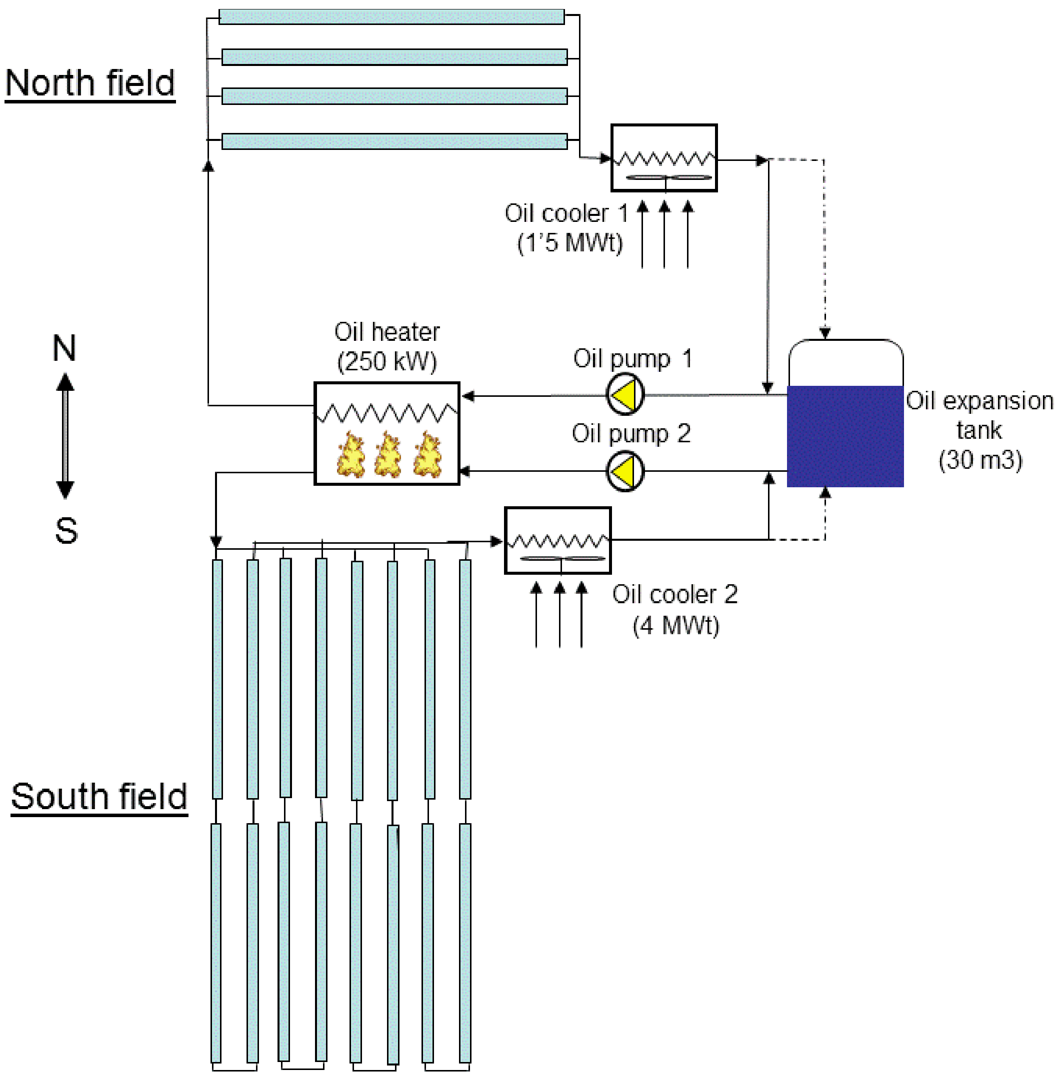


Figure 16. Simplified scheme of the PTTL facility.

The FRESDEMO Loop

The FRESDEMO loop is a "Linear Fresnel concentrator" technology pilot demonstration plant (Figure 17). This 100m-long, 21-m-wide module has a primary mirror surface of 1433 m^2, distributed among 1200 facets mounted in 25 parallel rows spanning the length of the loop. This collector loop is designed for DSG at a maximum pressure of 100 bar and maximum temperature of 450°C.

This pilot facility is presently connected to the piping system of the PSA DISS plant from where it is supplied with solar steam at different pressures and temperatures for testing in the three working modes: preheating, evaporation and superheating.

CAPSOL Facility

CAPSOL is a concentrating solar thermal energy test facility designed and built at the PSA for testing of small-sized, high-precision parabolic-trough solar collectors under real environmental conditions.

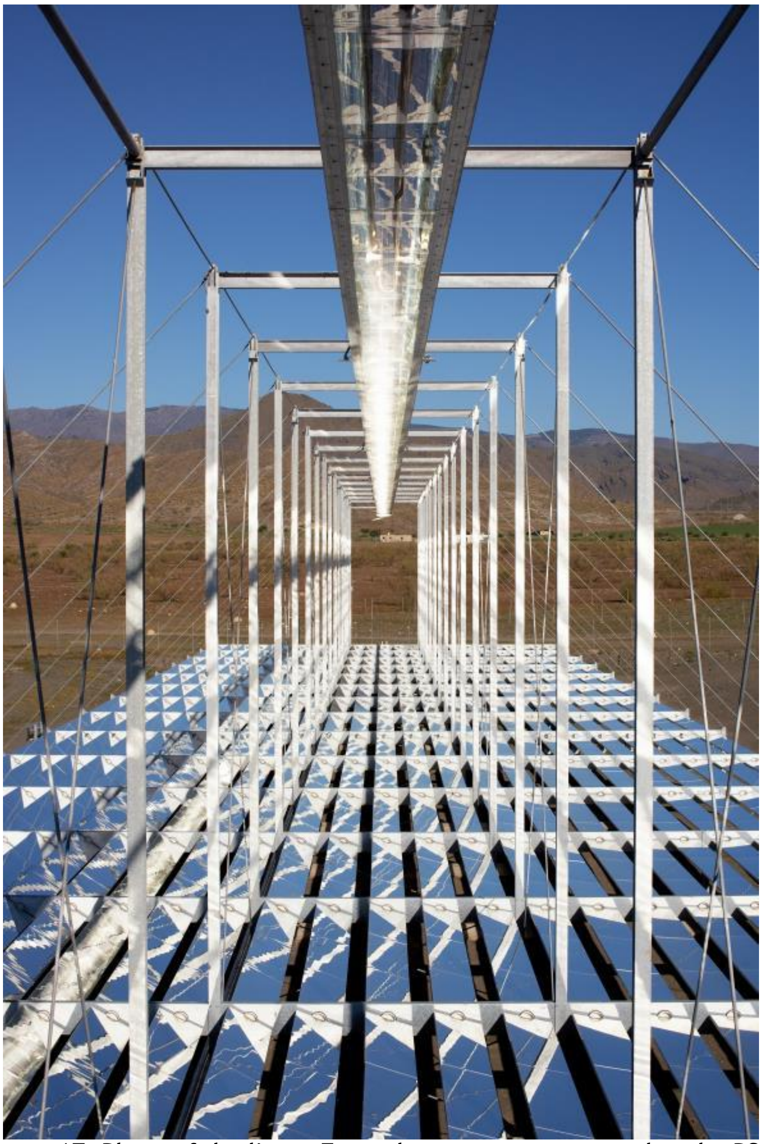


Figure 17. Photo of the linear Fresnel concentrator erected at the PSA.

The facility is designed to operate with pressurized water under a wide range of operating conditions: fluid temperatures from ambient to 230ºC, flow rates from 0.3 to 2.0 m^3/h and pressures up to 25 bar. It also allows testing of different collector orientations and sizes (apertures up to 3 m). High-precision instrumentation has been installed for measuring all of the parameters required for adequate evaluation of parabolic-trough collectors. In particular, the facility has a mass flowmeter (Coriolis-type, with a ±0.1% measurement accuracy), a pyrheliometer (Eppley, with 8 $\mu V/Wm^{-2}$ sensitivity) and two types of temperature sensors at the inlet and outlet of the solar field (4-wire PT-100 with an accuracy of ±0.3°C in a 100 to 200°C range). In addition to these instruments, the facility has sensors for measuring other parameters, such as fluid temperature at various points in the circuit, pressure, tank level, ambient temperature, wind speed and direction, etc.

This test facility makes it possible to find the efficiency parameters required for characterizing small parabolic-trough collectors: peak optical-geometric efficiency, incident angle modifier, overall efficiency and thermal losses when collectors are out of focus. The stationary state conditions needed for performing these tests are reached thanks to the inertia of the expansion tank and auxiliary heating and cooling systems. The data acquisition and control system facilitates monitoring and recording of the parameters measured as well as system operation from the control room.

Both complete small-sized parabolic-trough collectors and their components, such as absorber tubes, reflectors or tracking systems, can be tested in this facility. Furthermore, the facility also allows analysis of technical aspects of the collectors, such as materials durability, structural resistance, component assembly, etc. under real operating conditions.

Figure below shows a photo of the CAPSOL test facility with two prototypes of small-size parabolic-trough collectors installed.

Figure 18. CAPSOL solar thermal test facility for small-size parabolic-trough collectors.

KONTAS: Rotary test bench for parabolic trough collectors

A rotary test bench for parabolic trough collector components, KONTAS, was erected at Plataforma Solar de Almeria 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 collected on the way through the module and ensures a constant HTF temperature (±1K) 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 19. Side view of Kontas test bench and the heating cooling unit.

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 Plataforma Solar de Almeria. 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-PSA 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 *Syltherm 800®*

thermal oil as heat transfer fluid (HTF) 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 energy and ensures a constant HTF temperature (±1K) 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 20. View of the PROMETEO test facility.

2.1.1.3 Parabolic DISH Systems

Accelerated ageing test bed and materials durability

This installation consists of 4 parabolic dish units, 3 DISTAL-II type with 50 kW total thermal power and two-axis sun tracking system, and 1 DISTAL-I type with 40 kW total thermal power and one-axis polar solar tracking system. In the 4 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 DISTAL-I concentrator (Figure 21) is a 7.5 m diameter parabolic dish, able to collect up to 40 kW_{th} energy, which is applied to the probes to obtain the accelerated ageing. The concentrator is made of a stretched membrane, which maintains the parabolic shape with a small vacuum pump. It has 94% reflectivity and can concentrate the sunlight up to 12,000 times in its 12-cm diameter focus. It has a focal distance of 4.5 meters and polar solar tracking.

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 slightly larger than the DISAL-1 above described (8.5 m) and the thermal energy delivered in the focus is 50 kW_{th}. The focal distance is 4.1 m and the maximum concentration is 16000 suns at the focus.

These concentrators can be used for any experiment requiring a focus with the characteristics above mentioned (50 kW_{th} maximum and 16,000 suns peak concentration at the focus). The tracking consists in a two-axis azimuth-elevation system.

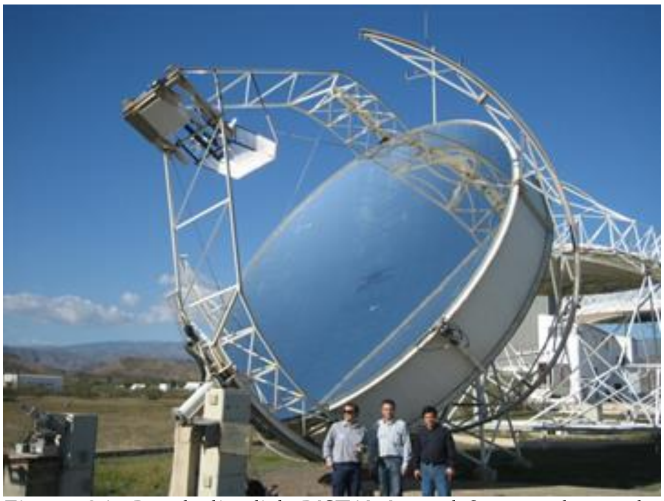


Figure 21. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

Figure 22. View of a parabolic-dish DISTAL- II.

EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected, discarding the stretched-membrane technology and applying a moulded composite-material system. These parabolic dishes can be used to test new prototypes of Stirling engines, or to perform any other test requiring a focus with 50 kW_{th} maximum and a maximum concentration of 16.000 suns at the focus. The tracking system is azimuth-elevation.

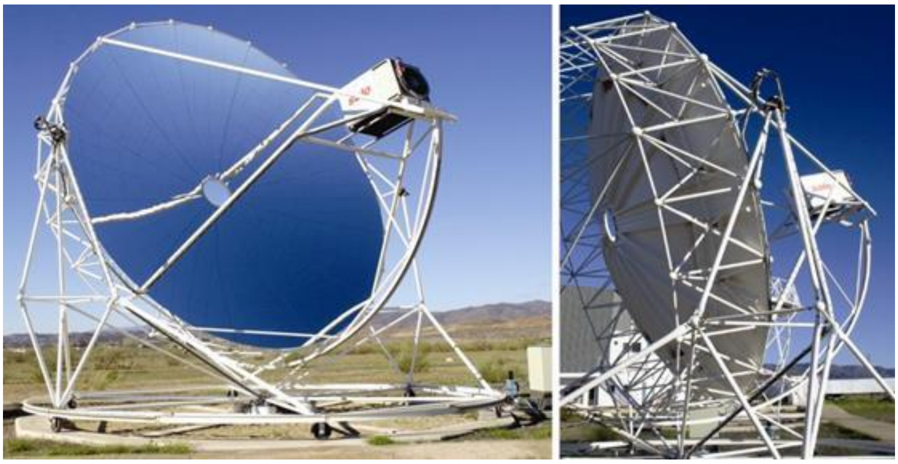


Figure 23. Front and back views of the EURODISH.

2.1.1.4 THE SOLAR FURNACES AT PSA

Solar furnaces can be defined as optical systems that concentrate solar radiation in a small area called focus where high temperatures and thermal fluxes can be reached. They can reach concentrations of over 10000 suns, the highest energy levels achievable in a solar concentrating system. Their main field of application are materials testing, either at room conditions, controlled atmosphere or vacuum, and solar chemistry experiments using chemical reactors associated with receivers.

A solar furnace essentially consists of a continuously solar-tracking, flat heliostat, a parabolic-dish concentrator, an attenuator or shutter and the test zone located in the concentrator focus.

The flat heliostat reflects the incoming solar beams on the parabolic-dish concentrator, which in turn reflects them on its focus (the test area). The amount of incident light is regulated by the attenuator located between the concentrator and the heliostat. Under the focus, a test table movable in three directions (East-West, North-South, up and down) places the test samples in the focus with great precision.

There are three solar furnaces fully operational at the PSA: Solar furnace SF60 which has been in operation from 1991, solar furnace SF5, in operation from 2012 and solar furnace SF40 which started operating in 2014.

SF-60 Solar Furnace

The SF60 consists basically in a 120 m^2 flat heliostat that reflects the solar beam onto a 100 m2 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.

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 24 and Figure 25 show the new heliostat and a detail of the back side of the facet respectively.

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 26) 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.

Figure 24. HT120 heliostat with new PSA facets.

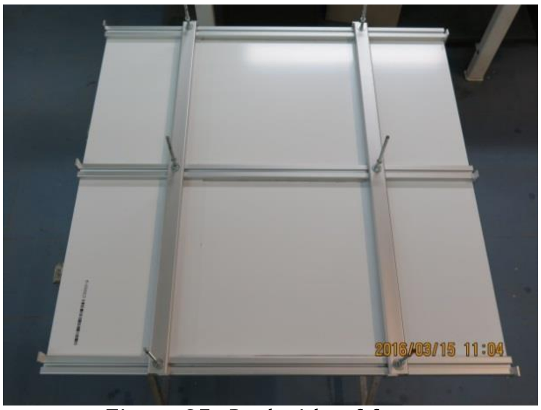


Figure 25. Back side of facet.

The test table is a mobile support for the test pieces or prototypes to be tested that is located under the focus of the concentrator. It moves on three axes (X, Y, Z) perpendicular to each other and positions the test sample with great precision in the focal area.

The combination of all of 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 1000 W/m^2 are: peak flux, 300 W/cm^2, total power, 69 kW, and focal diameter, 26 cm.

Figure 26. HT120 heliostat in tracking.

SF-40 Solar Furnace

The new SF-40 furnace consists mainly of an 8.5-m-diameter parabolic-dish, with a focal distance of 4.5 m. The concentrator surface consists of 12 curved fiberglass petals or sectors covered with 0.8-mm adhesive 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 5000 suns and has a power of 40 kW, its focus size is 12 cm diameter and rim angle is 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.

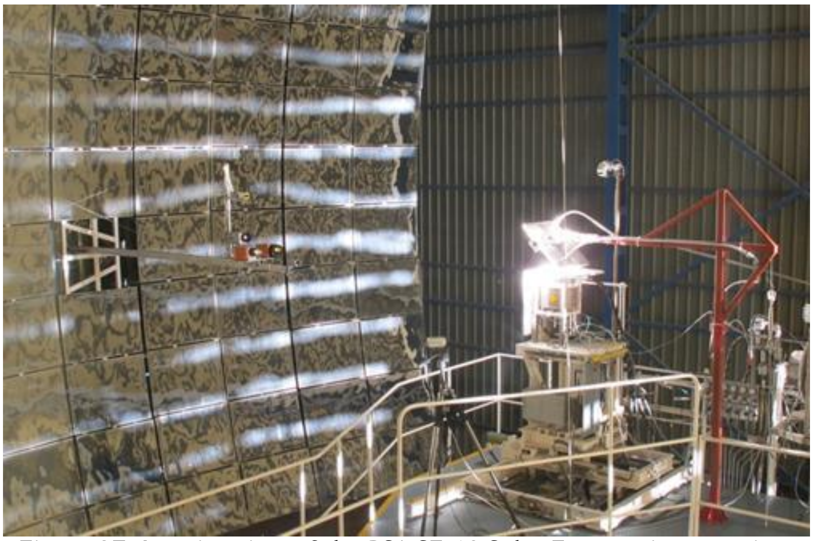


Figure 27. Interior view of the PSA SF-60 Solar Furnace in operation.

It basically consists of a 100 m^2 reflecting surface flat heliostat, a 56.5 m^2 projecting area parabolic concentrator, slats attenuator, 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 in focus is rotated 90º, 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, so that the specimens are not oxidized during tests.

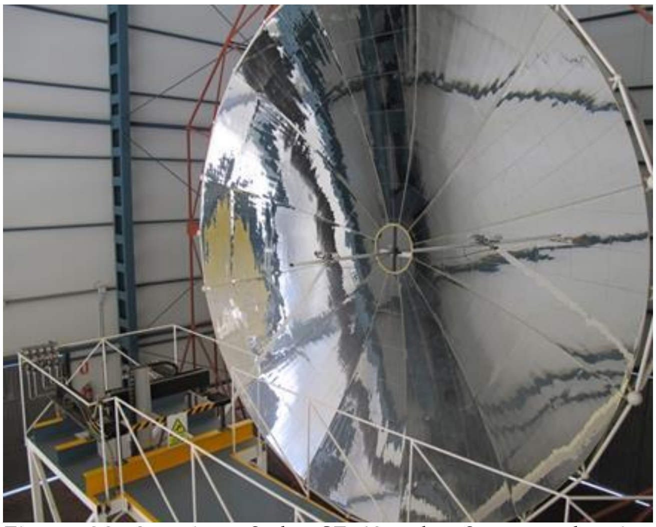


Figure 28. Interior of the SF-40 solar furnace showing the parabolic concentrator.

SF-5 Solar Furnace

Designed and built at the PSA, this system is in operation 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 7000 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 are used.

It differs substantially from that 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 that in most existing solar furnaces, 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 a 8.7 m^2 concentrator mirror, placed upside-down with the reflecting surface facing the floor, on a 18 m high metallic tower; in the centre of the base of the tower there is a 100 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 louver attenuator is placed.

Figure 29. Concentrator of the SF-5 Furnace.

2.1.1.5 Thermal Storage Facilities

This molten salt test loop is a replica of a thermal energy storage system with molten salts and a two-tank configuration. With 40t of molten salts plant, this facility consists basically in:

- Two tanks, one vertical, for hot molten salts, and another horizontal, for cold molten salts.
- A thermal oil loop that can be used for heating the salt up to 380°C and cooling it to 290°C.

- A CO_2-molten salt heat exchanger for heating the salt up to 500°C with CO_2 supplied by parabolic trough collectors.
- Two flanged sections, where different components for this type of loops (e.g. valves, flow meters, heat trace, pumps…) can be tested.

Figure 30. Molten Salt Test Loop (MOSA) for Thermal Energy Systems.

Being a setup, which is a reduced scale of a commercial two-tank molten salt storage system, everything related to this type of systems can be tested in this facility. Some applications of this facility are:

- Checking of components (pumps, valves, flowmeters, etc.) for their use in a 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 heat exchangers for molten salt/gas.
- Characterization of thermocline tanks.

2.1.2 Laboratory of Solar Concentrating Systems Unit

The PSA Solar Concentrating Systems Unit has a large distributed laboratory covering several activity lines and provided with equipment located in Almeria and Madrid. The activity lines included in this laboratory are the following:

1. Durability and characterization of materials under concentrated solar radiation
2. Development and testing of advanced optical coatings (i.e., selective and anti-reflective coatings)
3. Solar reflectors durability analysis and optical characterization
4. Receivers testing and characterization for concentrating solar thermal systems
5. Solar hydrogen
6. Radiometry
7. Materials and components for molten salt circuits
8. Materials for thermal storage
9. Geometrical characterization of solar concentrators

The equipment and capacities of this laboratory related to each of these activity lines are described in the next sections

2.1.2.1 Durability and characterization of materials under concentrated solar radiation

This activity line of the 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, fatigue and breakage of these materials at high temperatures under concentrated solar radiation.

The equipment associated to this activity is composed of devices located both indoor and outdoor. 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, every one of them dedicated to different kind of analyses:

- The Metallography Room
- The Microscopy Room
- The Thermogravimetry Room

The lab's equipment is currently as listed below:

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 75ºC with heater
- Fume cupboards: Flores Valles VA 120 960 M-010-02
- Power Source programmable: Iso-Tech IPS 405 for electrochemical attack
- Analytical sieve shaker: Retsch AS 200 Control (Sieves: 20, 10, 5, 2.5 and 1.25 mm and 710, 630, 425, 315, 250, 160, 150, 90, 53 y 32 µm)
- Digital Camera with reproduction table

Figure 31. View of the Metallography Room in in the Solar Furnaces building.

Microscopy Room

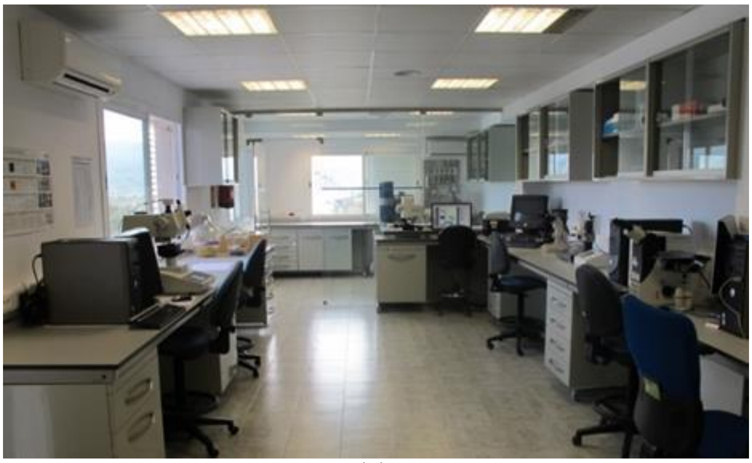
- 3D Optical Surface Metrology System: Leica DCM 3D
- Leica DMI 5000 optical microscope with Leyca-IM50 image acquisition system and motorized table.
- Olympus optical microscope Union MC 85647.
- Struers micro hardness tester Duramin HMV-2 with visualization system and software micro Vickers hardness tester HMV-AD 3.12.
- Manual hardness tester
- Surface Finish Measuring Unit ZEISS Surfcom 480 with data processor
- Balance: Mettler E2001/MC max 60Kg
- Balance: Mettler Toledo classic max 320g / min 10mg

Thermogravimetry Room

- The thermogravimetric Balance SETSYS Evolution18 TGA, DTA, DSC (Temperature range ambient to 1750°C) 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 MicroGC simultaneously to the equipment. This thermogravimetic Balance has different possibilities of tests:
    a) Tests under pure Hydrogen atmosphere up to 1750°C
    b) Tests under pure Oxygen atmosphere

c) Tests under H_2O steam with other gases simultaneously.
d) Tests under corrosive atmosphere up to 1000°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 32. View of a) the Microscopy Room, b) Thermogravimetric balance inside this room.

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,

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 AMES and SCS units, and with the following specifications.

- Scanning electronic microscope (SEM) - Hitachi, model S-3400N II, high/low vacuum, secondary electron image, backscattered electron image, cooling stage and magnification 5x to 300.000x.
- Energy dispersive x-ray spectrometer (EDS) Quantax 400

Besides, the SEM room also has environmental secondary electron detector (ESED), a critical point dryer and sputterer.

The outdoor equipment is composed of several solar-dish concentrators located close to the PSA solar furnaces building. These solar dishes are used for thermal cycling under real solar conditions, with very high solar flux (up to 1200 kW/m^2) and high temperatures (from 200°C to 1200°C) and are equipped with different test benches for volumetric and tube configuration testing.

2.1.2.2 DEVELOPMENT AND TESTING OF ADVANCED OPTICAL COATINGS

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 600°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 33a).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 33b)
- *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 (Figure 33c). For measuring emissivity, it has a semi-cylindrical tunnel which emits infrared radiation at 70°C (Figure 33e).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 33d).
- BROOKFIELD LVDV-I+ Viscometer.
- KSV CAM200 goniometer for measuring contact angles (Figure 33f).
- Kilns. There are three kilns for thermal treatment:
  - 120x100x300 mm kiln with a maximal temperature of 1200°C.
  - Controlled atmosphere kiln with a maximal temperature of 800°C.
  - 500x400x600 mm forced convection kiln with a maximal temperature of 550ºC.

2.1.2.3 SOLAR REFLECTOR DURABILITY ANALYSIS AND OPTICAL CHARACTERIZATION

This activity line of the PSA Solar Concentrating Systems Unit laboratory is the result of a joint collaborative initiative between CIEMAT and DLR called OPAC. It is provided with the necessary equipment to completely characterize the materials used as reflectors in solar concentrating systems. This line is devoted to evaluate the characteristic optical parameters of solar reflectors and their possible deterioration. The equipment associated to this activity line allows for both quantitative and qualitative measurement of the reflectance of solar mirrors. The following equipment is available for the optical analysis of solar mirrors (see Figure 34, left):

- 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 SR2, designed and patented by DLR).

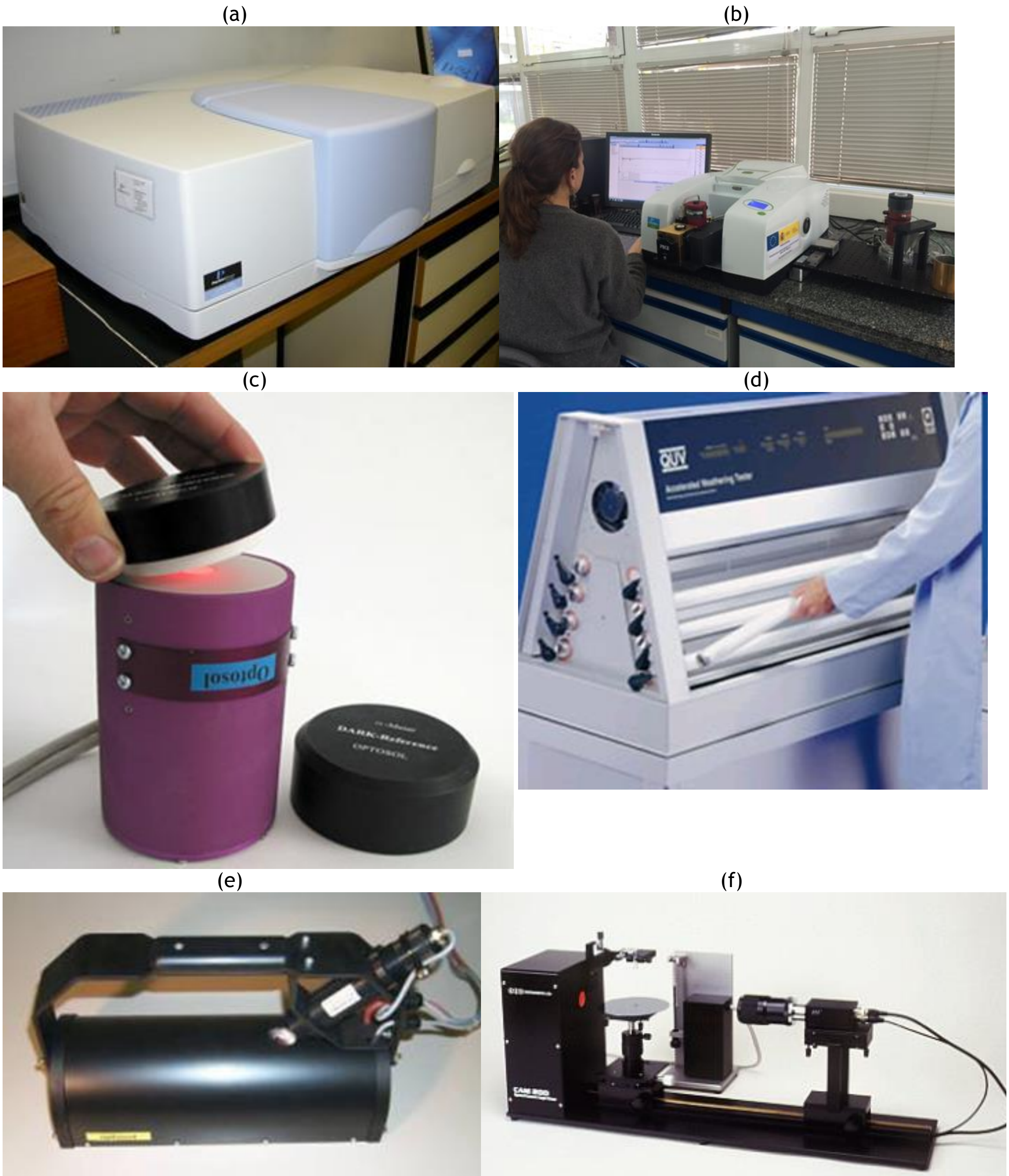


Figure 33. Advanced optical coatings laboratories equipment.

