GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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Plataforma Solar de Almería

PSA: Largest European research centre devoted to Concentrating Solar Energy

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Introduction and Background

The Plataforma Solar de Almería (PSA) belongs to the Department of Energy of the Centro de Investigaciones Energéticas, Medioambientales y Tercnológicas (CIEMAT), a public research organization under the Spanish Ministry of Economy and Competitiveness. The PSA is without doubt the largest research, development and test centre in the world dedicated to the technologies of concentrated solar radiation. This fact makes Spain, and in particular the PSA, as the centre of excellence for visitors and researchers related with these systems from all around the world.

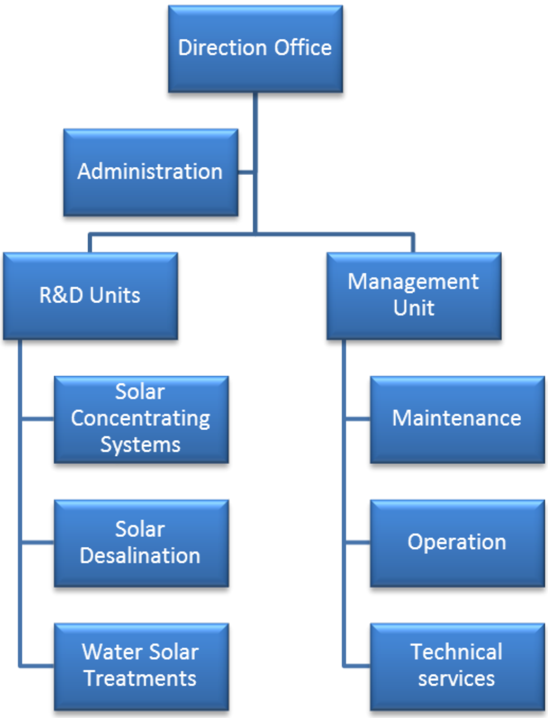
Aerial view of the Plataforma Solar de Almería

The PSA took root in the late 70's with the construction in the desert of Tabernas (Almería) of two projects (i.e., SSPS promoted by the International Energy Agency and CESA-I by the Spanish government) to demonstrate the technical feasibility of producing electricity by concentrating solar thermal systems (These have come down to us as first generation solar thermal power plants). Evaluation of both projects was completed in 1984. However, from 1985 to 1987 the CESA-I project served as a test bed for an ambitious technology program called GAST, a Spanish-German project aimed at the design, construction and testing of components for a second generation air-cooled plant.

During the same period, Spain the International Energy Agency (IEA) transferred to Spain the ownership of all the SSPS project assets and Germany signed a bilateral cooperation agreement for the joint use of the PSA as a centre of concentrating solar thermal technology research, development and demonstration. The two centres which assumed that agreement were CIEMAT for Spain and DLR (German Aerospace Agency) for Germany. Nevertheless, from January 1999 the scientific management of the PSA is now wholly responsibility of CIEMAT as owner of PSA facilities and the collaboration with DLR is now set in the context of specific projects only.

In the international sphere, the PSA participates in all the IEA's SolarPACES program Tasks I, II and III, the Alliance of European Laboratories on Solar Thermal Concentrating Systems (SolLAB), and the European Energy Research Alliance (EERA) Joint Programme on Concentrated Solar Power (CSP) and Energy Storage.

Furthermore, continuous and intensive collaboration with the University of Almeria (UAL) has been consolidated with the creation of a joint centre for joint research in solar energy applications, called CIESOL (www.ciesol.es). This centre is physically located in the UAL campus, which is partially financed by the European Regional Development Fund.



PSA organisation chart

Research activity at the Plataforma Solar de Almería 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 heat applications requiring solar concentration, whether for medium/high concentrations or high photon fluxes.

- Solar Desalination. It has the objective of new scientific and technological knowledge development in the field of brackish and seawater solar desalination.
- Solar Treatment of Water. Exploring the photochemical possibilities of solar energy, especially regarding to its potential for water detoxification and disinfection.

Supporting the R&D Units mentioned above are the maintenance, operation and technical services, which are grouped together in the PSA Management Unit.

Solar Concentrating Systems Unit (SCSU)

Although the changes introduced in the Spanish legal framework for solar thermal electricity (STE) plants in 2012 and 2013 have significantly reduced the profitability of these solar systems, the high number of plants already in operation in Spain keeps alive a strong collaboration between the STE sector and this PSA Unit. The reduction of the R+D activities promoted by Spanish companies in the last years has been compensated by the growing interest shown by foreign Companies on R+D activities for technology improvement and development of new components for projects promoted in other countries.

Many new components have been evaluated and characterized by the SCSU at the PSA in the last two decades (five new parabolic trough collector designs, six new receiver tubes for parabolic troughs, four new heliostat designs, more than 10 solar reflectors, and many other components), thus proving the strong link between PSA and the STE sector. The SCSU gives the many companies that ask for it, the scientific and technological support they require, according to the resources available at PSA.

