Plataforma Solar de Almería

Annual Report 2002

MINISTERIO DE CIENCIA Y TECNOLOGÍA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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Introduction

Activity at the Plataforma Solar de Almería in 2002 was structured along three main lines of work: technologies for solar thermal electricity generation, use of solar radiation for environmental applications and activities spreading and making as well known as possible the applications of these technologies.

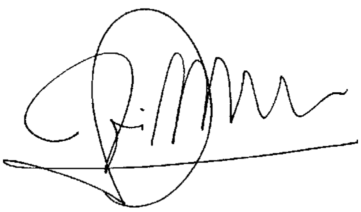
Solar thermal electricity generation has received a strong push to the forefront in 2002 as a consequence of the approval in Spain of Royal Decree 841/2002 which sets a premium of 0.12€ per kWh production. This long-awaited measure, will no doubt contribute to the construction of the first commercial plants in our country. In this context our activity this year was intense, both in parabolic-trough technology (PTT) and in central receiver technology (CRT).

In the area of PTT, the cost of electricity generation is expected to be reduced by around 30% due to the decisive advances toward consolidation of the direct steam generation technology. The INDITEP and PREDINCER projects, with strong participation of industry, are the clearest signs of this. In CRT also, in the SOLGATE and SOLAIR projects, the bases have been set for a mature technology, reliable and competitive and ready for the power market.

Our activity in environmental applications has centered on the already consolidated line of detoxification of industrial waste water and renewed activity in desalination of seawater. In few cases, is there such a clear coincidence between the existence of an environmental problem and its solution as the scarcity of drinking water and the use of solar energy to obtain it from seawater. The AQUASOL and SOLARDESAL projects have begun this year and I am sure that their results will not go unnoticed.

The training and information activities continue at a strong pace, since we are aware that we cannot ignore the facet of informing society about the existence of this renewable energy option. Educational agreements are maintained with various universities, participation continues in the access programs promoted by the European Commission and we have taken our own activities "into the street", with Science Week activities.

I do not want to end this introduction without dedicating a few words of acknowledgement to the personnel of the PSA, without whose daily dedication it would have been impossible to carry out any of these projects. CIEMAT is also to be acknowledged for their decisive support of this Center as proven by the significant investment made to improve our facilities under the Plan for Facility Improvement, and finally, to my predecessor in this position, Dr. Manuel Romero, for his fine labor and enormous dedication in spite of the circumstances.



Diego Martínez Plaza
Director of the Plataforma Solar de Almería

General Presentation

The PSA as a Large Solar Facility: General Information

The Plataforma Solar de Almería (PSA), a dependency of the Center for Energy, Environment and Technological Research[1] (CIEMAT), is the largest center for research, development and testing of concentrating solar technologies in Europe. PSA activities form an integral part of the CIEMAT Department of Renewable Energies as one of its lines of R&D.

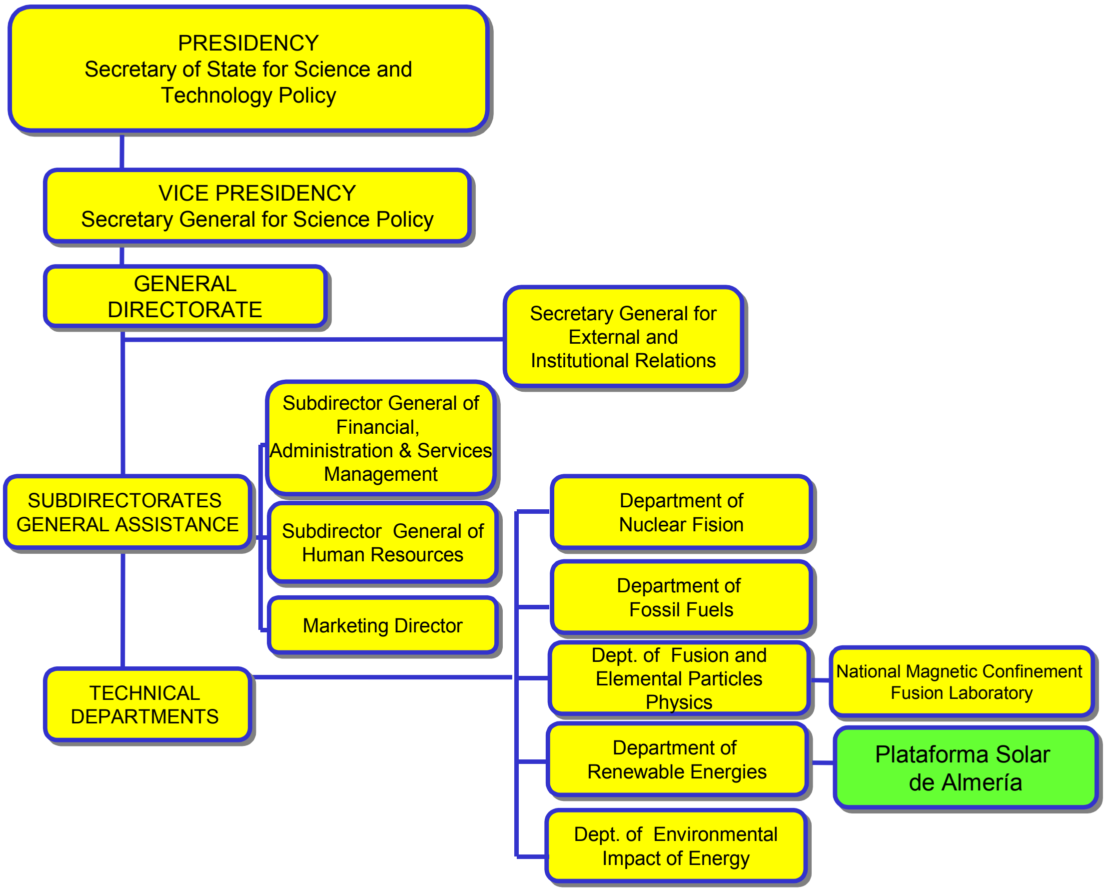


Figure 1. The PSA in the CIEMAT Organization Chart

[1] Centro de Investigaciones Energéticas Medioambientales y Tecnológicas

Figure 2. Aerial View of the Plataforma Solar de Almería

The objectives that inspire its research activity are the following:

- Contribute to the establishment of a sustainable, clean, world energy supply.
- Contribute to conservation of European energy resources, climate and environment.
- Promote market introduction of solar thermal technologies and derived solar chemical processes.
- Contribute to development of a competitive European solar thermal export industry.
- Reinforce cooperation between the business sector and scientific institutions in the field of research, development, demonstration and marketing of the solar thermal technologies.
- Boost cost-reducing technological innovation, thus contributing to increased market acceptance of the solar thermal technologies.
- Promote North-South technological cooperation, especially in the Mediterranean Area.
- Assist industry in identifying market opportunities related to the solar thermal technologies.

Organization and Functional Structure

Research carried out at the Plataforma Solar de Almería is structured around four main projects: "Parabolic-Trough Collector Technology", "Central Receiver Technology", "Solar Chemistry" and "Training and Access to the Plataforma Solar de Almería". The first two are devoted to the development of new and improved ways to generate solar thermal electricity. The third to exploring the possibilities of solar chemistry, especially with regard to its potential for detoxification of industrial effluents, the synthesis of fine chemicals and the desalination of water; finally, the objective of the fourth is to make the PSA infrastructure available to the national and international scientific community and train young researchers in the technologies under development here.

To assist the R&D projects mentioned above, the PSA also has the corresponding areas of management and services which, given the variety and complexity of the facilities, are extraordinarily important to daily operation in all the center's lines of action.

Each R&D project has a Project Leader and a technical staff whose work follows the master lines of PSA scientific activity and technological development, while remaining quite independent in the execution of their budget, planning of scientific objectives and technical management of their resources. Nevertheless, the four R&D projects all share a great deal of PSA resources, services and infrastructures, so that they must maintain fluent communication with the technical support and administration units at all times, through the Directorate, which must assure that the capacities, infrastructures and human resources are efficiently distributed. It is also the Directorate that channels requirements to the various Subdirectorates for General Assistance located at the CIEMAT in Madrid.

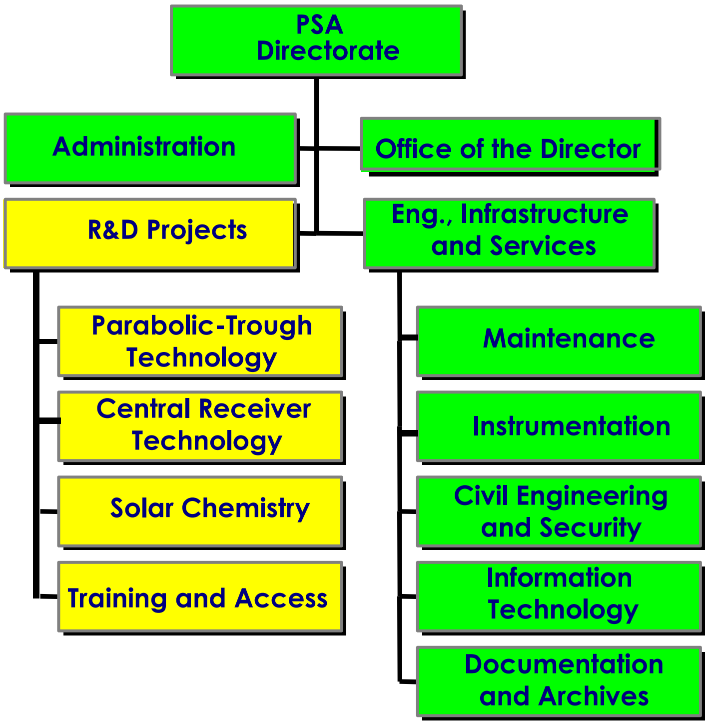


Figure 3. PSA Organization Chart 2001. Directorate Technical and Administrative Service Offices are Indicated in Green.

Human and Economic Resources

The scientific and technical commitments of the PSA and their associated workload are undertaken by a team of 87 persons who, as of December 2001, made up the permanent staff that lends its services to the Plataforma Solar. Moreover, in addition to this permanent staff, there is a considerable influx of trainees and visiting researchers who are handled through the Training and Access Project described later.

Of the 87 persons that work daily at the PSA, an important part come from auxiliary services, operation and maintenance contracts (39 persons). The auxiliary contracts are for three cleaning persons, six administrative personnel and five security guards. The O&M contracts are for eight facility operators, four operation watchers and 13 persons for mechanical, electrical and electronic maintenance. The rest of the personnel are composed of the 34 persons on the CIEMAT-PSA staff and the 14 who make up the DLR permanent PSA delegation that result from the current commitments of the Spanish-German Agreement.

Focusing on R&D personnel, the PSA has a still small staff of 26 persons of whom 16 are in Almería and 10, while integrated in PSA R&D projects, work at the CIEMAT in Madrid.

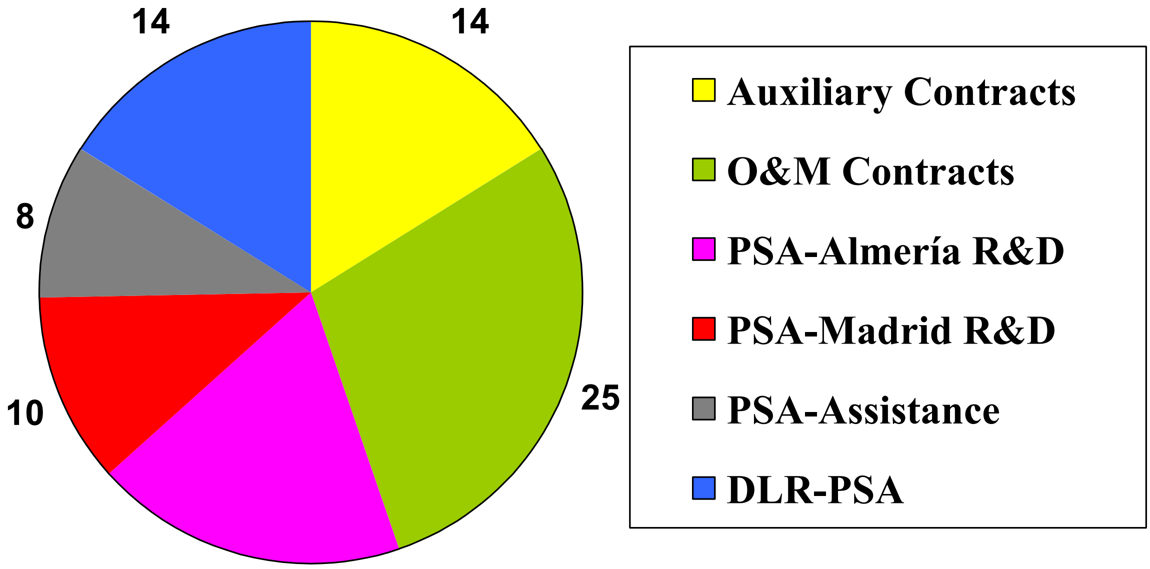


Figure 4. Distribution of PSA permanent personnel as of December 2002.