- 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 (see Figure 35).

Globally, the equipment associated to this activity line is designed for accelerated ageing tests of solar reflectors with the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime (see Figure 34, right). 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 simulation equipment is available for these accelerated ageing tests:

- ATLAS SC340MH weathering chamber for temperature (from -40 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 to 50°C (450L).
- Erichsen 608/1000L salt spray chamber with temperatures from 10 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.

Figure 34. Equipment for solar reflector optical characterization (left) and durability analysis (right).

- 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 (335L, see Figure 36).
- Ineltec CKEST 300 test chamber for humidity and condensation testing with temperatures up to 70ºC (300L).
- 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.

Figure 35. Attension Theta 200 Basic tensiometer for dynamic and static contact angle measurements.

Figure 36. Climate chamber with corrosive gases.

Along with this indoor equipment, 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 of them has been designed to test the influence of blocking on the coatings lifetime, while the second one was designed to accelerate the reflectors degradation due to UV radiation under outdoor weather conditions. Finally, this activity line is also provided with accessories necessary for their proper use, such as two precision scales, a thermos-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.

2.1.2.4 *Receivers testing and characterization for concentrating solar thermal systems*

This activity line comprises both linear receivers and volumetric receivers. The equipment associated to linear receivers is located at PSA and main devices are a test bench called HEATREC (see Figure 37, left) for measuring heat loss of single receiver tubes under indoor laboratory conditions and an outdoor test bench called RESOL (see Figure 37, right) 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. 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.

Figure 37. View of the HEATREC test chamber to measure heat losses in solar receiver tubes (left) and RESOL test bench to measure receiver's optical efficiency (right).

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 4060 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.

The lab equipment devoted to volumetric receivers is installed at CIEMAT-Moncloa (Madrid) site with the aim of studying in depth at lab scale the solar volumetric technology. Its main component is a test bench (see Figure 38) specially designed for the test of new volumetric absorbers and configurations and its ageing. This test bench has the flexibility to study:

- The pressure difference across the volumetric absorber for different fluid density and fluid velocity, for the determination of the main properties described by the Forchheimer extension to Darcy's law: the viscous permeability coefficient and, the inertial permeability coefficient. A differential pressure drop system is installed, with the previously described installation, for the properties determination
- 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.

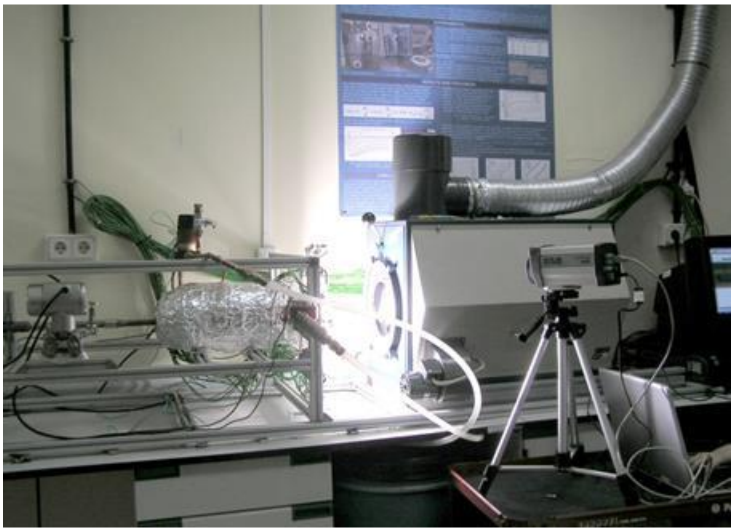


Figure 38. Test bench for volumetric receiver testing

The main equipment installed in this test bench is:

- 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,
- Extraction system: with 1 k-type thermocouple, 1 PT100 sensor, an air mass flow-rate measurement, and an air blower.
- A 4-kW solar simulator, installed in CIEMAT-Moncloa made up of a Xenon lamp and a parabolic concentrator (Figure 39) that can reach fluxes of up to 1400 kW/m^2.

The lab-equipment described above to study volumetric receivers at atmospheric pressure is complemented by an indoor small facility to study thermal storage materials for high temperature using hot air as heat transfer fluid. This small facility is composed of a thermocline storage test bench (of about 0.1 m^3) as experimental loop for static (Figure 40) and dynamic (Figure 41) thermal characterization of porous beds.

The system consists of six power heating resistor with a total power of 15000 watts electric energy. They heat the air up to a target temperature (maximum temperature limited by the resistor is 1000°C) by means of a temperature controller. An amount of 35 K-type thermocouples units of 400 mm long are used. The behaviour of the tank is measured at 7 levels with 5 measurement each level. The total power consumption is recorded, with a three-phase electrical measurement, to match the energy balances and the heat losses. Moreover, the external surface temperature mapping is registered by a thermograph camera, which offers a complete image of the external chassis of the tank.

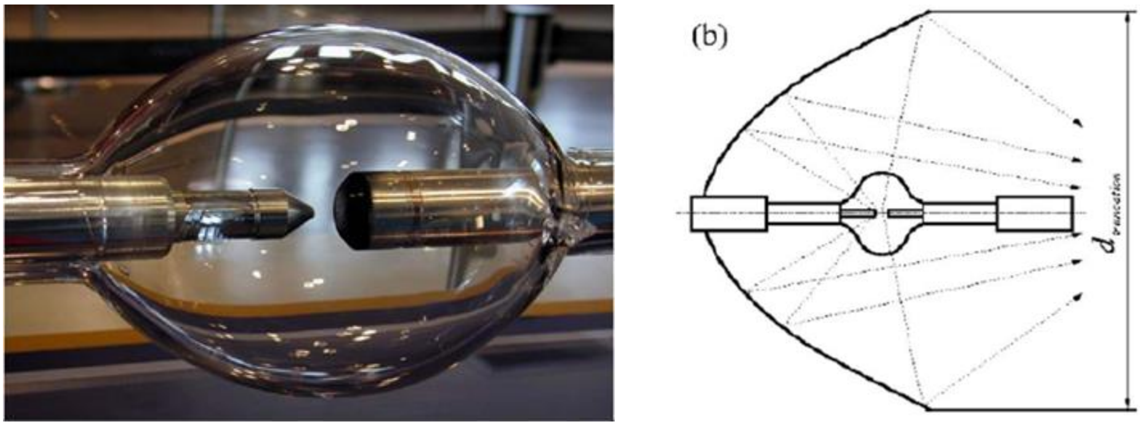


Figure 39. Xenon lamp used in the volumetric receiver test bench at CIEMAT in Moncloa.

The two possible configurations of this test bench are:

- Static configuration(Figure 40): In this configuration, the experimental loop allows the characterization of effective thermo-physical parameters of the bed; material thermal conductivity, thermal losses, stored energy, etc. for different filler materials,
- Dynamic configuration (Figure 41): In this configuration, the experimental loop allows an agile characterization of the global storage at different working temperatures, filler materials, charges and discharges strategies, etc.

2.1.2.5 Solar Hydrogen

Application of solar concentrating technologies to high-temperature processes is another field of enormous importance in PSA. The best known application so far is bulk electricity generation through thermodynamic cycles, but other applications have also been demonstrated, such as production of hydrogen and solar fuels.

Figure 40. Front view of the lab-scale regenerative storage system in static arrangement.

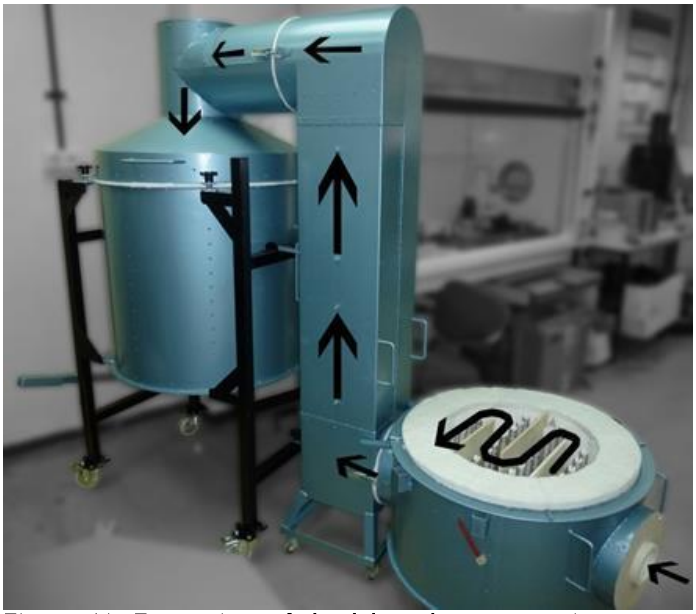


Figure 41. Front view of the lab-scale regenerative storage system in dynamic arrangement.

Some high temperature endothermic reactions for converting solar energy into chemical fuels are been investigated by CIEMAT-PSA through a range of indirect water-splitting techniques, as well as hybrid systems involving solar-driven fossil fuels transformation to hydrogen. A specific activity line for solar hydrogen exists at the laboratory of the Solar Concentrating Systems Unit to support at lab scale the PSA R+D activities related to solar hydrogen, which are performed in the outdoor test facilities. This lab activity line uses an indoor versatile solar characterization loop located at CIEMAT-Moncloa (Madrid), a view of which is shown in Figure 42.

Figure 42. Solar Simulation Loop for evaluation of hydrogen production processes.

The characterization loop installed at Madrid has the following capabilities:

- A set of lab equipment with the instrumentation necessary for evaluation of innovative processes for hydrogen production: A tubular furnace, a high-temperature kiln; and for analysis, a gas chromatograph (Varian CP4900) equipped with a molecular sievecolumn and a TCD detector etc.

- A Thermogravimetric Equipment STA 449 F1 for simultaneous TGA-DSC analysis. This equipment has two exchangeable furnaces: a SiC for high temperature reaction (1600°C) and water vapour kiln up to 1200°C.

2.1.2.6 Radiometry

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.

Figure 43. View of the PSA Radiometry laboratory.

Calibration of radiometers is performed in a specific furnace for this purpose. 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 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 and 1000ºC accurate to ±0.25% and with a resolution of 1ºC. 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 to 150ºC 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 44. IR sensor calibration using a black body.

2.1.2.7 *Materials and components for molten salt circuits*

Molten salts are becoming not only a standard thermal storage medium, but also a working fluid for central receiver solar plants. However, there are still open questions regarding the durability of components and materials currently available at the market for molten salt circuits. Keeping this in mind, a specific activity line was implemented in the laboratory of Concentrating Solar System Unit for this purpose. The equipment associated to this activity is installed indoor at PSA and it is composed of two test benches, BES-I and BES-II especially designed and manufactured for testing of valves, pressure transmitters and other molten salts components under real working conditions up to 600ºC and 40 bar. Components with a nominal diameter from 2” up to 6” can be evaluated in these test benches.

Figure 45. Test bench BES-I for evaluation of molten salt components.

2.1.2.8 Materials for Thermal Storage

The performance of phase change materials (PCM) for latent storage is usually evaluated with differential scanning calorimetry (DSC) or T-history techniques. Nevertheless it is important to check their behaviour under service conditions in order to assure their feasibility as storage media. For this purpose the Concentrating System Unit has three set ups: HDR and AgH, where the PCM is tested in atmospheric air, and SUBMA, where the PCM is tested in inert atmospheres.

The main features of these devices are the following:

HDR:

- Small furnace under ambient air atmosphere
- Accurate control of heating/cooling rates
- Sample temperature monitoring
- Allows melting/freezing cycles up to 500ºC
- Subsequent cycles or cycles with stand-by periods
- Sample size: 2-5 g

SUBMA:

- Small closed device inside a furnace
- Allows tests under inert atmosphere (N2, Ar)
- Furnace temperature and gas flow control
- Sample temperature monitoring
- Allows melting/freezing cycles up to 500ºC
- Subsequent cycles or cycles with stand-by periods
- Sample size: 30-40 g

Figure 46. The HDR device.

Figure 47. The SUBMA device.

AgH:

- Furnace under ambient air atmosphere
- Accurate control of heating and cooling
- Allows melting/freezing cycles up to 350ºC

- Subsequent cycles or cycles with stand-by periods
- Sample size: 10-20g

2.1.2.9 Geometrical characterization of solar concentrators

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.). The laboratory of the Concentrating Solar Systems Unit 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
- Etc.

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 20mm f/2.8 USM and CANON EF 24mm f/2.8 USM lenses.
- Photomodeler Scanner 2012 photogrammetry software.

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 under request.

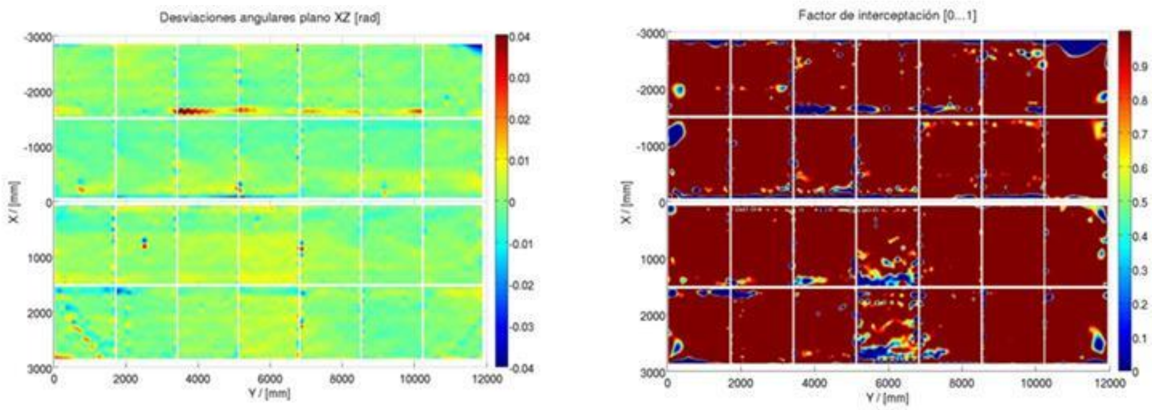


Figure 48. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry.

2.2 Experimental Installations for Solar Desalination of Water

2.2.1 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 CPC (compound parabolic concentrator) solar collectors
- A water 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 factor (number of kg of distillate produced per 2326 kJ of thermal energy consumed) over 9. The saline concentration of the distillate is around 5 ppm. The nominal temperature gradient between the first cell and the last one is 40°C with a maximum operating temperature of 70°C in the first cell. The system heat transfer fluid is water, which is heated as it flows through the solar collectors to the storage system. The hot water from this storage system provides the MED plant with the thermal energy required for its operation.

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 (More details about the solar field are supplied within its specific subsection).

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) produced 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.

Figure 49. The PSA SOL-14 MED Plant (left), double-effect $LiBr-H_2O$ absorption heat pump (upper right) and 500-m^2 CPC solar collector field (bottom right).

2.2.2 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 at 60-90°C temperature levels.

The collector selected was LBM 10HTF with an aperture area of 10.1 m^2, manufactured by Wagner & Co. The static solar field is composed of 60 collectors with a total aperture area of 606 m^2 and a total thermal power output of 323 kW_{th} under nominal conditions (efficiency of 59% for 900 W/m^2 global irradiance and 75°C as average collector temperature). It consists of 4 loops with 14 large-aperture flat plate collectors each (two rows connected in series per loop with 7 collectors in parallel per row), and one additional smaller loop with 4 collectors connected in parallel, all of them tilted 35° south orientation. Each row has its own filling/emptying system consisting in 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 permit to have an equal distributed flow rate without further regulation. Also, 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 water tanks connected to each other for a total storage capacity of 40 m^3. This volume allows the sufficient operational autonomy for the fossil backup system to reach nominal operating conditions in the desalination plant.

Figure 50. The 606-m^2 large-aperture flat plate solar collector field (AQUASOL-II).

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

2.2.3 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 are able to produce steam at different pressures, which allow recreating any of the typical intermediate extractions or the exhausted steam available at a turbine of a thermal power plant. The low pressure steam is obtained by making the steam from the generators to flow through two different pipe sections (12-inch diameter) equipped with control valves, which allows achieving saturated steam at two different levels: 0.074 bar/42 °C (nominal flow rate of 119 kg/h, maximum flow rate of 360 kg/h) and at 0.16 bar/58 °C (nominal flow rate of 195 kg/h, maximum flow rate of 360 kg/h). Both, the high and low pressure steam can be used as motive and entrained vapour, respectively, in a train of four steam ejectors coupled to the PSA MED plant, simulating the behaviour of a MED plant working with thermal vapour compression. The steam ejectors can work in a wide range of pressure conditions for the motive steam (40 - 6 bar; 4 - 2 bar), which also makes this test bed useful for the characterization of such kind of devices. The low pressure steam can also be condensed through two conventional air condensers without passing by the steam ejectors, with the aim of allowing research in CSP cooling topics. The flexibility of the test facility also allows the on-site evaluation of innovative dry coolers prototypes for their comparison with respect to the conventional air condensers currently available at the market.

Figure 51. View of the outside of the CSP+D test bed building with the air coolers (left) and partial view of the interior of the CSP+D test bench (right).

2.2.4 Facility for polygeneration applications

Polygeneration is an integral process for the purpose of producing two products from one or several 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, desalinating water for drinking water supply and the rest for heating sanitary water (ACS).

The purpose of this facility is preliminary study of the behaviour of a parabolic trough solar field of small concentration ratio, 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 an efficiency over 55% in the range of 120-220°C (for 1000 W/m^2 of direct normal irradiance).

The field is configured in 8 collectors placed in 4 parallel rows, with two collectors in series in 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.

Figure 52. NEP PolyTrough 1200 solar field.

Currently the solar field is going to be used to generate steam for supplying the double-effect absorption heat pump coupled to the PSA MED plant.

2.2.5 Test-bed for Solar Thermal Desalination applications at pilot-scale

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 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, and 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 one, and hot water can be supplied with temperature up to about 90°C.

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 open loop or closed loop. In the latter case, both the distillate and brine fluxes are collected and mixed together, to be fed again into the desalination units after a heat dissipation system. The installation currently with Membrane Distillation (MD) modules, and has a wide range of different commercial and pre-commercial units from all manufacturers. The list of MD modules that have been evaluated or are under evaluation is:

Figure 53. Internal (left) and external (right) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility.

- Plate and frame AGMD commercial modules from Scarab (total membrane area 2.8 m^2).
- Two plate and frame LGMD prototypes from Keppel Seghers (both with total membrane area 9 m^2), a compact one (M33) and another which is split in three separate modules connected in series for higher energy recovery (PT5).
- Spiral-wound LGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
- Two spiral-wound AGMD modules from Aquastill with membranes area of 7 m^2 and 24 m^2 each.
- WTS-40A and WTS-40B unit from Aquaver, based on multi-stage vacuum membrane distillation technology using modules fabricated by Memsys (5.76 m^2 and 6.4 m^2 total membrane area respectively).

2.2.6 Bench-scale Unit for testing vacuum membrane distillation

The installation consists of a test-bed with a small plate and frame module for evaluating vacuum membrane distillation. The module is designed so that the membrane can be replaced very easily, in order to test different membranes. An on-board feed vessel allows for the application of different types of feed. This feed is transported alongside of the membrane by a fluid pump that expels the remaining feed as brine. The feed can be heated to a set temperature by an electric heating element that is installed in the feed vessel. On the other side of the membrane an under-pressure is created by a vacuum pump. When hot feed passes on the front side of the membrane, vapour (or other substances in the gas phase) is sucked through the membrane to the other side. The vapour passes through a condenser then, and the resulted condensate is collected in a distillate tank. Before entering the tank, a sampler unit allows for collecting distillate samples for a quality check.

Figure 54. Laboratory unit for testing membranes on vacuum MD

2.2.7 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 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.

2.2.8 Bench-scale unit for tests with forward osmosis and pressure-retarded osmosis

The installation consists of a test-bed with a small plate and frame module 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.

2.2.9 Bench-Scale Unit for Flat Sheet Membrane Distillation Testing

The facility is a high precision laboratory grade research equipment designed for testing fundamental and feasibility test trials on membrane distillation. It possesses the following unique features that are essential for representative and upscalable 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 K.
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 55. Bench-scale unit for testing membranes on isobaric MD

Figure 56. Bench-scale unit for testing MD with flat-sheet membranes.

2.2.10 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 in parallel. 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 have each a total effective membrane area of 100 cm^2, and hydraulic channels in zig-zag 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.

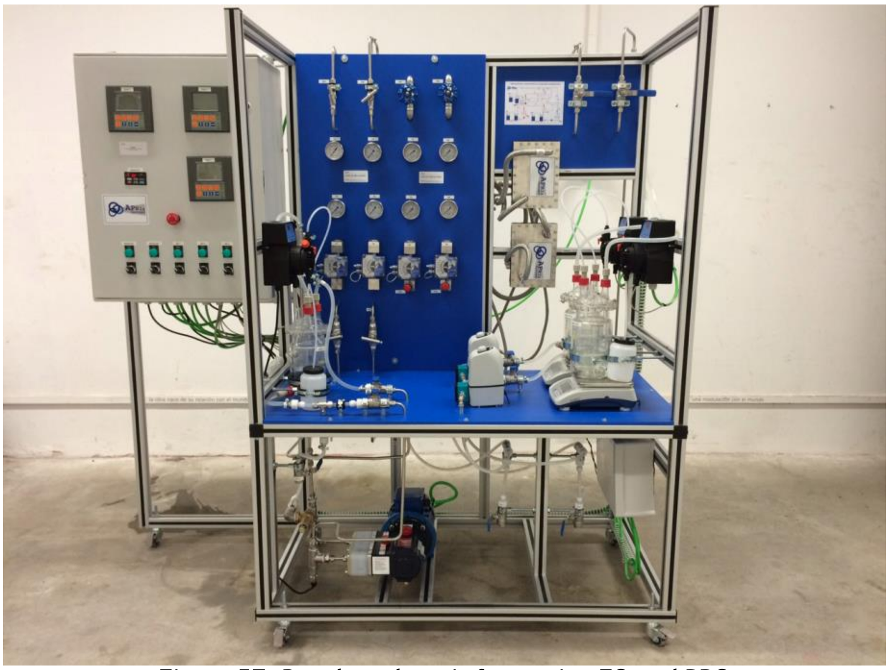


Figure 57. Bench-scale unit for testing FO and PRO

2.2.11 Pilot plant for studying combinations of forward osmosis and reverse osmosis

The plant has three different units that can be coupled in different ways between them: (i) a 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 4 vessels that can be connected in series or in parallel, each of which hosting 4 membranes. The nominal flow rate is 3 m^3/h, and the pumping system is able to 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 a microfiltration (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.

Figure 58. Test bed for FO-RO combination research

2.3 Experimental Installations for Solar Detoxification and Solar Disinfection of Water

The unit of Water Solar Treatment has different facilities and instrumentation related with the application of technologies for water purification (decontamination and disinfection). Since 2010, and as one of the activities co-funded by the Ministry of Science and Innovation under 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) and FEDER, the facilities have been updated and new scientific instrumentation and facilities have been acquired for solar water treatment unit activities (SolarNova Project).

2.3.1 Solar Treatment of Water Facilities

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

- Solar CPC (compound parabolic-trough collector) pilot plants.
- Solar simulators.
- Pilot plants for biological treatment.

- Ozonation pilot plant.
- Nanofiltration pilot plant.
- UVC-pilot plant.
- Test facility for photocatalytic production of hydrogen based on solar energy.
- Experimental culture camera.

Solar CPC pilot plants

A number of solar photo-reactors are currently installed at PSA facilities (Figure 59). 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 Parabollic Collector (CPC) shape to optimize solar photons collection in the photo-reactor tube. The modules are placed on a platform tilted at 37º from the horizontal to maximize the global solar collection of photons throughout the year. In addition, the pilot plants may be 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 summary of the already installed solar CPC reactors is shown in Table 1.

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

Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added system/Characteristic
1994	3	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	-Plexiglass screen
2008 (FIT)	4.5	60/45	Flow	50	-Monitoring (pH, T, O_2, flow rate) and control (T, flow rate). -Sedimentation tank
2010 (FIT-2)	4.5	60/45	Flow	50	-Monitoring (pH, T, O_2, flow rate) and control (T, O_2, flow rate). -Sedimentation tank
2011	2.1	25/14.24	Flow	32	-Couple with H_2 generation pilot plant
2011 (CPC25)	1	25/11.25	Flow	50	
2013	2	40/25	Flow	50	-Couple with electro-photo-Fenton plant
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

Figure 59. View of several CPC photo-reactors for purification of water. Top: Reactor facilities I. Bottom: Reactor facilities II.

As mentioned in table 1, CADOX photoreactor was hooked up to a 50L-ozonation system with an ozone production of up to 15 g O_3/h. It is completely monitored (pH, T, ORP, O_2, flow rate, H_2O_2, O_3) and controlled (pH, T, flow rate) by computer. Besides, there is a biological water treatment system connected to this photo-reactor, consisting of three tanks: a 165 L conical tank for wastewater conditioning before treatment, 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 to 90-95 L and can be colonized by active sludge from a MWWTP.

A 2m^2 CPC collector with 10 borosilicate glass tubes (50 mm diameter), an illuminated volume of 25 L and a total volume of 40 L (Figure 60) for experimental research on electro-photo-Fenton processes for decontamination and disinfection of water.

Figure 60. Electro-Fenton pilot plant coupled with a 2 m^2 CPC (ELECTROX).

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 61). 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 and automatically controlled by a UVA solar sensor. In addition, the pilot plant is equipped with a solar water heating panel which permits to increase the water temperature prior to discharging it in the photoreactors.

Figure 61. 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 detoxification and disinfection experiments. In both systems, the radiation intensity can be modified and monitored. One of the solar simulator XLS+ contains a UV filter (Suprax) with wavelength limitation to 290 nm simulating external daylight solar radiation. Temperature can be also modified in both systems by a cooling system (SUNCOOL) (Figure 62).

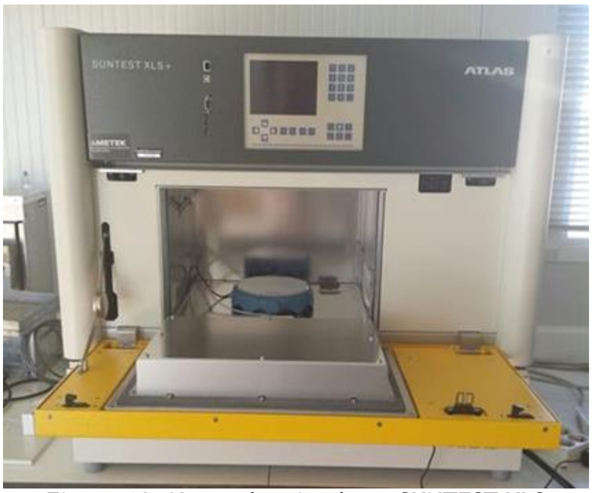


Figure 62. New solar simulator SUNTEST XLS

Ozonation pilot plant

The ozonation system has a contact column reactor with total volume of 20L (minimum operation volume of 8L), a reagents dosing system and pH automatic control. The pilot plant is equipped with pH and redox sensors, inserted in the recirculation line. In 2016, new instrumentation has been added to the ozonation pilot plant: (i) equipment for humidity elimination in the ozone gas outlet (Figure 63.a); (ii) Thermo-catalytic ozone destructor (Figure 63.b); (iii) dissolved ozone sensor (Figure 63.c). This ozonation system can work in batch and continuous mode allowing its combination with other technologies such as CPC photoreactors and the UV pilot plant.

a) b) c)

Figure 63. a) Equipment for humidity elimination in ozone gas outlet; b) Thermo-catalytic ozone destructor; c) Dissolved ozone sensor.

Nanofiltration pilot plant

The nanofiltration (NF) system has two working modes, in series and in parallel. The basic system consisted of two FILMTEC NF90-2540 membranes, connected in parallel, with a total surface area of 5.2 m^2. These polyamide thin-film composite membranes work at a maximum temperature of 45ºC, a maximum pressure of 41 bar and a maximum flow rate of 1.4 $m^3\ h^{-1}$, whereas operation pH range is 2-11. A third membrane was installed later and so the filtration total surface area was increased to 7.8 m^2. 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 64, left). In 2016 the nanofiltration system has been automatized by including electro-valves and automatic acquisition of the signals from the different instruments (flow, pressure, temperature, etc.) with the final aim of controlling by a computer (software Labview was employed, see Figure 64, right) the generation of permeate and concentrate flow rates.