Two other important activities are performed by the SCSU:

- training and knowledge dissemination: participating in many seminars, Master courses and Congresses related to solar concentrating technologies.
- standardization activities for STE sector. Concerning standardization, the SCSU participates in all of the forums and working groups that are active for this purpose:
  - The ASME PTC-52 standardization committee created in the USA.
  - AEN/CTN Subcommittee 206/SC “Solar Thermal Power Systems”, jointly created in Spain by AENOR, PROTERMOSOLAR, CENER and CIEMAT
  - The STAMP Working Group, created within the framework of SolarPACES
  - The IEC/TC-117 “Thermal Electric Plants” Committee launched in 2012. The kick-off meeting of this committee was hosted by CIEMAT on 7th-8th March, 2012

The priority R+D lines of SCSU are

- Development and evaluation of new components for parabolic trough and central receiver systems

- New working fluids, with higher operating temperature and lower environmental footprint
- Thermal storage systems
- Accelerated ageing and durability studies for key components with high solar fluxes
- New processes for hydrogen production with solar energy and optimized solar reactors for these processes

This PSA Unit has participated in many R+D projects related to solar concentrating systems, at both national and international level. Some projects are: INDITEP (EU-DGXII FP5 C.N. ENK5-CT-2001-00540) y DISTOR (EU-DGXII FP6 C.N. SES6-CT-20045003526), OPTS (Proyecto EU-DGXII, FP7 Ref: 283138), TESCONSOL (KIC-InnoEnergy), ConSOLI+DA (CDTI-MICIN) y SFERA (EU-DGXII FP6 Ref. 228296). Participation of the SCSU in these projects has been devoted to basic research, technology development and know-how transfer to the industry.

The SCSU has collaborated with many of the commercial STE plants currently in operation in Spain, performing yield analysis, components and plant evaluation, as well as providing scientific assistance. Good examples of these projects are the first commercial STE plants implemented in Spain with central receiver and parabolic trough collectors (i.e., the PS10 and ANDASOL-I plants). The heliostat and parabolic trough designs installed at these plant were evaluated at the PSA by the SCSU.

Another remarkable collaboration of the SCSU with the Spanish STE sector is the joint development with the company SENER Ingeniería of the prototype of the first commercial molten-salt central receiver installed in the World: the receiver of the plant GEMASOLAR, promoted by TORRESOL Energy. This plant has been an important step forward in the technology of central receiver plants, because is the first commercial plant in the World using a molten-salt receiver. This technology seems to be one of the best options for central receiver plants at present, due to its good dispatchability and overall efficiency. The technological seed of this type of STE plant was the American 10-MWe Solar Two plant, with molten salt technology and thermal storage of over 12 equivalent hours, carried out in Barstow, California from 1996 to 1999, and demonstrating the feasibility of this technology first commercialized by TORRESOL Energy with the plant GEMASOLAR.

Spain has become the World leader in the STE market, with the installation of more than 2000 MWe of STE plants during the period 2007-2013, while in EEUU there was only 450 MWe in July 2013. This commercial deployment of STE plants in Spain has provided Spanish companies with a valuable Know-how and this is the reason why Spanish companies are leading many of the commercial STE projects in the World, not only in Spain. However, the dramatic changes implemented in 2012 and 2013 in the Spanish legal framework for STE plants is a significant barrier to keep this leadership, because the profits have been significantly reduced and in some cases even turned into financial losses.

The cost of electricity produced by STE plants depends on many parameters (DNI available, local labour cost, loan interest, etc..) and it changes not only from one country to another, but also from one plant to another within the same country. So, the electricity cost for power purchasing agreements is of about 0.15 US$/kWh in California, while is higher than 0.20 €/kWh in Spain. Technological improvements implemented during recent years as result of the development of the learning curve of STE technologies are proving the existing great potential for cost reduction, which is expected to be higher than 30% by 20120 (some optimistic cost analysis even expect a reduction of more than 50% by 2025).

The 'GEMASOLAR' central receiver plant in Seville (Spain)

The installation of hybrid plants with a parabolic trough solar field connected to the steam cycle of a combined cycle plant (the so-called "Integrated Solar Combined Cycle System" configuration) has become a very interesting option for those countries willing to learn about STE technologies without undertaking a significant risk, because this type of hybrid plant is basically a combined cycle plant powered by natural gas, with a yearly solar contribution of about 10% only. Three ISCCS plants have been built in the recent years: in Hassi R´mmel (Argelia), Kuraymat (Egypt) and Ain-Beni-Matar (Morocco), showing a good performance and meeting expectative.

At present, there are many different technology options for STE plants: saturated steam central receivers, molten-salt central receivers, superheated-steam central receivers, volumetric receivers, falling-particles central receiver, parabolic trough with thermal oil as working fluid, parabolic troughs with molten-salt as working fluid, parabolic troughs with water as working fluid,….. This large number of options is due to the early development stage of STE plants. The more promising options cannot be validated until they all are commercially implemented and run. So, a significant effort for R+D and demonstration is still needed to find the best technology for STE plants. It can even be expected not only a single winning option, but several good options could come up from this process, depending on the boundary conditions for each STE plant.

Aerial view of the commercial PS10 plant under construction in Sanlúcar La Mayor (Seville)

Most of commercial projects developed within the period 2004-2013 use parabolic trough collectors with thermal oil as working fluid. The reason for this is the good reliability shown by this technology (the so-called HTF technology) at the SEGS plants installed in California (EEUU) in the period1985-1991. However, the STE sector seems to be shifting towards molten-salt central receiver plants for future projects.

For parabolic trough plants, a significant effort is devoted to find new working fluids to replace the thermal oil currently used in commercial plants. The fire hazards and the environmental risk associated to leaks of thermal oil, as well as its thermal limit for stability (i.e., 398ºC) are a significant barrier for these plants. This is the reason why one of the strategic R+D lines of the SCSU is the study and evaluation of new fluids for parabolic trough collectors. In this line, priority has been given to the use of water as working fluid in parabolic trough collectors, the so-called Direct Steam Generation (DSG) technology. This line of research was started with the project DISS (Direct Solar Steam) in 1996 and is being carried out in collaboration with DLR. The goal of this PSA activity is to bring about a 30% reduction in the final cost of the electricity generated. The experimental results obtained up to now have demonstrated that direct steam generation in PTC is feasible and has a high potential for substituting the HTF technology that uses oil as the thermal fluid

The PSA DISS test loop has accumulated over 9000 hours of solar operation, producing 390ºC superheated steam at up to 100 bar directly in the PTC absorber tubes. This facility has been upgraded within the framework of the German project DUKE to continue these R+D activities related to DSG.