Another 12 DLR delegation staff members also work in R&D totaling 38 persons devoted to R&D at the PSA. This is without doubt one of the first improvements to be made and it is the firm desire of CIEMAT that in the coming years the ratio of personnel devoted to R&D be continually increased.

In the PSA budget, it is clear that in spite of the withdrawal of DLR from the basic budget for O&M expenses, the upward trend has been maintained, thanks in good measure to more revenues being received and to the CIEMAT itself, which has assumed the greater part of the budget previously absorbed by the Spanish-German Agreement.

Successfully raising of external revenues, mainly from the European Commission, has been an outstanding contribution of DLR. The proposal of a good number of new joint

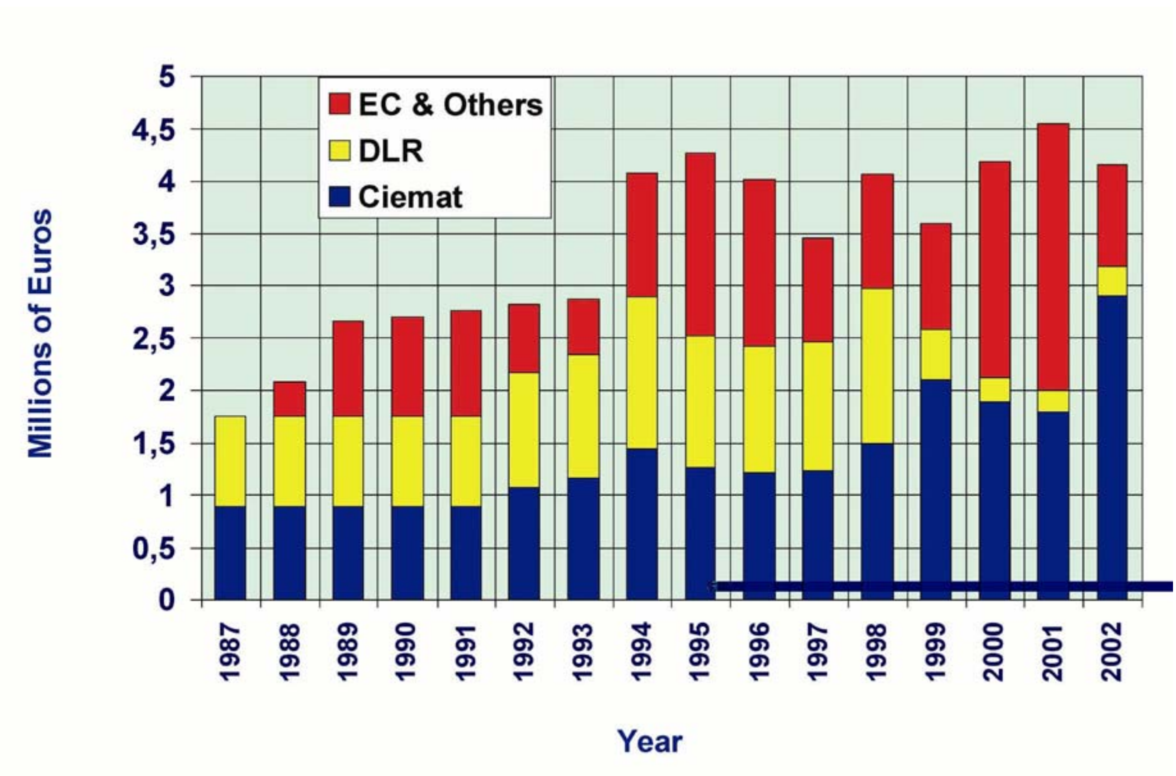


Figure 5. Evolution of PSA budgeted expenses and distribution of source of financing

projects to the EC has allowed DLR to remain at the PSA in a new relationship based on specific projects. The fruit of this success is the relevancy of the German PSA delegation.

The PSA budget reached 4.15 million Euros in 2002. Of this amount, 0.98 million Euros were received as income from EC projects and other subsidies from other entities. The decrease in income from the EC is the result of the typical life cycle of European Union Framework Programs, since in 2002, were in final stretch of the 5th R&D Framework Program and so the majority of the projects associated it were already in their last stage when there is less income from them. The contribution by DLR to the Spanish-German Agreement improved slightly over the year before to 0.28 million Euros. The contribution by CIEMAT increased to be able to undertake the activities approved in the PSA infrastructure plan. These improvements were begun in 2002 with important construction of buildings such as the new visitors building, new office building, installation of the new meteorological station, replacement of the solar furnace, repairs in the DCS field and improvements in the heliostat fields.

Scope of Collaboration

As mentioned above, since 1987, the PSA has maintained the Agreement for Spanish-German cooperation, commonly known as the CHA, with the DLR. At the present time, the relations and Annex IV of this Agreement includes a Delegation at the PSA in 2003, 2004 and 2005. 2002 was a transition year in which new conditions and their extent were set for collaboration the CHA. The Agreement was signed by both parties in the central offices of CIEMAT on December 10, 2002.

Altogether, the scope of cooperation in which the PSA moves is outstandingly broad. In the sphere of international relations, the PSA actively participates in Tasks I, II and III of the IEA-SolarPACES program, under which information is exchanged and cost-sharing tasks are carried out with similar centers in other countries (USA, Mexico, Brazil, Germany, France, UK, Switzerland, South Africa, Israel, Russia, Australia, Algeria and Egypt).

Under the Training and Access Project, as one of the large scientific installations in the EC IHP (Improving Human Potential) program, the PSA maintains relations with over 60 research teams and universities from different European countries. There is also an agreement for joint management of grants with the University of Almería, as well as educational agreements with the as well as educational agreements with the Ecôle Nationale des Ponts et Chaussées of Paris and the ETH (Polytechnical University of Zurich). An agreement is also being forged with the CNRS Solar Materials Laboratory in Odeillo (France) and intense participation in the European EUROCARE Network for Solar Energy and Advanced Combustion Projects is ongoing.

In parabolic-trough technology, the scope of collaboration continues to be quite broad, since the PSA has contractual relations with a wide range of domestic and international institutions. Collaboration continued in the year 2001 with the University of Seville, research centers (DLR, ZSW and the Fraunhofer Institute for Solar Energy Systems of Germany), the National Institute of Chemistry of the University of Ljubljana in Slovenia, the National Testing and Research Institute of Sweden; the Dutch TNO, the Greek CRES and the Swiss Solartechnik Prüf und Forschungsstelle), electric utilities (the Spanish ENDESA and IBERDROLA), industry (Spanish INABENSA and German FLABEG Solar International) and engineering firms (the German FICHTNER and SBP and Spanish INITEC).

In the national scope of central receiver technology, the PSA collaborates in projects with INABENSA, GHERSA, AICIA, IBERESE and SERLED and universities such as the University of Sevilla, Almería and UNED[2]. In 2001, the EHN Company, because of its Montes del Cierzo Solar Plant initiative in Tudela, joined in this collaboration. Under the umbrella of the 5th Framework Program's Energy Program and the Spanish German Agreement, collaboration with the DLR has been intense in several projects with other European institutions and companies such as ORMAT (Israel), TUMA (Switzerland), Heron (Netherlands), FICHTNER (Germany), STC (Denmark), Forth-Cperi (Greece), Saint Gobain (France), Nexant (United Kingdom) and SIMTECH (Austria).

In 2002, the area of collaboration of the Chemical Applications of Solar Radiation Project under went a strong outward thrust and enlargement of the already extensive list of institutions with which it had been collaborating in previous years. As of December 31st, the list of contractual relations in effect includes all the possible spheres, from local (Univ. of Almería, DSM Deretil, Cajamar, Coexpal, Comunidad de Regantes Cuatro Vegas) to national (Abengoa Group, Ecosystem, Aragonesas Agro, Emuasa, Indoor Air Quality, Inasmet Foundation, Barcelona Autonomous, Complutense, Alcalá and La Laguna universities, ICP-CSIC and the San Carlos Hospital in Madrid), to European (Weir-Entropie, Ao Sol, Hellenic Saltworks, Trailigaz, Janssen Pharmaceutical N.V., Ahlstrom Paper Group, IPM, Protection des Metaux, y las universidades ETH, NTUA, INETI, EPFL, Claude Bernard Lyon 1, Poitiers, L'Aquila, etc.) and non European (where there are currently collaboration contracts with institutions in Mexico, Morocco, Argentina, Peru, Colombia, Egypt and Tunesia).

2 Universidad Nacional para Educación a Distancia (National University for Education by Correspondence)

Facilities and Infrastructure

General Description of the PSA

The PSA is located in southeastern Spain in the Desert of Tabernas at 37º05'27.8" north and 2º21'19" west. It receives a direct annual insolation above 1900 kWh/(m^2·year) and the average annual temperature is around 17ºC.

The capacity to offer researchers a place with climatic and insolation conditions similar to those in developing solar-belt countries (where the greatest potential for solar energy is found) but with all the advantages of a large scientific installation in the most advanced European countries, makes the PSA a privileged site for evaluation, demonstration and transfer of solar technologies.

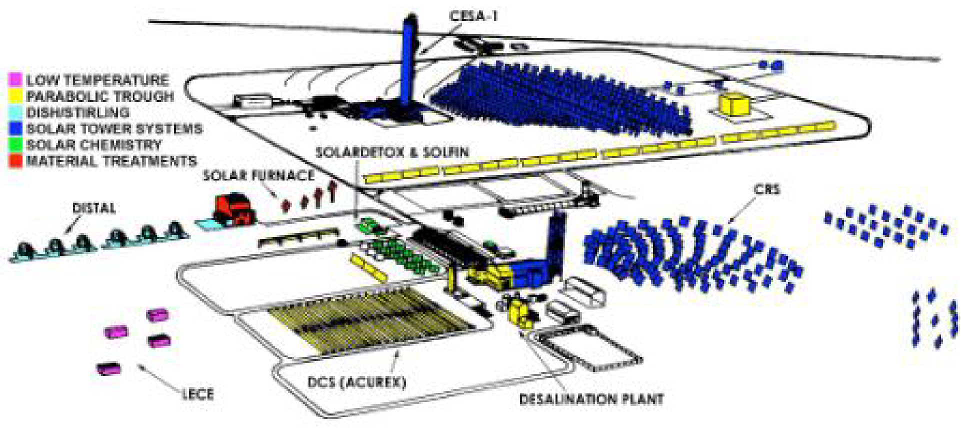


Figure 6. Location of the main PSA test facilities

At present, the main test facilities available at the PSA are [SolarPACES, 1996]:

- CESA-1 and SSPS-CRS central receiver systems, 7 and 2.7-MWt respectively.
- SSPS-DCS 1.2-MWt parabolic-trough collector system, which has an associated thermal storage system and water desalination plant.
- The 1.3-MWt DISS test loop, which is an excellent experimental system for two-phase flow research and direct steam generation for electricity production.
- The HTF test loop, which has a complete oil circuit that allows evaluation of new components for parabolic trough collectors.
- A facility with 6 dish/Stirling systems called the DISTAL.
- A 60-kWt solar furnace for thermal materials treatments.
- A multiple facility for solar detoxification applications consisting of a parabolic-trough loop with two-axis tracking and three CPC photoreactors for different types of trials.
- The SOLFIN (Solar Fine Chemicals Synthesis) facility for synthesis of fine chemicals,
- The Laboratory for Energy Testing of Building Components[3] (LECE).
- A meteorological station.

[3] El Laboratorio de Ensayo Energético de Componentes de la Edificación

Central Receiver Facilities: CESA-1 y CRS

7-MW_T CESA-I FACILITY

The CESA-I project, inaugurated in May 1983, was promoted by the Spanish Ministry of Industry and Energy to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-1 does not produce electricity, but is operated as a very flexible test facility for subsystems and components such as heliostats, solar receivers, thermal storage and control systems. It is also used for other applications that require high flux concentrations on relatively large surfaces, such as chemical processes for methane reforming, surface treatment of materials or astrophysical experiments.

Figure 7. Aerial view of the CESA-I, top

The facility collects direct solar radiation by means of a field of 300 39.6-m^2-surface heliostats distributed in a 330-x-250-m north field into 16 rows. The heliostats have a nominal reflectivity of 92%, the solar tracking error on each axis is 1,2 mrad and the reflected beam image quality is 3 mrad. North of the heliostat field there are two additional test zones for new heliostat prototypes, one located 380 m from the tower and the other 500 m away. The maximum thermal power delivered by the field onto the receiver aperture is 7 MW. At a typical design irradiance of 950 W/m^2, a peak flux of 3.3 MW/m^2 is obtained. 99% of the power is focused on a 4-m-diameter circle, 90% in a 2.8-m circle.

The 80-m-high concrete tower, which has a 100-ton load capacity, has three test levels: A solar furnace for materials testing at 45 m, the REFOS test bed for pressurized volumetric receivers with calorimetry bench at 60 m and the 2.5-MW TSA facility for testing of atmospheric volumetric receivers at 80 m. The tower is complete with a 5-ton-capacity crane at the top and a freight elevator that can handle up to 1000-kg loads. Finally, for those tests that require electricity production, the facility has a 1.2-MW two-stage turbine in a Rankine cycle designed to operate with 520°C 100-bar superheated steam.