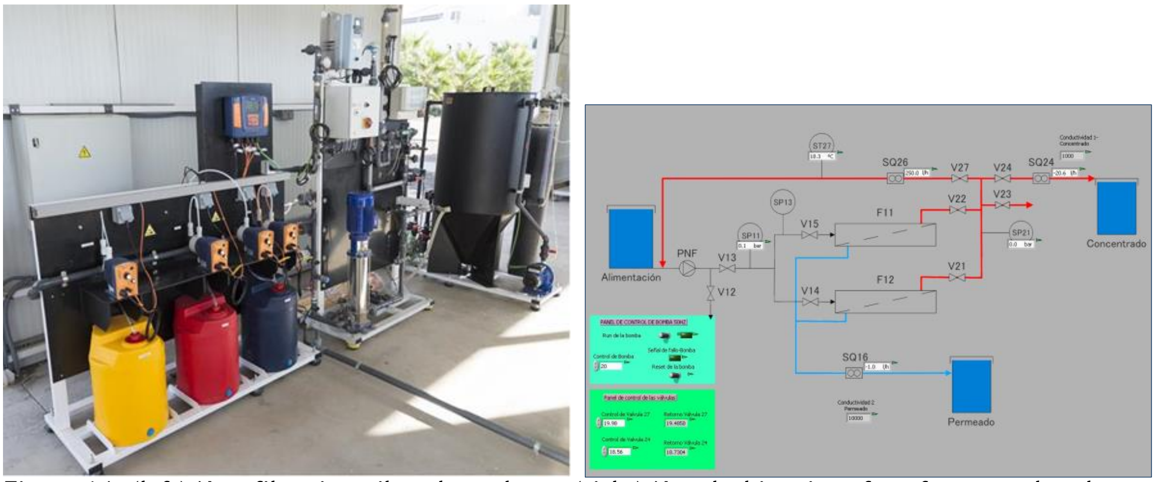


Figure 64. (left) Nanofiltration pilot plant photo. (right) New lavbiew interface for control and automatic operation of the pilot plant.

UVC-H_2O_2 pilot plant

Ultraviolet pilot plant was designed to treat and disinfect water for purposes and research and comparison with the solar technologies. This plant consists of three UV-C lamps (max. flow rate 25 m^3h^{-1}, 254 nm peak wavelength, 400 Jm^{-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 of this plant is 200-250 L, with illuminated volume of 5.5 L per lamp module. 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 65).


Figure 65. UVC pilot plant installed at PSA facilities.

Biological pilot plant

A biological pilot plant with a double depuration system (Figure 66, left) and Immobilised Biomass Reactor system with a total volume of 60-L: three IBRs of 20-L each one; and a Sequencing Batch Reactor system: two SBRs 20-L each one, is installed at PSA facilities. These modules use the same reception tank (200L) as well as the pH and oxygen dissolved 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 the three MULTIMETERS (M44 CRISON) is done by means of programmable relays and the main parameters are monitored by a SCADA system.

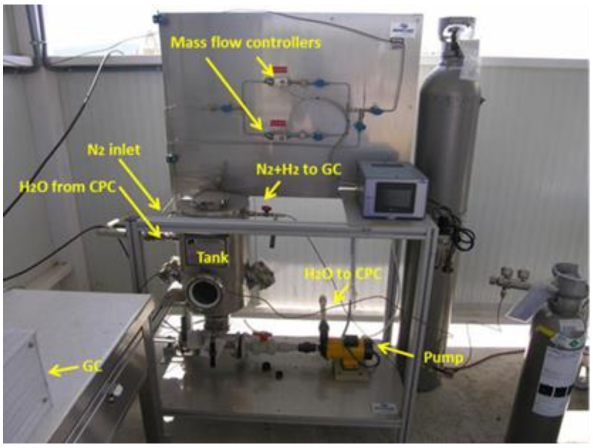


Figure 66. (left) Biological pilot plant installed at PSA facilities. (right) Solar pilot plant for photocatalytic generation of hydrogen.

Hydrogen pilot plant

This plant is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions. The pilot plant for photocatalytic generation of hydrogen consists on a stainless steel tank with a total volume of 22 L, 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 filling step. The CPC photo-reactor couple with this system was described above (Figure 66, right).

Wet Air Oxidation pilot plant

A pilot plant designed and installed in 2016 as a harsh pre-treatment to reduce the complexity of industrial effluents and reaction time of a subsequent solar AOP. 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 1000 mL, 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 mixture.

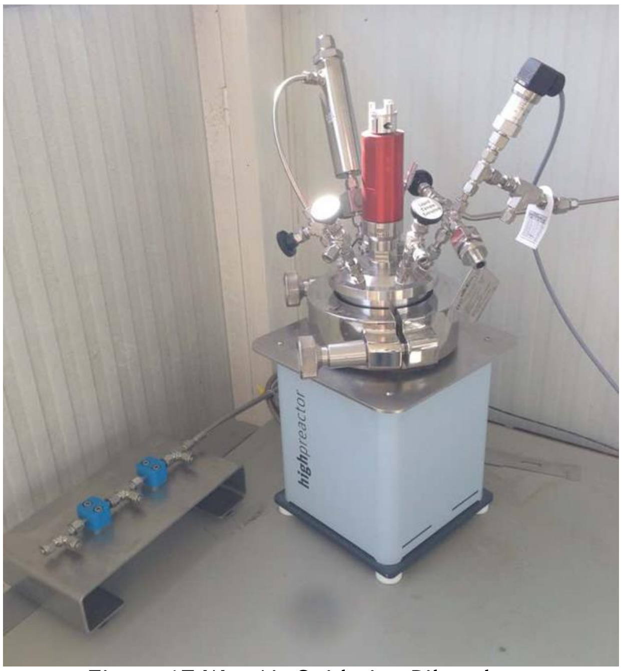


Figure 67.Wet Air Oxidation Pilot plant.

Solar UVA monitoring equipment

UV and global solar radiation data monitoring and storage system has different pyranometers (Figure 68), including global solar radiation in the range of 310 – 2800 nm (Kipp and Zonen CMP-6 with sensitivity 5 – 20 V W^{-1} m^{-2}, max. value: 2000 W m^{-2}), and the global UVA radiation in the range 300 – 400 nm (Kipp and Zonen CUV-5 with sensitivity 1 mV W^{-1} m^{-2}, max. value: 100 W m^{-2}). Besides this, a spectral photometer with double channel was installed to monitor the solar spectral irradiance at the location of the solar tests. This equipment (AVANTES) has UVA sensors and filters to measure in the whole spectral range of 200 – 1100 nm.

Figure 68. CUV-5 radiometer (left). View of all solar UV radiometers (inclined and horizontal setup) used in the Solar Water Treatment Unit (right).

Cultivation chamber

The culture crop chamber of 30 m^2 is used for treated wastewater re-use experience since 2014 (Figure 69). This controlled chamber is made of 10 mm-thick polycarbonate supported by white rolled steel (Sendzimir) to avoid ultraviolet radiation The shoulder height is 2.5 m with a roof slope of 40%. The camera consists of 4 individual areas of 3x2.5 m^2. 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. The measurement of sensors (temperature, humidity and solar radiation) and temperature control of each individual area (by the cooling and heating system, windows and top plastic cover) is made using the Ambitrol® software which permits to keep a comfortable temperature for crops (approximately 25ºC) during the different seasons.

Figure 69. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

2.3.2 PSA Water Technologies Laboratory

Under 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 then, acquisitions of new instrumentation have been done within the SolarNova Project.

The PSA water technologies laboratory consists of 200 m^2 floor area distributed in six rooms as listed below. Two of these rooms are dedicated to: i) chemicals and other consumables storage. It is a 30-m^2 storeroom with direct access from outside. It is organized on numbered and labeled 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 analyze the data from the experiments carried out at the PSA. The 4 technical rooms are listed and described below:

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

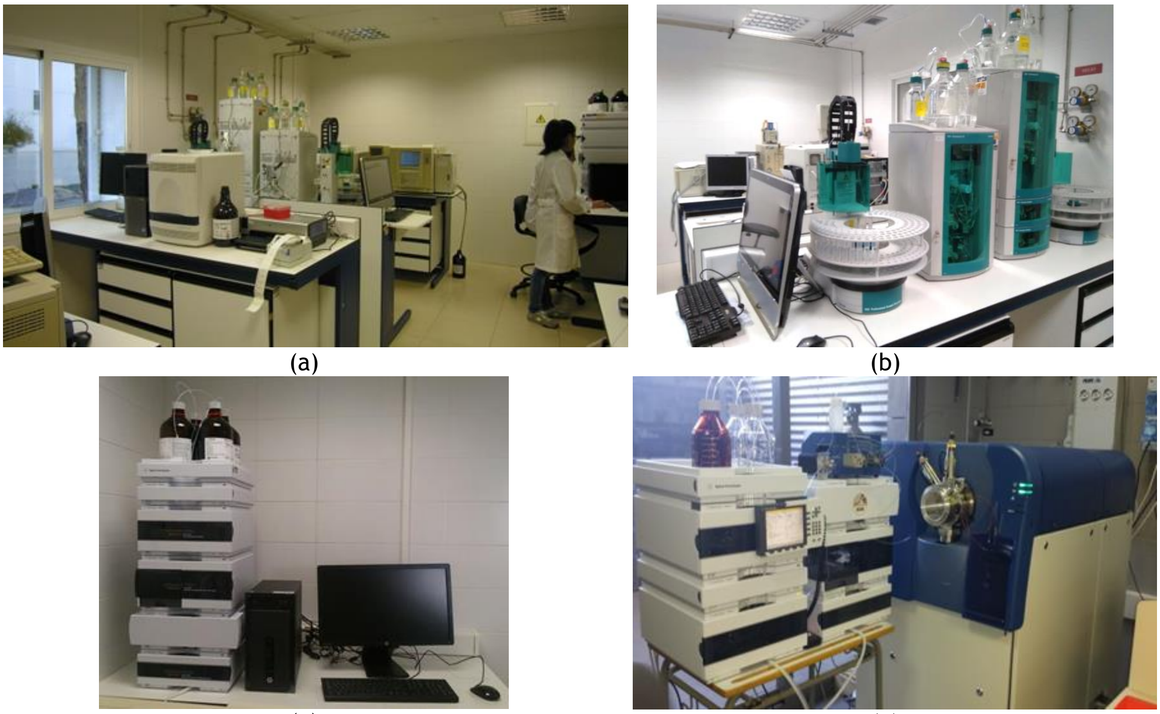
General laboratory

The main laboratory has a floor area of 94 m^2 (Figure 70). It is equipped with four large work benches, two gas extraction hoods, a heater, a kiln, a ultrasonic bath, three centrifuges, two UV/visible spectrometers, a vacuum distillation system, ultrapure water system, pH gauge 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 *Vibrio fischeri* and activated sludge respirometry toxicity measurement devices, biodegradability measurement by two respirometers for suspended activated sludge and for immobilized activated sludge as well as equipment for the analysis of BOD and COD. Automatic Solid Phase Extraction (ASPEC) permits working with low concentrations of pollutants. There is also a Jar-Test system for the optimization of separation of solids for water treatment.

Figure 70. General view of the new PSA Water Technologies Lab.

Chromatography laboratory

This lab (Figure 71(a)) is equipped with three high performance liquid chromatographs with diode array detector (HPLC-DAD and two UPLC-DAD) with quaternary pump and automatic injection; one gas chromatograph/mass spectrometer (GC/MS) with purge and trap system (analysis of volatile compounds dissolved in water), two ion chromatographs (Figure 71(b)): 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) analyzers by catalytic combustion at 670ºC and a total nitrogen (TN) analyzer with autosampler. 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 71(c)).



(a) (b)

(c) (c)

Figure 71. a) General view of the chromatography lab at PSA facilities; b) Metrohm Ion chromatograph System; c) Agilent Ultra-fast UPLC-DAD analyser; d) SCIEX TripleTOF 5600+ equipment.

Microbiology laboratory

A 47-m^2 microbiology laboratory with biosafety level 2 (Figure 72) is equipped with four microbiological laminar flow (class-II) cabinets, two autoclaves, three incubators and a fluorescence and phase contrast combination optical microscope with digital camera attachment. Besides, automatic grow media preparer and plaque filler and a filtration ramp with three positions are available. 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 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.

Figure 72. General view of the microbiology lab at PSA facilities.

Microscopy laboratory

The microscopy lab is a 11 m^2 room (Figure 73(a)). A Scanning Electron Microscope (SEM) is located in this room. For the preparation of microbiological samples and catalysts to be analyzed in the SEM, the system is completed with a metal coater and critical point dryer. In this room two optical microscopes are located also: i) A fluorescence and phase contrast combination optical microscope and ii) 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 in a heterogeneous population (Figure 73(b)). 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.

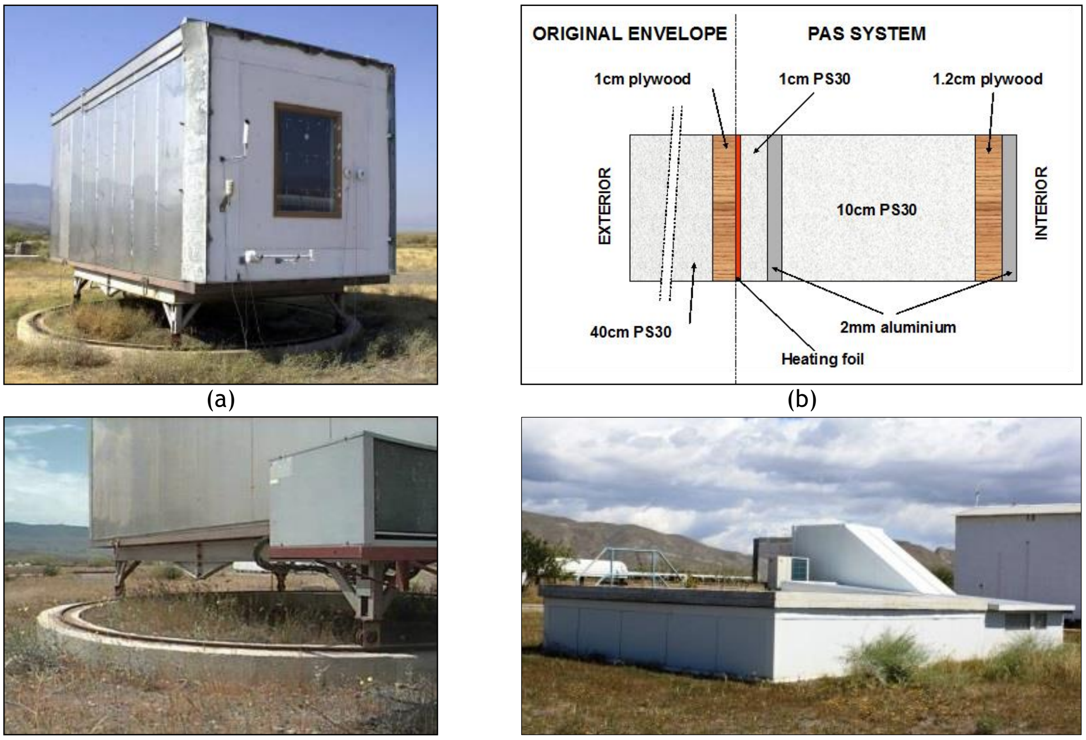
(a) (b)

Figure 73. a) SEM (Scanning Electron Microscope). b) Optical microscope for FISH technique

2.4 Experimental Installations for the Evaluation of the Energy Efficiency in Building

The Building Component Energy Test Laboratory (LECE), one of the facilities at the "Plataforma Solar de Almeria" (PSA), is part of 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: 1.- Energy Analysis in Urban Environments, and 2.- 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 in the test room consists of an aluminium sheet which makes it uniform 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 allowing easy access to the test component is used for this.
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) Monozone building: This is a small 31.83 m^2 by 3.65 m high simple monozone building built in an area free of other buildings or obstacles around it that could shade it except for a twin building located 2 m from its east wall. Its simplicity facilitates detailed, exhaustive monitoring and setting specific air conditioning sequences that simplify its analysis for in-depth development and improving energy evaluation methodologies for experimental buildings.



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

Figure 74. (a) CIEMAT's PASLINK test cell, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

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 1000 m2 built area. One of them is also 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, conventional auxiliary systems to supply the very low demand that cannot be supplied with solar energy, using renewable energy resources, such as biomass insofar as possible.

(a) (b) (c)

Figure 75. (a) Solar Chimney, (b) Reference monozone building, (c) ARFRISOL Building Prototype in use.

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

3. Solar Concentrating Systems Unit

3.1 Introduction

Activities performed by the Solar Concentrating Systems Unit (USCS) are aimed at promoting and developing solar thermal concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes. This PSA Unit is composed of four R&D Groups:

- Medium Concentration Group,
- High Concentration Group,
- Solar Fuels/Solarization of Industrial Processes Group, and
- Thermal Storage Group

In 2016 the R+D activities of USCS Unit have been devoted to projects started before 2016 (STAGE-STE, EU-SOLARIS, SFERA-II, CAPTURE, DETECSOL, ALCCONES, PRESOL, SITEF, REELCOOP, DNICast) and also to new projects launched in 2016 (WASCOP and RAISELIFE). This R+D activities have been complemented with services rendered to clients requesting our technical&scientific support, for characterization of new components mainly.

We have also continued with our dissemination activities in conferences, workshops and seminars to explain the benefits and technical features of concentrating solar thermal systems. In 2016 we have reinforced our activities in Latin-America, participating in three seminars (in Argentina, Guatemala and Mexico) and two training courses (in Chile and Mexico) devoted to concentrating solar thermal systems and their applications. We have also continued with our deep involvement in the standardization activities developed within the umbrella of the committees IEC/TC-117 and AEN/CTN-206.

We have also participated very actively in international working groups defining the special actions for the SET Implementation Plan concerning solar thermal electricity (STE). The STE sector is at a critical stage because a significant cost reduction is urgently needed to continue with the commercial deployment required to develop the expected learning curve, and PSA is contributing to this effort as much as possible. However, we believe it is time to pay attention to process heat applications, a very important market niche for CST systems that is still at a very early stage of development.

Activities and results achieved in 2016 by the four R&D Groups of the PSA USCS Unit are summarized in the sections below, starting with those projects where several Groups are simultaneously participating."

3.2 Projects

Concentrating Solar Thermal Energy for Iberoamérica, ESTCI

Participants: CIEMAT (Spain), CENIDET (Mexico), DICTUC (Chile), EPM (Colombia), Grupo Ibereólica (Spain), PUCC (Chile), SOLINOVA (Brazil), UAEMex (Mexico), UFPE (brazil), UNAM (Mexico), UNINORTE (Colombia), UNLP (Argentina)

Contacts: Eduardo Zarza (Technical coordinator), eduardo.zarza@psa.es

Funding agency: Programa CYTED. Red Temática Ref.714RT0487.

Background: There are many Latin American Countries with good solar resources that could be used to supply a significant fraction of their energy needs. Since Spain has a great experience and know-how about concentrating solar systems and their applications, collaboration between Spain and these countries would be very interesting and of mutual benefit.

Objectives: The dissemination in Latin American countries of the experience and know-how gained by PSA about concentrating solar systems and their applications. The strengthening of scientific collaboration between PSA and R&D groups from these countries, together with the preparation of future joint projects, are also included in the objectives.

Achievements in 2016: ESTCI is a thematic network coordinated by PSA and supported by the Ibero-American Program CYTED (www.cyted.org). It was launched in January 2014 with a planned duration of 4 years. Additionally to the maintenance of the official web page of ESTCI (www.redcytedestci.org), two major activities have been developed in 2016:

- The survey of the solar radiation data currently available in Argentina Brazil, Chile, Colombia and Mexico, as well as the legal framework existing in these countries regarding solar concentrating systems installation and use was finished and the results were published in the document *"Informes finales de las Tareas 1 y 2"*, which is available in the web site of ESTCI;

- Important dissemination activities were developed abroad by PSA researchers to explain the basic principles, different technologies, applications and commercial potential of concentrating solar thermal systems. These researchers participated in a 2-day training course in Cuernavaca (México), one-day Seminar with the title *"Sistemas Solares Térmicos de Concentración"* at the Universidad Nacional Autónoma de México (Mexico city) on December 2nd 2016, and two one-day Seminars also devoted to these solar systems were organized in Argentina (ciudad de La Plata) and Guatemala (ciudad de Guatemala) in November 2016, to explain to local authorities, industries and researchers the basic principles and benefits of concentrating solar thermal systems.

Figure 76. ESTCI Project partners in the yearly meeting held at Mexico in November 2016.

Standardization Activities at Spanish and International Level. Technical Committees IEC/TC117 and AEN/CT206

Participants: From Spain: ABENER, ABENGOA, ACS-COBRA, AENOR, ALATEC, AICIA, ARIES, ASTROM, CENER, CIEMAT, CSP Services, CTAER, ELECNOR, Garrigues, GTAER, Iberdrola Ingeniería, PROTERMOSOLAR, SAMCA, Schott Solar, SENER, TECNALIA, TEKNIKER; From Germany: DLR, NOVATEC Solar, SUNTRACE, Fraunhofer; from France: CEA and SolarEUROMED; From Italy: ENEA and Archimede Solar; From other countries: IEECAS (China), LNEG (Portugal), Solar Design Co. (United Kingdom), EVORA University (Portugal)

Contacts: Eduardo Zarza, eduardo.zarza@psa.es

Funding agency: CIEMAT and European Commission, FP7 ENERGY-2013-IRP.

Background: Since Solar Thermal Electricity (STE) plants are a relatively young technology, the STE 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 committee AEN/CTN-206 within the Spanish AENOR is the development of standards for the STE sector by putting together the experience of R&D centres, Industries, Engineering companies, components manufacturers and promoters.

Achievements in 2016: PSA has participated very actively in the international and national standardization committees IEC/TC-117 and AEN/CTN-206 coordinating several working groups and participating in all the groups. As Coordinator of the working Groups WG1 and WG3 of the subcommittee AEN/CTN206 PSA has contributed in 2016 to the development of two new standards within these two working groups:

- "Verificación del rendimiento de campos solares con captadores cilindroparabólicos (*Tests for the verification of the performance of solar fields with parabolic trough collectors)*". This new standard was finished in 2016 and it is expected to be issued by AENOR in 2017

- The new standard UNE-206012 "*Caracterización del Sistema de almacenamiento térmico para aplicaciones de concentración solar con captadores cilindroparabólicos* (Characterization of the thermal energy storage system for applications with parabolic-trough collectors)" was finished in 2016 and it will be issued by AENOR in 2017.

PSA has also contributed in 2016 within the WG2 of AEN/CTN-206 to the development of several standards related to qualification of components (e.g., parabolic trough collectors, receiver tubes for parabolic trough collectors, solar reflectors and working fluids), for concentrating solar thermal systems. Several of these new standards will be issued in 2017. PSA has also contributed to the revision of the Standard ISO-9806 (2016).

Within the framework of IEC/TC-117, PSA has coordinated in 2016 the Team PT62862-1-1, which is devoted to the development of a new IEC standard on "Terminology" for concentrating solar thermal systems. More than 100 comments made by the members of this Team to the draft standard initially proposed have been discussed and clarified in 2016. It is expected that this standard will be finished in Spring 2017 and issued by IEC in Summer 2017. The original version proposed to IEC/TC-117 for this new standard has been significantly improved during its discussion at international level.

New developments for a more efficient solar thermal technology, DETECSOL

Participants: CIEMAT

Contacts: Eduardo Zarza, eduardo.zarza@psa.es

Funding agency: MINECO –Retos Investigación 2014: Proyectos I+D+i (Ref. ENE2014-56079-R)

Background: Commercial deployment of concentrating solar thermal (CST) technologies has grown significantly. The installed capacity of STE (Solar Thermal Electricity) plants in the World was 354 MWe in 2016, while it is currently of about 5 GWe (2.3 GWe in Spain). However, optimization of existing technology and innovative solutions are needed to reduce the installation and operational and maintenance (O&M) costs.

Objectives: The project DETECSOL aims to advance in the development of new components and solutions to improve the efficiency of CST technologies, with the following objectives:

- Study the use of alternative heat transfer fluids (HTFs) in solar receivers
- Improve the performance of solar receivers suitable for their use with new HTFs
- Improve the performance of solar reflectors used as primary or secondary concentrators

- New methodologies and solutions in the short-, medium- and long-term development of solar thermal energy storage systems.

Achievements in 2016: Thanks to the conversion efficiency achieved, the CO_2 was identified as suitable heat transfer fluid in line-focus solar collectors. Supercritical CO_2 has been considered in a preliminary study of a tubular solar receiver for tower systems too. A selective coating stable in air up to 700°C is under development. The degradation of the coating is slow with temperature over 500°C due to the diffusion of the infrared reflector layer in the stainless steel substrate. To minimize this effect, the use of a double layer of platinum is under study.

Durability analysis of solar reflectors in corrosive atmospheres, such as industrial areas, has continued in 2016. Three reflector materials were subjected to accelerated aging tests which combined a number of environmental parameters, such as temperature, relative humidity, time, and controlled concentrations of the most prevalent air pollutants (H_2S and SO_2). Standardized norms were selected as an initial reference. As a validation of the selected accelerated parameters, samples were also exposed at four targeted outdoor sites

Regarding thermal storage systems a commercial valve for molten salt systems was tested. This valve had a new packaging because the original one was previously tested failed because of some leakages. Concerning new thermal storing materials for latent heat, the thermal stability of 10-BPhCOOH has been studied. Unfortunately, the results show that it suffered a strong degradation under cycling.

Concerning volumetric receiver technology, the numerical determination of the convective heat transfer coefficient between an air flow and stagger stacked plain-weave wire mesh screens is vital for a proper numerical simulation of this type of receiver. For this purpose the commercial code STAR-CCM+8.04.010® has been used as Computational Fluid Dynamic tool over different 3-D detailed geometries to get a further knowledge of this parameter. After the numerical analysis, the heat transfer correlations were obtained and verified in a homogeneous equivalent model.

Figure 77 depicts the qualitative velocity field for the stagger stacked plain-weave wire mesh screens for two different meshes: mesh type A (70.1 % volumetric porosity) and mesh type F (46.9 % volumetric porosity). For the two geometries, the fluid velocity in the non-equilibrium zone increases as the volumetric porosity increases for the same numerical conditions.

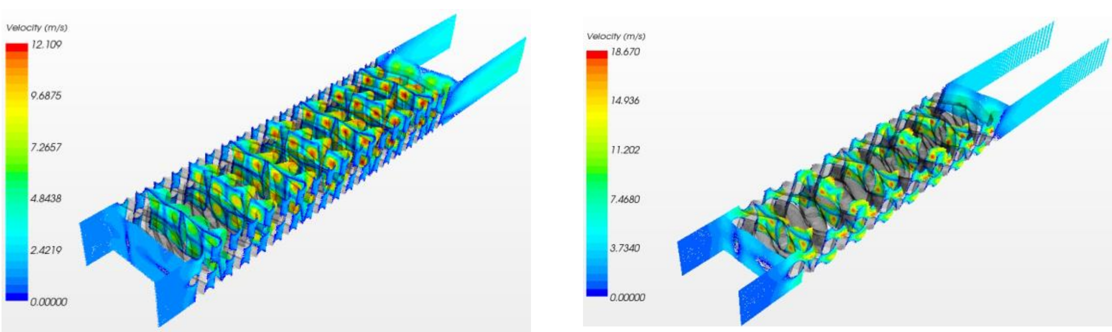


Figure 77. Velocity vector for two different stagger stacked plain-weave wire mesh screens for a wall temperature of 1100 K and a 1 m/s superficial velocity. (left) Mesh A; (right) Mesh F.

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

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

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

Funding agency: European Commission, 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 2016: During the first 9 months, the activities related to the durability analysis of primary reflector coatings (front anti-soiling coatings and back-side paints) were initiated, in close cooperation with DLR. In particular, 9 types of reflectors were received at the PSA from the manufacturer (Flabeg) and the initial optical characterization for the outdoor exposure was started. Some of them were already installed at 3 testing sites located in Morocco (see Figure 78). Another activity already accomplished was the design, manufacturing and installation of an outdoor test bench to study the influence of the heliostat blocking on the durability of the back side of the reflectors.

Concerning the activities about the durability of high-temperature mirrors for secondary concentrators, the first type of reflectors was sent by the developer (Fraunhofer) to the PSA and the optical characterization was initiated. Additionally, the design of the solar test bench for the test at the PSA solar furnace was started. Regarding materials improvement for non-evacuated HCE, new infrared reflector layers are being tested to reduce thermal emittance of selective absorbers and mechanical properties of the AR coating has been increased.

In addition, CIEMAT-PSA is leading the work package dedicated to the dissemination and exploitation of results. In this first period, the project web site (including the repository) was created and launched, and the project leaflet and poster was prepared and distributed among partners.

Figure 78. Test bench exposed outdoor in Morocco.

3.3 Medium Concentration Group.

3.3.1 Introduction

The Medium Concentration group has conducted activities in the field of development, testing, and evaluation of components for line-focus solar collectors (OCT, OPAC, DETECSOL and STAGE-STE WP8 projects), testing of a new silicone fluid for parabolic troughs (SITEF project), modeling and simulation of power plants with parabolic-troughs using different heat transfer fluids (DETECSOL and STAGE-STE WP11 projects), integration of nowcasting methods with simulation models (DNICast project).

(a)

(b)

Figure 79. Medium Concentration Group staff working a) at the Plataforma Solar de Almeria in Tabernas (Almeria) and b) at the CIEMAT Headquarters in Madrid.

Two new H2020 projects started during the year, i.e. the WASCOP and RAISELIFE projects (see Section 6), where the participation of the group is decisive and even we coordinate the participation of CIEMAT in both project consortia. Besides, the collaboration with the industry continues in the context of collaboration agreements or technical services.

3.3.2 Projects

Research and development of selective absorber for low and medium temperature

Participants: CIEMAT-PSA, Seenso Renoval S.L. España.

Contacts: Ángel Morales, angel.morales@ciemat.es

Funding agency: CIEMAT and Spanish private companies.

Background: The improvement of selective coatings for solar absorbers promote the concentrating solar thermal technologies as the efficiency of the systems can be increased and moreover for a long time.

Objectives: Development of air stable selective absorbers for low and medium temperature applications.

Achievements in 2016: Selective absorber stable in air at 350°C, developed for flat and parabolic trough collectors for industrial applications, has been improved resulting in the following optical properties: absorptance = 0,956 and emittance@100°C = 0,037. Preliminary tests show a good thermal stability at 350°C and excellent weathering resistance (Figure 80).