View of the DISS direct steam generation loop located at the Plataforma Solar de Almería

So, it is evident that a significant R+D effort is still needed in the STE sector, and the experience and know-how of the SCSU of the PSA, together with the valuable test facilities available at PSA, can make a significant contribution to this effort.

Solar Desalination Unit (SDU)

The Solar Desalination Unit at the PSA is currently focused on solar desalination process and applications, topic with more than 25 years of research background at PSA. Specific experience of present PSA team on solar desalination stands for about 15 years by developing a significant number of industry contracts and competitive R&D+i projects both at national and international level. All these projects and activities, together with the unique infrastructures developed or improved during its development, has provided the group a deep knowledge and expertise in the following aspects of solar desalination processes and technologies: (i) Solar assisted MED seawater desalination; (ii) Use of heat pumps to MED performance improvement; (iii) Integration of MED into Concentrated Solar Power facilities; (iv) Modeling and simulation tools for steady state and dynamic study of suitable power and desalination technologies; (v) Solar assisted membrane-distillation technologies; (vi) Solar driven Organic Rankine Cycles + reverse osmosis desalination; (vii) Use of medium temperature solar heat to drive poly-generation processes involving production of water, power and cooling.

Main current research lines are the following:

- Multi-Effect Distillation (MED) using solar thermal Energy and/or hybrid solar/gas systems.
- Introduction of Double Effect Absorption Heat Pumps (DEAHP) into solar MED plants, coupled with advanced control strategies
- Integration of desalination technologies into solar thermal electricity plants (CSP+D).
- Development of integrated solutions based on Membrane Distillation technologies driven by solar thermal energy.
- Integration of Reverse Osmosis (RO) into Organic Rankine Cycle (ORC) processes, also driven by solar thermal energy.
- Development of solar polygeneration integrated solutions (power/cooling/water/heat production) based on small parabolic trough technology.

A clear increase in the interest about solar desalination processes and technologies has been observed during the last years. The prospects of more expensive energy and more scarce water resources, especially in the countries/regions with higher solar resources availability, is driven the necessity to accelerate the development of more competitive solar desalination technologies, being near the implementation of the very first large solar desalination projects. In this context, the international relevance of the developed activities is clearly demonstrated by the current following positions hold by the unit:

- Operating Agent of SolarPACES (Solar Power and Chemical Energy Systems) Task VI (Solar Energy and Water Processes and Applications).
- Coordination of EERA (European Energy Research Alliance) Joint Programme on Concentrating Solar Power (JP-CSP).
- Coordination of EERA Subprogramme on CSP and Desalination (CSP+D).
- Coordination of the Renewable Energy Desalination Action Group within the European Innovation Partnership on Water (EIP Water, European Commission).

The SDU has recently promoted or participated into many projects directly related with technical analysis and engineering design and demonstration of solar energy driven desalination systems, such as:

- Solar Thermal Power&Water Cogeneration Systems (CSP+D): Techno-economic assessment of coupling solar thermal power and desalination (Activity 12, CONSOLIDA CENIT-Project), Assessment of CSP+D potential in the MENA area (SOLARPACES project), Feasibility study of CSP+D integrated plant in Port Safaga, Egypt (SOLARPACES project)
- Non-Tracking Solar Thermal Powered Multi-Effect and Membrane Distillation Systems: SOLARDESAL (Contract REN2000-0176-P4-04), AQUASOL (FP5 contract

EVK1-CT-2001-00102), MEDESOL (FP6 contract 036986) and ZCR (SWITCH Asia Programme, contract 2009/203331)

- Performance Enhancement of Low Temperature Thermal Desalination Processes by Absorption Heat Pumps: AQUASOL (FP5 contract EVK1-CT-2001-00102), TE-COAGUA (Activity 11, CENIT-Project)
- Solar Powered Reverse Osmosis processes driven by Organic Rankine Cycles: OSMOSOL (Contract ENE2005-08381-C03-01), POWERSOL (FP6 contract 032344), CPV-RANKINE (FP7 contract 315049)
- Technical and economic analysis of the different RE-Desalination technologies: PRODES (FP6 contract IEE/07/781/SI2.499059)

Within the framework of AQUASOL Project an important solar desalination demonstration facility was implemented where a multi-effect distillation pilot plant (72 m^3/day) was coupled to a 500-m^2 non-tracking CPC (compound parabolic concentrator) solar field that supplies the 200-kW thermal energy required by the distillation unit. The facility is also provided by a 100-kW double-effect absorption heat pump prototype coupled to the MED unit allowing to reduce by half the energy consumption required by the desalination process. The thermal energy (180 ºC) required by the heat pump can be provided either by small aperture parabolic trough solar collectors either a steam gas boiler for 24-h operation. The experimental assessment of this facility has allowed the development of computational models that have been employed within the techno-economic assessment of the configurations analysed within the CSP+D projects above mentioned.

Prototype of Double-Effect LiBr-H2O Absorption Heat Pump coupled to the Multi-Effect Distillation Plant at the Plataforma Solar de Almería.

EU-funded MEDESOL Project was the start of the research activities of the SDU within the field of membrane distillation technologies. A full-equipped experimental facility was implemented under the framework of this project for the testing of the different prototypes and pre-commercial designs available in the market, in order to assess their performance working with solar energy under real climatic conditions. Today, two experimental facilities are devoted to the assessment of membrane distillation modules, driven with solar thermal energy up to 85 ºC, allowing the development of performance models that can be used within simulation tasks and techno-economic studies.

Collaboration with private companies (both local Spanish and international ones) has been also very intense within the last years as a direct consequence of the unique expertise and knowledge of PSA staff in the field of solar desalination processes and technologies.