The TSA facility is really a calorimetric test bench that enables measurement of solar receiver efficiency up to 2.5 MW_t. The TSA consists of a receiver with a 3.4-m-aperture metal mesh absorber that heats air at atmospheric pressure up to 700°C. The air circuit has two blowers and valves that allow hot and cold air to be sent to either a steam generator or thermal storage. The steam generator, which has a nominal capacity of 1.8 MW, receives the hot air and cools it to approximately 200°C. The energy that is collected here produces 340°C 45-bar steam of sufficient quality to feed a steam turbine. The 18-ton insu-

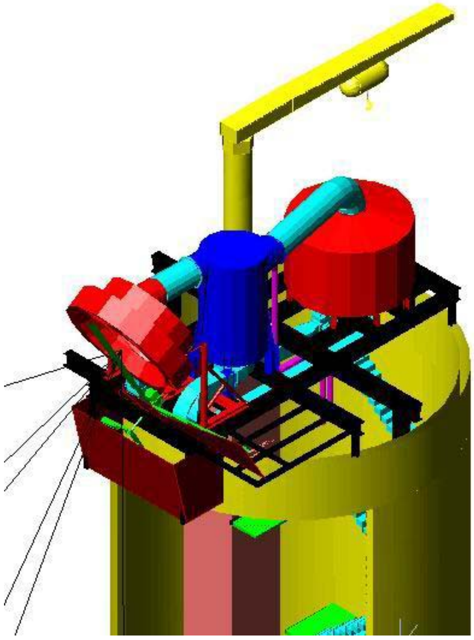


Figure 8. View of the of the TSA facility at the 80-m level of the CESA-1 tower. At the left and at an angle is the solar receiver and in the center, in blue, the steam generator.

lated cylindrical storage tank, which contains a bed of ceramic balls (Al_2O_3), has a capacity of 1000 kWh.

THE 2.7 MW_T SSPS-CRS FACILITY

The SSPS-CRS plant was inaugurated as part of the International Energy Agency's SSPS project (Small Solar Power Systems) en September 1981. It was originally a demonstration electricity production plant and used a receiver cooled by liquid sodium that also acted as the thermal storage medium. At the present time, as with the CESA-I plant, it is a test facility devoted mainly to testing small solar receivers in the 200 to 350-kW thermal capacity range. The heliostat field is made up of 91 39.3-m^2 first generation units. A second field north of it has 20 52-m^2 and 65-m^2 heliostats that are controlled by radio and that can be used as support. The nominal average reflectivity of the field is 87%, 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 thermal capacity of the field is 2.7 MW and peak flux obtained 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 metal tower has two test platforms. The first is a two-level open area at 32 and 26 m prepared for testing new receivers for chemical applications. The second is at the top, at 43 m, and houses an enclosed room with crane and calorimetric test bench for the evaluation of small atmospheric-pressure volumetric receivers.

Figure 9. A CRS field heliostat reflecting the tower.

Figure 10. Front view of the 200-400-kW volumetric receiver test bed in the CRS tower

Tower infrastructure includes a 600-kg-capacity crane and 1000-kg-capacity rack elevator.

The test bed (Figure 10)consists of a air-recirculation circuit with axial fan and 40-kW electric heater to control the air-return temperature as well as instrumentation to measure the temperature, pressure and flow rate. The absorber outlet air is cooled by a water-cooled heat exchanger, which is used as an indirect method of thermal balance. The calorimetric bench has been successfully employed since 1986 with the logical improvements and updating, for the evaluation of all kinds of metal and ceramic volumetric absorbers.

Two PROHERMES II (Programmable Heliostat and Receiver Measuring System II) measurement systems are used to measure the flux of the concentrated solar radiation on both towers. For this, the concentrated incident solar beam is intercepted by a lambertian target, located on a plane parallel and immediately in front of the receiver aperture, at which moment a high-resolution CCD camera records the image.

After exhaustive treatment of the image (removal of electronic background noise, correction of aberrancies produced by the viewing equipment and geometric rectification), the gray-scale value associated with each pixel undergoes a transformation called calibration. This operation consists of experimentally finding a specific rule or criterion that unmistakably associates each value given the solar irradiance (W/cm^2) at a specific point on the target to a gray-scale value for the pixel corresponding to the same position previously obtained with the camera. Once the pixel map has been calibrated and the area that they represent individually on the target is found, the total power can be integrated, and the calculation of the rest of the magnitudes of interest, such as peak irradiance or distribution, is possible.

Linear focusing facilities: DCS, DISS, EUROTROUGH and LS3

The PSA has several parabolic-trough solar collector facilities. Some of them, such as the SSPS-DCS, were pioneers in Europe, while other more modern facilities, such as the DISS experimental plant, are unique worldwide and place the PSA in a privileged position for research and development of new parabolic-trough collector applications. The main characteristics of these facilities are briefly explained below.

THE DISS EXPERIMENTAL PLANT

This facility was erected and put into operation in 1998 for experimenting with direct generation of high-pressure high-temperature (100 bar/400ºC) steam in the parabolic-trough collector absorber tubes. The DISS experimental plant is the only facility in the world where two-phase flow (water/steam) processes in parabolic trough collectors can be studied under real solar conditions. It is very appropriate not only for the study and development of control schemes, but also for the study and optimization of operating procedures, that must be implemented in direct steam generation solar fields. Another of the possible applications of this plant is the study of the heat transfer coefficients in horizontal tubes through which the two-phase water/steam flow circulates.

Figure 11. View of the DISS solar field in operation

The DISS plant consists of two subsystems: the Solar Field of parabolic-trough collectors, and the Power Block. In the solar field, the feed water is preheated, evaporated and converted into superheated steam as it is circulated through the absorber tubes of a 550-m-long row of parabolic trough collectors having a total solar collecting surface of 2,750 m^2. The facility can produce 0.8 kg/s of 100-bar 370°C steam.

Superheated steam generated in the solar field is condensed, processed and reused again as feed water for the solar field (closed-circuit operation) in the Power Block.

Facility operation is highly flexible and can work at three different pressure levels: 30, 60 and 100 bar and in any of the three basic direct steam generation modes: Recirculation, Injection and Once-Through, or any combination thereof. Furthermore, it is provided with a complete range of instruments that allows thorough system monitoring and evaluation.

The figure below (Figure 12) shows a simplified diagram of the DISS loop in which the solar field is shown as one row of 11 parabolic-trough collectors with north-south-oriented rotating axes. The collectors are composed of 12-m-long by 5.76-m-wide reflective parabolic-trough modules. The solar field consists of two parts, the preheating+evaporating section and the superheating section. At the end of the preheating+evaporating section there is a recirculation pump and a water/steam separator which augments the operative flexibility of the system.

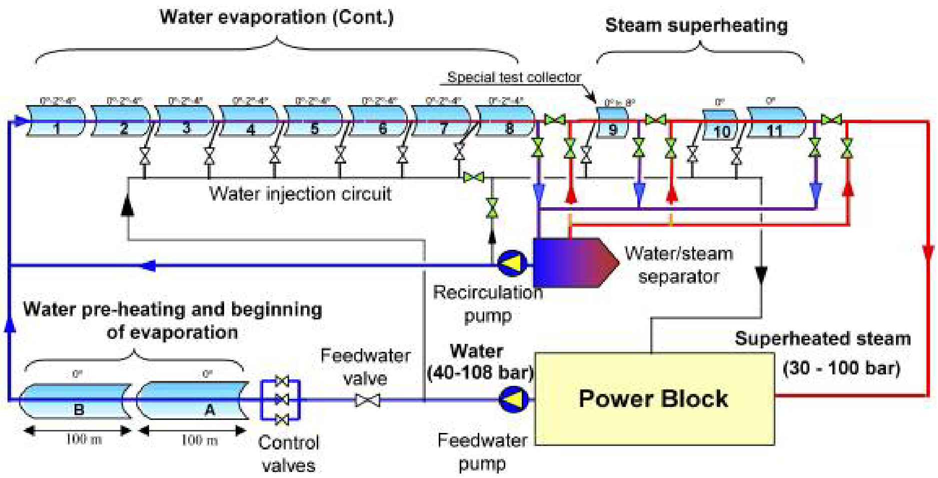


Figure 12. Simplified diagram of the PSA DISS loop

The Power Block is where the superheated steam produced by the solar field is condensed, processed and reused as feed water in the solar field (closed circuit operation).

One of the most important characteristics of the DISS loop is the possibility of measuring the thermal gradient in the cross sections of the parabolic-trough solar collector absorber tubes.

THE LS-3 (HTF) TEST LOOP

The LS-3 test loop, also called the HTF test loop, which was erected in 1997, is an ideal facility for evaluating parabolic-trough collector components under real solar energy operating conditions. Mirrors, absorber tubes, solar tracking systems, etc., can be installed and evaluated in this facility, which is provided with the appropriate measurement and monitoring instrumentation.

Figure 13. General view of the LS-3 test loop

The facility consists of a thermal oil circuit connected in a closed loop to a solar collector made up of four 12-m-long by 5.7-m-wide LS-3 parabolic-trough modules with a total collecting surface of 272.5 m^2. The thermal oil used in this facility (Syltherm 800) has a maximum working temperature of 420°C, and a freezing point of –40°C. The rotating axis of the solar collector is oriented east-west, which increases the number of hours per year in which the angle of incidence of the solar radiation is less than 5°.

The facility's oil circuit, which has a maximum working pressure of 16 bar, is made up of the following elements:

- 1-m^3-capacity oil expansion tank, with automatic nitrogen inertization system
- Oil circuit sump tank
- Mechanical draft oil cooler, with air speed control and 225-kW maximum cooling.
- Centrifugal oil pump, with a flow rate of 0 – 2,8 liters per second
- 40-kW, 3-x-380 V electric oil heater.

In the HTF test loop, and in parallel to its solar collector, is the EUROTROUGH collector prototype. The EUROTROUGH collector design was developed by a European consortium which, with the financial aid of the European Commission, designed, built and erected it at the PSA and evaluated it under real conditions. The new parabolic-trough collector is apt not only for solar thermal power plants, but also for other applications, such as desalination of seawater or industrial process heat in the 150°C-425°C range. At the conclusion of the EUROTROUGH project, the Consortium donated this first prototype to CIEMAT for its operation and maintenance, which now forms part of the PSA parabolic-trough collector facilities.

SSPS-DCS PLANT WITH SOLAR DESALINATION SYSTEM

This 1.2 MW_t-capacity facility, as shown in the diagram below (Figure 14), consists of four main subsystems:

- A solar field made up of 40 ACUREX 3001 parabolic-trough collectors in 10 parallel rows of 4 collectors connected in series. Its total solar collecting surface is 2,672 m^2 and the rotating axis of the collectors is oriented east west. The fluid used by this collector field is Santotherm 55 oil, which has a maximum working temperature of 300°C. The collector absorber tubes are not evacuated and have a black chrome selective coating. This solar field has an overall performance of 50%, with peak power of 1.3 MW_t for direct solar radiation of 950 W/m^2. The average daily thermal energy delivered is 6.5 MW_t.
- A 5-MWh_t-capacity thermal storage system consisting of a 140-m^3 thermocline oil tank for charging/discharging temperatures of 295°/25°C with automatic fire-extinguishing system, automatic venting valves and volatile-condensing system. It also has a water-cooled oil cooler for quick cooling during transient testing.
- A 500-kWe water/steam Rankine cycle electricity generating system consisting of a steam generator fed by the hot oil delivered by the solar field and/or storage tank; degasifier; steam turbine; electric generator and mechanical draft closed-loop cooling tower.
- The MED desalination plant, called the SOL-14, consists of a 14-stage multi-effect distillation plant, which is connected to the thermal storage system described above. For a nominal production of 3-m^3/h distillate, plant consumption is 190 kW_t, with an efficiency factor (number of kg of distillate produced for every 2,300 kJ of energy consumed) over 9. The saline concentration of the distillate is around 50 ppm. The nominal temperature gradient between the first and last stages is 40°C, with an operating temperature of 70°C in the first stage.