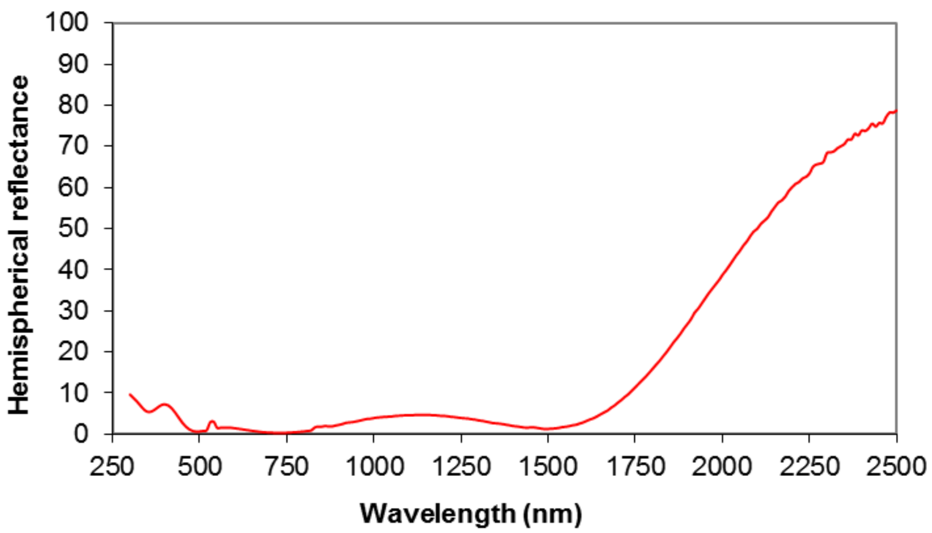


Figure 80. Hemispherical reflectance in solar spectra range of a new selective absorber stable in air at 350°C.

Optical Characterization and Durability Analysis of Solar Reflectors, OPAC

Participants: CIEMAT-PSA and DLR

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Florian Sutter, florian.sutter@dlr.de

Funding agencies: Rioglass Solar S.A.; Flabeg FE GmbH; Taiwan Glass Group.

Background: One of the key aspects to assure the feasibility of solar concentrating technologies is to achieve suitable solar reflector materials. Proper accelerated ageing tests are needed to predict the durability of solar reflectors under outdoor conditions. Guarantees required for highly efficient components can only be issued after the sucessful application of appropriate standardized testing methods.

Objectives: This collaborative project between CIEMAT-PSA and DLR is devoted to establish appropriate optical qualification and durability test methods of solar reflectors. The degradation processes of solar reflectors are investigated under accelerated aging conditions and in several outdoor exposure sites with the goal of establishing lifetime prediction models.

Achievements in 2016: One of the OPAC priority research lines is to study the effect of sand erosion on the durability of solar reflectors. During 2016, two outdoor sites in Morocco were analyzed in matters of their erosion characteristics. Wind velocities and direction, as well as the aeolian particle size distribution, were evaluated and a novel parameter, the single particle momentum density (SPMD) was derived. This variable was applied to both outdoor sites and two accelerated erosion simulation setups, a sand trickling device and a closed loop wind channel. Additionally, a new open-circuit testing chamber was developed to simulate sand storms (see Figure 81).

Figure 81. Open-circuit testing chamber for the study of sand erosion.

In this device, sand is projected against the sample only once, so its degradation due to the interaction with the chamber pipes is minimized. Furthermore it facilitates the application of various different natural and artificial test dusts. This is a clear advatage over the closed loop erosion setup where a change of the erodent material would have only been possible after excesive cleaning and recalibration of the setup.

Technical support and services were offered to industry, through specific agreements with several companies to evaluate the optical quality and the durability of their products under several accelerated aging conditions in order to assess and improve their performance. Finally, OPAC group has actively participated in standardization activities (SolarPACES and AENOR), both in reflectance measurements and durability testing of solar reflectors.

Direct Normal Irradiance Nowcasting Methods for Optimized Operation of Concentrating Solar Technologies, DNIcast

Participants: OME, CENER, UniPatras, METEOTEST, ARMINES, RIUUK, SMHI, DLR, TROPOS, CIEMAT, MeteoSwiss, CyI

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

Funding agencies: European Commission, FP7-ENERGY-2013.2.9.2.

Background: The efficient operation of concentrating solar technologies (CSTs) requires reliable forecasts of the incident irradiance for two main reasons: (i) for better management of the thermodynamic cycle, as it becomes possible to dynamically fine tune some of its parameters (flow rate of HTF or the defocusing mirrors), (ii) because electricity production can be optimally connected to the grid.

Objectives: The main objective is to establish a portfolio of innovative methods for the nowcast of DNI and to combine these methods, validate the nowcasts and assess the influence of improvement in DNI nowcasting on nowcasting of concentrating solar power (CSP) and concentrating photovoltaic (CPV) power plants output.

Achievements in 2016: Since the solar plant outputs are in relation with the incoming solar energy, the nowcasted DNI will be combined with plant performance models to allow the nowcasting of the plant output. The first step was the definition of three CSP reference plants and four CPV plants (technology, dimentions, etc.) to utilize concentrated sunlight for electricity production. These desigs was the start point for the development of simulation models which allows the final study of the impact of DNI nowcasting on annual electricity yield. The work of PSA-CIEMAT in this project, in 2016, has been the development of a 35 MWe parabolic trough simulation plant with Eurotrough-100 parabolic trough collectors, using water as heat transfer fluid and without thermal energy storage system. As there is not a thermal storage system, the optimization of the CSP production depends on the solar irradiation. Therefore, the operation strategy has to be focused on the solar field control that is more sensitive to differences in solar radiation along the field area. The simulation model of the solar field has as meteorological imput a value of ambient temperature and values of

DNI distributed spatially along the field area. This allows us to develop new control strategies and to know the effect on the electricity production of different irradiation values in the solar field, in cloudy days.

Silicone Fluid Test Facility, SITEF

Participants: DLR (coordinator), CIEMAT, Wacker Chemie AG, TSK Flagsol Engineering GmbH, Senior Flexonics GmbH, TÜV NORD SysTec GmbH & Co. KG.

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es
Anne Schlierbach, Anne.Schlierbach@dlr.de

Funding agency: Solar-ERA.NET Transnational Call CSP 2 2014; MINECO – Retos 2014 Acciones de programación Conjunta Internacional (Ref. PCIN-2014-083) and the German Federal Ministry of Economy and Energy and German Federal Ministry of Innovations, Science and Research.

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 SITEF (Silicone fluid Test Facility) project aims to demonstrate the loop scale functionality and applicability of a new Wacker Chemie AG silicone heat transfer fluid named HELISOL®5A and associated parabolic-trough solar collector (PTC) components 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 efficien.cy. This innovate project is based on a German-Spanish cooperation making use of the so called PROMETEO test facility located at Plataforma solar de Almeria (PSA).

Achievements in 2016: During this year the PROMETEO pilot plant has been operated with the new SHTF manufactured and supplied by Wacker Chemie AG in the solar collectors. More than 150 hours of operation at 400°C were accumulated (Figure 82). In parallel, DLR, TSK Flagsol, and CIEMAT, with the support of other partners in the consortium, continued with the engineering work in order to perform a technical upgrade of the pilot plant to be operated at least with fluid temperatures up to 450°C, which mainly implies new receiver tubes and a new system to cool down the heat transfer fluid coming from the outlet of the solar field. The refurbishment and commissioning of the facility considering the new changes will be completed during first months of 2017 as the continuous operation of the solar collector field at fluid temperature above 400°C.

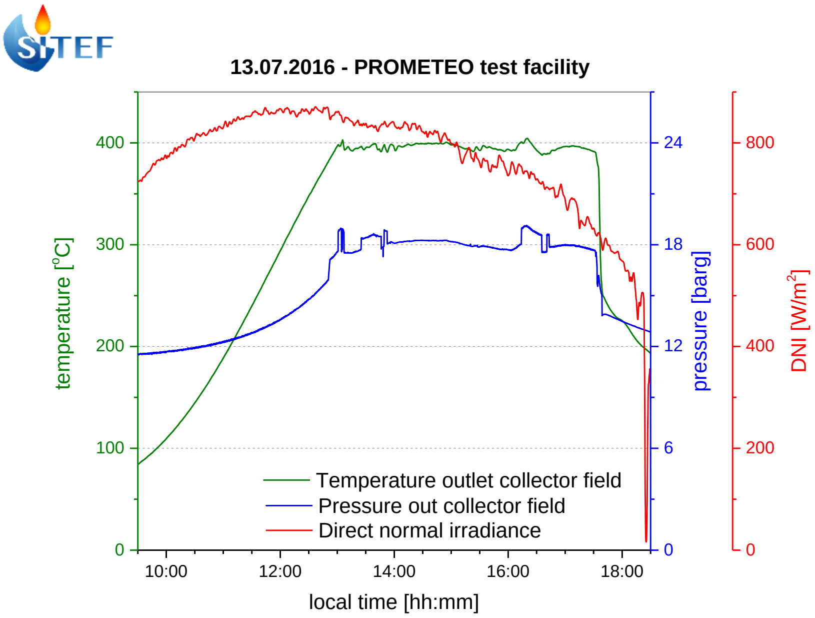

Figure 82. SITEF project: Experimental data during early operation of PROMETEO test facility with Helisol®5A.

3.4 High Concentration Group.

3.4.1 Introduction

In 2016, we continued our activities in the projects that started the previous year, focusing in particular on the development of volumetric absorber technology (CAPTURE, DETECSOL and ALCCONES Projects), research into new fluids that improve the efficiency of high Solar concentration (DETECSOL, ALCCONES), and the implication that the atmospheric characteristics have in the central tower systems (PRESOL).

Last, but not less, the activity of heliostats testing continue with a high implication of group staff: several heliostats prototypes has been tested during 2016 in our facilities, thus supporting companies in the product development, as well as we have improved our testing protocols adding new equipment for a deeper evaluation of the different prototypes.

Figure 83. High Concentration Group staff working at the Plataforma Solar de Almeria (left) and CIEMAT-Madrid (right).

3.4.2 Projects

Competitive Solar Power Towers, CAPTURE

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

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

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. Being a strategic technology field of the High Concentration Group, CIEMAT has worked on this technology since 1990 having tested more than 15 different volumetric receiver prototypes in the last 20 years.

Objectives: The aim 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 (Figure 84). This configuration not only increases cycle efficiencies but also avoids frequent transients and inefficient partial loads thus maximizing overall efficiency and reliability as well as dispatchability; all of which are important factors directly related to cost competitiveness on the power market.

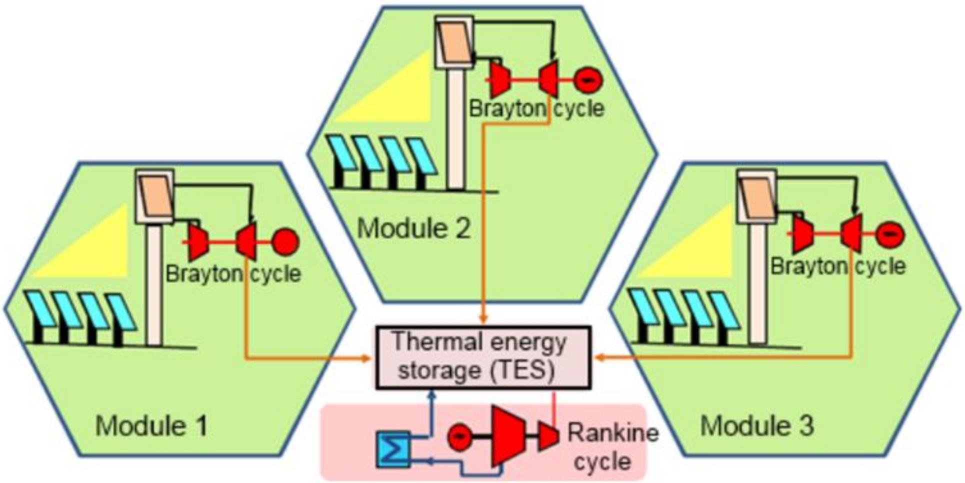

Figure 84. Decoupled Solar Combined Cycle (DSCC).

Achievements in 2016: The CIEMAT activity during 2016 in CAPTURE Project has been related with the testing and evaluation of foam samples developed by FRAUNHOFER-IKTS porous material laboratory. Testing has been carried out at the solar simulator of CIEMAT. In addition, a test bed for single cup testing at the PSA solar dishes has been set up.

In particular, a complete set of foams with different geometries and porosity, including gradual porosity, have been tested for behaviour comparison at the 4kW CIEMAT solar simulator (see Figure 85). With the conclusions of these preliminary tests, a set of final size foams has been prepared for testing at the PSA during 2017.

Forecast of Solar Radiation at the Receiver of a Solar Power Tower, PRESOL

Participants: CIEMAT-PSA, University of Almeria, University of Huelva.

Contacts: Jesús Ballestrín, jesus.ballestrin@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nacional I+D+i (2013). Subprograma de Proyectos de Investigación Fundamental, ENE2014-59454-C3-3-R.

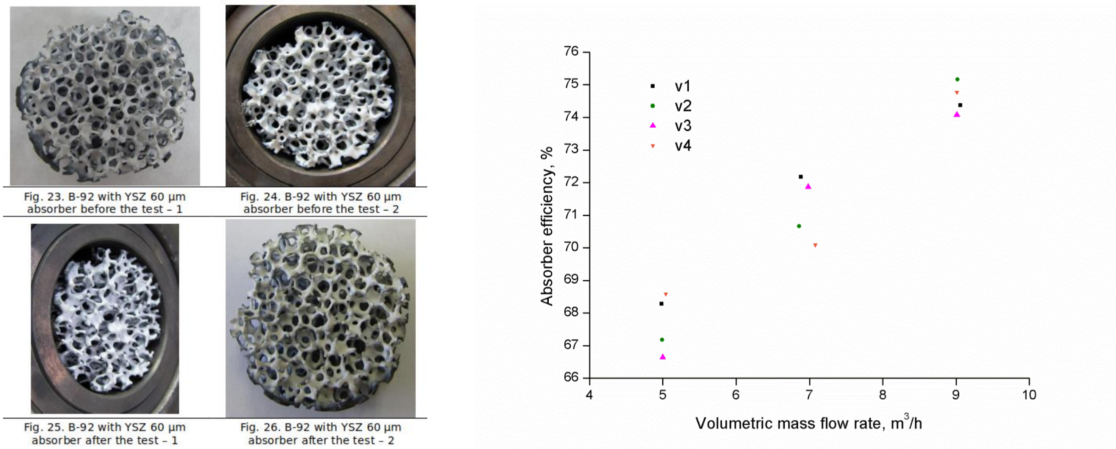

Figure 85. Foam samples tested on the solar simulator and thermal performance results of the different absorbers.

Background: Power generation from Solar Power Towers (SPTs) where DNI is a critical input is experiencing a rapid growth worldwide. The greatest challenge posed by these large solar installations is the grid integration. To this end, it is crucial to have an accurate forecast of the DNI levels reaching the receiver, which affects not only the plant operation but the energy price in the market.

Objectives: The project goal is to produce a short-term forecast of the DNI reaching the SPT receiver. To this end, we propose to forecast the DNI arriving to the heliostat field and develop techniques to determine and forecast the reflected solar radiation attenuation on its path to the receiver.

Achievements in 2016: Atmospheric extinction of solar radiation reflected by heliostats to receiver is recognized as an important cause of energy loss in the increasingly large solar tower power plants. During the design of these plants, extinction maps similar to those of direct normal irradiance would be desirable. Unfortunately, the reality is that, currently, there is no reliable measurement method for this parameter, so these plants are designed, built and operated without knowing this local parameter.

Nowadays digital cameras are used in many scientific applications for their ability to convert available light into digital images. Its broad spectral range, high resolution and low signal-to-noise ratio, make them an interesting device in solar technology. A method for atmospheric extinction measurement based on digital images has been presented. The possibility of defining a measurement setup in circumstances similar to those of a tower plant increases the credibility of the method. This procedure is currently being implemented at PSA (Figure 86).

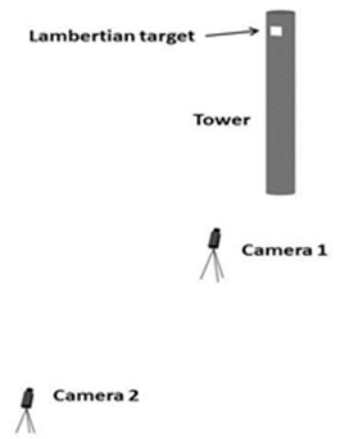

Figure 86. Digital cameras take images of the target

Storage and Conversion of Concentrating Solar Power, ALCCONES

Participants: IMDEA Energía-UPAT (Coordinator), CIEMAT-CSSU, URJC-GIQASOL, CSIC-IPCPA, SENER, AH, EA.

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Antonio Ávila, antonio.avila@ciemat.es

Funding agency: Comunidad de Madrid, S2013/MAE-12985.

Background: During the last years, concentrating solar power has been the renewable energy with the highest year-on-year growth rate. Nevertheless, the technology used up to now reaches a 18-20% performance in the solar radiation to electricity conversion and the investment cost of solar thermal electricity plants is still high. Therefore, it is required to improve the efficiency of the thermal conversion processes and turn solar energy into a dispatchable one by the integration of thermal storage systems.

Objectives: CIEMAT-PSA is focused on the preliminary study of innovative thermal fluids to increase both the thermal efficiency of the receiver and the temperature of the heat transfer fluid. Moreover, the volumetric receiver technology made of metallic plain-weave wire meshes screens are a promising option that allow different designs and configurations to prove the “gradual porosity absorber” concept. This concept addresses the main thermal problems of the technology which is the absorption of the radiation in the depth of the structure, by reducing the frontal surface of the absorber, which means lower radiative losses, while the heat transfer is enhanced by the porous matrix itself.

Results in 2016: CIEMAT and IMDEA Energía are involved in a task focused on the use of innovative heat transfer fluids. CIEMAT has developed a first estimation of the operating conditions for supercritical CO_2 (s-CO_2) considering a previous solar tubular receiver for a commercial fluid (molten salts) and has evaluated the thermal properties of the s-CO_2 according to the temperature (300-1100 K) and pressure (7.4 - 20 MPa). After the numerical evaluation of a more optimized s-CO_2 receiver design, the heat gained by the supercritical fluid was 12.5% greater than that gained by the molten salts considering the same mass flow and inlet temperature (715 K) but taking into account high operating pressures (around 24 MPa). In this preliminary optimization, the temperature reached by the s-CO_2 (903 K) was higher than the maximum working temperature of the molten salts (873 K), which enables the integration of more efficient thermodynamic cycles.

Ciemat-PSA is the coordinator of a task titled “Solar receivers/reactors for high temperatures processes”. Experimentally, the “gradual porosity” concept shows significant potential for improving, or at least matching, the performance of the baseline/reference absorbers in the literature (TSA and SOLAIR). For single porosity absorbers, the performance is improved when the geometric parameters (volumetric porosity, wire diameter and mesh size) have intermediate values. For double and triple porosity absorbers the performance is enhanced when high volumetric porosity is selected in the first layers while a high specific surface area is the main parameter for the rear layers. In addition, the location of the meshes of the second porosity influences the re-radiation losses significantly.

Figure 87 shows the mean air outlet temperature for the baseline volumetric absorbers, (TSA for absorbers with metallic material and SOLAIR for absorbers with ceramic material), with the best five configurations tested experimentally for different volumetric flow rates.

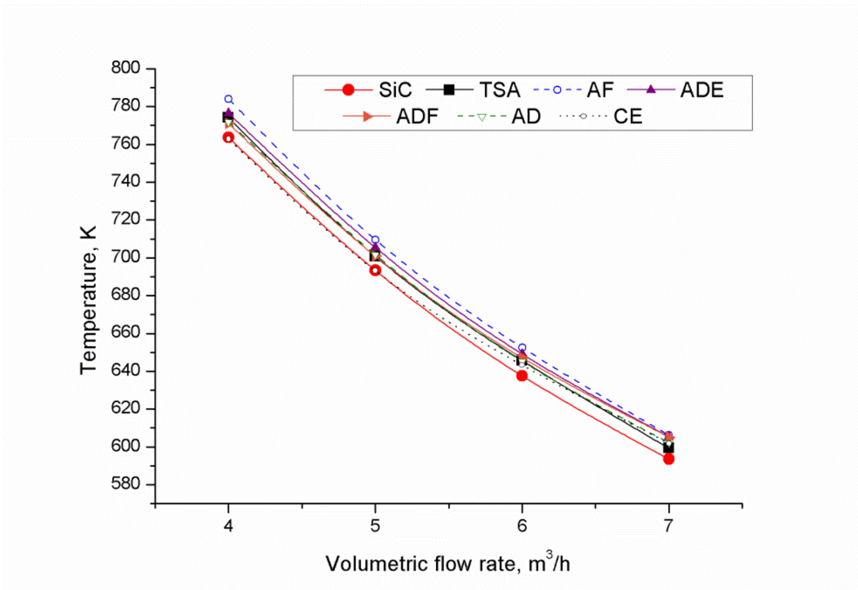

Figure 87. Mean air outlet temperature for the baseline absorbers (TSA and SOLAIR), for the best five absorbers tested (AF, ADE, ADF, AD and CE) and at different volumetric flow rates

Tests and Evaluation of Heliostats Prototypes

Participants: CIEMAT-PSA

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Raúl Enrique, raul.enrique@psa.es

Funding agency: Several Spanish and foreign companies.

Background: Deployment of Solar Central Receiver power plants has induced companies to design and build heliostat prototypes to be installed in different projects that are currently under development worldwide. Since the beginning of the activities at PSA, CIEMAT has been developing testing procedures for characterizing heliostats performance (Table 2).

Table 2. PSA Standard Heliostats Test Protocol

Items	Test	Explanation
1	**Characterization of the Local Control** **T1.** Behaviour of the local control with specific master control basic instructions (tracking, emergency stop, cleaning, shutdown, etc.). **T2.** Performance test of local control in case of failure or emergency. **T3.** Check heliostat angular speeds of both pure azimuth and zenith movements.	**T1.** The goal is to check the heliostat operative status before starting the test campaign **T2.** For safety reason, the goal is to check the heliostat reaction to critical operation cases e.g. high wind, emergency stop, motor failure etc. **T3.** Verify if angular speeds fulfil the design specifications.
2	**Optical surface state** Qualitative checking of mirror waviness and canting errors prior to start optical quality test of the heliostat.	Qualitative checking of mirror waviness and/or canting error for better understanding current optical status. Canting correction if necessary.
3	**Campaign to characterise the optical quality of the heliostat** **T1.** Testing of optical quality of individual facets. **T2.** Optical quality test of the heliostat as a whole. **T3.** Test diurnal evolution of the optical quality of the heliostat.	Real pictures of both facets (sample) and whole heliostat are taken at different times of the day and outdoor temperatures to know the corresponding optical quality
4	**Campaign to characterise the tracking quality of the heliostat** **T1.** High frequency test for checking canonical heliostat tracking movement. **T2.** Repeatability of the heliostat pointing from different standby points. **T3.** Diurnal evolution test of tracking.	Test tracking accuracy repeatability by taking long series of both high and low frequencies images. Limited duration from few minutes to whole day tracking.
5	**Power consumption** **T1.** Total power consumption test of the heliostat **T2.** Test power consumption by local control only	Measure power consumption for whole day of tracking drives and local controller.
6	**Wind test** Heliostat Test under critical wind condition (speed, direction)	Checks the deviations of the heliostat tracking and optics quality under *critical* wind values, i.e., out of heliostat nominal working operation.

Objectives: To completely characterize heliostats prototypes performance: Optical, tracking and energy following test presented in Table 2.

Achievements in 2016: During the year 2016 three heliostat prototypes have been tested and evaluated at PSA in the test bench called Heliostat Testing Platform, located to the northern side of the CESA-1 Heliostat Field, i.e. the STELLIO Heliostat, the TEWER Heliostat, and the EASY Heliostat.

In addition to the traditional testing techniques, a new measuring tool has been used with excellent results this year 2016, the so-called laser-scanner device, in order to explore the heliostat surface to find out its geometrical features directly (Figure 88).

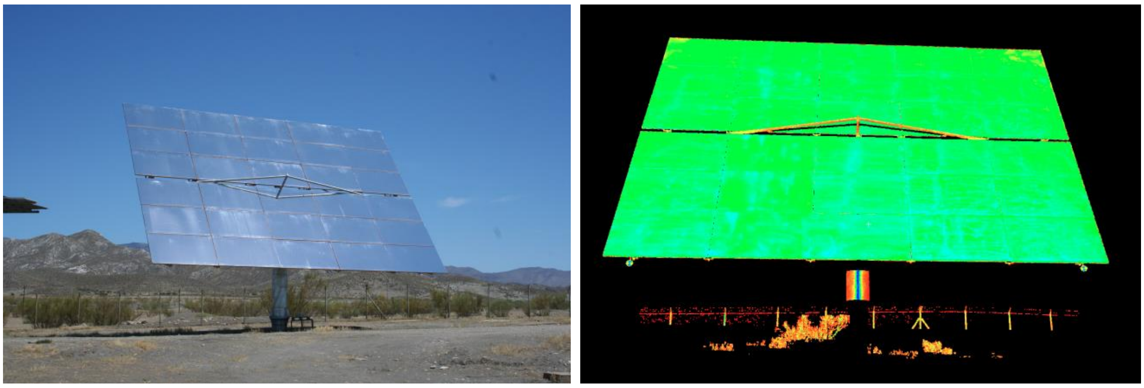

Figure 88. (left) TEWER Heliostat prototype. (right) TEWER Heliostat prototype under laser-scanner measuring

3.5 Solar Fuels/Solarisation of Industrial Processes Group

3.5.1 Introduction

Solar Thermal Electricity (STE) is a very promising renewable source of energy. The best known application so far is bulk electricity generation through thermodynamic cycles. Nevertheless, other applications of STE have also been demonstrated, such as production of hydrogen and high temperature solar heat production.

The lines of activity are focused in the following fields:

- Development of hybrid solar/fossil endothermic processes with special attention to low quality carbonaceous materials.
- Pre-commercial scale demonstration of the technical and economic feasibility of water splitting for hydrogen production through the use of thermochemical cycles with concentrated solar energy.
- Technological feasibility of the use of solar thermal energy as the energy supply in high temperature industrial processes.

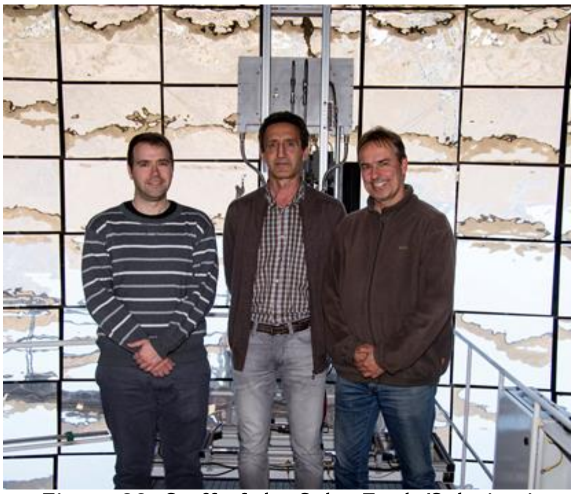

Figure 89. Staff of the Solar Fuels/Solarisation of Industrial Processes Group.

3.5.2 Projects

Thermochemical HYDROgen production in a SOLar monolithic reactor: construction and operation of a 1MW PLANT, HYDROSOL-Plant

Participants: APTL, DLR, Hygear, HELPRES, CIEMAT-PSA.

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Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: European Commission, FCH-JU-2012.

Background: The principal objective of HYDROSOL-PLANT is the development and demonstration operation of a plant for solar thermo-chemical hydrogen production from water in a 750 kW scale on a solar tower, based on the HYDROSOL technology.

Objectives: The specific objectives are: (i) construction of a solar hydrogen production demonstration plant in the 750 kW range to verify the developed technologies for solar thermochemical H_2O splitting, (ii) operation of the plant and demonstration of H_2 production and storage on site (at levels higher than 3 kg/week), and (iii) detailed techno-economic study for the commercial exploitation of the solar process.

Achievements in 2016: In 2016, CIEMAT has been focused on preparation of the second platform. The platform that will host the HYDROSOL-Plant is divided into two: (i) the receiver-reactor, as a fully assembled and fully functional system will be mounted on the 28-m platform, and (b) the second floor (4 metres below) which will accommodate the rest of the peripheral components.

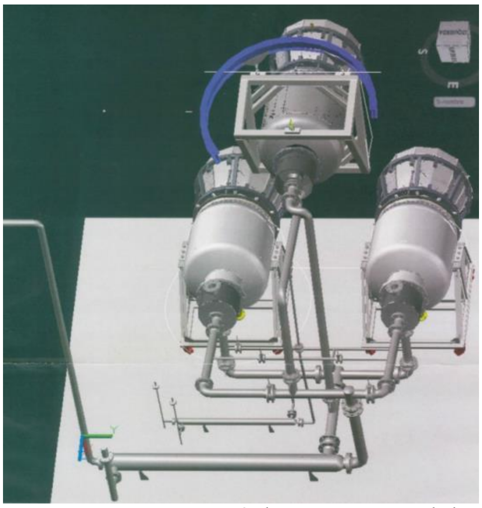


Figure 90. Diagram of the reactor module.

Figure 91. Photograph of the premises in the second floor.

The solar chemical reactor, schematically depicted in Figure 90 consists of a 3 cylindrical cavity-receiver containing a windowed aperture and a CPC (Compound Parabolic Collector). They are arranged in an equilateral triangle. Space between optical axes was determined based on vertical space available on the tower and operation variables like spillage losses and control temperature.