Solar Treatment of Water Unit

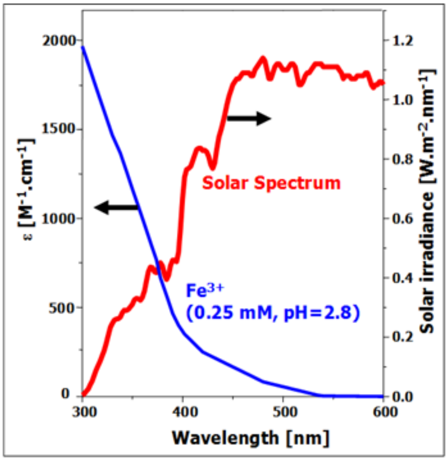
The unit of Solar Treatment of Water was born in 2012, from the Environmental Applications of Solar Energy unit, as a consequence of the strategic plan of CIEMAT to encourage the research activities and applications of solar photochemistry carried out at Plataforma Solar de Almería. The main objective of this research is the use of solar energy for promoting photochemical processes (i.e. heterogeneous photocatalysis, photo-Fenton) in water at ambient temperature for treatment and purification applications.

$$[Fe^{3+}L] + h\nu \longrightarrow [Fe^{3+}L]^* \longrightarrow Fe^{2+} + L^{\bullet}$$

$$[Fe(H_2O)]^{3+} + h\nu \longrightarrow Fe^{2+} + OH^{\bullet} + H^{+}$$

$$[Fe(OH)]^{2+} + h\nu \longrightarrow Fe^{2+} + OH^{\bullet}$$

$$[Fe(OOC-R)]^{2+} + h\nu \rightarrow Fe^{2+} + CO_2 + R^{\bullet}$$



Solar homogeneous photocatalysis by means of photo-Fenton reactions catalysed by solar radiation and generation of hydroxyl radicals (•OH). Solar spectrum irradiance and Fe^{3+} absorbance profile.

Solar Treatment of Water research group knowledge about solar detoxification and disinfection processes at pilot and pre-industrial scale is backed up by 20 years of research activity, after been involved in the 4th, 5th, 6th and 7th EC FPs, (SODISWATER, AQUACAT, INNOWATECH, PHOTONANOTECH, GREENTECH, RITECA II, SFERA, etc.). At present several European projects are running in collaboration with different International Institutes and Universities (GREEN-TECH, RITECA II, SFERA and SFERA II).

At national level, this group is involved in different projects on the development of solar technologies for decontamination and disinfection of water. These projects permit the group to participate in different high skill activities related with water treatment: (i) evaluation and improvement of advanced oxidation processes for industrial WW treatment; (ii) solar disinfection (SODIS) of water for preventing diseases in developing countries without confident sources of potable water; (iii) collaboration in International Programs related with R&D not only in EU but also in South America and Mediterranean area; (iv) wastewater treatment and reuse; (vi) coupling advanced oxidation processes and biotreatment, etc. In addition, this group has been involved also in different contracts with private companies due to its expertise in environmental technologies (HIDROCEN, Janssen Pharmaceutica, AQUALIA INDUSTRIAL, BEFESA, etc.

The accumulated experience in the field of solar detoxification and disinfection has enabled the development and continuous enlargement and improvement of this unit experimental solar facility until it is one of the most important in Europe. This facility has been widely used in recent years by many European research groups under different European Commission 'Access to Large Scientific Facilities' programs.

The research activities already consolidated by this unit are:

1) Using solar photocatalytic and photochemical processes as tertiary treatment of the effluents from secondary treatment of municipal wastewater treatment plants, for production of clean water. For this, the presence of both emerging pollutants and pathogens are investigated.
2) Using solar photocatalytic and photochemical processes for treating industrial wastewaters contaminated with several types of pollutants and water reclaim for several applications. Pharmaceuticals, pesticides, and other emerging contaminants are studied.
3) Combining Advanced Oxidation Technologies with other water treatment techniques such as nano- and ultra-filtration, ozonation, biological treatments, etc. for improving the water treatment efficiency and reducing costs.
4) Assessment of photocatalytic efficiency of new materials under real solar light conditions, and their use in solar CPC reactors.
5) Using solar photocatalytic and photochemical processes for water disinfection. Several types of contaminated water sources with a number of water pathogens are under study.
6) Developing solar CPC reactors for different purposes (drinking water, water reclamation, irrigation, etc.), either water decontamination or water disinfection. Experimental models are being used for the design and construction of new solar reactors.

The PSA has become the leader in scaling up applications and systems from the laboratory to demonstration plants with real solar radiation. Several pre-industrial scale plants have been designed and developed in the frame of European Projects such as SOLARDETOX, CADOX and INNOWATECH focused in the combination of advanced solar technologies with biological treatment for the remediation of complex industrial wastewater such as pharmaceutical wastewater.

Solar detoxification plant based on CPC technology combined with an IBR biological reactor for the treatment of industrial wastewater containing pesticides (ALBAIDA company, La Mojonera, Almería, Spain)

Regarding disinfection activities within the Unit, it has become a strategic research line given the deep interest that drinking water problems have awakened around the world. Nowadays disinfection research line is fully considered into the work programmes elaborated for recent and new European and National projects focused on treatment and reusing of municipal and industrial wastewater. In addition, other applications such as the elimination of phytopathogens in water through photocatalytic processes for irrigation water are under study.

Several disinfection prototypes installed at strategic locations for different water disinfection applications.