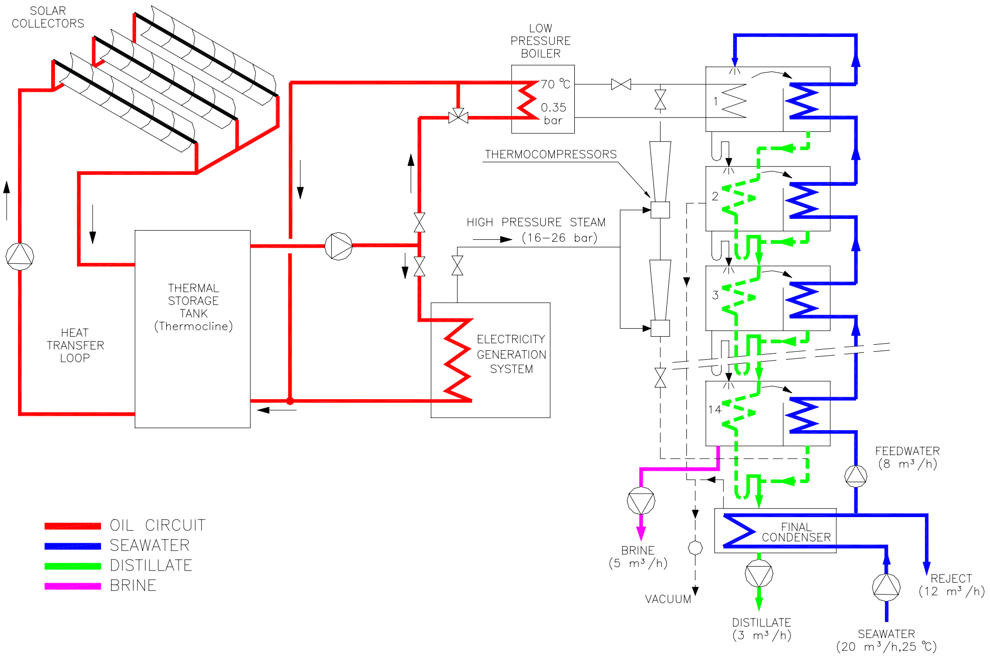


Figure 14. General diagram of the SSPS-DCS plant

- The vacuum system, which is made up of hydroejectors fed by 3-bar seawater, is used to evacuate the air from the unit at startup and to compensate for any small amounts of air and gas liberated from the feed water, as well as any slight losses that might be produced in the various connections.

There is also a double-effect absorption heat pump, which represents the first real prototype of a device of its kind for this application [*Blanco et al., 2002(e)*]. Condenser heat loss recovery with this pump increases the performance ratio of the MED plant to 20 over operation without it.

Capacity:	3 m³/hour
Number of effects:	14
Feed water:	Seawater (35,000 ppm)
Product:	Distillate (≤50 ppm)
Recovery Factor:	38%
Feedwater flow rate:	8 m³/hora
Thermal consumption (FR):	63 kWh/m³ (>9)
Electricity Consumption:	3 kWh/m³
Solar field capacity:	1.2 MWp
Solar field performance:	50%
Collector surface:	2762 m²
Type of collectors:	ACUREX 3001 (CCP)
Storage:	5 MWh (Therminol 55)
Maximum oil temperature:	300°C

Figure 15. **Technical specifications of the PSA SOL-14 solar desalination plant and aerial view with ACUREX field in foreground, thermal storage tank at upper left and MED upper right**

Dish/Stirling Systems: DISTAL and EURODISH

PRINCIPLES

A dish/Stirling system consists of a wide-diameter parabolic mirror with a Stirling-type external combustion motor installed in its focal area. The parabolic dish-mirror continuously tracks the sun, so that the sun's rays are reflected onto its focal plane, obtaining a Gaussian-shape concentrated solar energy map and several tens of kW. The Stirling motor is an external combustion motor that employs the thermodynamic cycle of the same name and that has two advantages that make it appropriate for this application:

- Combustion is external, that is, the energy contribution may from sunlight collected by the parabolic dish and concentrated on its focal zone.
- It is a high-performance thermodynamic cycle.

An alternator is connected to the Stirling motor, so that the luminous energy can be transformed into electricity or delivered to a nearby application for direct consumption right in the same block at the focus of the concentrating dish.

The most obvious application of dish/Stirling systems is the production of electricity for self-producers in remote areas or rural communities where there is no grid, for pumping water, etc.

The optimum niche on the energy market would be a power range of a few tens of kilowatts, where it would compete with the already commercial photovoltaic systems or diesel generators.

Since the beginning of activities in 1992, three generations of prototypes have been erected and routinely operated at the PSA for their technical evaluation, DISTAL I, DISTAL II and EUROdish.

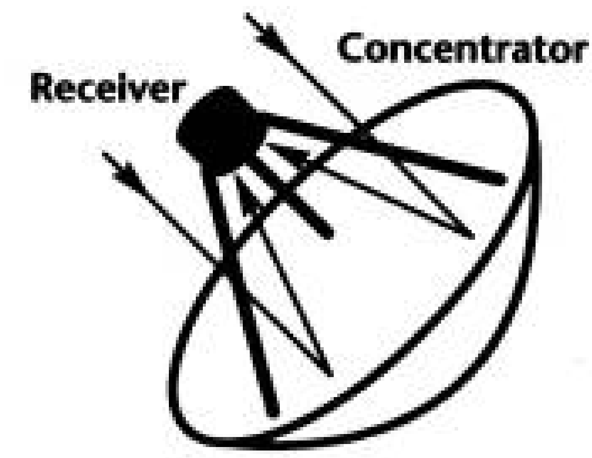


Figure 16. Functional diagram of a parabolic dish with Stirling motor at the focus.

DISTAL I

In operation since 1992, this installation initially consisted of 3 7.5-m-diameter parabolic dish units capable of collecting up to 40 kW_t energy with a SOLO V160 9-kW_e Stirling motor located in its focal zone.

The concentrator prototype was made using the stretched membrane technique, 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. Two DISTAL I units were disassembled in the year 2000 and replaced by third generation EUROdish units.

Figure 17. A DISTAL I dish in operation

DISTAL II

The DISTAL II was a first attempt at a system with better features and per-kWe cost. Three new stretched-membrane prototypes were erected and put into routine operation in 1996 and 1997. Their slightly larger 8.5-m-diameter delivers 50 kW_t to the motor. The focal distance is 4.1 m and the maximum concentration is 16,000 suns at the focus. The Stirling motor, which had also evolved, is now a 10-kW_e SOLO V161 and the tracking system is azimuth-elevation, which allows automatic sunrise-to-sunset operation.

Figure 18. DISTAL II unit

EURODISH

The second and latest attempt to make this technology economical is the Spanish-German EUROdish project. Two new prototypes were designed and erected with the following goals:

- Reduce the price of components by using standard industrial elements.
- Develop a new dish manufacturing system discarding the stretched-membrane technology and applying a "composite"-material molding system.
- Improve the Stirling SOLO V161 motor, especially those components used in the receiver cavity.
- Develop a new optimized system assembly procedure that uses new specially developed tools.
- Remote control and monitoring over the WWW.
- Test pre-commercial units as reference systems.

Figure 19. New Stirling motor receiver cavity absorber tubes.

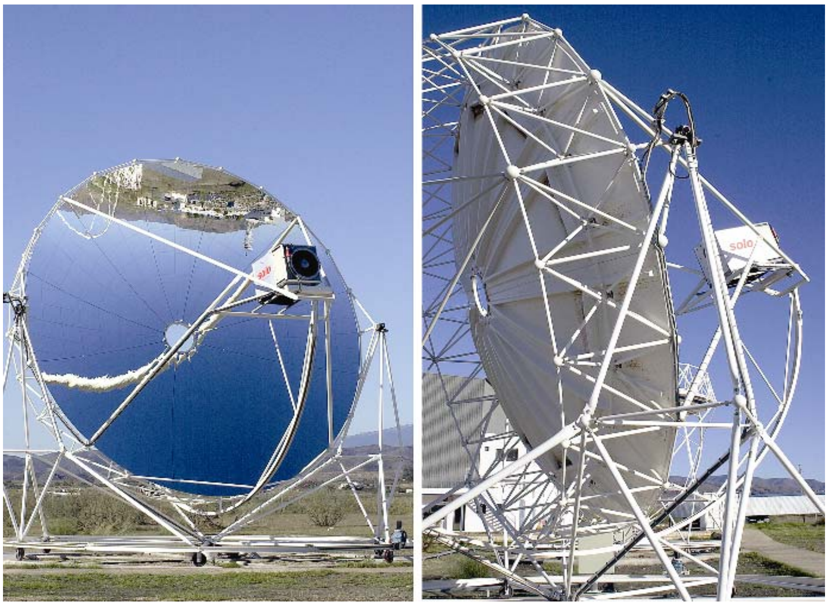


Figure 20. Front and back views of the EUROdishes.

The Solar Furnace

GENERAL DESCRIPTION AND PRINCIPLES OF OPERATION

Solar furnaces reach the highest energy levels obtainable with a solar concentrating system, having attained concentrations over 10,000 suns. Their main field of application is materials testing, either in ambient conditions, controlled atmosphere or vacuum, and solar chemistry experiments using chemical reactors associated with receivers.

The solar furnace essentially consists of a continuously solar-tracking flat heliostat, a parabolic concentrator mirror, an attenuator or shutter and the test zone located in the concentrator focus [Martínez and Rodríguez, 1998].

The flat collecting mirror, or heliostat, reflects the parallel horizontal solar beams on the parabolic dish, 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 there is a test table movable in three directions (East-West, North-South, up and down) that places the test samples in the focus with great precision.

HELIOSTATS

The reflective surface of the heliostats is made up multiple flat non-concentrating facets that continually track the solar disk and reflect its parallel horizontal beams onto the optical axis of the concentrator.

The PSA solar furnace has four heliostats arranged on two levels, each one of which focuses on a fourth of the concentrator, so that complete illumination of the concentrator is assured during the operating period. The heliostats have 16 3.35-m^2 sandwich-type facets, for a total of 53.58 m^2. Each one is made up of two mirrors with 90% reflectivity held to a supporting frame by 30 suction cups.

CONCENTRATOR

The concentrator disk is the main component of the solar furnace. It concentrates the incident light from the heliostat, multiplying the radiant energy in the focal zone. Its optical properties especially affect the flux distribution at the focus. It is composed of 89 spherical facets with a total surface of 98.5 m^2 and 92% reflectivity. Its focal distance is 7.45 m. The parabolic surface is achieved with spherically curved facets, distributed along five radii with different curvatures depending on their distance from the focus.

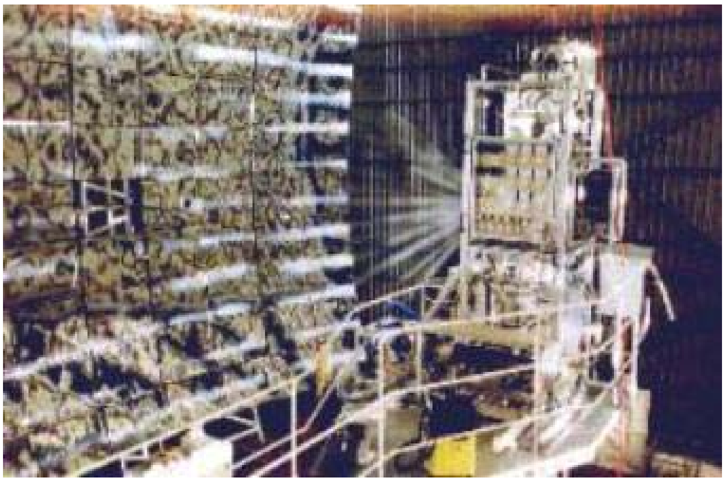


Figure 21. Solar Furnace: Concentrator (left) and receiver in operation at the focus (right).

ATTENUATOR

The attenuator consists of a set of horizontal louvers that rotate on their axes, regulating the amount of entering sunlight incident on the concentrator. The total energy on the focus is proportional to the radiation that passes through the attenuator.

It is composed of 20 louvers arranged in two columns of 15. In closed position the louvers form a 55° angle with the horizontal and 0° when open.

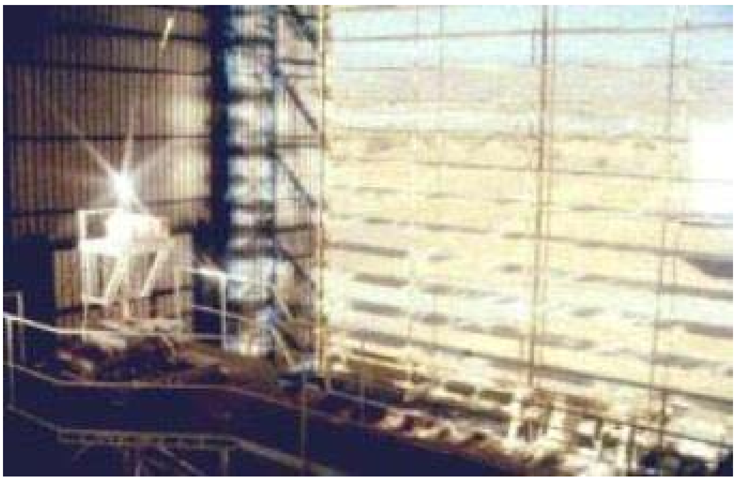


Figure 22. The focus and the test table on the left. On the right, the attenuator, completely open, allows the rays from the heliostats outside to enter.

TEST TABLE

This mobile support 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.

DISTRIBUTION OF THE FLUX DENSITY IN THE FOCUS

The concentration and distribution of the flux density in the focus characterize 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, 3000 kW/m^2, total power, 58 kW and focal diameter, 23 cm [Neumann, 1994].