Finally, a preliminary simulation of the heliostat field was done with the new reactor design in order to achieve the best performance (e.g. homogeneous flux, low spillage etc.). The main goal of these activities consists of giving accurate data to design an aiming point strategy which yields an optimal distribution of concentrated solar flux onto the 3 modules within a limit for spillage. For doing that, a preliminary database containing the optical characteristics of each individual heliostat is created. Then, a definition of a set of aiming points which forms a grid on the aperture plane is created. Finally the optimization process computes the best aiming point strategy. The process produces a great number of solar flux distributions in the aperture plane by superposing simulated individual flux distributions delivered by each heliostat. A special attention will be paid to the validation of our model through the comparison of simulated results with experimental measurements.

Clean technologies for solar hydrogen production based on mixed-ferrites thermochemical cycle, HITERSOL

Participants: ABENGOA Hydrogen, CIEMAT

Contacts: María Maynar, maria.maynar@abengoahidrogeno.com
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: CTA-IDEA.

Background: Some high temperature endothermic reactions for converting solar energy to chemical fuels have been investigated around the world. Many of the activities to this point dealt with identifying, developing and assessing improved receiver/reactors for efficient running of thermochemical processes for the production of H_2.

Objectives: Hitersol pursues to develop clean technologies for solar hydrogen production based on water splitting by mixed-ferrites thermochemical cycle. To achieve this aim, an installation was designed, constructed and commissioned within a previous project named SolH2. Present collaboration pursues to complete the evaluation of a 200 kW pilot plant erected in PSA.

Achievements in 2016: The SolH2 plant was evaluated for several months along 2016. The purpose of this experimental campaign was to investigate the receiver performance and its operational region. An operation strategy previously performed by ray tracing simulations was applied to supply the required power with the optimal flux distribution onto the alumina tubes.

For the first two groups of heliostats, G1 and G2, the heating is very progressive, and temperature stabilization takes a long time (Figure 92). When 20 heliostats (4 groups) are focused on the cavity a total power of 44.1 kW is achieved and 750-800ºC is reached. With 28 heliostats, power is 57.5 kW and 1000ºC is obtained. Finally, with a total of 36 heliostats, and the power about 80 kW, 1200 ºC is reached. These values agree with previous simulations indicating that a power of 80 kW is needed to achieve the nominal conditions for activation step. Additionally, those levels of temperature are crucial in thermochemical cycles with ferrites. A first oxidation is produced at 750-800ºC, and also at 1000ºC, while reduction occurs at 1200ºC.

During non-steady tests, investigation was concentrated over possible ways of obtaining regulation of transients to avoid continuous start-up and shut down operations both for economic and technical reasons. In order to simulate changes in solar conditions such as cloud transients, the number of heliostats focused on the targets is modified manually to reach the desired power requirements. Temperatures sharply decrease mainly in the tubes with higher values, becoming very similar for all of them after a few minutes. Temperatures increase faster by adding additional heliostats when the clouds have gone, and the time needed can be further reduced by focusing more additional heliostats.

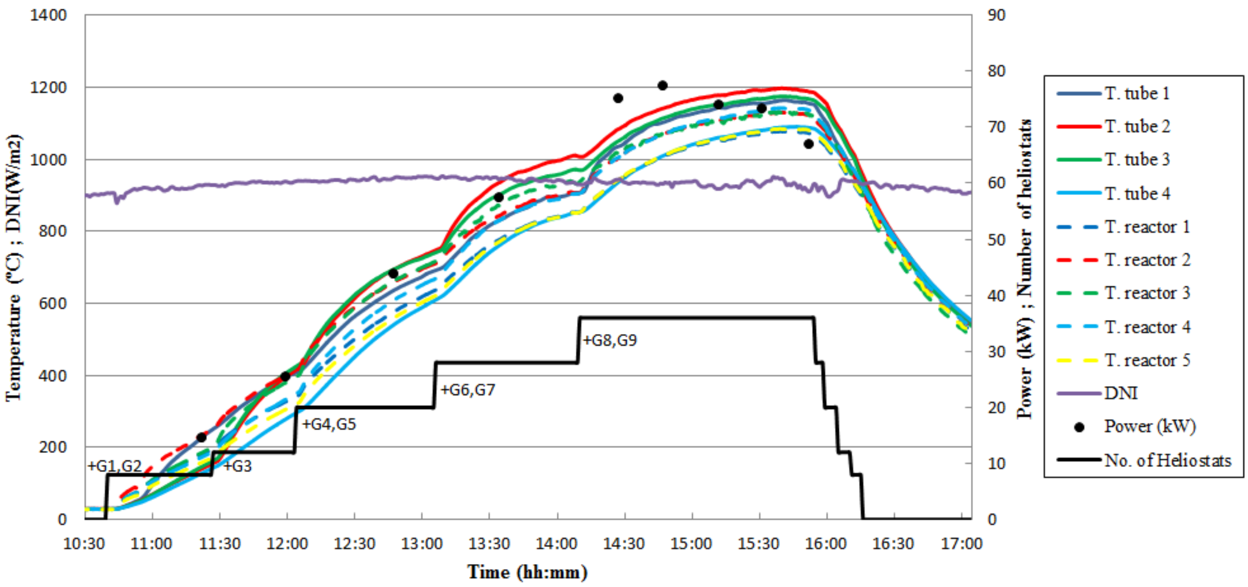


Figure 92. Evolution of temperatures: T. tube corresponds to the thermocouples inside the tubes, in contact with the ferrites, while T. reactor refers to the thermocouples located behind the tubes. Number of heliostats focused on the receiver and the power measured. Order of aiming of the groups of heliostats: G1+G2, G3, G4+G5, G6+G7, G8+G9.

The cavity receiver showed a slow response to changing operating conditions, indicating high thermal inertia which is characteristic for this type of configurations, in contrast to volumetric receivers. With short or small cloud transients, the temperature is not much affected indicating that cavity receivers are a good choice to achieve an easy regulation capability of the process.

Storage and Conversion of concentrated thermal solar energy, ALCONNES

Participants: IMDEA Energía (Coordinator), University J. Carlos I, ICP-CSIC, CIEMAT.

Contacts: Manuel Romero, manuel.romero@imdea.org
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: Comunidad de Madrid.

Background: The ALCONNES project is a very ambitious initiative which focuses its R&D objectives onto the heart of CSP systems, that is, the loop involving conversion from high flux solar to thermal energy, including the storage system needed to optimized dispatch on demand for further use of energy in the production of electricity, solar fuels or chemicals.

Objectives: CIEMAT is exploring new solar receivers and reactors for the efficient operation at high temperatures and with high penetration of photons for high incident flux. Furthermore, CIEMAT will explore the possibility of the use of new perovskite materials as candidates for thermochemical cycles.

Achievements in 2016: Some work conducted in 2016 was focused to study the technical feasibility of chemical reactors concepts based on directly-heated fluidised bed reactors. The goal of this study is to improve the understanding of fluidized bed hydrodynamics by determining the effects of bed height and material density on the time average gas holdup in a cylindrical fluidized bed. To accomplish this goal, this research will complete the following objectives: i) Determination of the effects of bed height on the minimum fluidization velocity; ii) Classification of the bed material into Geldar Scale and Pressure Drop over the Distributor Plate. The later should be 30% of Total Pressure Drop (bed and distribu-tor) according to general rules for this type of configurations.

This work is carried out in collaboration with IMDEA Energy. This activity involves joint experiments with IMDEA using the same reactor (to make easier extrapolation of results). IMDEA Energy contributes to this task by evaluating the fluidized reactor in a solar simulator and a beam-down test bench which has been designed and assembled for this purpose. CIEMAT and IMDEA have planned tests with ferrites in a fluidized bed reactor, using IMDEA's solar simulator and beam-down test bench and a solar dish located in Madrid Labs. IMDEA has designed and assembled a laboratory test bed using a "beam-down" type chemical reactor for the analysis of the reducing step of non-volatile metal oxides, such as cerium oxide.

CIEMAT is also exploring new perovskite materials such as LaxSr1-xMnyAl1-yO3 and LaxSr1-xFeyAl1-yO3 as candidates for thermochemical cycles. The research efforts are directed towards testing of these materials in the laboratory. Some perovskites are being investigated under various reaction conditions, improving the kinetics and reducing the working temperatures.

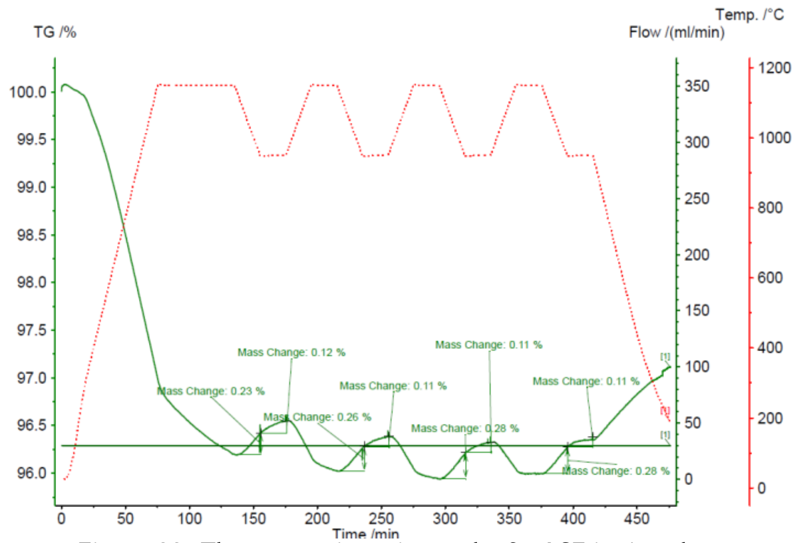


Figure 93. Thermogravimetric results for LSF in 4 cycles.

First hydrolysis test carried out with these materials in a thermogravimetric analyser indicated that they are good candidates for further tests (Figure 93). First hydrolysis test carried out with LaxSr1-xMnyAl1-yO3 (LSMA) and LaxSr1-xFeyAl1-yO3 (LSF) within

4 cycles at 1150 ºC for activation and 950 ºC for hydrolysis indicating that in these materials the recovery of O_2 is complete within the operation conditions.

Multidisciplinary analysis of indirectly-heated particles receivers/reactors for solar applications in extreme conditions, ARROPAR-CEX

Participants: IMDEA Energia (Coordinator) and CIEMAT

Contacts: Manuel Romero, manuel.romero@imdea.org
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: RETOS Initiative. Spanish Ministry of Economy and Competitiveness

Background: The research program ARROPAR-CEX proposes a multidisciplinary analysis on novel concepts of indirectly heated receivers/particle reactors for solar applications under extreme conditions. Extreme operating conditions are understood to be those which involve the combination of high irradiance, in excess of 1000 kW/m^2, and very high temperatures, typically above 800 °C. ARROPAR-CEX is divided into three sub-projects in order to achieve significant advancements in several scientific and technological knowledge areas, in particular CIEMAT leads subproject 3 'Methodology and characterization of materials and components for receivers for solar applications under extreme conditions'.

Objectives: The main objective is to establish a procedural methodology that leads to the reliable qualification of materials, components and solar reactors, and which thus ensures their reliability and durability under extremely demanding operating conditions - and with the ambition of becoming the standard. This methodology will be validated in real operating conditions of solar radiation by employing solar furnace facilities.

Achievements in 2016: During 2016 some efforts have been made to advance in task 3.1.1. Bibliographic review and existing standards and 3.1.2. Selection of commercial materials on which the tests will be applied. Second task will be addressed based on two main factors: (i) Operating conditions (temperature, solar flow and cycling), and (ii) properties of the heat transfer fluid. In a first approach the study of the structural material of the reactor, i.e. walls, body, etc., is planned. Currently the only ceramic materials used for solar receivers are alumina and silicon carbide (SiSiC and ReSiC can reach temperatures of 1200°C and SiC of 1500°C). Alumina is a metal oxide characterized by a very high thermal stability, resistance to oxidation and very refractory, but, being white, does not have an optimal absorption. SiC, however, is a gray semiconductor, with good absorption of sunlight and high resistance to oxidation, but also with a high thermal emittance. Ultra-High Temperature Ceramics (UHTCs) are a family of materials including borides and carbides of transition metals, characterized by their high melting point, exceeding 3000°C, good thermo-chemical and thermo-mechanical properties, high hardness, and high electrical and thermal conductivity. Thanks to their spectral selectivity and low emittance at high temperatures, they present interesting characteristics compared to reference materials such as Al_2O_3 and SiC. All these materials will be evaluated to define the best option for further tests.

Release of Oxygen from Lunar Regolite using concentrated solar energy. ORESOL

Participants: CIEMAT-PSA.

Contacts: Thorsten Denk; thorsten.denk@psa.es

Funding agency: CIEMAT

Background: The ORESOL project originated from the "ERA-STAR Regions" program, a joint initiative between Andalusia and Bremen (Germany). PSA continued the activity due to the unique possibility to investigate a promising type of solar chemical reactor for reactions that need the processing of large quantities of solids.

Objectives: The principal goal of the project is the development and testing of a solar powered fluidized bed reactor for the extraction of oxygen from lunar regolith. This is done by the reduction of one constituent of lunar soil, ilmenite ($FeTiO_3$), with hydrogen, and the subsequent electrolysis of the obtained water.

Achievements in 2016: The first tests of the reactor with concentrated solar radiation were executed in July. In this testing phase 1a, the goal was to determine the overall behaviour and control properties of the system. Eight of the nine tests were done with air as fluidization gas. The tests were limited to 400°C, no chemical reaction was carried out, and the gas was not recirculated.

In parallel, the downstream section was improved. This included the design and acquisition of a particle separator with fine filter, an additional high-capacity cooler, and an active water separator with Peltier-cooler. After completion of test phase 1a, these elements were installed in the system together with the pressure control valve and the recirculation pump.

With all components in place, the solar testing was resumed in December (Figure 94). This phase 1b was to learn about the behaviour and the handling of the complete system including recirculation. The goal was to optimize all procedures before switching to operation with much more expensive inert gas (argon), needed to reach higher temperatures (up to 900°C) to enable finally the desired chemical reaction. The obtained results matched well the expectations.

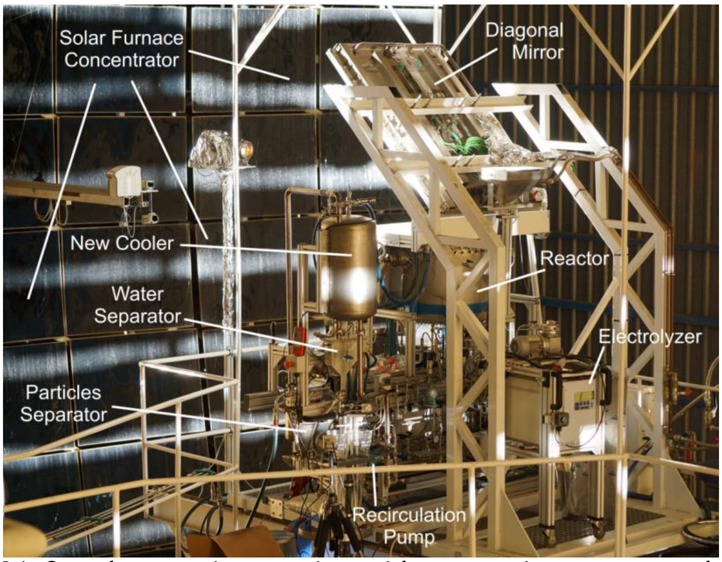


Figure 94. Oresol reactor in operation, with some major components labelled.

3.6 Thermal Storage Group.

3.6.1 Introduction

The Thermal Storage Group (TSG) was born in 2015 to give more visibility to those activities on storage that the SCS Unit was performing since 2004. Composed by people formerly in the MCG, it deals with most of the storage activities of the unit. The activity during 2016 has been focussed on testing materials and equipment. A protocol and an oven to verify thermal cycling of storage materials were prepared. These have been very useful for our contributions in WASCOOP, DETECSOL and Alccones projects and also pave the way for our participation in the next joint Anex33/Task58 "Material and Component Development for Thermal Energy Storage" (ECES/SHC TP). A latent prototype of a CIEMAT patent was tested (REELCOOP project). The collaboration with companies and other research centres have been promoted thanks to test facilities, both own ones (BESis and MOSA) and others' (test campaign in a thermocline storage tank in CEA-France).

Figure 95. Members of the Thermal Storage Group.

3.6.2 Projects

Research Cooperation in Renewable Energy Technologies for Electricity, REELCOOP

Participants: UPORTO (coordinator), UoR, DLR, UoE, CIEMAT, ENIT, IRESEN, YU, ONYX, MCG, Termo, Sol, ZE, AES, CDER.

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

Funding agency: European Commission, FP7- ENERGY.2013.2.9.1

Background: In order to change the fact that today still 17% of the world population have no access to electricity, with 2 out of every 3 living in rural areas of Africa and Asia, and to achieve “electricity for everyone” by 2030, the expansion rate has to double. Besides, in developed countries electricity demand is higher than supply and prices are increasing at high rates; where only 18% of the electricity comes from renewable sources (20% in EU).

Objectives: The aim is to develop, construct and teste three prototypes:

- Prototype#1: a building integrated PV system (with ventilated facades),
- Prototype #2: a hybrid (solar/biomass) micro-cogeneration ORC system, and
- Prototype #3: a hybrid concentrating solar/biomass mini-power plant (P1).

A special effort is being made to transfer and disseminate the developed technologies by organising Workshops on Renewable Electricity Technologies open to junior researchers and outside public.

Achievements in 2016: The main contribution of Ciemat/PSA is the development of an, already patented, own design of thermal storage for latent heat with low-thermal conductivity phase change materials. Searching for a suitable and feasible PCM in the required temperature range (130ºC-170ºC) was not an easy task since some candidates that literature proposes degrade under cycling. The chosen PCM has been tested under different atmospheres in order to assuring the lack of any degradation. Due to budget limitations for manufacturing a specific prototype with the design proposed for this project, a commercial spiral heat exchanger has been modified accordingly. This commercial spiral heat exchanger was installed and tested at PSA facilities, after the necessary modifications to adapt it for this purpose.

Figure 96. REELCOOP storage prototype installed for testing at PSA.

4. Solar Desalination Unit

4.1 Introduction

The Solar Desalination Unit (UDeS in its Spanish acronym) has the objective of new scientific and technological knowledge development in the field of brackish and seawater solar desalination. Main current research lines are the following:

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

During 2016, the PSA Solar Desalination Unit has continued with its relevant activity in the field of solar thermal desalination. The joint organization together with the European Desalination Society (EDS) of a yearly course about solar desalination is a proof of this reference position. Likewise, this year has led to the consolidation of new lines of activity within the unit, identifying new applications for thermal separation techniques beyond brackish and seawater desalination, like the regeneration of

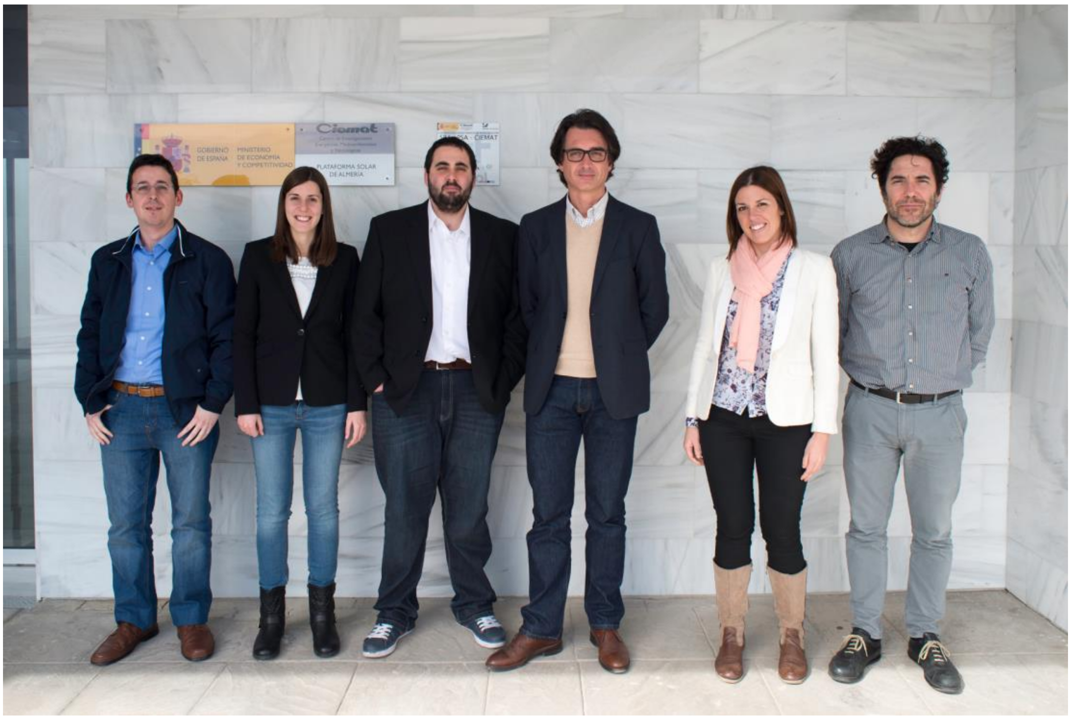


Figure 97. Members of the UDeS Unit.

diluted solutions in close-loop salinity gradient power generation processes and the treatment of industrial waste waters for water saving and valuable metal recovery.

The international relevance of the developed activities is clearly supported by the following positions currently hold by the unit:

- Member of the European Desalination Society (EDS) Board of Directors (2016-2018)
- Coordination of the Renewable Energy and Desalination Working Group of the European Water Platform (WssTP)
- 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).
- Coordination of EERA Subprogramme on CSP and Desalination (CSP+D).

During 2016 research activities were developed within the framework of projects covering both national and international activities with academic and industrial involvement.

4.2 Projects

Zero Carbon Resorts towards Sustainable Development of the Tourism Sector in the Philippines and Thailand (ZCR2)

Participants: GrAT (Coord.), PCSD, GLF, HPPF, CIEMAT-PSA

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

Funding agency: European Commission, SWITCH-Asia Programme.

Background: This project builds upon the success and achievements of the ZCR in the Philippines (2009-2014) for replication and upscaling. Regional approach will be implemented through ZCR intervention in Thailand and Green Certification in the Philippines, while increasing the access to green finance and improving policy exchanges on SCP in tourism in both countries.

Objectives: The overall objective of this project is to contribute to sustainable development of the tourism sector and its value chain in the Philippines and Thailand with a focus on reduction of resource consumption and CO_2 emissions.

Achievements in 2016: Activities in the project continued with the selection of appropriate technologies for a more sustainable supply (and use) of energy and potable water, as well as for waste water treatment; the evaluation of audit reports; and the participation on a Water conference in Thailand. Also, a preliminary definition of a waste water treatment system based on passive solar energy was made for installation in the demo site.

Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis (RED-Heat-to-Power)

Participants: WIP, University of Palermo, FUJIFILM, REDSTACK, CIEMAT-PSA, University of Edinburgh, Universitat Politecnica de Catalunya

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

Funding agency: European Commission, H2020 programme

Background: The concept is based on the generation of electricity from salinity gradient using Reverse Electrodialysis with artificial saline solutions operating in a closed-loop. The original salinity gradient is regenerated by a separation step that uses heat at 40 - 100°C.

Objectives: The overall objective is to prove this revolutionary concept, develop the necessary materials, components and know-how for bringing it to the level of a lab prototype generating electricity from low-grade heat at higher efficiencies and lower costs than ever achieved to date. The specific objective of CIEMAT-PSA is to select the most suitable technologies for the regeneration process and the combinations of salts and solvents that can maximise the system performance.

Achievements in 2016: During this year the role of CIEMAT-PSA has been to evaluate the energy efficiency of thermal regeneration systems with different salts. Simulations have been done for multi-effect distillation (MED) and membrane distillation (MD) using solutions with different salts. The results show that the specific thermal energy consumption increases with salinity more in MD than in MED, and the effect of changing the type of salt is not that important whenever the solutions have similar water activities.

Figure 98. Bench-scale facility used in MD experiments for RED-HtP Project at PSA: a) full installation (left), b) MD test cell (right).

Control and energy management strategies in production environments with support of renewable energy, ENERPRO: Efficient energy control and management of solar thermal desalination systems, EFFERDESAL.

Participants: UAL (ENERPRO), CIEMAT-PSA (EFFERDESAL)

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

Funding agency: MINECO, Plan Estatal I+D+i 2013-2016.

Background: Due to increasing demand for energy and water, most countries are promoting the efficient use of these resources to reduce costs and increase sustainability. Generally, energy efficiency is not only associated with technological improvements, but also with the improvement of control and energy management. This project ENERPRO/EFFERDESAL is a natural evolution of a previous project, POWER, where both UAL and CIEMAT-PSA subprojects focused on heat/cooling and water management.

Objectives: The main objectives are: (i) Dynamic modelling of solar-gas hybrid desalination plants, (ii) Analysis of energy storage systems and auxiliary systems for energy cost reduction, (iii) Design of simplified models for control purposes, (iv) Development of MPC strategies for desalination plants, (v) Coupling of solar desalination plants to supply water to greenhouses and buildings, and (vi) Testing of control algorithms both in simulation and in the real installations.

Achievements in 2016: In this second year of the project, the following relevant results have been obtained:

- Experimental campaigns at AQUASOL-II to model the heat flow rate exchanges, the production obtained and the gas consumption at different operating conditions.
- Experimental campaign at the solar membrane distillation facility to characterize each one of the available membrane distillation modules (Aquastill-7.2 m^2, Aquastill-24 m^2 and SolarSpring).
- A detailed study on several kinds of models for heat exchangers with different degree of complexity has been performed.
- The double effect absorption heat pump dynamic model based on physical equations has been validated with experimental data.
- A multi-objective optimization has been performed to obtain the best operating points in which the MED unit must work.
- An MPC hierarchical controller has been proposed in the AQUASOL facility to maintain a distillate volume for greenhouse irrigation.
- A minisymposium called “Modelling and simulation in solar thermal power plants” was organized in the frame of EUROSIM 2016 congress.

Figure 99. ENERPRO coordination meeting held at PSA

Resource recovery from industrial waste water by cutting edge membrane technologies (REWACEM)

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

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

Funding agency: European Commission, H2020 Program

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 of 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, waste water 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 waste water treatment and liquid stream recovery.

Achievements in 2016: The project started in October and during its first three months the activities were focused on the compilation of operational information towards the definition of the pilots to be built in each case.

5. Water Solar Treatment Unit

5.1 Introduction

The main objective of the Unit for Water Solar Treatment 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 photofuels. Our knowledge about solar photochemical systems and processes at pilot and pre-industrial scale is backed by 25 years of research activity. Since the first pilot solar photocatalytic water treatment plants in the world were started up in the early nineties, the group has been involved in almost all of the international projects related to their development. This involved in the FP4, FP5, FP6, FP7 EU and H2020 programs, all of them related to environmental, material sciences, chemical engineering, chemistry and microbiology. This unit is also pioneer in the use of advanced analytical techniques for the evaluation of advanced oxidation treatments. This line of development is continually underway incorporating new techniques. At present, several R&D projects are running in collaboration with different International Institutes and Universities. Most of them aim to improve the chemical and microbiological quality of contaminated waters by optimizing advanced water treatment technologies, mainly those which use solar energy.

Figure 100. Staff of the Water Solar Treatment Unit

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

- Solar photocatalytic and photochemical processes as tertiary treatment of wastewater for the removal of pollutants of emerging concern and microorganisms, related with **NEREUS** and **PHOTOCAT** networks, and **WATER4CROP** project.

- Solar photochemical processes for the remediation of industrial wastewaters containing biorecalcitrant compounds (pharmaceuticals, pesticides, landfill leachates, textile and wine industry), related with **TRICERATOPS** project.
- Integration of Advanced Oxidation Processes with other water treatment technologies (NF/UF; Ozone, Bioprocesses, etc.) for improving efficiency and reducing costs, related with **TRICERATOPS** project
- Evaluating photocatalytic efficiency of new materials under solar light in pilot reactors, related with **FOTOFUEL** network and **HIDROPILSOL** project.
- Photocatalytic and photochemical processes for water disinfection in different scenarios (different wastewaters and drinking water including resistant pathogens), related with **WATERSPOUTT** project
- Pilot solar photo-reactors for production of hydrogen and other photofuels, related with **FOTOFUEL** network and **HIDROPILSOL** project.

5.2 Projects

Network: New Challenges in solar photofuels, FOTOFUEL.

Participants: IMDEA Energía (Coord.), CIEMAT-PSA, ICP-CSIC, UPV-CSIC, IMDEA Materiales, INSTITUT CATALA DE INVESTIGACIO QUIMICA, LABORATORIO DE LUZ DE SINCROTRÓN (ALBA-CELLS), UB, UJI, MATGAS 2000 AIE

Contacts: Sixto Malato Rodríguez; sixto.malato@psa.es

Funding agency: Spanish Ministry of Economy and Competitiveness, Network of Excellence (Reference ENE2014-52280-REDT)

Background: Solar fuels as an alternative to fossil fuels represents one of the most promising ways to combat climate change given that they are produced from simple and abundant resources like CO_2 and H_2O by using sunlight as a renewable energy source. FOTOFUEL goal is to reach a significant advance in the development of materials and devices for the efficient production of solar fuels by seeking synergies and cooperation between leading research groups in this field while offering them an international outreach platform.

Objectives: The scientific program consists of five major areas (i) Design and synthesis of advanced multifunctional materials, (ii) Development of theoretical and experimental tools; (iii) Design and manufacture of efficient photoreactors; (iv) Feasibility and standardization of the process; (v) Studies of scientific, environmental, economic and social impact. To achieve these objectives the main key is the cooperation between leading scientists and young researchers from different institutions and research-industry collaboration to ensure the exploitation of results.