Concentrating Solar Power Systems

The most widely used concentrating solar concepts are: parabolic-through collectors, central receivers, linear Fresnel reflectors and parabolic dishes. Briefly, these systems collect the solar radiation and concentrate it to heat a working fluid, which may differ according to the case, and that in turn is commonly used to generate steam. When water is the working fluid the concentrated solar radiation directly converts the liquid water into steam. The steam is then expanded in a conventional turbine to generate electricity the same way any conventional Rankine power plant does. Sometimes, when the working fluid is a gas the hot gas directly drives a thermodynamic cycle (i.e., Brayton or Stirling cycle). This is the case of parabolic dishes (PD) using H_2 or He as working fluid, because electricity is generated directly by an Stirling engine driven by the hot H_2 or He.

Parabolic through collectors

The parabolic trough (PT) is currently the most widely used technology around the world, particularly in Spain and in the United States where the total installed power with PT plants at the beginning of 2013 was over 2000 MWe and 450 MWe respectively .

These are line-focusing concentrators with solar tracking on only one axis, concentrating radiation from 30 to 80 times and usually having a nominal capacity per field of from a few MWe to more than 100 MWe.

Current PT plants in Spain have a unit power equal or lower than 50 MWe because 50 MWe is the limit imposed by the Royal Decree RD-661/2007. About 60% of current PT plants in Spain include a molten salt two-tank system providing 7.5 hours of storage. In the United States, power plants are being built with much larger turbines (>100 MW), taking advantage of the fact that, in this technology, while energy collection performance is practically unaffected by size, costs of generation are lowered considerably.

Linear Fresnel reflectors

This technology is also based on solar collector rows or loops. However, in this case, the parabolic shape is achieved by almost flat linear mirrors. The radiation is reflected and concentrated onto fixed linear receivers mounted over the mirrors, in orders of from 10 to 50 times, combined or not with secondary concentrators. The capacity per field is from a few MWe to more than100 MWe.

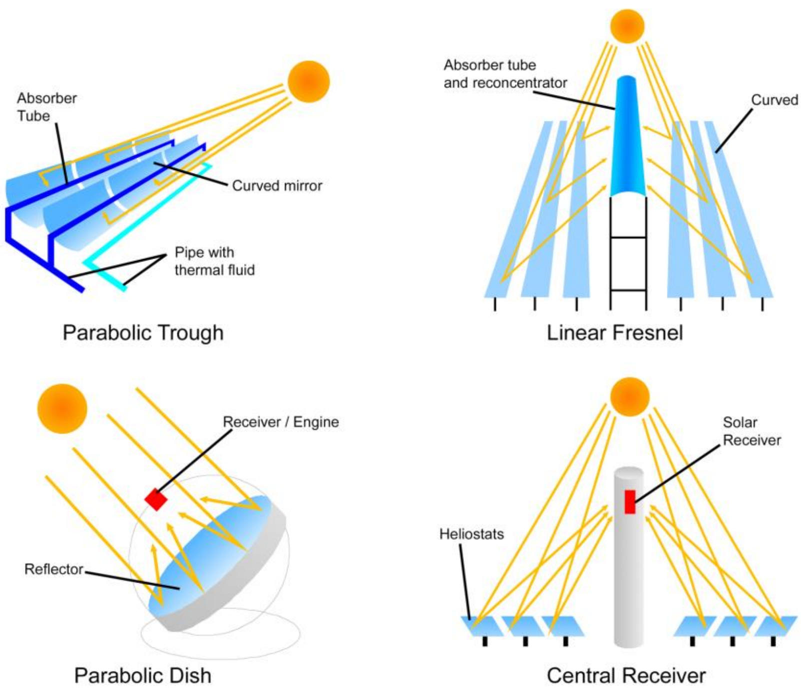
One of the advantages of this technology (“linear Fresnel reflectors”, or LF) is its simplicity and the possibility to use low cost components. The working fluid of LF systems is usually water, which is converted into saturated or superheated steam in the receiver , thus eliminating the need for an intermediate Heat Transfer Fluid (HTF) and associated heat exchangers.

Central receivers

These consist of a field of heliostats that track the Sun's position at all times (elevation and azimuth) and redirect the reflected rays towards the receiver located at the top of a tower. The orders of concentration are from 200 to 2000 times and the unit capacity is nowadays from 10 to more than 100 MWe.

The efficiency of these plants is usually better than PT plants, when fluid temperatures are higher, ranging from 550°C up to 1000°C depending on the HTF used. This leads to better thermodynamic performance and it also facilitates storage: smaller volumes are possible because of the higher temperature difference between the cold and the hot tanks of the thermal storage system.

Although the number of commercial Central Receivers (CR) plants in 2013 is still small, it is estimated that the cost (LCOE) of the electricity from such plants could be lower than that generated in PT plants, even though land use is slightly less efficient. The requirements for "flat land" are less demanding than for PT. Growing confidence for this type of plant is expected as more of them go into operation. Although these plants can have a rated power of more than 100 MWe their efficiency decreases slightly with the size due to optical and atmospheric attenuation constraints.



The four configurations for CSP systems

Parabolic dishes

These are small independent units which consist of two basic components: a 3D concentrator or solar dish, and a Stirling-engine power generator. The structure rotates, tracking the sun and thus concentrating the rays onto the focus where the receiver – connected to the engine – is located. Each complete unit produces electricity by itself. The orders of concentration are from 1000 to 10000 times. The power of the current devices varies from 3 kW to 25 kWe per unit.

The efficiency of these plants is much higher than those of the other three technologies already described. This technology can be installed modularly and PD's are easier to site on uneven land than other collecting systems. Therefore, parabolic dishes (PDs) could be a solution for distributed generation. However, unsolved technical problems related to the Stirling engine when it operates at high temperature/pressure are nowadays a significant barrier for the commercial deployment of this technology.