Solar Chemistry and Desalination Facilities

DETOX/SOLFIN FACILITIES FOR SOLAR PHOTOCHEMICAL APPLICATIONS

The first pilot plants with reactors for solar decontamination at the Plataforma Solar de Almería were developed at the beginning of the nineties. The present configuration of the photochemistry parabolic-trough collector pilot plant is composed of four two-axis solar-tracking Helioman solar collectors with a total collecting surface of 128 m^2. The concentrating factor achieved is 10.5 suns. Each solar collector consists of a column supporting 32 mirrors in four parallel parabolic troughs for a total area of 32 m^2. The working flow may be varied between 500 and 4000 L/h. All the piping, tanks and accessories are HDPE (high-density polyethylene), a material highly resistant to the majority of chemicals. The module absorber tubes (56-mm-diameter, 2-mm-thick borosilicate glass) are each 16 m long, totaling 64 linear meters of photochemical reactor.

Later, other CPC (Compound Parabolic Collector) pilot plants were installed that can use diffuse radiation as well as direct. The CPC reflectors are made of anodized aluminum. At the PSA there are now three such plants. The largest has two modules, each with a 3-m^2 surface tilted 37° (local latitude) from the horizontal. The complete includes a pump, tank and connecting piping. The total system volume is approximately 190 L and

Figure 23. General view of the solar photochemistry facilities based on CPC collectors with the new collector in the foreground.

the absorber tube (illuminated) volume is 72 L. At this time, a new 15-m^2 collector is being installed that will increase the volume to 300 L. Furthermore, two twin prototypes are also available for parallel experiments. Each reactor is made up of three modules of eight glass tubes each. The three modules (3.08 m^2) of each reactor are mounted on a fixed platform also tilted 37° . The total reactor volume is 40 L, of which 22 L is the total irradiated volume and the rest is in the piping and tank.

There are also three sensors for measuring ultraviolet solar radiation, one with a solar tracking unit for direct radiation and two horizontal units tilted 37° (the same angle as the CPCs) to the earth's surface for global. All the data are sent to a computer where they are stored for their later evaluation.

The solar collectors associated with the SOLFIN (*Solar Synthesis of Fine Chemicals*) facility is made up of CPC collectors of various sizes and geometries that allow study of the parameters affecting scale-up of chemical processes (basically organic synthesis) previously optimized in the laboratory. The system basically consists of a closed circuit in which a pump circulates the reagents and dissolvent through the photoreactors on the collector axis where they are irradiated. The whole system can be thermostatized by water that circulates through the internal reactor tube (made up of two coaxial tubes), the temperature of which is controlled by a heat-pump cooling system.

The PSA Solar Chemistry Laboratory is a 75-m^2 building designed to hold all the conventional chemical laboratory equipment: work tables, gas extractor fan hood, storeroom for small amounts of chemicals, central distribution of technical gases, UPS, safety systems (extinguishers, shower, eyewash, etc.) precision-scale workbench, water ultra-purification system, ultrasound bath, centrifugal vacuum distillation system, as well as many other systems normally used in a chemistry laboratory. Furthermore, it has the following analytical equipment, all of them related to Environmental Chemistry: Liquid chromatograph (quaternary pump with automatic injector and diode detector), gas chromatograph (FID and TCD) with purge and trap system (analysis of volatiles dissolved in water), ion chromatograph, TOC analyzer (with automatic injector), UV-visible spectrophotometer, COD and BOD. [*Cáceres y col., 2002(a),(b)*]. All these systems are completely computerized and networked. Furthermore, it has the only Andalusian network (14 stations) node in Almería for UVB/UVA/PAR measurement

SOLAR CHEMISTRY TEST BENCH

This test bench, located in the CIEMAT's Department of Renewable Energies (Madrid), enables laboratory-scale experimentation to determine the feasibility of processes that will

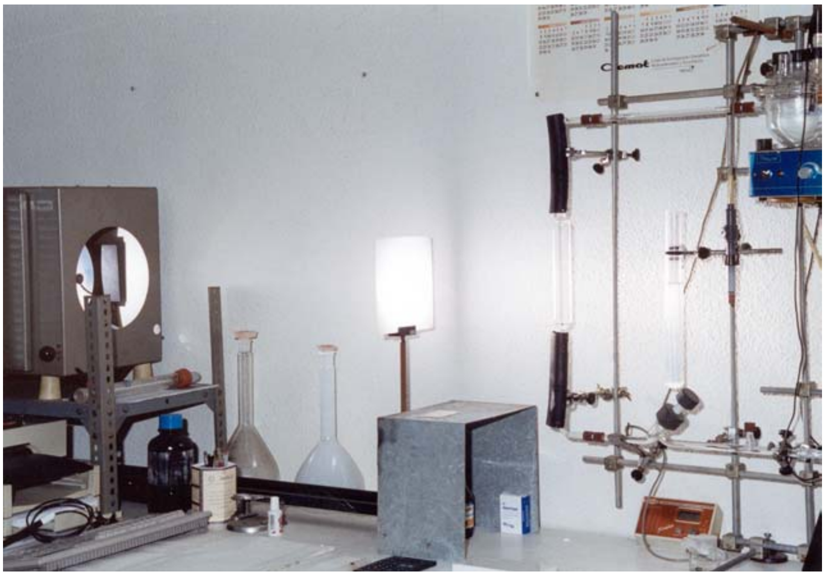


Figure 24. Solar Chemistry Project test setup

later be carried out in the various solar facilities mentioned above. The use of this test bench has basically been to determine process thermodynamics and kinetics. The facility consists of Pyrex photoreactors that operate in recirculation or batch mode and use a solar simulator with a 1000-W Xenon lamp as the light source. All the parts of this system have been fabricated with inert materials that guarantee that the tests are carried out under nearly ideal conditions. Furthermore, the test bench analytical infrastructure guarantees continuous monitoring of all the variables under study.

Among the different laboratory-scale studies now underway, the following may be highlighted:

- Synthesis of new, more efficient semiconductors. Aging, deactivation and regeneration of these photocatalysts.
- Feasibility of the detoxification process with concentrated radiation for the Fe^{+2} - H_2O_2 system [Vidal y col., 2002].
- Photo-assisted CO_2 reduction with RuO2-TiO2 catalysts [Vidal y col., 2002].

GAS PHASE DETOXIFICATION LABORATORY

The Gas Phase Detoxification Laboratory, also located in the Dept. of Renewable Energies in Madrid, allows testing under controlled conditions of any volatile organic compound (VOC) that can be destroyed by solar energy or UV lamps. It is provided with a gas inlet and control system, Xenon lamp solar simulator and analytical instrumentation made up basically of GC and GC-MS, associated with a system of thermal desorption system and continuous NOx, SO_2 and CO_2 analysis. This system allows complete control of laboratory as well as real solar radiation tests located on the roof of the building immediately above the laboratory.

Figure 25. a) GC-MS system for discontinuous sample analysis

Figura 25. b) Testing with continuous tube reactor

Other Facilities

Among its other facilities, the PSA has a demonstration area for other technologies like photovoltaic panels, solar cookers and domestic water heaters, as well as the Laboratory for Energy Testing of Building Components (LECE). The LECE is part of the European PASLINK network for energy testing of building components. It consists of four test cells with thermal instrumentation for the complete monitoring of conventional and passive solar building components. The LECE makes use of the PSA infrastructure and its excellent conditions for solar applications, but it is integrated in and managed directly by the Solar Energy in Building Group of the CIEMAT Department of Renewable Energies.

The purpose of the LECE facility is to contribute to improving our knowledge of the energy quality of building elements through thermal characterization experiments, which find the overall heat transfer coefficient, solar gain factor or system response times, etc. Knowledge of such properties can help improve building design with a view to increasing energy savings without loss of comfort and predict their thermal behavior.

The LECE performs the following activities:

- Experimental support for the writing of policies and regulations.
- Experiments for the CIEMAT Solar Energy in Buildings R&D Group.
- Cooperation with and service to the manufacturers of building materials and components.

Figure 26. View of the solar collector used as a tilted enclosure

R&D Projects

Introduction

2002 was a decisive year in unblocking the impasse existing in commercial Solar Thermal Power (STP) Plants. After a long wait of over three years, the publication of Royal Decree 841/2002 of August 2, 2002 (BOE September 2, 2002), which sets a premium of 0.12€/kWh for solar thermal electricity, has now provided a regulatory framework and clear scenario for STP exploitation. Although the premium published is less than that initially expected and furthermore, requires solar-only operation without fossil support, the first projects, such as Andasol and Sanlúcar Solar have started. The PSA actively participates in both these projects and will play a significant role in the evaluation of operating results, once the plants go into operation.

In central receiver technology, 2002 has culminated the development of two air-cooled volumetric receiver systems (SOLAIR and SOLGATE) which allows us to affirm that the atmospheric and pressurized air technology is already qualified at pilot-plant scale, in the range of a few megawatts. The PSA has also kept up its continual activity in the development and testing of new heliostat concepts. Specifically, validation of a new 120-m^2 heliostat for the future Sanlúcar Solar plant has begun and a stand-alone heliostat prototype has been developed that will serve as a model for the retrofitting the entire CRS heliostat field, making it the first stand-alone heliostat field known.

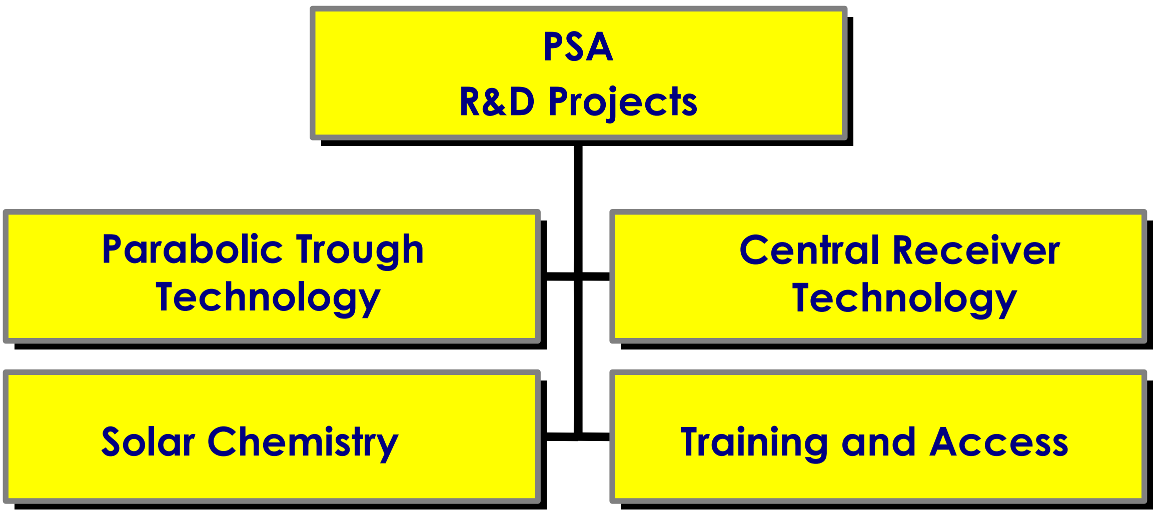


Figure 27. Projects that comprise PSA R&D activity

In so far as the parabolic-trough technology is concerned, the difficulties encountered by the various consortia that have been promoting thermal power plants with using this technology, basically due to the low premium stipulated for the electricity generated by them, are thinking about the advisability of trying to penetrate the energy market with other types of applications. In this sense, the coupling of fields of parabolic-trough collectors to industrial processes that require thermal energy in the 150ºC –400ºC range seems to be a good way to start to implant commercial parabolic-trough collectors. Up to now almost all of the R&D effort in parabolic troughs carried out at the PSA has focused on electricity generation, so it seems wise to redirect strategy and work on the development of other industrial applications that do not require such large fields of collectors as the solar thermal power plants. This change in strategy means beginning to work on the development of smaller collectors than the current LS-3 or EUROTROUGH. On the other hand, direct generation of steam was consolidated in 2002 as a very promising option for lowering the cost of thermal energy supplied by parabolic-trough collectors, which encourages us to continue its development and component optimization.

Results in 2002 were absolutely key to the development and future evolution of Solar Chemistry activities, since the ambitious jump from what had basically been limited to photochemistry to a wider scope of activities of much more global concern planned the year before, was undertaken, while still maintaining the former. The finalization in 2002 of negotiations with the European Commission and start-up of the AQUASOL, CADOS and SOLWATER (with its twin project AQUACAT), projects, all of them coordinated by the PSA, is, at once an important challenge to the capacity for management and leadership of the Solar Chemistry group, and an outstanding opportunity to move the nucleus of Project activities from photocatalytic degradation of pollutants (in water and gas phase) to other diverse, yet complementary fields concerning the major issue of water: degradation of pollutants, water treatment for human consumption and desalination of water, all of it by solar chemical processes. All of the recent reports published by United Nations agencies coincide in pointing out that water will be one of the most transcendent issues during at least the first decades of this century due to its impact on a very significant sector of the world population. The strong synergy that exists between solar radiation and the applications associated with water processes enables us to predict important activity in this field sustained in the coming years.