Achievements in 2016: Network of excellence. The work is based on scientific collaboration and joint implementation of a work program based on cutting-edge research, information, dissemination and communication and technology transfer. Results are focused on joint scientific papers and workshops sharing information from the projects of each group, not experimental work. See: http://fotofuel.org/

Network: New photocatalytic materials and reactors for removal of micropollutants and pathogens, FOTOCAT

Participants: Universitat Rovira i Virgili–URV (Coord.), PSA-CIEMAT, UEX, URL, UAL-CIESOL, ICRA, UPV, URJC

Contacts: M. Ignacio Maldonado, mignacio.maldonado@psa.es

Funding agency: *Spanish Ministry of Economy and Competitiveness, Network of Excellence (Reference CTM2015-71054-REDT)*

Background: To achieve a sustainable use of water resources, it is necessary to increase the volume of reclaimed water. To obtain an effluent of suitable quality for the different uses permitted for reclaimed water it is necessary to reduce the content of pathogens and persistent organic pollutants. This could be achieved through the proper development of photocatalytic processes.

Objectives: The aim of the FOTOCAT network is to achieve a significant progress in the development of materials and photocatalytic reaction systems for the treatment and reuse of wastewater. The research groups that comprise the FOTOCAT network have altogether a wide experience in the synthesis of new catalytic materials, photocatalytic reactor design and implementation of these processes for the treatment and reuse of wastewater, allowing them to face the challenges identified for their industrial application. The various actions planned to be undertaken will contribute to the training of new researchers in the application of photocatalytic processes for water treatment and reuse and the need for its sustainable use.

Achievements in 2016: Network of excellence. The work is based on scientific collaboration and joint implementation of a work program based on cutting-edge research, information, dissemination and communication and technology transfer. Results are focused on joint scientific papers and workshops sharing information from the projects of each group, not experimental work. See: http://fotocat.es/

Networking: New and emerging challenges and opportunities in wastewater reuse, NEREUS

Participants: 336 participants from 40 countries (EU and associated countries). NIREAS-International Water Research Center (Cyprus), coord. CIEMAT-PSA is member of managing committee and co-coordinates Working Group 4.

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

Funding agency: European Cooperation in Science and Technology, H2020- Cost Action (ES1403)

Background: Treated urban wastewater is currently widely reused to compensate for dwindling water supplies, as it is considered to be a reliable alternative water source. Several knowledge gaps associated with wastewater reuse still exist, including: (a) accumulation of metals/elements in the soil and their subsequent uptake by plants and crops, (b) fate of organic microcontaminants in downstream environments, and (c) epidemiological potential of antibiotic resistant bacteria and/or resistance genes (ARB&ARG) discharged from treated effluent. Contamination of the environment, the food chain, drinking water, etc with ARB&ARG is presently considered to be a serious public health problem.

Objectives: The Action intends to (i) deliver best-practice recommendations to wastewater reuse in irrigation, (ii) develop uniform means for assessing wastewater quality with respect to contaminants of emerging concern and also ARB&ARG, (iii) establish specifications for technologies able to produce wastewater with minimal levels of such contaminants, and (iv) compile valid and reliable information to be used in regulatory frameworks.

Achievements in 2016: The work is based on scientific collaboration and joint implementation of a work program based on cutting-edge research, information, dissemination and communication and technology transfer. Results are focused on joint scientific papers and workshops sharing information from the projects of each group, not experimental work. See http://www.nereus-cost.eu/

Reducing the water cycle demand in vegetables process industry by novel water treatment: reuse for vegetables washing and agricultural reuse, WATER4CROP

Participants: Univ. Rey Juan Carlos (coordinator), CIEMAT-PSA.

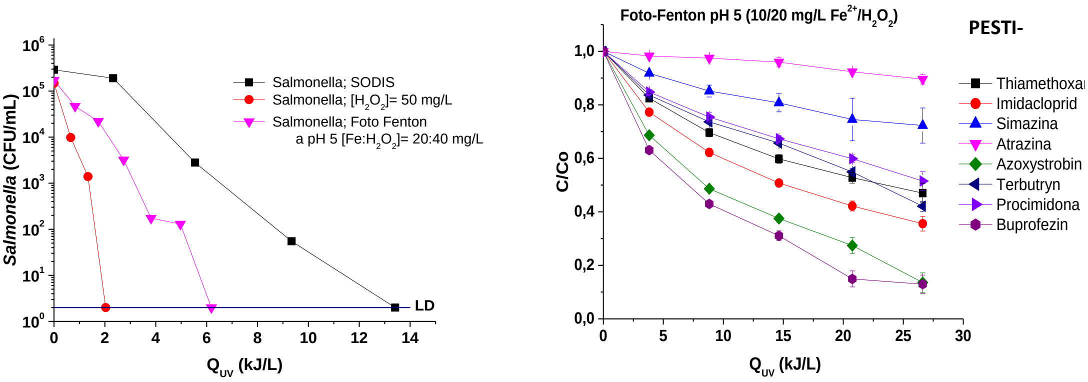
Contacts: Pilar Fernández Ibáñez, pilar.fernandez@psa.es

Funding agency: Programa Estatal de Investigación, Desarrollo e Innovación Orientada a los Retos de la Sociedad, 2013-2016.

Background: Water scarcity is currently a big issue in many areas of the world. This scenario leads us to explore different ways to save fresh water, like the reuse of wastewater effluents for agriculture. AOPs have demonstrated to be a promising treatment to enhance the wastewater effluents quality, reducing the presence of emerging pollutants (chemical and biological) to regulated limits (RD 1620/2007).

Objectives: The main objective is the assessment of several AOPs (i.e. O_3/H_2O_2, solar photo-Fenton, H_2O_2/solar radiation) for the treatment of fresh-cut industry wastewater (FCWW) contaminated with E. coli O157:H7, Salmonella and a cocktail of pesticides in pilot reactors and further reuse for raw-eaten crops irrigation in an experimental greenhouse.

Achievements in 2016: i) Assessment of the capability of solar processes (SODIS, photo-Fenton and H_2O_2/solar) for water disinfection and decontamination at laboratory scale. The inactivation of pathogens (E. coli O157:H7 and Salmonella enterica) and the removal of several pesticides were simultaneously investigated in distilled water. Figure 101.a shows the most significant results for both, water disinfection and decontamination. ii) Physico-chemical and microbial characterization of real wastewater (FCWW) samples provided by a fresh-cut industry (Verdifresh, S.L). FCWW samples were collected from washing tanks used in the individual lines of production/preparation of lettuce and spinach (Figure 101.b). iii) Develop of a chemical receipt simulating main characteristics of wastewater for proper evaluation under controlled condition. Main parameters were: pH 6-6.5, turbidity 100 NTU, conductivity 1 mS/cm and TOC 150 mg/L. iv) Study of optical limitation of photo-Fenton for water disinfection. Experiments were conducted in a solar simulator using E. coli and S. enterica and synthetic fresh-cut WW. It was investigated the effect of different irradiances (20-30-40-50 W/m^2) on: Fe^{2+}-only, Fe^{2+}/H_2O_2, Fe^{3+}-only, Fe^{3+}/H_2O_2 and H_2O_2-only at low reagents concentrations (Fe: 2.5 mg/L and H_2O_2 < 50 mg/L). Future work will include validation of these results in solar reactors. In addition, the assessment of the chemical and microbiological fate in irrigated crops from treated and untreated WW will be carried out.



WW samples of lettuce wash

WW samples of spinach wash

Figure 101. a) S. enteriditis inactivation by solar processes and pesticides degradation by solar photo-Fenton at near neutral pH in distilled water and solar 200mL-batch reactor. b) Image of wastewater samples of lettuce and spinach washing collected from Verdifresh S.L (Spain).

Water Sustainable Point Of Use Treatment Technologies, WATERSPOUTT

Participants: CIEMAT-PSA; Univ. 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 López, m.polo@psa.es

Funding agency: European Commision. Horizon 2020. H2020-WATER-2014-2015/H2020-WATER-2015-two-stage.

Background: In 2015 nearly 660 million people remain without access to safe drinking water in rural areas. Solar water disinfection (SODIS) is a household water treatment that uses solar energy to inactivate pathogens in water stored in transparent containers. Nevertheless, some limitations are still affecting the efficiency and acceptability of this process by users.

Objectives: To increase the user uptake of SODIS by bringing to market novel solar based technologies providing larger volumes (≥20L) of treated water per day in each household. CIEMAT objective is to develop new reactors for disinfection of harvested rainwater providing 125 litters/day. The final reactor will be evaluated in South Africa and Uganda.

Achievements in 2016: During the first months of the project, two concepts of SODIS-reactors were considered, developed and constructed. Figure 102.a and b shows both concepts of SODIS-reactors coupled with rainwater tanks design. Testing of the solar reactor prototypes started on December 2016 and is still in progress. SODIS reactors are being tested using a microbial consortium commonly present in harvested rainwater (E. coli, Enterococcus, phage MS2, Salmonella, Aeromonas, Pseudomonas and Cryptosporidium) and using a synthetic rainwater pH 5-6, COD 5-10 mg/L, TOC: 2-3 mg/L, Al (1.2 mg/L), Fe (<0.5 µg/L). The influence of mild-heat temperatures driven by solar heating (T range between 25 and 55 ºC), air injection, water recirculation and the influence of mirror shape on solar water disinfection efficiency will be investigated (CPC-type versus U-type Aluminum reflectors) (Figure 102.c). Water disinfection efficiency will be assessed according to WHO testing protocol for Household Water Treatment and Storage Systems. Our target will be to attain a highly protective level for our proposed solar technologies, which means that after solar processes conducted in SODIS-reactors ≥ 4-Log of bacteria, ≥ 5-Log of viruses, and ≥ 4-Log of protozoa should be reduced in harvested rainwater. See also: http://www.waterspoutt.eu/

Fundamental and solar pilot plant scale studies of photocatalytic hydrogen production with simultaneous removal of water pollutants, HIDROPILSOL

Participants: CIEMAT-PSA

Contacts: M. Ignacio Maldonado, mignacio.maldonado@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i (2013). Subprograma de Proyectos de Investigación Fundamental. Reference CTQ2013-47103-R.

Background: The present project is intended to deepen into the knowledge of the heterogeneous photocatalytic processes for obtaining hydrogen from water and organic contaminants that might be dissolved on it, taking the research to a pre-industrial solar pilot plant scale.

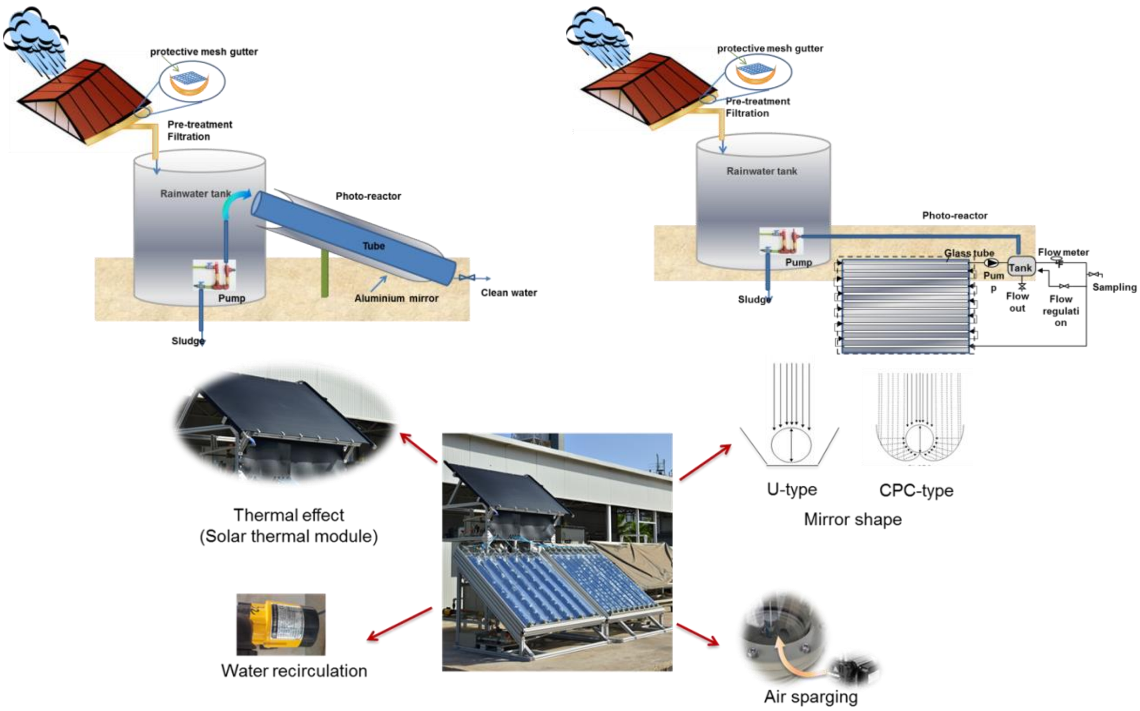


Figure 102. Concept of SODIS based reactor developed for rainwater harvesting disinfection, a) PROTOTYPE #1: Static batch system and b) PROTOTYPE #2: 'flow' system. c) Imagen of prototype #2-flow system remarking the physical parameters that will be assessed during solar disinfection of synthetic rainwater.

Objectives: The main objectives are (i) to determine the semiconductor "composite" that yields a larger efficiency of hydrogen generation from water and organic pollutants at pilot-plant scale, (ii) to scale-up the process from laboratory to pilot-plant scale, and (iii) to perform mechanistic studies of the process.

Achievements in 2016: An Au/TiO_2 catalyst (0.5% Au weight) was use for photocatalytic hydrogen production (see 2015 Annual Technical Report). Au nanoparticles were deposited onto commercial TiO_2 (Evonik P25) by deposition-precipitation using urea. Au/TiO_2 photocatalyst showed the following features: BET surface area 56 m^2g^{-1}, non-porous morphology, bandgap energy of 2.68 eV, and Au 0.5 wt.%. The XRD patterns of Au/TiO_2 showed only peaks corresponding to anatase JCPDS 21-1272 and rutile JCPDS 21-1276. XPS characterization for Au/TiO_2 catalysts synthesized has shown that Au is completely reduced in agreement with Temperature Programmed Reduction (TPR) results. The position of the Au 4f peaks showed the characteristic signal $4f_{7/2}$ core level, thus gold was completely reduced. Gold in dried Au/TiO_2 was mainly present in the oxidized state III. Figure 113 shows HRTEM images of gold nanoparticles on TiO_2. In all cases the particles are smaller than 5 nm and in some of those particles gold lattices can be observed.

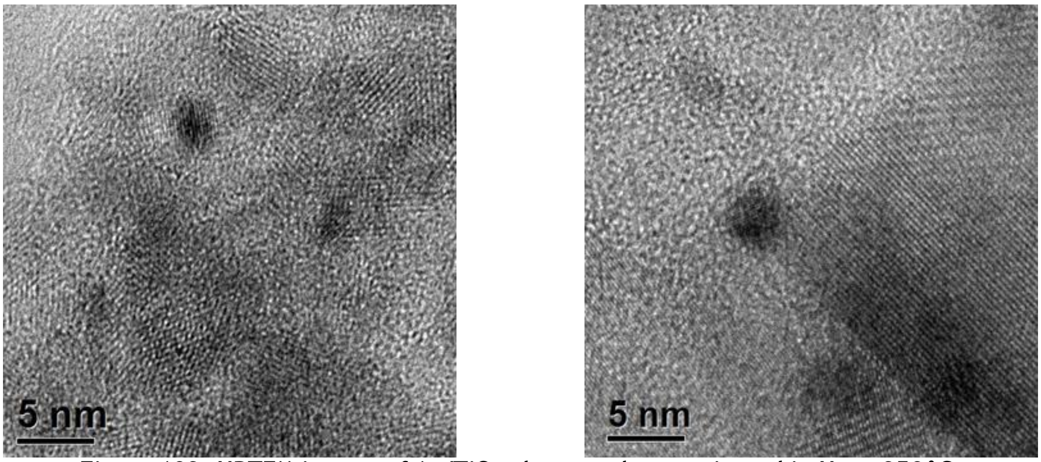


Figure 103. HRTEM images of Au/TiO_2 photocatalysts activated in H_2 at 350°C.

Efficient technologies for removal of contaminants of emerging concern, listed in 2013/39/EC Directive or significant risk substances according to 2008/105/EC Directive, TRICERATOPS

Participants: CIEMAT-PSA, UPV (Escuela politécnica Superior de Alcoy), Instituto Catalán de la Investigación de Agua (ICRA)

Contacts: S. Malato Rodríguez, sixto.malato@psa.es

Funding agency: Spanish Ministry of Economy and Competitiveness (Reference CTQ2015-69832-C4-1-R)

Background: The initial hypothesis focuses different advanced oxidation processes, operational procedures and different ways of combining them for wastewater treatment. The project will focus water containing microcontaminants (MCs) of important concern identified by EU or already identified as risk substances for water.

Objectives: (i) Elimination by novel technologies of priority or emerging concern MCs present in wastewaters and listed in EU legislation; (ii) Propose photoreductive electron transfer processes for the elimination of contaminants recalcitrant to oxidation; (iii) Waste and wastewater valorization for elimination of MCs; (iv) Design of new photoreactors based on solar irradiation and LEDs; (v) Integration of nanofiltration procesess and novel AOPs.

Achievements in 2016: CIEMAT-PSA experiments have been focused on different tasks of the project. MCs have been selected (Terbutryn, chlorfenvinphos, pentachlorophenol and diclofenac) and analytical protocols have been developed. Poliphenols evaluation in agro-industrial wastewater (olive mill wastewater and cork boiling wastewater) as Fe-complexing agents to work in circumneutral pH. Comparison by PCR technique of microorganisms from municipal wastewater treatment plant and from immobilized bioreactor adapted to landfill leachate. Developing of ozonation coupled to solar AOPs installing a new ozonation reactor connected to a 70-mm CPC photoreactor (Figure 104). Cork Boiling Wastewater (CBW) was evaluated for regeneration of iron during the Fenton and photo-Fenton, opening the way for its reuse. Small quantities of CBW (1:50 related with wastewater to be treated) have been shown to increase availability of iron in natural water up to pH 5 and enhance the degradation of a mixture of contaminants at near-neutral pH. Significant mineralization (> 70%) of these compounds was also achieved at pH 5. See also: http://www.psa.es/es/projects/triceratops/index.php

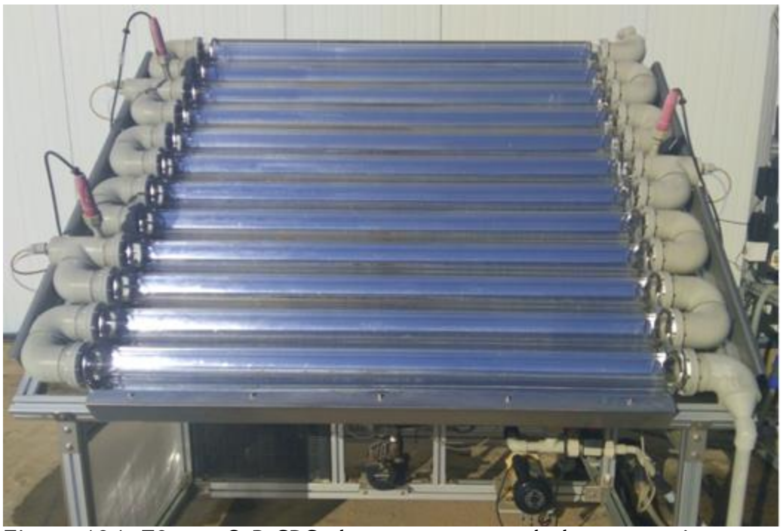


Figure 104. 70-mm O.D CPC photoreactor coupled to ozonation system to test in Triceratops project.

6 Horizontal R&D and Innovation activities

6.1 Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy, STAGE-STE

Participants: CIEMAT (Spain), DLR (Germany), PSI (Switzerland), CNRS-PROMES (France), FRAUNHOFER (Germany), ENEA (Italy), ETHZ (Switzerland), CEA (France), CYI (Cyprus), LNEG (Portugal), CTAER (Spain), CNR (Italy), CENER (Spain), TECNALIA (Spain), UEVORA (Portugal), IMDEA (Spain), CRANFIELD (UK), IK4-TEKNIKER (Spain), UNIPA (Italy), CRS4 (Italy), INESC-ID (Portugal), IST-ID (Portugal), SENER (Spain), HITTITE (Turkey), ACCIONA (Spain), SCHOTT (Germany), ASE (Italy), ESTELA (Belgium), ABENGOA SOLAR (Spain), KSU (Saudi Arabia), UNAM (Mexico), SUN (South Africa), CSERS (Libya), CSIRO (Australia), FUSP (Brazil), IEECAS (China), UDC (Chile), UCAM (Morocco), FBK (Italy), CNIM (France) and COBRA (Spain).

Contacts: Julian Blanco Galvez (Project Coordinator), julian.blanco@psa.es,
Ricardo Sanchez (Project Manager), ricardo.sanchez@psa.es

Funding agency: European Commission, FP7-ENERGY-2013.10.1.10

Background: STAGE-STE project is an IRP (Integrated Research Programmes) initiative addressed to integrate and finance the activities of EERA (European Energy Research Alliance) Joint Programme on Concentrating Solar Power (JP-CSP). EERA (www.eera-set.eu) is an organization involving more than 150 European energy research institutions and officially one of the pillars of the EU SET-Plan (http://setis.ec.europa.eu). EERA main objective is to reinforce the collaboration in the development of energy technologies (through joint R&D) and support the competitiveness of European industry at international level. To this end, STAGE-STE consortium (equivalent at beginning of the project to EERA JP-CSP) involves a large majority of EU research organizations relevant to CSP/STE (Solar Thermal Electricity) topic.

Objectives: To convert the STAGE-STE consortium into the natural reference institution for STE/CSP research in Europe providing to both the Commission and the Industry a natural gatekeeper for R&D investment and technology transfer in the field. This is intended to be achieved with the alignment of the different STE EU national research programs and addressing a comprehensive number of coordinated and integrating activities to lay the foundations for long-lasting research cooperation in Europe, such as:

- Joint activities to foster the use of existing research facilities.
- Training activities and exchange of researchers to facilitate the co-operation between research organisations.
- Transfer of knowledge activities to reinforce the partnership with industry.
- International cooperation activities.

Achievements in 2016: With regard to the Coordination and Supporting Activities (CSA) carried out during 2016 the main project achievement is clearly the successful contribution to the Implementation Plan for the achievement of CSP/STE SET-Plan defined technological targets. Based on the previous creation of National Working Groups (in Cyprus, France, Germany, Italy, Portugal, Spain, Switzerland and UK) to progress on the alignment of national programmes, the definition and classification (by potential relevance) of 12 projects to provide the industry technological innovations suitable to be introduced into innovative commercial CSP/STE plants, could be finished into a remarkable short time period. This contribution was one of the 3 final pillars of such Implementation Plan.

Figure 105. 3rd General Coordination Meeting (Villigen, Switzerland), 29th -30th June 2016.

On the other hand, the Solar Concentrating Systems Unit has been actively involved in the CSA activities of STAGE-STE project in 2016. In WP2, we have participated in the temporary working group implemented to define the high-priority special actions required for the SET Implementation Plan in order to achieve a significant cost reduction of solar thermal electricity. In WP3 we have coordinated Task 3.2 and arranged an international workshop with the industrial sector in Abu-Dhabi on October 2016 to identify the industry need concerning research infrastructures.

In WP4 researchers from the PSA Unit for Concentrating Solar Systems have participated in staff exchanges with CEA, CENER, CNRS and Fraunhofer-ISE. We have also participated in the definition of the 1-week Reference Course on CSP/STE planned in Task 4.3.

In WP5 we have coordinated the activities of Task 5.4, mainly devoted to standardization in the sector of concentrating solar systems and their applications. The document D5.4 "*Guidelines for Standardization on STE*" explaining the national and international standardization initiatives currently underway regarding this sector was issued in February 2016.

In WP6 we have coordinated the Task 6.1, which is devoted to collaboration with IRENA, ISES and SolarPACES. Additionally, STAGE-STE progress reports were presented at the SolarPACES Executive Committees in March and October 2016 to inform the international community of SoalrPACES about the status of STAGE-STE, thus contributing to dissemination activities.

WP7: Thermal Storage

Participants: CIEMAT-PSA, CENER, CNR, CNRS, CRS4, CYI, DLR, ENEA (WP7 coordinator), ETHZ, Fraunhofer-ISE, IMDEA, LNEG, Tecnalia, Tekniker, UEVORA, Abengoa Solar NT, SENER

Contacts: Esther Rojas, esther.rojas@ciemat.es, Tasks 7.3 (coordinator)

Background: Direct Steam Generation (DSG) is seen as one of the most promising approaches to reducing LEC for Solar Thermal power plants. Using storage materials that change phase from solid to liquid statically, electrical power decreases during discharge due either to a decrease of steam generation rate, when working at constant temperature and pressure of the heat carrier, or to a decrease of electrical efficiency, when working with sliding pressure.

Objectives: Ciemat proposes to solve the aforementioned problem with a new concept which involves storage material changing phase from one liquid state to another. This kind of behaviour is only displayed by liquid crystals (LCs), which are substances that, rather than passing through a single transition from solid to isotropic liquid, exhibit a sequence of one or more transitions involving intermediate fluid phases, called mesophases. Thus, a nearly constant power curve is possible, and an efficient exchange of energy is assured since convection is the main heat transfer mechanism.

Achievements in 2016: An oven for thermal cycling of samples of 1-5 g has been prepared (HDR). It has a controlled heating by PID and cooling by natural ventilation. A testing procedure for checking the cycling of storage materials has been prepared and used for testing the liquid crystal candidate that showed the best enthalpy behaviour with DSC.

WP8: Materials for Solar Receivers and STE Components

Participants: CIEMAT, DLR, CNRS, FISE, ENEA, CEA, LNEG, CNR, CENER, TECN, CRAN, TKN, IST-ID, SENER, HITIT, SCHOTT, ASE, ASNT, COBRA.

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es, Tasks 8.1 and 8.3);
Rafael López Martín, rafael.lopez@psa.es, Task 8.2.4;
María Isabel Roldán Serrano (mariaisabel.roldan@psa.es, Task 8.2.6).

Funding agency: European Commission, 7FP-ENERGY-2013.

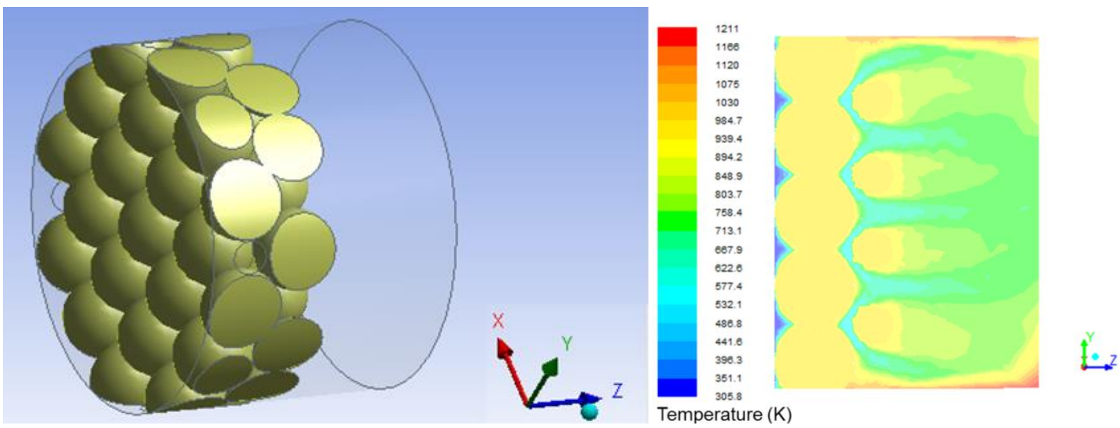
Background: Research has been conducted towards developing a durability testing guideline for solar reflectors to predict material failure in advance. By and large, the study of new solar receiver designs is a required investigation due to the need to improve their thermal performance at high temperatures. In addition, it has appeared several methods for the measurement of parameters in linear receivers and it is necessary to validate them.

Objectives: CIEMAT's participation is focused on: i) developing methods of accelerated ageing for reflectors that provide estimations of degradation over lifetime; ii) comparing test benches for heat losses measurement of line focusing receivers; iii) analysing the suitability of enhanced materials for high temperature applications; iv) investigating the occurrence of abrasion under desert conditions and simulate it under laboratory conditions.

Achievements in 2016: Concerning the topic related to the development of a guideline for durability testing of solar reflectors (Task 8.1), a round robin test among the participating partners (CEA, CENER, CIEMAT/DLR, LNEG and TECNALIA) was accomplished to compare methodologies and protocols. All partners except one have already finished the experimental campaign and results comparison is under preparation. Also, several reflectors that have been exposed outdoors in commercial plants were analysed by CIEMAT/DLR to identify the degradation mechanisms appearing during operation.

Regarding to task 8.2.4, it has been submitted Deliverable 8.4 about the Round Robin Test results for the comparative of heat loss measurements of parabolic through receivers. These results were also presented in the international conference SolarPACES 2016. The participating laboratories are CENER, DLR, CIEMAT and ENEA.

The main objective of task 8.2.6 is the design and testing of a high-temperature solar absorber using a low-cost material and a simple manufacturing process. The absorber concept consists of alumina pebbles with improved absorptance (Figure 106). Therefore, the selection of both the absorber configuration and the type of coating are the main activities of this task. Several absorber configurations as well as different coatings (Pyromark 2500 and the ones developed by CIEMAT) have been characterized by theoretical and experimental methods. Testing of coated pebbles absorbers will determine the best configuration.



(a) (b)

Figure 106.CFD simulation of the alumina pebble receiver (task 8.2.6): (a) geometry, (b) thermal profile.

With respect to the study of the erosion of reflectors under desert conditions (Task 8.3), a guideline with the adequate methodology to conduct accelerated aging tests was developed. A round robin test is under preparation to check the suitability of this guideline. Three different testing setups (closed loop, open loop and sand trickling) are under investigation by DLR/CIEMAT with the goal of properly reproducing the outdoor degradation.