PSA Facilities and Capacities

The scientific and technical commitments of the PSA and the associated workload that this involves are undertaken by a team of over 130 persons, around 50 of them being scientists with expertise in central receiver technologies, parabolic-through collector, parabolic dish and linear Fresnel technologies, environmental applications of solar energy and, solar disinfection and detoxification of water. To this staff comes to add an important human assets as visiting researchers and students from different countries that are managed through the Training and Access Program.

At present, the main test facilities available at the PSA are:

(1) CESA-1 and SSPS-CRS central receiver systems, 5 and 2.5 MWth respectively.
(2) TCP-100 2.3-MWth parabolic-trough collector field with associated 115-m^3 thermal oil storage system.
(3) DISS 2.5-MWth test loop, an excellent experimental system for two-phase flow and direct steam generation with parabolic trough collectors in different working conditions, up to 500ºC and 100bar.
(4) The FRESDEMO "linear Fresnel" technology loop.
(5) Pressurized gas cooled parabolic-trough collectors system coupled to two-tank molten salts thermal energy storage test facility.
(6) A parabolic-trough collector test facility with thermal oil (the HTF-PTC Test loop) for qualification of solar components.
(7) A rotary test bench for parabolic trough collectors, named KONTAS.
(8) 4-unit dish/Stirling facility, named DISTAL, and 2 EuroDish units.

(9) A group of 3 solar furnaces, two of them with horizontal axis 60 kWth and 40 kWth, and a third one with vertical axis 5 kWth.

(10) A test stand for small evaluation and qualification of parabolic trough collectors, named CAPSOL.

(11) A 14-stage multi-effect distillation (MED) plant.

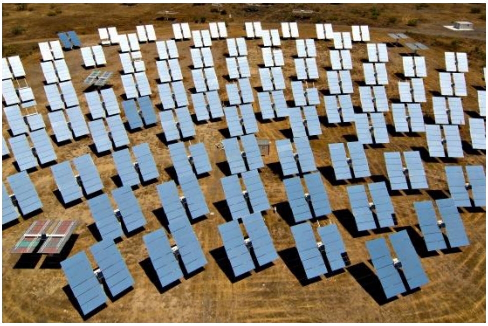
(12) A multiple solar detoxification and disinfection application facilities.

(13) The ARFRISOL building, an energy research demonstrator office building prototypes.

(14) A meteorological station integrated in the ‘Baseline Surface Radiation Network’.

Location of the main PSA test facilities

The 5 MWth 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. The 80-m-high concrete tower has four test levels. A peak flux of 3.3 MW/m^2 is achieved with a DNI of 950 W/m^2.



The 2.5 MWth SSPS-CRS facility is mainly devoted to testing small solar receivers in the 200 to 500-kWth capacity range. The 43-m-high metal tower has three test platforms. The two first (at 28 and 26 m) are prepared for testing new receivers for thermochemical applications. The third test platform is suitable for evaluation of small volumetric receivers and solar reactors for hydrogen production.

The 2.5 MWth DISS experimental plant is designing for component testing for parabolic-trough collector solar fields with direct steam generation of high-pressure-high temperature (up to 100 bar and 500ºC) This installation is suitable for studying and developing control schemes for solar fields with direct steam generation, operating procedures, and thermo-hydraulic studies of two-phase of water/steam in horizontal tubes with non-homogeneous heat flux.

The FRESDEMO loop is a 26m x 100m "Linear Fresnel concentrator" technology pilot demonstration plant designed for direct steam generation at a maximum pressure of 100 bar and maximum temperature of 450ºC.

The HTF-Test Loop is a test bench currently used for qualification of collector components and complete collectors or half collectors of a length of up to 75 m. The test facility permits up to 3 different collectors' prototypes are installed in parallel.

The Innovative fluids PTC test loop, which is a parabolic trough collector system using compressed gas as heat transfer fluid in the receiver, is connected to a two-tank molten salts thermal energy storage test facility where all type of equipment and instrumentation working with molten salts can be tested.

The rotary test bench for parabolic trough collectors, named KONTAS, 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.

These six parabolic dishes units are actually used to perform accelerated temperature cycling for a large variety of applications: materials tests, air-cooled volumetric receivers tests (metal or ceramic), tests of small-size receiver prototypes with or without heat transfer fluid, etc. Two parabolic dishes are provided with a Stirling engine.

The main field of application of the three PSA solar furnaces is materials testing at very high temperatures, including thermal shocks, either in ambient conditions, controlled atmosphere or vacuum; and solar chemistry experiments using chemical reactors associated with receivers.

SF60 and SF40 are horizontal axis solar furnaces of 60 and 40 kW respectively. SF60 has a peak concentration of 3000 kW/m^2 and focus size 25 cm diameter. SF40 is a high concentration solar furnace, with peak concentration about 6000 kW/m^2 and its focus size is 12 cm diameter.

SF5 is a 5 kW vertical axis solar furnace with peak concentration 7000 kW/m^2 and focus size 25 mm diameter.

The CAPSOL test stand was specially designed for evaluation and qualification of small-size parabolic trough collectors. This facility is designed to operate with pressurized water with fluid temperatures from ambient to 230ºC, flow rates from 0.3 to 2.0 m3/h and pressures up to 25 bar.

The 14-stage multi-effect distillation (MED) facility is a pilot demonstration plant designed to perform brackish water and seawater solar desalination, using a solar field composed of 252 stationary solar collectors arranged in four rows of 63 collectors (see below) to heat the water entering the facility.

This CSP+D test bed facility is devoted to the research of the coupling of a concentrating solar thermal power plant (CSP) and a water desalination plant (CSP+D), which makes use of the steam turbine (extracted or exhausted) to drive the thermal desalination process. The basic purpose is to simulate and analyse the various possible configurations for integrating a thermal desalination plant in a solar thermal power plant. The test bench enables the operating conditions of different types of commercial turbines and interconnection configurations to the PSA multi-effect (MED) desalination plant to be simulated.