The Training and Access Project, based on the PSA's classification as a Large Scientific Installation by the IHP program (Improving Human Potential) of the European Commission, completes R&D activities. Thanks to this project, 60 European research groups have had access to the PSA facilities between 2000 and 2002.

In general, R&D activities in 2002 have been highly satisfactory, with clear consolidation of lines of work in solar receivers and concentrators, thermal storage, desalination, detoxification of effluents and the appearance of new activities in solar thermochemical production of hydrogen. This situation allows us to foresee a stable work environment, consolidated projects and some objectives, with commitments that in some cases mark an R&D activity horizon as far as 2006. Within the national context, the PSA has been maintaining close collaboration with the majority of the companies related to solar concentration for electrical, thermal and chemical applications and with universities such as the Universities of Seville, Almería and the UNED. The PSA's human resources and infrastructure are unique in solar concentrating technologies, so participation of CIEMAT is a must for any solar thermal power plant in Spain. In international circles, the PSA's participation in Tasks I, II and III of the IEA SolarPACES program should be highlighted. In these tasks, information and costs are shared in projects with similar centers in the USA, Germany, Switzerland, Australia, Russia, Israel, France, etc. At the present time, it is the only expert network on solar thermal concentrating technology and systems. Under the umbrella of the 5th Framework Energy Program and the Spanish-German Agreement, there has been intense collaboration with the German Aerospace Center (DLR), with which it has maintained its traditional participation in joint projects.

Central Receiver Technology

Tower systems, or Central Receiver Technology (CRT), consists of a large field of heliostats, or mirrors, that track the position of the sun at all times (elevation and azimuth) and direct the reflected beam onto the focus at the top of a tower. The orders of solar concentration are from 200 to 1000 and the power from 10 to 200 MW. It is a technology in which the PSA has a long tradition of research, since it has two absolutely privileged facilities in the CESA-1 and CRS plants, which are both very flexible test benches for the testing and validation of components and subsystems.

Because of the high flux of the incident radiation (typically between 300 and 1000 kW/m^2), high working temperatures and thereby, integration into more efficient cycles, from Rankine with superheated steam to Brayton cycles with gas turbines are possible, easily admitting hybrid operation in a wide variety of options and have the potential for generating electricity with high capacity factors through the use of thermal storage, with today's systems exceeding 4500 equivalent hours per year.

Although the maturity of CRT systems was already validated by the successful demonstration projects carried out in the eighties and more recently, by the interest shown by cities, private venture companies and utilities in Europe and the Americas, which have placed them in the lead with projects such as the PHOEBUS-TSA, Solar Two, Solar Tres and PS10, their high capital cost is still an obstacle to the realization of their full commercial potential [Romero, Buck y Pacheco, 2002]. The first commercial applications, which are just starting out, still have an installed power cost of 2800 Euro/kW and for electricity produced of around 0.18 Euro/kWh. A reduction in the cost of the technology is therefore essential for the extensive number of commercial applications in potential sites. Conscious of this problem, the PSA permanently maintains an R&D project focused on the development of component and system technology in order to reduce costs and improve their efficiency.

The objective in this line of R&D is to facilitate the market penetration of central receiver solar thermal systems. This general goal is structured around the following specific points:

- Significant improvement of the overall economics of central receiver solar thermal systems, through reduction in the cost of their components, especially those which bear the most weight in the total plant cost (heliostat field, receiver and control), and the simplification of associated O&M.
- Improve central receiver system integration through the development of advanced components that enable it to approach more efficient production schemes, for electricity generation as well as for industrial processes.
- Facilitate the development and the consolidation of an own industry, through technology transfer, performance of appropriate market studies and the definition of actions that tend to eliminate the non-technological barriers impeding the penetration of this technology.

The above objectives can be achieved by the following strategy based on three essential elements:

- Technological consolidation and cost reduction.
- Advanced integration component and concept development
- Technology transfer and augmentation of feasibility.

Research activity carried out by the CRT group at the PSA in 2001 had at its nucleus the following seven projects, all of them financed by public R&D programs:

1) Project: "SOLAUT: Solar Thermal Electricity Generation in Stand-Alone Modules[4]"; Ref. FIT-120102-2001-7. Year: PROFIT-2001, Ministry of Science and Technology. Participants: CIEMAT, INABENSA, IBERESE and SERLED. Coordinator: M.J. Marcos (CIEMAT). Period: January 2001/April 2002.

2) Project: "PS10: 10-MW Solar Thermal Power Plant for Southern Spain"; Ref. NNE5-1999-00356. Year: 1999/C 77/13. Fianancing: CEC- DG XVII (ENERGIE Program). Participants: CIEMAT, SOLUCAR (E), DLR, Fichtner (D). Researcher responsible: Rafael Osuna (SOLUCAR). Period: July 2001/July 2004.

3) Project: "PCHA: First field of stand-alone heliostats – Phase I[5]"; Ref. FIT-120102-2002-13. Year: PROFIT-2002, Ministry of Science and Technology. Researcher responsible: Ginés García (CIEMAT). Participant: CIEMAT (January/December 2002).

4) Project: "SOLAIR: Advanced solar volumetric air receiver for commercial solar tower power plants"; Ref. NNE5-1999-10012 Year: 1999/C 77/13. Financing: CEC- DG RTD (ENERGIE Program). Participants: CIEMAT, SOLUCAR, IBERESE (E), STC (DK), DLR (D) and FORTH/CEPRI (GR). Researcher responsible: Rafael Osuna (SOLUCAR). Period: February 2000/June 2004.

5) Project: "SOLGATE: Solar hybrid gas turbine electric power system"; Ref. ENK5-2000-00333. Financing: EC- DG XII (ENERGIE Program). Participants: ORMAT (IS), INABENSA, CIEMAT (E), DLR (D), Heron (NL) y TUMA (CH). Coordinator: C. Sugarmen (ORMAT). Period: January 2001/September 2003.

6) Project: "HST: Hocheffiziente Solarturm-Technologie –High-efficiency Solar Tower Technology"; Ref. Z II 6 (D) -46040 - 1/3.3. Financing: BMU-Ministerio de Medio Ambiente Alemán-2001 and Kreditanstalt für Wiederaufbau-KfW. Participants: CIEMAT (E), DLR, KAM, G+H, Isolite (D). Coordinator: R. Buck (DLR). Period (January 2002/April 2004).

7) Project: "ALTER: Test of new thermal storage nucleus elements in a solar thermal plant for electricity generation with tower and heliostat field technology[6]", Ref. FIT-120102-2002-19. Edition: PROFIT-2002, Ministry of Science and Technology. Participants: CIEMAT and SOLUCAR. Coordinator: J. Enrile (SOLUCAR). Duration: January/December 2002.

THE SOLAUT PROJECT

In the PSA's permanent search for integration of central receiver systems into the most efficient electricity generation schemes, in January 2001, a new project called SOLAUT was begun with financing from the Ministry of Science and Technology PROFIT Program. The final report on the feasibility study for this concept was sent in April 2002.

The PSA's final goal in the SOLAUT concept is to design a pilot facility to demonstrate the technical and economic feasibility of solar thermal electricity generation with a large solar field of hundreds of stand-alone 1-MWe units, with continuous electricity generation through thermal storage. This modular concept absolutely breaks with a traditional history that has always postulated that CRT systems have their market niche in centralized electricity generation, demonstrating that the CRT is not challenged by small-sized high-performance designs (Figure 28).

The new solar thermal electric technology proposed is based on the volumetric atmospheric air receiver with solid storage elements, but eliminates the steam cycle and uses as the conversion system fluid the same air heated in the receiver at atmospheric pressure in

[4] "Generación Eléctrica Termosolar mediante Módulos Autónomos"

[5] "Primer campo de helióstatos autónomos-Fase I"

[6] Ensayo de nuevos elementos del núcleo en un almacenamiento térmico de una planta solar-térmica para generación eléctrica con tecnología de torre y campo de helióstatos

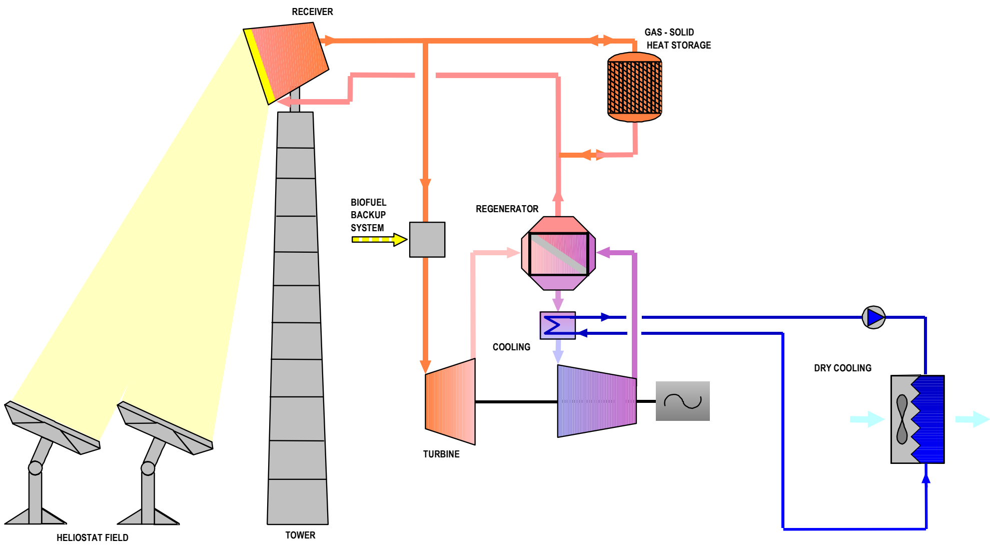


Figure 28. Schematic Drawing of the SOLAUT Plant

an inverse regenerative Brayton cycle, with or without intermediate cooling of compression and without consuming water for cooling.[Marcos, Romero, Mendoza y Díez, 2002). This allows the optimum thermal level of concentration of the radiation to be taken direct advantage of for high performance in a power cycle of around 1 MWe, which is very compatible with the optimum size of the solar field and yielding much better performance than larger fields, with excellent land-usage factors and a wide capacity for adapting to any terrain or application. The overall net average annual incident solar-to-electric conversion performance of such a 1-MW module could be as high as 21%, far surpassing the values foreseen for current demonstration plants (10.6 to 13.2%) and even the maximum values foreseen for large 200-MWe commercial plants (15%). Under optimum conditions, the scheme proposed could even attain a peak solar-to-electric performance of 30%.

The following figure (Figure 29) shows the result of the studies carried out for different reverse Brayton cycles applied to the SOLAUT scheme operating at a maximum temperature of 850°C. As can be seen, the use of a closed regenerative cycle has certain important advantages, in spite of the low pressure ratios used.

The SOLAUT scheme does require, however, considerable technological development of the solar receiver, which demands high-performance operation despite recycling very

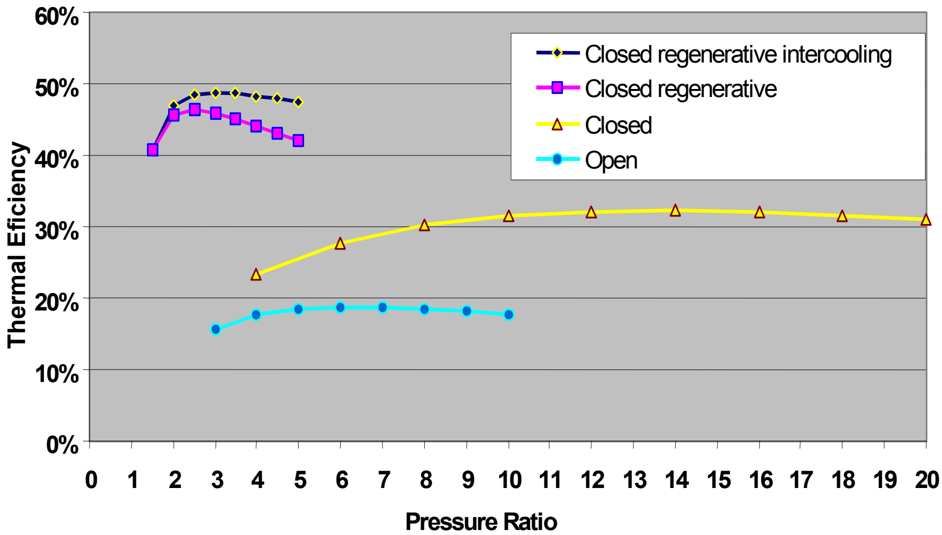


Figure 29. Thermal performance of reverse Brayton cycles

high temperature air. Therefore, after completion of the feasibility study on the basic concept in April, a search was begun for collaborators and technological partners to define a project with a wider scope. Its objective would be the development of key cycle systems and their experimental validation in a pilot plant, with possible integration with biomass [Romero, 2002a]. The search identified a nucleus of companies and research centers interested in developing the technology and applying for financial aid to the EC in upcoming editions of the 6th Framework Research Program. These partners are: IPASA (R), CIE-UNAM (MEX), ABB and ETH (CH), KEM (DK), PCA (UK), SOLUCAR, SERLED, IBERESE and CIEMAT (E), JASPER (D), CRES (GR) and MEERI (PL).