WP10: Solar Thermal Electricity + Desalination

Participants: CIEMAT-PSA (WP10 coordinator), FISE, ENEA, CEA, CYI, LNEG, CENER, UEVORA, UNIPA, SENER, HITTITE, FBK

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

Background: Combined electricity and fresh water production by means of solar thermal concentrating technologies can be proposed as a solution in many locations of the world where water scarcity usually coincides with the availability of high solar irradiation levels.

Objectives: The main objective is to answer the basic question about under which conditions a solar thermal cogeneration scheme can be more feasible than the separate production of power by a STE plant and the use of such power to run a desalination process.

Achievements in 2016: During the third year of the project, a set of simulation libraries for the joint assessment of thermal desalination processes (LT-MED[1], MED-TVC[2], MSF[3], and MD), membrane processes (i.e. reverse osmosis) and solar thermal concentrating power plants has been developed. Such implementation has been carried out in a computer environment that will allow the generation of runtime applications easy to be distributed between the scientific community and decision-makers in order to promote the implementation of such systems.

WP 11: Line-focusing STE Technologies

Participants: CIEMAT (WP11 coordinator), CNRS, Fraunhofer-ISE, ENEA, CEA, LNEG, CTAER, CENER, Tecnalia, University of Evora, Cranfield University, Tekniker, SENER, HITIT Solar Enerji, Acciona Energía, Archimede Solar Energy, Abengoa Solar NT, COBRA.

Contact: Loreto Valenzuela (loreto.valenzuela@psa.es)

[1] Low Temperature Multi Effect Distillation
[2] Multiple Effect Distillation with Thermal Vapour Compression
[3] Multi-Stage Flash Distillation

Funding agency: European Commission, 7FP-ENERGY-2013

Background: A big deployment of large commercial solar fields for electricity generation, specially using parabolic troughs has appeared in the last 10 ten years. In addition, it has been identified by different stakeholders the big potential for the application of line-focusing solar collectors' technology for distributed power and process heat generation, and solar heating and cooling applications.

Objectives: CIEMAT's participation is focused on: i) explore and develop new concepts of medium temperature line-focusing collectors; ii) work in the modelling and simulation of parabolic troughs fields using water-steam as heat transfer fluids; iii) define and validate dynamic solar field testing procedures; iv) define and analyse new methodologies for on-site characterization of line-focus collectors and their components in large commercial solar fields.

Achievements in 2016: CIEMAT defined the layout of a 35 MW_e solar field with parabolic troughs for direct steam generation that has been analysed with TRNSYS to calculate the yield annual performance (see Figure 107), and with RELAP to analyse thermo-hydraulic phenomena in the solar receivers, with special focus on the two-phase flow region. Results of the simulation studies were compared to the results obtained by CEA using Dymola/Modelica (Task 11.1.3). TRNSYS and Dymola models apply homogeneous approaches to deal with two-phase fluid, using average parameters, while RELAP handles the two phases in a separate way. As a conclusion of the study, for energy and long-term simulations homogeneous models can provide a proper estimation of useful thermal power since their results match quite well in steady-state conditions.

In the context of Task 11.2.1, IK4-Tekniker and CIEMAT collaborated in calibration and validation of an object-oriented simulation model of PTCs developed in Modelica language. A join test campaign was done in the HTF test loop at the PSA during summer 2016.

CIEMAT coordinates the working groups of thermal inspection of receivers, inspection of reflectance/soiling of reflectors, and inspection of other components (structures, tracking mechanisms, etc.) in large solar fields (Task 11.2.2). Main activities run this year are:

- Two test campaigns were conducted in commercial PTCs power plants from Acciona and Sener in September 2016. The purpose of these tests is a round robin test to check the characteristics and measurement protocol with three different portable reflectometers. Results of this round robin test will be finished in 2017.

- CIEMAT completed indoor and outdoor test campaigns at the PSA to quantify vacuum status level of solar receiver tubes for PTCs by mean of infrared thermography.

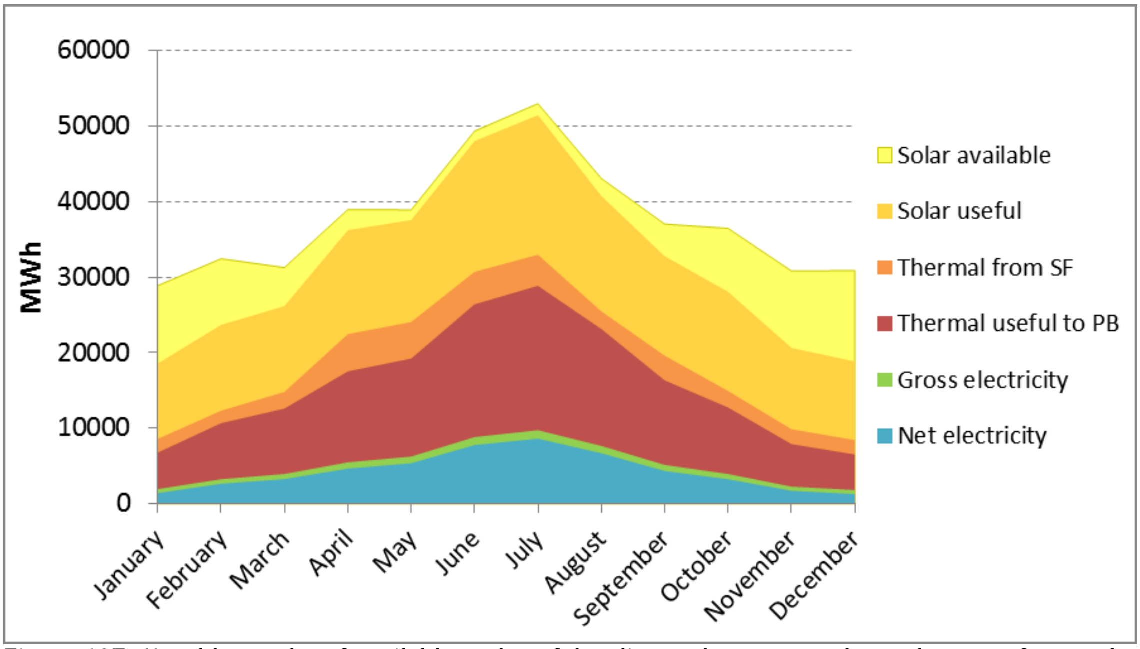


Figure 107. Monthly results of available and useful radiant solar energy, thermal energy from a the solar field and useful to power block, gross and net electricity production of a 35 MW_e DSG solar plant defined, modelled and simulated in the context of STAGE-STE project (Task 11.1.3).

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

Participants: CTAER (Spain), CIEMAT (Spain), CNRS (France), DLR (Germany), ENEA (Italy), CyI (Cyprus), ESTELA (Belgium), MINECO (Spain), LNEG (Portugal), SELKUC U (Turkey), GUNAM (Turkey), U. EVORA/IPES (Portugal), APTL (Greece), WEIZMANN (Israel), CRESS (Greece).

Contacts: Eduardo Zarza (Technical coordinator), eduardo.zarza@psa.es

Funding agency: European Commission, FP7-INFRASTRUCTURES-2012-1

Background: An effort is needed to maintain Europe at the forefront of the Concentrating Solar Thermal and Solar Chemistry technologies. The scientific communities, industries and universities involved must be efficiently linked and the European RI must be coordinated to provide the most complete, high quality RI portfolio, facilitating researchers' access to them through a single access point.

Objectives: The creation of a new legal entity to explore and implement new and improved rules and procedures for Research Infrastructures (RI) for Concentrating Solar Thermal (CST) and Solar Chemistry technologies, in order to optimize European RI development and Research and Technology Development (RTD) coordination in this field (www.eusolaris.eu).

Achievements in 2016: PSA activities in 2016 were mainly devoted to the Work Package 2 "Legal status & User access policies" of this project, undertaking its overall coordination and the finishing of Tasks 2.5 ("Users support") and 2.6 ("Access rules"). Several EU-SOLARIS documents were elaborated and issued by PSA in 2016:

- The deliverable ID2.5 "*Protocol for Users support in EU-SOLARIS*" was issued by PSA in March 2016.
- The deliverable ID4.2.4 "*Recommended Ways to Align EU-SOLARIS new Research Infrastructures and Strategy with Industrial Needs*" was issued by PSA in September 2016.
- The document MS19 "*Report on the viability of the new services to be offered based in users' demand*" was issued by PSA in December 2016.
- The document D3.3 "*Services to be offered by EU-SOLARIS during the Implementation Phase*" was issued by PSA in November 2016. This document describes all the services that will be offered by EU-SOLARIS, including both the services already offered by the Partners and the additional services that would be offered after some improvements and upgrades proposed by the Partners for existing facilities.

Year 2016 was a very fruitful year concerning the issue of deliverables and milestones of EU-SOLARIS. One of the main documents issued in 2016 was the Business Plan for EU-SOLARIS, which was issued in October. The final project meeting took place in Brussels in the morning of September 26th, while the main project conclusions and results were presented the same day in the evening. The EU-SOLARIS preparatory phase official ended on October 31st, 2016, and all the documents required for the legal implementation of EU-SOLARIS as an ERIC (European Research Infrastructure Consortium) were finished. Afterwards, the Partners must check whether the consensus required for the legal implementation of EU-SOLARIS according to the Business Plan elaborated and proposed in 2016 exists or not.

Figure 108. Participants in the 8th EU-SOLARIS Steering Committee Meeting held in Evora (Portugal).

6.3 Solar Facilities for the European Research Area: Second Phase, SFERA II

Participants: CIEMAT-PSA (coordinator), DLR (Germany), CNRS (France), PSI (Switzerland), ETHZ (Switzerland), ENEA (Italy), CEA (France), INESC-ID (Portugal), UEVORA (portugal), UNILIM (France), ESTELA (Belgium) and UTV (Italy).

Contacts: Isabel Oller Alberola (Project Coordinator), isabel.oller@psa.es
Ricardo Sánchez (Project Manager and Transnational Access Coordinator), ricardo.sanchez@psa.es

Funding agency: European Commission, FP7-INFRASTRUCTURES-2012-1.1.1

Background: CSP Research Infrastructures in Europe have served through the last 30 years as research tools to demonstrate the concept feasibility by exploring different pathways on how to produce high temperature heat, electricity and, solar fuel using concentrating solar radiation. Nowadays, the key point is to cooperate with the industry in order to gain a significant market share.

Objectives: The purpose of this project is to integrate, coordinate and further focus scientific collaboration among the leading European research institutions in solar concentrating systems that are the partners of this project and offer European research and industry access to the best-qualified research and test infrastructures.

Achievements in 2016: SFERA II project is divided into three main activities: Networking, Transnational Access and Join Research Activities. Results obtained through 2016 in Research Activities lead by CIEMAT are presented below.

Regarding Networking activities, PSA-CIEMAT organized the 3rd SFERA Doctoral Colloquium from the 6th to the 8th of June 2016, by PSA-CIEMAT to improve sharing between the PhD students of the different partners' institutions. There were 31 PhD students registered from all partners of the project (Figure 109). 3rd SFERA Summer School was also organized by PSA-CIEMAT from the 8th to the 10th of June, 2016. This 3rd SFERA School was dedicated to Heat Transfer Fluids & Innovative R+D Subjects

The 3rd USP meeting for free Transnational Access to the SFERA-II facilities took place in Rome (at ENEA premises) on the 31st of March, 2016, coordinated by the Access Coordinator (Ricardo Sánchez, CIEMAT). CIEMAT-PSA received in SFERA-II 2016 access campaign 46 user proposal forms, including 9 user proposal forms to access the third-party beneficiary UAL-CIESOL. After the USP meeting, 33 user proposal forms were finally accepted while 7 of them were rejected, i.e. 6 user proposals to access CIEMAT-PSA and 1 user proposal to access UAL-CIESOL.

Under SFERA-II, a person of the Thermal Storage Group has proposed and performed a test campaign in the STONE facility at CEA premises in Grenoble. Apart from closing the collaboration between both institutions, a result of the research stay was a paper presented in the SolarPACES2016 conference in Abu Dhabi, UAE.

Figure 109. 3rd SFERA Doctoral Colloquium organized by PSA-CIEMAT at Hotel Rodalquilar, Almeria (Spain), from 6 to 8 June 2016.

Participation of the Solar Concentrating Systems Unit in SFERA-II WPs devoted to joint R&D activities (WP11, 12, 13, 14 and 15)

Participants: CIEMAT (Spain), CNRS (France), DLR (Germany), ENEA (Italy), ETH (Switzerland)

Contact: Eduardo Zarza Moya, eduardo.zarza@psa.es

Funding agency: European Commission, FP7-INFRASTRUCTURES-2012-1.1.1

Background: Common test protocols and new experimental facilities and devices are required to provide the industrial sector of concentrating solar thermal technologies with the high-quality services required to maintain Europe at the forefront of these technologies.

Objectives: The objective of the SFERA-II work packages devoted to Joint R+D (WP11, 12, 13, 14 and 15) is to develop common test protocols, new test devices and new procedures for specific topics demanding a high level of expertise and background.

Results in 2016: Although PSA has participated in very different activities included in the SFERA-II WPs devoted to joint R+D activities in 2016, the main contribution has been devoted to WP14, which is coordinated by PSA. The main activities in WP14 have been:

- a draft protocol for mirror characterization using different techniques has been prepared and it is under discussion. A comparison of three different

methodologies (deflectometry, Photogrammetry and Laser scanner) was carried out at the PSA in 2016 and the results are under evaluation
- assembly and testing of a new outdoor device to measure the angular torsion of parabolic-trough collectors using high-resolution inclinometers
- collaboration in the preparation of the a draft protocol proposed by DLR to define the geometrical and optical quality of heliostats, and
- a new test bench suitable for evaluating all types of parabolic-trough collectors inter-connection devices (i.e., ball-joints, flexible hoses and hybrid devices) has been mechanically and electrically implemented at the PSA.

PSA has also participated in WP11, 12, 13 and 15 collaborating with DLR, CNRS, ENEA and PSI in the activities planned in those WPs. So, in WP11 PSA has collaborated with DLR in the improvement of the local meteo station, and has participated in calibration campaigns of pyrheliometers and pyranometers using the special device manufactured by PSA in 2014. In WP12 and WP13 PSA has collaborated with CNRS and ETH in the development and evaluation of new methods to measure the temperature and optical properties of materials under concentrated solar radiaction. In WP15, PSA has prepared a first draft of the deliverable D15.10 "*Report on CO_2 as HTF*".

Figure 110. Overall view of the metallic building housing the new test bench for parabolic trough collectors interconnections.

6.4 Network for Excellence in Solar Thermal Energy Research, NESTER

Participants: CYI (coordinator), CIEMAT-PSA (Spain), ENEA-UTRINN (Italy), CNRS-PROMES (France), RWTH-AACHEN university (Germany)

Contacts: Julian Blanco (Technical Coordinator), julian.blanco@psa.es
Diego-César Alarcón-Padilla, diego.alarcon@psa.es

Funding agency: European Commission, H2020-TWINN-2015

Background: The geopolitical placement of Cyprus offers excellent opportunities for cultivating a research and innovation niche in solar technologies. At the same time the remoteness of the corresponding centres of Excellence of EU is a major impediment. The NESTER Project strives to enhance the advantages and ameliorate the disadvantages of this geographical placement.

Objectives: The NESTER Project aims in upgrading the scientific and innovation performance of the Cyprus Institute (CyI) in the field of Solar Thermal Energy. The upgrade will be achieved by embedding the Institute's activities in a network of excellence, which will provide access to the latest know-how and facilities, train CyI's scientific and technical personnel and link it with the European Industry. The substantial investments made/planned by CyI in infrastructure and personnel will thus become more efficient and competitive allowing claim to international excellence.

Achievements in 2016: During this first year of the project the most remarkable activities have been the establishment of the agenda of winter schools, specific workshops, secondments and mentoring visits during the next three years of the project. From November 7-17, CIEMAT-PSA participated in the first STE Autumn School in Nicosia (Cyprus), the first of a series of annual events on CSP to be held in Cyprus and directed to graduate (Masters and Doctoral) students and to early career professionals. The school offers a fast paced comprehensive overview of the field, to be followed by intermediate and advanced lectures on selected topics of keen interest to the field, delivered by world experts. In addition, visits and hands-on activities take place in the state-of-the-art research infrastructures of the Cyprus Institute.

Figure 111. First Winter School, held in Nicosia on 7th -17th November 2016.

First week of this Autumn Scholl has been dedicated to the General Modules and the lectures at the second week focused on Advanced Modules on Optics and on Desalination, with an outstanding participation of PSA's Water Desalination Unit staff.

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

Participants: FRAUNHOFER (Germany), AEE-INTEC (Austria), CIEMAT (Spain), DLR (Germany), CNRS (France), ENEA (Italy), ETHZ (Switzerland), CEA (France), CYI (Cyprus), LNEG (Portugal), CTAER (Spain), CNR (Italy), CENER (Spain), TECNALIA (Spain), UEVORA (Portugal), IMDEA (Spain), CRANFIELD (UK), IK4-TEKNIKER (Spain), UNIPA (Italy), IST-ID (Portugal), FBK (Italy), CRES (Greece), METU (Turkey), EERA AISBL (Belgium), UNINA (Italy), UNIFI (Italy), US (Spain), CIC Energigune (Spain).

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

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

Background: Process heat is recognized as the application with 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 ºC.

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 2016: Though official starting date for this project is 1st January 2017, it is worth mentioning the huge effort carried out by the project consortium in the preparation and submission of a winning proposal, responding 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).

Figure 112 Kick-off meeting, held in Brussels on 13-14 January 2017.

6.6 Water Saving for Solar Concentrating Power, WASCOP

Participants: CEA, DLR, CIEMAT-PSA, Cranfield University, Fundación Tekniker, MASEN, Rioglass Solar, Archimede Solar Energy, OMT Solutions, Hamon D´Hondt, AMIRES.

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

Funding agency: European Commission, H2020-LCE-02-2015.

Background: CSP plants use significant amounts of water to function properly. Water is a restricted resource in the parts of the world where the majority of CSP plants are installed. Water saving is therefore one of the major issues to ensure a financially competitive position of CSP plants and their sustainable implementation.

Objectives: To develop a revolutionary innovation in water management of CSP plants, a flexible integrated solution (or toolbox) comprising different innovative technologies and optimized strategies for the cooling of the power block and the cleaning of the solar field, with the aim of a significant reduction in water consumption (up to 70% - 90%).

Achievements in 2016: CIEMAT-PSA is involved in this project through its Desalination and Solar Concentrating Technologies Units.

During the first year of the project, CIEMAT-PSA's activity has been focussed on establishing the technical and economical toolbox requirements, the technical specifications of the technologies and the test plan and validation methods.

The application of anti-soiling coatings on reflectors and absorber tubes has been evaluated to decrease water consumption in cleaning. Samples preparation was started during 2016. In addition, a literature revision of the dust barriers to reduce the amount of particles achieving the solar field was performed.

Figure 113. Accelerated aging tests of mirror samples performed in weathering chambers.

CIEMAT-PSA has contributed this year in the elaboration of the modelling strategy for the development of an overall model of the CSP plant, in which the different cooling approaches of the power block considered in the project are included.

After preparing a technical inventory of hybridized coolers, CIEMAT-PSA has contributed to the design of a new prototype of hybridized cooler that will be installed at the PSA which allow the water saving without penalizing the efficiency of the power block.

A first technical options inventory for heat rejection via latent storage for nocturnal exhaust has been done, based on a literature review in both scientific journals and commercial products. A shorter list of potential phase change materials has been defined and chosen two of them in order to test them for checking their cyclability and verify the thermophysical properties the available information claim they have. Melting/freezing cycles of 24 hours are currently running. Our model for latent storage is being adapted to reflect the thermal behaviour of a storage system of the type when used as equipment for shifting day time heat exhaust to night time.

On 29th November 2016, CIEMAT held at the PSA a workshop for plant operators, plant owners and service providers. The workshop was organized by WASCOP project in collaboration with MinWaterCSP project, also EU funded. After presenting both projects' objectives, approaches and work to date, representatives were open to discuss how these projects can help the CSP stakeholders to reduce the all-over water consumption of CSP plants and gather input from participants.

6.5 Automatic Control Group

6.5.1 Introduction

The Automatic Control group belongs to the Direction unit and its purpose is to collaborate with the different R&D units in the research activities carried out by developing dynamic models of solar thermal plants, designing control algorithms and applying optimization techniques to improve the operation of the systems. In 2016, the Automatic Control group addressed diverse activities mainly related with the international project HYSOL and the national project ENERPRO (in collaboration with the desalination unit):

1. Experimental campaigns devoted to modeling and control strategies validation at hybrid demonstrator plants, thermal storage facilities and solar desalination plants.
2. Analysis of delay uncertainties causes based on experimental campaigns and dynamic model simulations at hybrid demonstrator plants and solar fields with novel industrial collectors. Study of robust control strategies to improve the control performance.
3. Multi-objective optimization applied to solar desalination units.
4. Model predictive control for micro-grid systems composed of greenhouses and solar desalination plants.
5. Hierarchical model predictive control for solar desalination plants.
6. Development of virtual simulators for hybrid demonstrator plants.

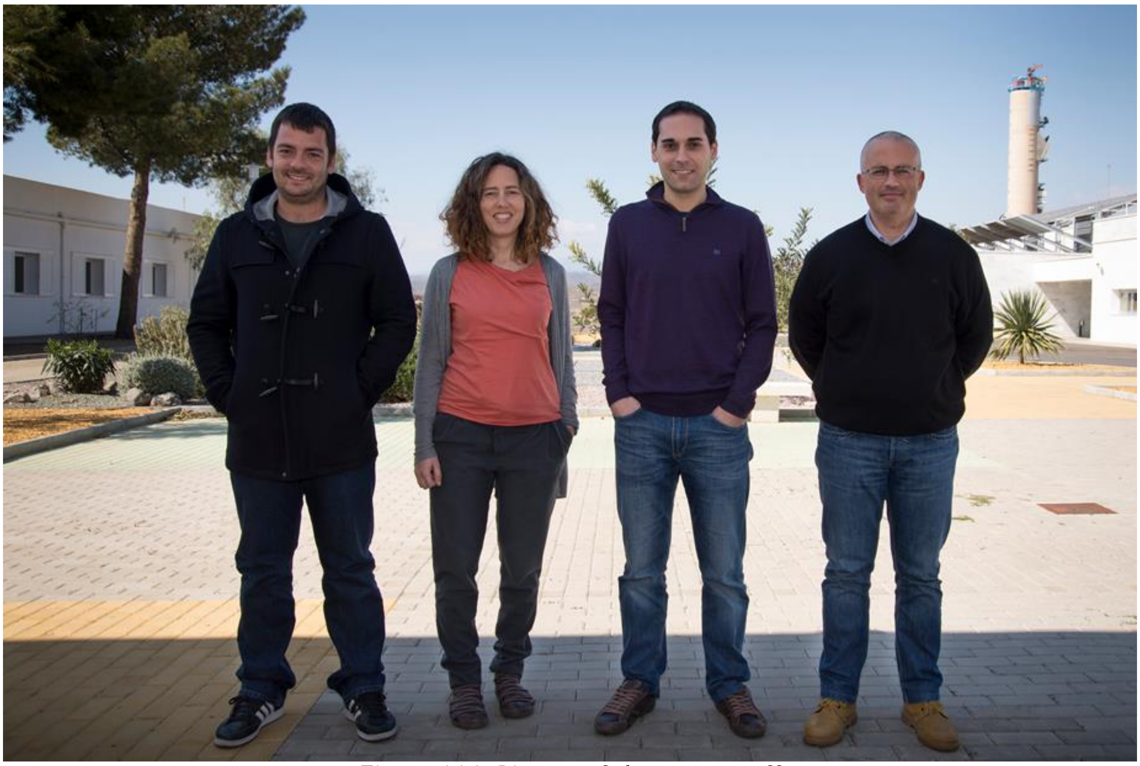


Figure 114. Picture of the group staff

6.5.2 Projects

Innovative Configuration for a Fully Renewable Hybridcsp Plant, HYSOL

Participants: ACS-COBRA, CIEMAT-PSA, ENEA, IDIE, AITESA, DTU-MAN-SYS, UPM, SDLO-PRI.

Contacts: Lidia Roca, lidia.roca@psa.es
Javier Bonilla, javier.bonilla@psa.es

Funding agency: European Commission, FP7-ENERGY-2012.

Background: One of the main challenges in power plants based on renewable energies is to supply power to the electrical grid in a stable, firm and reliable manner. Hybrid technologies, such as the combination of CSP with biomass or biogas plants, could be a solution to produce energy continually.

Objectives: The main goal of the HYSOL project is the study, design, optimization and construction of a pre-industrial demonstrator based on an innovative hybridization configuration of CSP and biogas for a 100% renewable power plant. A pre-industrial scale demonstrator is being set up in an existing CSP plant. The demonstrator is based on an aeroderivative gas turbine (AGT) exhaust gases simulator coupled with a heat recovery system (HRS) (gas-molten salt).

Achievements in 2016: The following main achievements have been obtained in the final year of the project.

1. Development and validation of dynamic models based on physical equations: heat recovery system (gas-molten salt heat exchanger), thermal oil-molten salt heat exchanger, molten salt storage system. These models have been validated with experimental data from experimental campaigns performed at HYSOL demonstrator and MOSA facility at PSA.
2. Development of dynamic black box models based on experimental data (gas heater), literature information and/or parametric correlations developed together with other project partners (gas turbine).
3. Design, testing and validation of control strategies for the HYSOL demonstrator targeting safety and performance goals.
4. Development and validation of the whole HYSOL demonstrator dynamic model.
5. Development of an operating training software tool for the HYSOL demonstrator. This tool is useful for studying the system dynamic, test control strategies and train plant operators.

Figure 115. HYSOL demonstrator at the cluster of thermosolar innovation of Manchasol in Ciudad Real (Spain).

7 TRAINING AND EDUCATIONAL ACTIVITIES

The ruling principle of the Plataforma Solar de Almeria training program is the creation of a generation of young researchers who can contribute to the deploy-ment of solar thermal energy applications. Through this program, about forty students of different nationalities are admitted each year so that we can transmit the knowledge of solar thermal technology accumulated at the PSA in its thirty years of experience to new generations of university graduates.

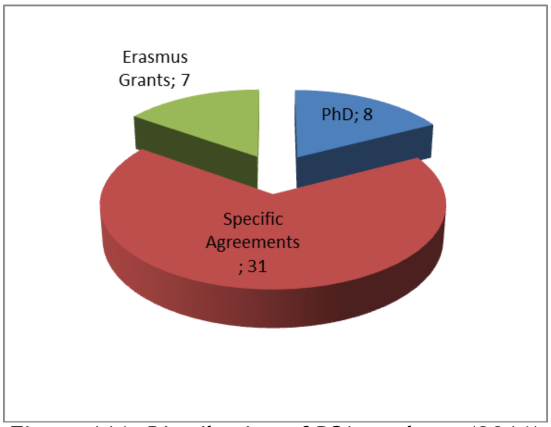


Figure 116. Distribution of PSA students (2016)

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with an annual agreement with the University of Almeria (UAL) and with the own program to young researcher of CIEMAT.
- European funded 'Erasmus' grants, for students from other countries, mainly German.
- Management of miscellaneous specific educational cooperation agreements with other entities for sending students to the PSA (Universities of Cádiz, Almeria, País Vasco, Dalarna-Sweden, Politecnico di Torino-Italy, Blida-Algeria, CDER-Algeria, UIR-Morocco, Antofagasta-Chile, Santiago de Chile-Chile, AUCC-Chile, Veracruzana-Mexico, Royal College of Surgeons-Ireland, Hamburg University of Technology, Salesiana-Ecuador, Concepción-Chile, ICO-Mexico, Palermo-Italy etc.)

The PSA is a founding member of the 'Alliance of European Laboratories on Solar Thermal Concentrating Systems' (SolLab). This virtual laboratory is made up of the main European concentrating solar energy research institutes, that is, PROMES-CNRS in Odeillo (France), the DLR Solar Energy Division in Cologne (Germany), the Renewable Energies Laboratory of the Federal Institute of Technology in Zurich (ETHZ, Switzerland), the Paul Scherrer Institute in Zurich (PSI, Switzerland) and CIEMAT itself.

Founding in 2004 of SolLab opened new possibilities for scientific development of researchers in training at the PSA. One of the joint SolLab activities is an annual seminar for Ph.D. students from the five different institutions (Doctoral Colloquium), which is part of the activities of the European project so-called SFERA-II (Solar Facilities for the European Research Area - Second Phase) at the same time. The 12th SolLab was organized by the Plataforma Solar de Almeria and took place in Rodalquilar (Almeria), Spain. The Colloquium was held between the 6th to the 8th of June 2016. Afterwards, the SFERA Summer School was hosted at the same location from the 9th to the 10h of June, 2016. It was focused on Heat Transfer Fluids and Innovative R&D Subjects.

The International Doctorate School of UAL published the list of the Extraordinary Doctorate Awards for the period 2007-2015 on 28th September 2016, recognizing the exceptional quality of the thesis of six PSA researchers: Isabel Oller, Lidia Roca, Mª Inmaculada Polo, Aránzazu Fernández, Javier Bonilla and Sara Miralles.

		
Isabel Oller	Lidia Roca	Mª Inmaculada Polo
		
Aránzazu Fernández	Javier Bonilla	Sara Miralles

8. Events

12/01/2016
Institutional visit
The Delegate of Government in Andalucia, D. Antonio Sanz, accompanied by the Sub-Delegate in Almeria, visited in detail the PSA research facilities receiving technical information about the overall activities and showing the capabilities for potential contributions in regional technological development.