The purpose of this facility for polygeneration applications 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 Solar ORC facility was designed to evaluate the feasibility of solar organic Rankine cycles for electricity production at medium temperatures.

The Low temperature Solar Thermal Desalination applications facility consists of a test-bed for evaluating solar thermal desalination applications. The installation currently operates with membrane distillation modules but allows for testing other thermal desalination applications.

The ARFRISOL building is an energy research demonstrator office building prototype for testing passive energy saving strategies and energy efficiency in building technologies.

The meteorological station is devoted to evaluate solar resource variability that impacts large penetrations of solar technologies; develop standardized and integrating procedures for data bankability; improve procedures for short-term solar resource forecasting, and advance solar resource modelling procedures based on physical principles.

The multiple solar detoxification and disinfection application facilities consist mainly in several photo-reactors based on Compound Parabolic Collectors (CPC) with different optical characteristics for detoxification and disinfection purposes. In addition, there are several additional pilot plants based on non-solar technologies, such as ozonation, nanofiltration and biological processes in order to facilitate comparison and possible combination tasks, and reliable economic studies. Finally, a UV disinfection continuous plant and a physic-chemical pre-treatment pilot plant for industrial wastewater applications are available.

PSA Laboratories

Material Laboratories

There are two material laboratories at PSA. One of them is devoted mainly to the metallographic preparation and the analysis of test pieces treated with concentrated solar energy and to the characterization of solar test by thermogravimetry. The main equipment of this lab is:

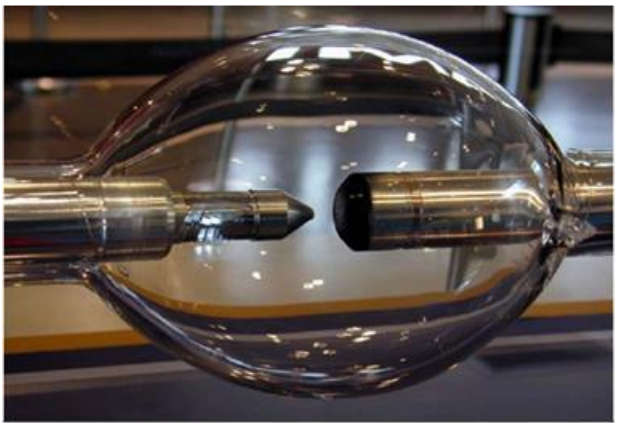
- Struers micro hardness tester
- Confocal Microscopy and Interferometry
- Digital inverted microscope
- Thermogravimetric balance

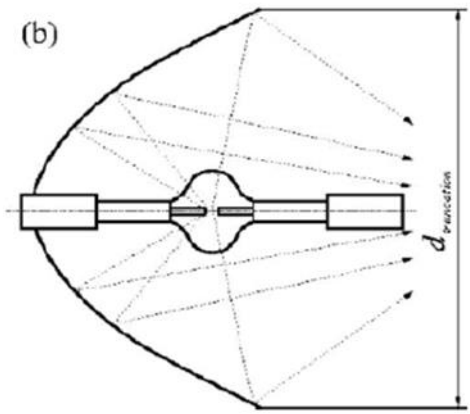
High-performance modular Thermogravimetric Analyzer

3D Optical Surface Metrology System

The second laboratory is devoted to accelerated ageing and durability studies of the most critical components of solar thermal power plants, not only absorbent materials, but also surface treatment and coatings. Main equipment:

- Two high-temperature muffle furnaces
- Weathering chamber for temperature (from -40 to+120ºC), humidity (from 10 to 90%), solar radiation (from 280 to 3000 nm) and rainfall of 340L.



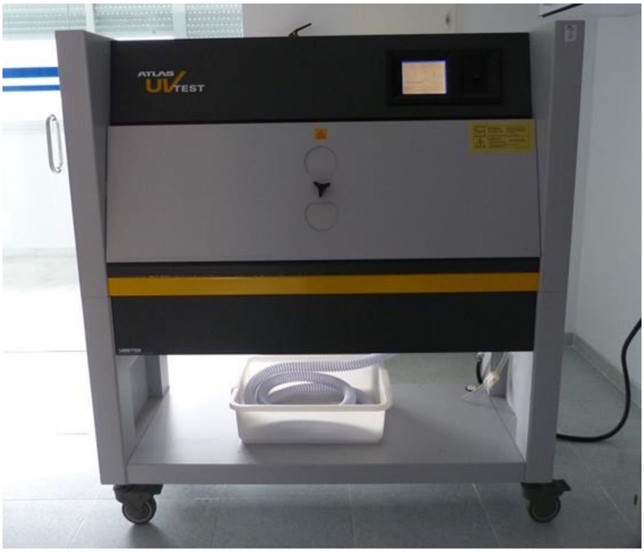


Xenon lamp used in the solar Simulator and configuration of the lamp and concentrator

Advanced Optical Coatings Laboratory

The PSA advanced optical coatings lab has equipment for development and complete study of new selective coatings for absorbent materials used in solar concentrating systems at medium and high temperature (up to 600ºC), as well as for anti-reflective treatments for glass covers used in some receiver designs, such as receiver tubes in parabolic-trough collectors. The laboratory has sufficient equipment 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 of this lab is also used for optical characterization of solar reflectors. A summary of the equipment available is given below:

- Spectrophotometer
- Nicolet Magna IR Spectrophotometer
- Portable Optosol absorber characterization equipment
- Weathering chamber for accelerated ageing tests
- Viscosimeter
- Goniometer for measuring contact angles