THE PS10 PROJECT

Within demonstration project development activities, participation in PS10 Project engineering has continued. The main objective of the PS10 project (Planta Solar 10), also known as Sanlúcar Solar, is the design, construction and commercial operation of a thermoelectric solar plant with tower/heliostat field system and a rated capacity of 10 MW. This plant will be erected in the city of Sanlúcar la Mayor, in the province of Seville. The plant is being promoted by ABENGOA, through its operating company Sanlúcar Solar (SOLUCAR), which is the project coordinator. The project has received a subsidy of five million Euros from the European Commission and two million Euros from the Regonal Government of Andalucía. The PS10 project constitutes an essential element of collaboration between the SOLUCAR company and CIEMAT, since it will generate an entire complementary technological program with development of heliostats, advanced concentrators, solar receivers, software codes and tools, as well as thermal storage systems; these also being the subjects that have generated the various projects financed by the Ministry of Science and Technology's PROFIT Program.

The current configuration of the project makes use of a field of glass/metal heliostats (Sanlúcar-90 heliostat), a volumetric air receiver, thermocline-type air/ceramic thermal storage system and a steam generator.

The system will use a total of 981 90-m^2 heliostats developed by the INABENSA company, a 90-m-high metal tower and a semicylindrical volumetric receiver with an absorber surface of approximately 173 m^2. The basic configuration of the PS10 consists of a field of North-type heliostats, with a receiver located at the top of a tower and a generator and thermal storage module at the bottom of it, the power block, two blowers and the corre-

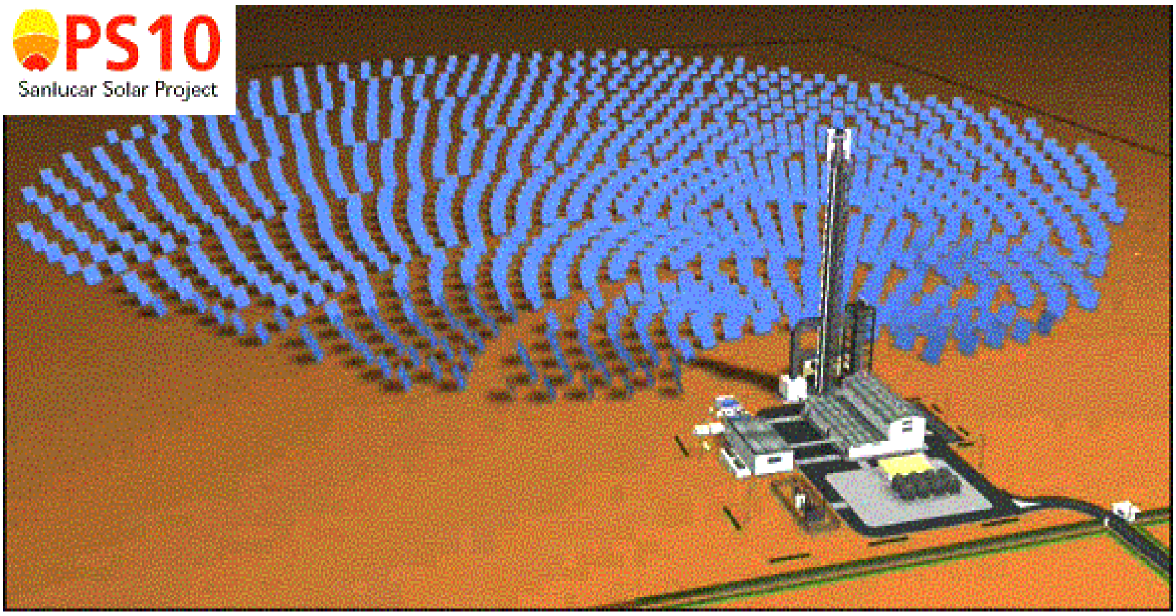


Figure 30. Artistic representation of the PS10 Plant.

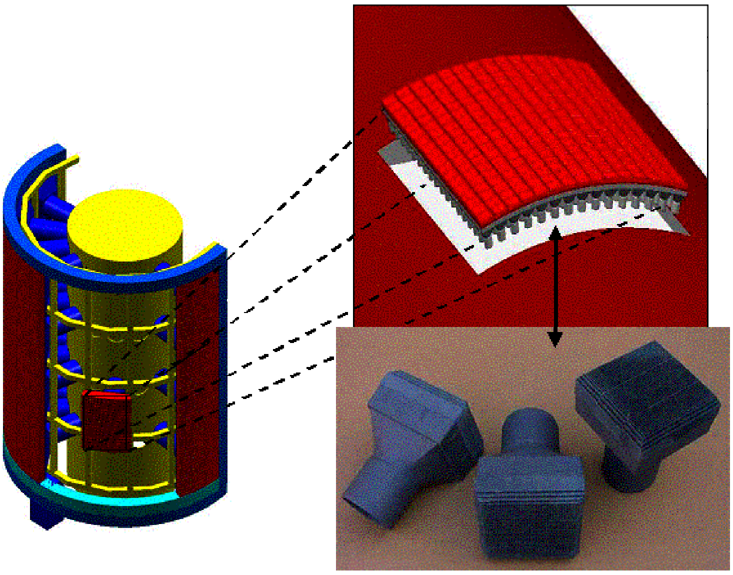


Figure 31. Design of a 50-MW receiver for the PS10 project using a modular concept based on 3-MW Solair modules.

sponding piping and valves.

Although the basic engineering was sufficiently defined in the first phase of the project, the complicated situation derived from the ambiguous legal frame of solar thermal power had brought the situation to an impasse in 2002. This situation has finally been unblocked by the publication of Royal Decree 841/2002 of August 2, 2002 (BOE of September 2, 2002), which sets a 0.12€/kWh premium for solar thermal electricity generation [Romero, 2002b].

In the second part of 2002 and coinciding with the completion of detailed engineering of the SOLAIR 3-MW volumetric receiver, the PS10 pre-project design for the air loop and solar receiver, based on this technology. The work was contracted to the German company, KAM. The 50-MW receiver and semicylindrical configuration was designed from the 3-MW receiver module designed by DLR, CIEMAT, SOLUCAR and HelioTech in the SOLAIR project [Hoffschmidt, Fernández, Pitz-Paal, Romero, Stobbe, Téllez, 2002]. The SOLAIR technology has been offered to the promoter of the PS10 project for its economic evaluation. It is also available for other commercial plant initiatives that may come up in the future.

The PS10 project has also continued with its development of the heliostat to be used in the future plant. In 2002, th testing and evaluation of two 90-m² Sanlúcar 90 prototypes were completed at the PSA. The evaluation was mostly based on the worm-gear-drive heliostat, since the hydraulic-drive prototype was studied in detail in 2001. The tests have shown reflected-beam optical qualities of 2.7 mrad horizontal and 2.3 mrad vertical, which are within the specifications set for the PS10 plant. Although the hydraulic drive system revealed strong potential for cost reduction, above all in large-area heliostats, the greater maturity of the worm-gear drive system tipped the final decision in its favor.

In spite of the fact that the Sanlúcar 90 heliostat has gone through sufficient controls and complies with the technical specifications set for it, the SOLUCAR company has continued refining cost reduction in its design and manufacture. At the end of 2002, a new 120-m² heliostat prototype (Figure 32) representing an additional cost reduction and incorporating a local control based on programmable automatic local control was installed at the PSA. The new design is

Figure 32. Front view of the Sanlúcar-120 heliostat installed at the PSA by SOLUCAR in late 2002.

more rectangular and has a 33% larger reflective surface than the previous heliostat. It has 28 3.21-m-x-1.35-m facets arranged in 7 rows and four columns. This latest system is being tested and evaluation at the present time. Testing is scheduled for completion in mid 2003.

FIRST STAND-ALONE HELIOSTAT FIELD (PCHA):

One of the goals pursued in recent years at the PSA is the evaluation of the technical and economic feasibility of using intelligent stand-alone units. These heliostats are made up of an integrated autonomous photovoltaic power system for control and solar-tracking drivers, and a wireless communications system to govern the heliostat field, during security and emergency operations as well as during routine operation. This stand-alone concept has been patented by the PSA (patent no. P9901275).

In 2000, the final report on the extensive evaluation of the first stand-alone heliostat known, tested at the PSA, was published, confirming its low electricity consumption and the durability and reliability of communications by radio. The PSA MBB field of 20 heliostats was put into operation for these tests. The control boxes were modified with new communications cards, in ten of them a commercial radio-modem and in the remaining ten a radio developed specifically for this use. The tests allowed the FARELL S433MC Light commercial radio-modem to be selected for its low price, high data-transfer speed, possibility for teleconfiguration, message codification and 10-channel 175-kHz band width maximum capacity. An important feature was its low power that permits its use without a license. The radio-modem allows communication over distances of up to 1000 M [García 2002].

The excellent results obtained with the 20-heliostat MBB field have led the PSA to plan an even more ambitious goal for 2002-2004: the transformation of the entire CRS field of 92 heliostats into an autonomous field controlled entirely by radio, without doubt a worldwide milestone. The project will cost a total of 650,000€, partial subsidized by the Ministry of Science and Technology's PROFIT Program [Romero, Egea, Gázquez y García, 2002]. The first phase, carried out in 2002, included the electronic and information-technology design together with manufacture of a prototype heliostat and validation of the designs. In 2002, a good part of the materials and equipment necessary for assembly in 2003 of the local field controls was also acquired.

The electronic design of the prototype includes the design and assembly of an electronic servo-control card for the 12Vcc motors. This card allows two motor speeds and two directions of rotation to be controlled with 90% performance. An electronic interface card

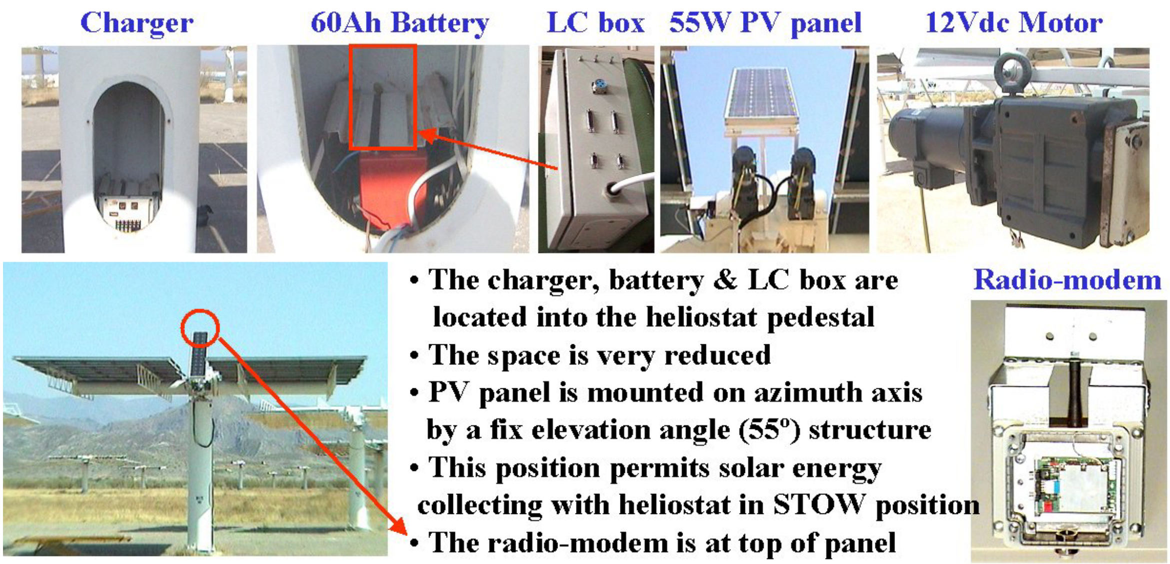


Figure 33. Stand-alone heliostat prototype in the CRS field and detail of the components developed in the PCHA project.

has also been designed and fabricated for input and output signals. Finally, the control board was also specially designed and assembled for use in solar tracking and heliostat control. Based on two general-use 8-bit microcontrollers, it has worked successfully in numerous prototypes at the PSA. In June 2002, assembly of the new CRS heliostat components was completed. These components are the motor reducers, photovoltaic panel, the battery, the charger and the radio-modem. In August of 2002, construction of the local control box was completed. Assembly of the entire prototype heliostat was finished in December 2002. Preliminary testing was done in November and December, establishing a basis for a second improved prototype at the beginning of 2003.

THE SOLAIR PROJECT

The receiver is the authentic nucleus of any power tower system, as it is the most technologically complex component since it needs an absorber of incident radiation with the least losses and in very demanding flux concentration conditions. Within the various options for thermal fluids and heat exchange configurations, the PSA has been concentrating its research since 1986 on the development of air-cooled volumetric solar receivers. Volumetric receivers are specifically conceived for optimizing the exchange of heat with air as the thermal fluid, the illuminated absorber being a matrix or porous media (metal mesh or ceramic monolith), through which the cooling gas flows. The PSA has accumulated the most experience in testing and evaluation of air-cooled volumetric solar receivers, with over 15 prototypes tested over the last 20 years in collaboration with the DLR [Téllez, Romero, Reche y Valverde, 2002].