15/01/2016
Lecture
Invited lecture of Sixto Malato in the workshop on "1ª Jornada Técnica sobre Oxidación Avanzada en el Tratamiento de Aguas", held at Castellón (Spain) and organized by Universitat Jaume I.

01/02/2016
Lecture
Invited lecture on Thermal and Thermochemical Storage, given by Esther Rojas, in the 3rd Symposium on Solar Energy – Solar Concentration and the Future, Evora, Portugal

04/02/2016
Lecture
Invited lecture of Rocío Bayón on "Storage in molten salts" in the Electricity Storage Workshop organized by Fundación Gas Natural, Sevilla (Spain).

09/02/2016
Official meeting
G. Zaragoza organized the executive meeting of the Renewable Energy Desalination Action Group during the EIP Water Conference in Leeuwarden (Netherlands).

22-26/02/2016
Dissemination and divulgation
J. Fernández gave lectures at the 2nd Course on Solar Thermal Energy in the Summer School of the University of La Plata (Argentina).

26/02/2016
Technical visit
A group of engineers and officers from TEWER and ACWA companies visited PSA as part of the training activities in Spain related to solar thermal power plants.

29/02-01/03/2016
International Workshop
Participation of J. Blanco in the international workshop on "EU-GCC Opportunities and Challenges on Sustainable Energies Research", organized by Qatar National Research Fund and the European Commission (Doha, Qatar), and representing the EERA Joint Program on CSP.

04/03/2016
Institutional event
S. Malato participated in the Annual Meeting "Alto Consejo Consultivo en I+D+I de la Presidencia de la Generalitat Valenciana" hosted by the President of the Regional Goverment of Valencia. Palacio de la Generalitat, Valencia.

05-07/03/2016
Official Meeting
Eduardo Zarza and Diego Alarcón participated as Spain National Representative and Operating Agent of Task VI (Solar Energy and Water Processes and Applications) respectively at the 90th Meeting of the SolarPACES Executive Committee held in Zurich (Switzerland).

07/03/2016
Technical visit
A group of engineers from FLAGSOL visited PSA facilities as part of the collaboration activities in projects related to solar thermal technologies.

16/03/2016
Lecture
Invited lecture of Rocío Bayón on "Solar thermal energy: CSP Plants" in the

Advanced Materials Master Curse at the Universidad Autónoma de Madrid (Spain)

17/03/2016
Technical visit
A group of engineers and representatives from Shanghai Electric (China) visited PSA as part of the R&D activities related to solar thermal power plants, aiming to identify the opportunities of collaboration.

31/03/2016
Technical Visit and Meeting
The kick-off meeting of the German-Spanish SITEF project (Solar-ERA.NET) was celebrated at PSA, including working sessions and technical visit to the Prometeo test facility.

31/03/2016
Institutional Meeting
The members of the Direction Board Committee of Ciemat, headed by the General Director, D. Cayetano López, celebrated their official yearly meeting at the PSA premises.

31/03/2016
Official Meeting
Participation of E. Zarza in the 8th meeting of the Steering Committee of EU-SOLARIS held at the University of Evora (Portugal).

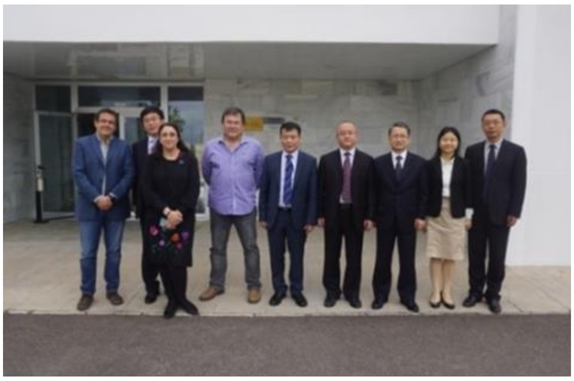
05/04/2016
Lecture
Invited lecture on "Solar Thermal Electricity (STE)" of Eduardo Zarza at the Euro-Arab Training Course held at Granada (Spain) and organized by the Fundación Euroárabe, ESCWA, GIZ and RCREEE.

06/04/2016
Official Meeting
Participation of Eduardo Zarza in the 90th SolarPACES Executive Meeting in Rome (Italy).

28/04/2016
Recording
Spanish TV show "Voy Volando" recorded at the PSA part of a chapter dedicated to the Tabernas Desert. Dr. Diego Alarcón was in charge of presenting the different experimental facilities and research activities to the documentary host, Jesús Calleja.

28/04/2016
Technical visit
A group of 12 engineers and representatives from CSP (China) visited PSA interested on research and technological development activities related to solar thermal power plants.

29/04/2016
Technical visit
A Delegation of 10 members of representatives from NARI Group Corporation, State Grid Corporation of China, headed by Mr. Wei Du, visited PSA to identify the opportunities of bilateral collaboration in R&D activities.



05/05/2016
Lecture
Invited lecture by Dr. Patricia Palenzuela (CSP Congeneration Schemes for Simultaneous Production of Electricity and Desalinated Water) at the International CSP Workshop: Learning from Noor-Ouarzazate (Casablanca, Maroc).

05/05/2016
Lecture
Invited lecture on “Phase Change Materials for thermal storage at high temperature” given by Rocio Bayón at the, EMRS (European Materials Research Society) Conference, Lille, France.

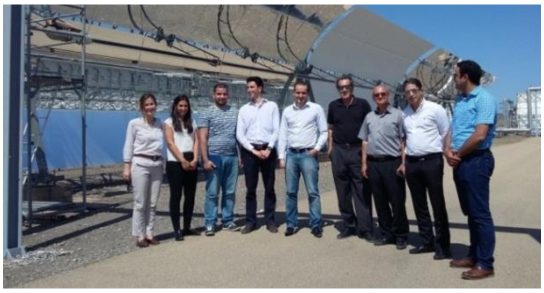
05/05/2016
Workshop
Esther Rojas participated in the workshop “Sistemas Solares de calor y Frío aplicados a la Edificación. La Participación española en la AIE y Smart Cities”, organized by Ciemat at its Headquarters in Madrid (Spain), presenting the Spanish participation on Thermal Energy Storage in the SHC TP.

10/05/2016
Institutional visit
The Delegate of Education of Soria, D. Javier Barrio, visited the research facilities receiving technical information and showing the capabilities for training and educational activities.

11/05/2016
Dissemination and courses
G. Zaragoza participated as a lecturer in the webinar training course “Estado del arte en tecnologías de desalación solar” organized by Instituto Nacional de Eficiencia Energética y Energías Renovables (INER-Ecuador).

12/05/2016
Technical Visit
In the context of CIEMAT-EDS Solar Desalination course (2016 edition, 10th-13th May), course participants made a visit to PSA installations. The visit included some practical activities on PSA Solar Desalination facilities.

31/05/2016
Technical visit
A Delegation composed by a group of representatives of several official institutions and organisms related to the energy sector from Morocco, invited by EXTENDA, visited PSA to receive information about ongoing research activities on CSP technologies.



31/05-03/06/2016
Official Meeting
Attendance of Dr. Isabel Oller to the Technological Mission on Environmental Technologies to Malaysia and Thailand organized by CDTI and PLANETA (Spanish Platform on Environmental Technologies).

01-03/06/2016
Official Meeting
Mª José Jiménez welcomed the participants in the 79th Executive Committee Meeting of the IEA Solar Heating &Cooling Program, carrying out the working sessions and also a technical visit to the PSA research facilities.

06-08/06/2016
Dissemination and networking
PSA organized the 12th Doctoral Colloquium in the frame of SolLab Alliance and SFERA-II project in Hotel Rodalquilar, Almeria. 31 PhD students from all the partners of the project were registered.

08-10/06/2016
Dissemination and networking
PSA organized the third Summer School in the frame SFERA-II project (within Networking Activities) in the Hotel Rodalquilar, Almeria. The topic of this School was: "Heat Transfer Fluids & Innovative R+D Subjects".

08/06/2016
Lecture
Invited lecture on "The use of galvanized elements in solar thermal power plants" of Eduardo Zarza at EGGA Asembly-2016 held at Seville (Spain) and organized by the European Galvanizers Association.

09-10/06/2016
Dissemination and divulgation

M.I. Roldán, M. Rodriguez, J. Fernández, R. Monterreal, R. Bayón, J. Ballestrín and E. Zarza gave lectures at the 7th SFERA Summer School held at Almeria (Spain).

16/06/2016
Lecture
Invited lecture on "Avances y retos en centrales termosolares" of Eduardo Zarza at GENERA-2016 exhibition held at Madrid (Spain) and organized by PROTERMOSOLAR and CIEMAT.

21/06/2016
Scientific meeting
G. Zaragoza organized and chaired a meeting of the Working Group Renewable Energy and Desalination of the European Water Platform WssTP in Brussels (Belgium).

22/06/2016
Doctoral Thesis
Mercedes Ibarra defended the Doctoral Thesis "Techno-economic Assessment of Systems based on Small Power Organic Rankine Cycles for their Integration in Solar Thermal Systems". UNED.

07/07/2016
Technical visit
Prof. Juan Ollivier from the Autonomous University of Chihuahua (México), visited the PSA installations invited by Ciemat, to know about CSP technologies in relation with the development and implementation of RE.

17/07/2016
Technical visit
The Deputy General Manager of the R&D Centre of the Indian Oil Corporation Ltd. (India) visited the PSA to identify and discuss opportunities of collaboration in R&D activities related to development and evaluation of components for solar thermal power plants.

19/07/2016
Lecture
Invited lectures by P. Palenzuela and G. Zaragoza on multi-effect distillation and membrane distillation respectively in the international seminar "Obtención de agua potable mediante tecnologías de desalación acopladas a energía solar" organized by Solar Energy Research Centre (SERC) in Arica (Chile).

12/09/2016
Lecture
Keynote lecture by G. Zaragoza on "Applications of Membrane Distillation to Water Treatment" at the 1st International Conference on Sustainable Water Processing organized by Elsevier from 11th to 14th September in Sitges (Barcelona).

14/09/2016
Official meeting
G. Zaragoza participated in the meeting of the Board of Directors of the European Desalination Society in Rome (Italy).

14/09/2016
Lecture
Invited lectures of Sixto Malato on "Solar Advanced Oxidation Processes for Water Treatment: Photoreactors, Applications and Economical Approach", and Diego Alarcón on "Solar Desalination Processes: from Large Capacity to Small Scale Applications", at the "3rd Water, Membrane Environment and Energy Technology Expo (WM2E-2016)". BITEC, Bangkok, Thailand.

15/9/2016
Workshop
Esther Rojas and Rocío Bayón organized and lectured at the workshop "Thermal storage for solar thermal concentrating plants", organized at IMDEA-Energía (Madrid)

19/09/2016
Scientific Committee
Participation of E. Zarza in the yearly meeting of Thematic Network Coordinators of the Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED), organized by CYTED and held in San Salvador (El Salvador).

22/09/2016
Technical visit
A Delegation from Argentina, headed by the Ministry of Planning and Industry of La Rioja Province, Mr. Ruben Gallegillo, visited the PSA installations to know about state of art on CSP technologies.

27/09/2016
Lecture
Invited lecture on of Esther Rojas at the workshop organized in conjunction with the General Assembly of Solar-Concentra, in Madrid (Spain).

20/09/2016
Technical visit
A group of 35 students from the University of Kassel in Germany, invited by the DLR, visited the PSA as part of the complementary training activities program of the Energy Systems Master Courses.

22/09/2016
Technical Visit and Meeting
A meeting with the international partners involved in the WP11 "*Line-focusing STE technologies*" of the European project STAGE-STE was held at PSA, including technical discussions and al visit to the PSA tests facilities.

28/09/2016
Workshop
E. Zarza participated in the European Conference organized by EU-SOLARIS (The European Infrastructure for Concentrated Solar Thermal and Solar Chemistry Technologies) to present the main results and conclusions of the project EU-SOLARIS, held at Brussles (Belgium).

28/09/2016
Awards
The International Doctorate School of UAL published the list of the Extraordinary Doctorate Prizes for the period 2007-2015, recognizing the excellent work of 6 PSA researchers in their Doctoral Thesis: Isabel Oller, Lidia Roca, Mª Inmaculada Polo, Aránzazu Fernández, Javier Bonilla and Sara Miralles.

11/10/2016
Technical visit
The PSA hosted the visit of the Delegation from Technology Center of Monterrey in México, headed by Mr. Ricardo Ramírez, in the frame of the ongoing cooperation with CIEMAT, with the aim of improve the training of specialists on renewable energy technologies and applications.

13/10/2016
Workshop
E. Zarza chaired the international Workshop on “RI needs of the STE Industrial Sector” organized by CIEMAT-PSA in collaboration with SolarPACES in Abu-Dhabi.

16/10/2016
Official Meeting
Eduardo Zarza and Diego Alarcón participated as Spain National Representative and Operating Agent of Task VI (Solar Energy and Water Processes and Applications) respectively at the 91st Meeting of the SolarPACES Executive Committee held in Abu Dhabi (UAE).

16/10/2016
Official Meeting
Participation of Eduardo Zarza in the 91th SolarPACES Executive Meeting in Abu-Dhabi (UAE).

17/10/2016
Workshop
G. Zaragoza was invited to participate and give a presentation on “Solar Desalination” in the workshop “Low Carbon Desalination” organized by the Global Clean Water Desalination Alliance and MIT in Boston (USA).

17-22/10/2016
Lecture
Invited professor of Sixto Malato in the course ”Agua + Humedales” in Prostgraduate School Universidad Nacional de San Martin, Argentina.

25-27/10/2016
Lecture
Invited lecture of Sixto Malato in the workshop on “1st Fotofuel School & Conference: Current challenges in solar photofuels”. Almeria, Spain.

07-17/11/2016
Lecture
D. Alarcón and P. Palenzuela participated as lecturers at the School on Concentrated Solar Thermal Energy held at The Cyprus Institute in Nicosia.

10/11/2016
Lecture
Invited lecture of Sixto Malato in the workshop on “XII Technical Conference on Wastewater Treatment, emerging pollutants in water. impact and potential removal strategies”, held at Murcia (Spain) and organized by ESAMUR and the Regional Government of Murcia.

11/11/2016
Dissemination and divulgation
The radio program ‘Andalucia en la Onda’ of Onda Cero Radio was broadcast ‘live’ from PSA facilities, contributing to the science and technology divulgation in the region.

13-16/11/2016
Scientific Committee
Participation of G. Zaragoza in the Scientific Committee of the International Desalination Workshop organized by Masdar Institute and the Global Desalination Research Centre of South Korea, which took place in Abu Dhabi from 13th to 16th November.

14/11/2016
Lecture
Invited lecture of Sixto Malato in the workshop on "Nanomateriales y su aplicación en tecnologia solar: Nanotecnosolar-2016". Universidad de Concepcion, Chile.

15/11/2016
Lecture
Invited lecture by M.I. Maldonado ("25 años de Innovación en el Tratamiento de Aguas") at the "Martes Coloquiales" seminar at the CCADET-Universidad Nacional Autonoma de Mexico (UNAM), Mexico.

16-18/11/2016
Lecture
Invited lectures on "Parabolic trough technology" of Eduardo Zarza at the International School on key principles of Solar Thermal Energy (FUPSE) held at University of Antofagasta (Chile).

16-18/11/2016
Lecture
Invited lecture of Sixto Malato in the workshop on "2º Taller latinoamericano de materiales de carbono (TLMC2). Termas de Chillán, Chile.

17/11/2016
Lecture
Invited lecture on "Solar Thermal Power Plants: business opportunities" of Eduardo Zarza at the Chamber of Commerce of Antofagasta (Chile).

17/11/2016
Lecture
Invited lecture by M.I. Maldonado ("25 años de Innovación en el Tratamiento de Aguas") at the "Jacobo Gómez Lara" seminar at the Universidad de Guanajuato, Mexico.

23/11/2016
Dissemination and divulgation
J. Fernández and E. Zarza participated in the International Seminar on Concentrating Solar Thermal Energy, held at University of La Plata (Argentina).

25/11/2016
Dissemination and divulgation
J. Fernández and E. Zarza participated in the II Seminario de Investigación y Transferencia de Tecnología, held at the Ciudad de Guatemala (Guatemala).

29/11/2016
Lecture
Invited lecture by G. Zaragoza ("Uso de energía solar térmica para refrigeración y riego de invernaderos") at the seminar "Aplicación de energías renovables a la agricultura intensiva", organized by Fundación Cajamar in El Ejido (Almeria).

29/11/2016
Workshop
CIEMAT held at the PSA the workshop "Water Consumption in CSP plants" organized in the framework of the WASCOP and MinWaterCSP EU projects with participation of CSP plant stakeholders (CSP plants operators, CSP plants owners, and services providers).

07/12/2016
Lecture
Invited lecture of E. Zarza on "*Solar thermal power plants: current status and main R+D Lines*" at the Universidad Autónoma de Madrid (Spain).

08/12/2016
Lecture
Invited lecture by G. Zaragoza ("Membrane distillation: a review of commercial modules and their performance") at the 9th International Membrane Science and Technology held from 5th to 8th December in Adelaide (Australia).

13/12/2016
International Workshop
Participation of J. Blanco in the event "The EU-CELAC Common Research Area –Renewable Energies & Research Infrastructures Workshop" (Gran Canaria, Spain, 12th-14th December), providing the experience of PSA as large European research infrastructure.

13/12/2016
International Symposium
Participation of several PSA researchers at the 3rd IPES symposium (Evora, Portugal, 1st-2nd February), where several presentations of ongoing research projects were made.

13/12/2016
International Conference
Participation of D. Martinez at IRSEC'2016 (4th International Renewable and Sustainable Energy Conference, November 14-17, Marrakech, Morocco), in the context and framework of COP22 Conference.

13/12/2016

International Forum

Participation of J. Blanco in the 2nd Solar Forum ENERSOL (October 5th, Antofagasta, Chile), discussing the current and project cost of CSP/STE technology.

21/12/2016

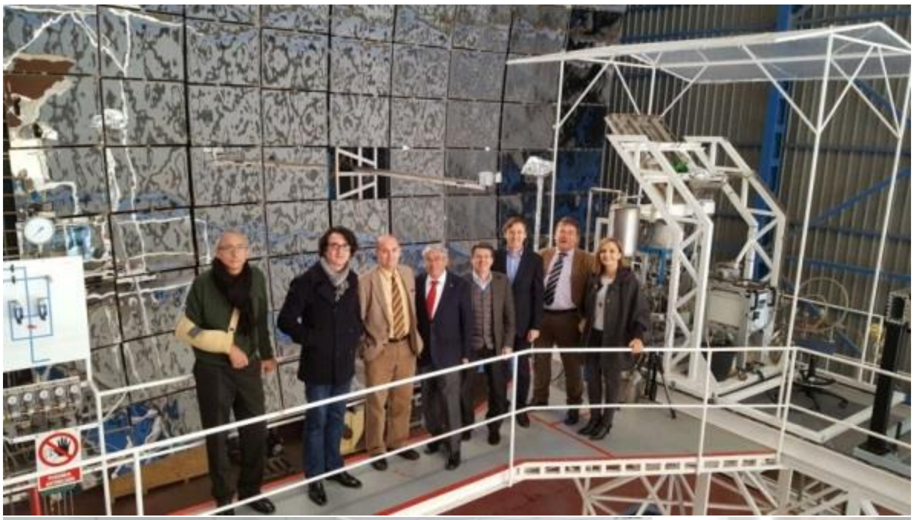
Doctoral Thesis

Bartolomé Ortega defended the Doctoral Thesis “Theoretical Analysis of High Efficient Multi-Effect Distillation Processes and their Integration into Concentrating Solar Power Plants”. University of Seville.

29/12/2016

Official Visit

The PSA received the visit of a group of representatives of the PP Party, headed by Mr. Rafael Hernando, showing their interest in receiving technical information about the PSA facilities and ongoing R&D activities.



22/12/2016

Social Act

The Director of PSA, Sixto Malato, invited to all the personnel to the Social Act where the overall resume of R&D activities carried out along the year 2016 and the planning for next year were exposed, with the participation of the heads of PSA research units.

9. Publications

PhD Thesis

Ávila-Marín, A. (2016). Thermal-Fluid-Dynamic Analisys of Gradual Porosity Volumetric Absorbers with Metallic Wire Meshes: Experimental Satudy at Lab-Scale and Numerical Simulation with Local Thermal Non-Equilibrium Model. (Unpublished doctoral dissertation). UNED.

Ibarra Mollá, M. (2016). Techno-economic evaluation of systems based on small power Organic Rankine Cycles for their integration into solar thermal systems. (Unpublished doctoral dissertation). UNED.

Ortega-Delgado, B. (2016). Theoretical analysis of high-efficient multi-effect distillation processes and their integration into Concentrating Solar Power plants. Universidad de Sevilla, Sevilla. http://hdl.handle.net/11441/52421

Solar Concentrating Systems Unit

SCI Publications

Ballestrín, J., Monterreal, R., Carra, M.E., Fernández-Reche, J., Barbero, F.J., & Marzo, A. (2016) Measurement of solar extinction in tower plants with digital cameras. SolarPACES 2015. *AIP Conf. Proc.* 1734, 130002-1–130002-8 http://dx.doi.org/10.1063/1.4949212

Ballestrín, J., Rodríguez, J., Carra, M.E., Cañadas, I., Roldán, M.I., Barbero, F.J., & Marzo, A. (2016) Pyrometric method for measuring emittances at high temperatures". SolarPACES 2015. *AIP Conf. Proc.* 1734, 130003-1–130003-8 http://dx.doi.org/10.1063/1.4949213

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Fernández-García, A., Sutter, F., Heimsath, A., Martínez-Arcos, L., Reche-Navarro, T., & Schmid, T. (2016). Simplified analysis of solar-weighted specular reflectance for mirrors with high specularity. SolarPACES 2015. *AIP Conf. Proc.* 1734, 130006-1-130006-8. http://dx.doi.org/10.1063/1.4949216

García-Ortíz, Y., Yáñez-Mendiola, J., & Valenzuela, L. (2016). Colector cilindro parabólico a partir de material de bajo costo (acero inoxidable) aplicado a un sistema híbrido de deshidratado. *DYNA* 91, 0-10. http://dx.doi.org/10.6036/7540

García-Segura, A., Fernández-García, A., Ariza, M.J., Sutter, F., & Valenzuela, L. (2016). Durability studies of solar reflectors: A review. *Renewable and Sustainable Energy Rev.* 62, 453-467. http://dx.doi.org/10.1016/j.rser.2016.04.060

Hofer, A., Valenzuela, L., Janotte, N., Burgaleta, J.I., Arraiza, J., Montecchi, M., … Scholl, S. (2016). State of the art of performance evaluation methods for concentrating collectors. SolarPACES 2015. *AIP Conf. Proc.* 1734, 020010-1-020010-7. http://dx.doi.org/10.1063/1.4949034

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Roca, L., Bonilla, J., Rodríguez-García, M.M., Palenzuela, P., de la Calle, A., & Valenzuela, L. (2016). Control strategies in a thermal oil – molten salt heat exchanger. SolarPACES 2015. *AIP Conf. Proc.* 1734, 130017-1-130017-8. http://dx.doi.org/10.1063/1.4949227

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ORAL PRESENTATIONS

Alonso-Montesinos, J., Polo, J., López, G., Barbero, J., Bosch, J. L., Ballestrín, J., & Batlles, F.J. Modelling clear sky DNI under extreme aerosol loading: the case of Saharan outbreak in south-east Spain. *EuroSun*, 11 – 14 October, 2016, Palma de Mallorca, Spain.

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Ávila-Marín, A., Fernández-Reche, J., Casanova, M., Calliot, C. & Flamant, G. Numerical Simulation of Convective Heat Transfer for Inline and Stagger Stacked plain-Weave Wire Mesh Screens and Comparison with a Local Thermal Non-Equilibrium Model. *22nd SolarPACES Conference*, October 11-14, 2016. Abu Dhabi, UAE.

Crema, L., Horta, P., Roccabruna, M., Cardoso, J.P., Sallaberry, F., Guisado Otero, M.V., … Valenzuela, L. Schemes of integration in thermal application and power cycle for small scale concentrated solar system – INSHIP ECRIA. *EERA Conference 2016*, 24-25 November, 2016. Birmingham, United Kingdom.

Essence, T., Bayón, R., Bruch, A., & Rojas, E. Study of Thermocline Development Inside a Dual-media Storage Tank at the Beginning of Dynamic Processes, *22nd SolarPACES Conference*, October 11-14, 2016. Abu Dhabi, UAE.

Füssel, A., Beckert, W., Adler, Haase, D., Zaversky, F., Aldaz, L., Sánchez, M., Ávila-Marín, A., Roldán, M.I., Fernández-Reche, J., Quet, A. & Ravaux, A. Property adjustment of open-celled ceramic foams for high temperature applications assisted by numerical modelling. *4th Cellular Materials (CellMAT) Conference*, December 7-9, 2016. Dresden, Germany.

López, G., Gueymard, C. A., Bosch, J. L., Rapp-Arrarás, I., Alonso-Montesinos, J., Pulido-Calvo, I., … Barbero, J. Modelling Water Vapor Impact on the Solar Energy Reaching the Receiver of a Solar Tower Plant by means of Artificial Neural Networks. *EuroSun*, 11 – 14 October, 2016, Palma de Mallorca, Spain.

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Pernpeintner, J., Schiricke, B., Sallaberry, F., García de Jalón, A., Lopez Martín, R., Valenzuela, L., & de Luca, A. Results of the parabolic trough receiver heat loss round robin test 2015/2016. *22nd SolarPACES Conference*, October 11-14, 2016. Abu Dhabi, UAE.

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Sallaberry , F., Valenzuela, L., Gomez, L., León, J., Fischer, S., & Bohren A. Harmonization of Standard for Parabolic Trough Collector Testing in Solar Thermal Power Plants. *22nd SolarPACES Conference*, October 11-14, 2016. Abu Dhabi, UAE.

Sánchez, M., Burgaleta, J.I., Fernández-García, A., Fernández-Reche, J., Gómez, J.A., Lüpfert, E., … Valenzuela, L. Standards for components in concentrating solar thermal power plants – Status of the Spanish standardization committee. *EERA Conference 2016*, 24-25 November, 2016. Birmingham, United Kingdom.

Setien, E., Fernández-Reche, J., Ariza, M.J. & Álvarez-de-Lara, M. Study of Cyclic Thermal Aging of Tube Type Receivers as a function of the Duration of the Cycle. *22nd SolarPACES Conference*, October 11-14, 2016. Abu Dhabi, UAE.

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POSTERS

Ballestrín, J., Rodríguez, J., Carra, M. E., Cañadas, Roldán, M.I., Barbero, F. J., & Marzo, A. (2016, October). *Pyrometric method for measuring emittances at high temperatures*. Presented at the 22nd SolarPACES Conference, Abu Dhabi, UAE.

Biencinto, M., González, L., & Valenzuela, L. (2016, October). *Yield analysis of a power plant with parabolic-trough collectors and direct steam generation (DSG) using a quasi-dynamic simulation model in TRNSYS*. Presented at the 11th ISES EuroSun Conference. Palma (Mallorca), Spain.

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Sallaberry, F., Fernández-García, A., Lüpfert, E., Morales, A., San Vicente, G., & Sutter, F. (2016, October). *Towards standardized testing methodologies for optical properties of components in concentrating solar thermal power plants*. 22nd SolarPACES Conference. Abu Dhabi, UAE.

Zaversky, F., Aldaz, L., Sánchez, M., Ávila-Marín, A., Roldán, M.I., Fernández-Reche, J., Füssel, A., Beckert, W. & Adler, J. *Ceramic foam absorber modeling and optimization – Model benchmarking and validation against experimental data*. Presented at 22nd SolarPACES Conference, October 11-14, 2016. Abu Dhabi, UAE.

Solar Desalination Unit

SCI PUBLICATIONS

Altaee, A., Millar, G. J. & Zaragoza, G. (2016). Integration and optimization of pressure retarded osmosis with reverse osmosis for power generation and high efficiency desalination. *Energy* 103, 110–118.

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BOOK CHAPTERS

Altaee, A., Sharif, A. & Zaragoza, G. (2016) Forward Osmosis Pretreatment of Seawater for Thermal Desalination. In Terrell, J. (Ed.), *Water Filtration Systems: Processes, Uses and Importance*. (pp. 1-20). Nova Science Publishing, Incorporated.

PRESENTATION AT CONGRESSES

ORAL PRESENTATIONS

G. Zaragoza, A. Ruiz-Aguirre, J.A. Andrés-Mañas, P. Horta. Feasibility of solar-powered membrane distillation based on an experimental evaluation of commercial modules and dynamic simulations of solar energy supply. *2nd International Conference on Desalination and the Environment*, Doha (Qatar), 23-26 January 2016.

J.A. Andrés-Mañas, A. Ruiz-Aguirre, F.G. Acién, G. Zaragoza. Use of vacuum multi-effect membrane distillation for concentration of high salinity solutions. Desalination for the Environment Clean Water and Energy. Rome (Italy), 22-26 May 2016.

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M. Papapetrou, A. Cipollina, U. La Commare, G. Micale, G. Zaragoza. Towards a fair cost comparison for desalination methods: A review of the methodologies used and assessment of their strengths and weaknesses. Desalination for the Environment Clean Water and Energy. Rome (Italy), 22-26 May 2016.

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J.A. Carballo, J. Bonilla, L. Roca, A. de la Calle, P. Palenzuela, M. Berenguel. Optimal operating conditions analysis of a Multi-Effect Distillation plant. EuroMed 2016. Desalination for the Environment Clean Water and Energy. Rome (Italy), 22-26 May 2016.

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G. Zaragoza, P.A. Davies, M.A. Roccamante, A. Ruiz-Aguirre. Membrane distillation for cooling and irrigation in a solar-powered greenhouse. 9th International Desalination Workshop. 13-15 November 2016, Abu Dhabi (UAE).

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Water Solar Treatment Unit

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