Weathering chamber used for accelerated ageing tests of optical coatings

Solar reflector durability analysis and optical characterization laboratories

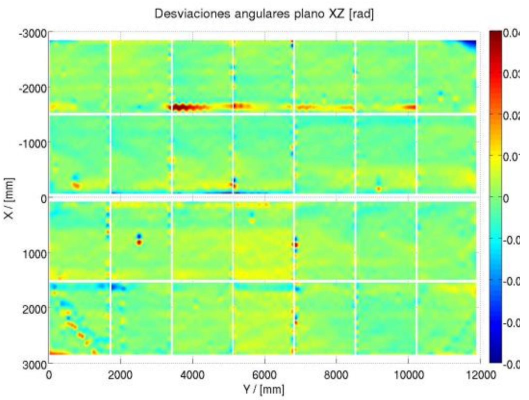
The PSA optical characterization and solar reflector durability analysis laboratories have the equipment necessary for complete study of the materials used as reflectors in solar concentrating systems. These labs allow the characteristic optical parameters of solar reflectors and their possible deterioration to be determined. These labs have the following equipment for both quantitative and qualitative measurement of the reflectance of reflective surfaces:

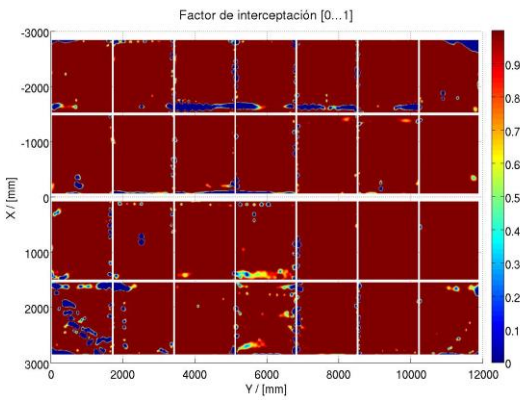
- Portable specular reflectometers
- A spectrophotometer
- 3D microscope
- Weathering chambers
- Abrasion tester


PSA solar reflector optical characterization lab (left) and durability analysis lab (right)

Geometric characterization of reflectors and structural frames

For the geometric characterization of the concentrators used in solar thermal systems (heliostats, parabolic-trough collectors, parabolic dishes, Fresnel lenses, etc.), the PSA has a laboratory in which 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.





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

The equipment and resources currently available at the PSA for photogrammetric measurements are:

- Several Cameras up to 21Mpxl and different lenses.
- A photogrammetry software, and
- 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.

Radiometry Laboratory

The PSA Radiometry Lab came out of the need to verify measurement of highly important radiometric magnitudes associated with solar concentration, i.e., solar irradiance (flux) and surface temperature of materials. This lab has the following equipment:

- Radiometer
- IR devices (infrared cameras and pyrometers)
- Black bodies

A radiometer calibration system at the PSA Radiometry laboratory.

Solar Hydrogen Evaluation Lab

This laboratory has the following capabilities:

- A laboratory equipped 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 sieve column and a TCD detector.

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

Solar Simulation Loop for evaluation of hydrogen production processes

Water Technologies Laboratory

The water technologies laboratory is about 200 m^2 distributed in six different rooms.

(1) The main laboratory is mainly equipped with two UV/visible spectrometers, three respirometers, and an Automatic Solid Phase Extraction (ASPEC).
(2) The chromatography room contains, among other equipment, two High Performance Liquid chromatographs (HPLC and UPLC) with automatic injection, two total organic carbon (TOC) analysers with autosamplers, two ionic chromatographs and an ultrafast real-time quantitative PCR (Polymerase Chain Reaction) equipment.
(3) The microbiology laboratory.
(4) The Scanning Electron Microscope (SEM) room for the preparation of microbiological samples and catalysts to be analysed in the SEM, the system is completed with a metal coater and critical point dryer.
(5) A storeroom with direct access from outside for chemicals and other consumables storage.

(6) An office with three workstations where visiting researchers can analyse the data from the experiments carried out at the PSA.

Images of the water technology labs: Chromatography (left) and SEM Lab (right).

Training and Access Activities

As the CIEMAT is a public research organization, this line of work is considered of great importance and therefore dependents directly from the PSA direction office.

On the one hand, the Visitors Centre contributes to spreading the knowledge acquired by PSA experimentation since it was opened 30 years ago. This centre offers a unique opportunity for contacting with the cleanest and most plentiful energy resource of all, the Sun. It has convenient opening hours, comfortable facilities, and a completely organised visit to help anyone to understand solar energy applications and their future.

On the other hand, the Plataforma Solar de Almería training program main goal is to create a generation of young researchers who can contribute to the deployment of concentrating solar energy in all its possible applications. By means of this program about thirty students from different countries has been admitted each year, thus contributing to the transmission to new generations of graduates the knowledge on solar thermal technology accumulated at the PSA during thirty years of experimentation.

The main aspects of the training program are the following:

– Educational agreement, signed annually with the University of Almeria (UAL): PhD grants and traineeships. PhD grants last 4 years. Traineeships last between 6 and 12 months.

– 'Leonardo da Vinci' grants, an activity for students from other countries. A grant of six months for final degree projects.

– Specific educational cooperation agreements with other entities for receiving students at the PSA. These generally arise after identifying a topic of common interest for any research group and a PSA research group. An agreement is signed between the two institutions for the student to come to the PSA for the time necessary to develop the project in question.

Not all of our training and education activities are based on stays of PhD students or coursework. Since 1990, the PSA is recognized by the European Commission as a 'Large European Scientific Installation'. In each of the successive ‘Framework Programmes for Research and Development’, the European Commission has included an horizontal activity intended to use those singular scientific installations in any of the European Union countries in a privileged manner by research groups from other countries who would not normally have access to them. The current programme in within the project “SFERA-II” (http://sfera.sollab.eu/).

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PSA infrastructures where updated under the frame of
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