The goal of the SOLAIR project is an air-cooled volumetric receiver with SiC ceramic absorber able to produce hot air at 700ºC with a modular concept easily scalable to large plants. The use of a ceramic matrix further improves the durability of the absorber, and its design in modular cups eliminates fluid dynamic instabilities found in previous de-

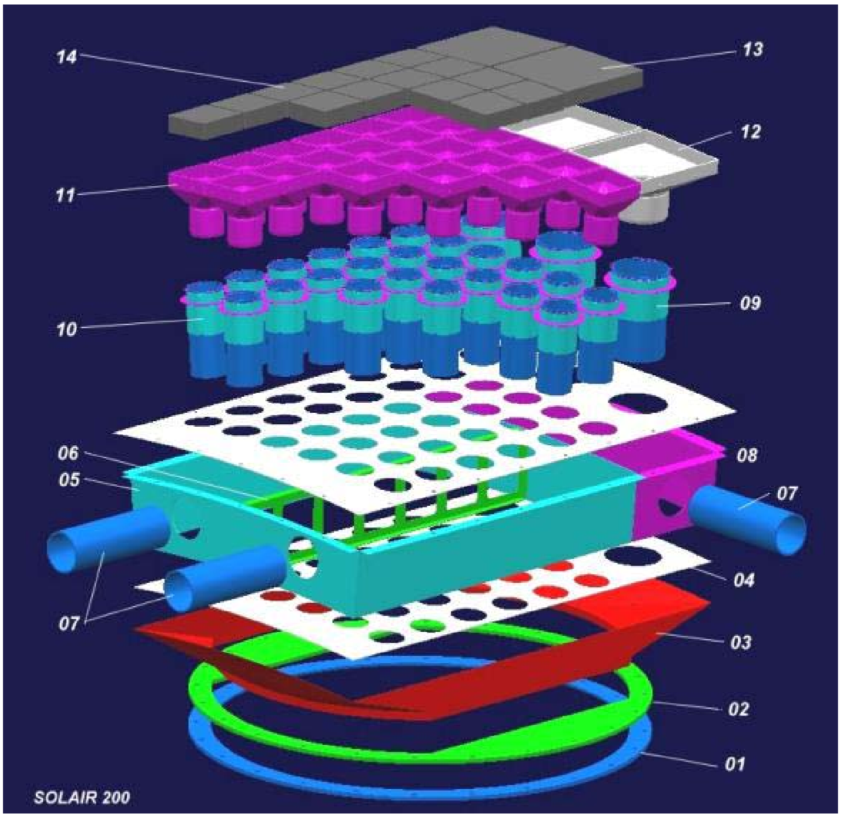


Figure 34. Section view of the elements in the SOLAIR-200 prototype tested at the PSA in 2002. 01-08 make up the support structure and air supply and intake. Elements 9 and 10 correspond to the metal cylinders that hold the ceramic cups (11 and 12). Finally, 13 and 14 represent two different kinds of SiC ceramic absorbers of different size.

signs. Finally, it includes a new air recirculation system that allows recirculation ratios of up to 70% to be attained. The SOLAIR project is a European project with EC financing and participation of CIEMAT, SOLUCAR and IBERESE (E), HelioTech (DK), DLR (D) and CPERI (GR). CIEMAT has a very active role in this project, leading the testing and evaluation of prototypes, analyzing and optimizing the hot air recirculation system using fluid dynamics codes such as FLUENT, selecting the geometry of the ceramic heads and thermomechanical analysis of the structure with the ANSYS code.

The SOLAIR project began in 2000 and in 2000 and 2001 the best ceramic materials were chosen, qualified mechanically and thermally in the DLR solar furnace at Cologne and of the first prototypes of ceramic cups were designed and fabricated. During this stage, CIEMAT actively contributed to the study and optimization of the air recirculation system [Marcos y Romero, 2002) and to the aerodynamic design of the cups [Marcos, Romero y Palero, 2002]. Then the support structure was designed and fabricated and a 200-kW prototype was installed at the PSA in November 2001.

Testing of the SOLAIR-200 prototype was carried out on 50 days of solar operation in 2002. The tests demonstrated the thermomechanical resistance of the structure, which accumulated almost 200 hours of solar operation. During these tests, an incident radiation flux of 900-kW/m^2 and air outlet temperatures of 750ºC were reached with a receiver thermal efficiency of 80% at 700ºC. These results are better than the prototype specifications [Hoffschmidt, Fernández, Pitz-Paal, Romero, Stobbe, Téllez (2002).

In 2002, the engineering of a 3-MW prototype solar receiver was begun. The 3-MW prototype will be installed in the PSA CESA-1 tower and will be tested in 2003. Its modular configuration was conceived for its possible application in the PS10 project as described above in the section on this demonstration project.

THE SOLGATE AND HST PROJECTS

The SOLAIR receiver is open to the atmosphere and therefore produces hot air at atmospheric pressure. In this case, the intended reference use is integration in a Rankin superheated steam cycle through heat exchange in a steam generator. Opposite this option, a second even longer-term line of research opens in which it is intended to integrate the solar receiver in a Brayton cycle with gas turbine, through the use of pressurized volumetric receivers. This alternative has as its main objective the formulation of hybrid solar plants with gas turbines. The hybrid solar thermal plants present an important potential for cost reduction of up to 30% over solar-only plants.

This is the proposal that underlies the REFOS pressurized volumetric receiver development project, in which the reciever is used to heat the compressed air of a gas turbine before entering the burner [Buck, Romero y Pacheco, 2002].

In 2002, the main development or application using the REFOS-type pressurized receiver at the PSA was the SOLGATE project. This project pursues the solarization of a Rolls-Royce Allison 250 C20B 240-kW turbine and its connection to a cluster of three REFOS receivers, as well as the various feasibility studies to identify possible applications of the REFOS technology in commercial gas turbines [Sugarmen, Ring, Buck, Uhlig, Beuter, Marcos y Fernandez, 2002]. The SOLGATE project is financed by the EC, and besides the DLR and CIEMAT, the ORMAT (IL), SOLUCAR (E) and TUMA (Ch) companies are also participating in it.

Figure 35 shows the SOLGATE system, located on the tower at a height of 60 m. The main components are the three receiver modules (high, medium and low temperature) that are connected in series, the gas turbine and the generator. In the cavity aperture there is a fast shutter, that allows the system to be shut down in case of emergency in just 1.6 seconds. The facility was erected in 2002. The first components were installed in April 2002 and it was finished in November. After the first adjustments and installation of the corresponding security systems, the system began its first tests with solar radiation on Decem-

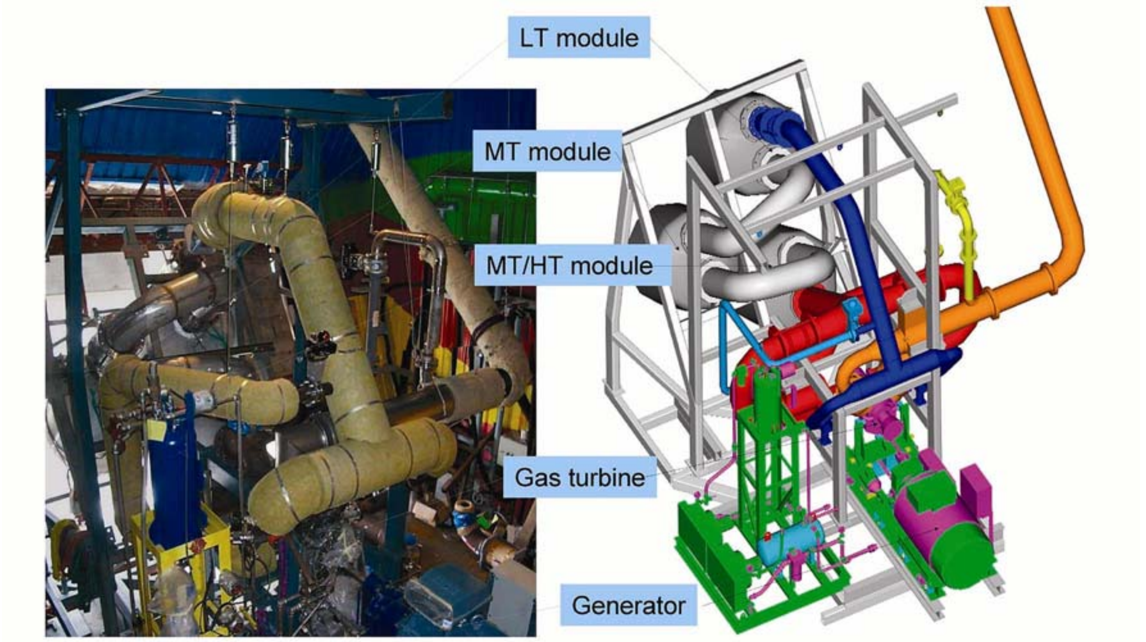


Figure 35. 240- kWe SOLGATE System installed in the CESA-I tower at the Plataforma Solar de Almería.

ber 15, 2002. In these preliminary tests, a 60% solar contribution was already obtained and it could be verified that the control system had no problems in reacting, adapting the fuel flow even during transitory conditions. When design conditions were reached, 55 heliostats were entered supplying 1 MW solar power onto the receiver. The target set for Spring 2003 is to reach 800°C air temperature with performance of 18% in the system and 80% in the receiver. CIEMAT has participated actively in this period of testing and in the evaluation of the results. It has also generated in collaboration with the DLR a software for simulation of annual turbine production, using the STEC-TRNSYS code and also for the optical simulation of the field with the HLFCAL code.

Although the basic goal in this phase of the SOLGATE project is the injection of hot air supplied by the solar receiver at 800°C in the combustion chamber of the turbine, in the second phase in 2003, it is intended to increase this temperature to 1000°C, by installing a high-temperature receiver with ceramic absorber. In parallel to this activity, an even more ambitious development under the HST project (Hocheffiziente Solarturm-Technologie – High efficiency solar tower technology), financed by the German BMU, has been begun in which it is intended to be able to reach 1100°C. CIEMAT participates in this project coordinated by DLR, which began in January 2002.

THE ALTER PROJECT

Financing was obtained from the PROFIT 2002 program for a small project in collaboration with the SOLUCAR company to test new elements in the thermal storage nucleus of a solar thermal plant for electricity generation with tower technology and heliostat field.

The intention of this project was to replace the alumina ceramic material in the TSA storage facility at the PSA with a new, lighter and more economical material based on saddle shapes. With this approach, the material used for thermal storage in plants with air as the thermal fluid should be considerably less expensive. The selection of the size of the material to be used was the fruit of several thermodynamic simulations. The thermocline zone and the usage factor were defined for a 1% temperature drop between hot and cold at the storage outlet. The results obtained indicate that the best size for ceramic saddles is ½". This is the smallest size available from suppliers.

Figure 36. Alumina balls previously used in the TSA facility (right) and new saddle-shaped material proposed for nucleus (left).

Figure 37. Overhead view of the storage tank filled with the new ceramic material.

The new material in the saddle-shaped geometry has a higher usage factor and thereby, performance, than one with a ball geometry with equal hydraulic radius (Area of the section perpendicular to flow divided by the perimeter washed by that fluid). Furthermore, the new saddle-shaped material has a lower load loss because it has a larger portion of holes or porosity than a ball with equivalent hydraulic radius. For these reasons and after the tests performed, the following conclusions were reached:

In high-capacity thermal storage systems for solar thermal plants, the load loss becomes a limiting factor since that loss must not exceed the receiver loss. In small storage systems, because a smaller bed is required, the loss of load is never equal to that of the receiver and is therefore not a limiting factor.

In storage systems where the loss of load is a limiting factor, the new material tested is technically and economically more efficient. This is because the new configuration there is less loss of load and therefore it is not necessary to increase the storage cross-section to increase its capacity. The cost of the a storage tank with proportional cross-section and height is lower. These advantages are increased since the higher surface/volume ratio produces a higher usage factor.

In storage systems where the loss of load is not a limiting factor, the spherical geometry of the material is technically and economically more efficient. This is because this material is commercially available in a smaller radius than the saddles. This makes for a higher usage factor. Moreover, a less storage volume is necessary due to the greater density of the ball bed and so the vessel is cheaper.

DEVELOPMENT OF TOOLS

As a complement to the activities directly related to the execution of the projects described above, the PSA, as a large central receiver system testing and characterization facility, has continued devoting a part of its efforts to the improvement and development of new design and evaluation tools, to the improvement of control and operating devices and to concentrated solar radiation flux measurement systems.

Within the software tools, and as mentioned above, new modules have been introduced in the STEC-TRNSYS libraries for annual modeling of SOLGATE-type systems. The FLUENT code has also been used to model the fluid dynamic behavior of air in volumetric receivers. The FIAT-LUX code continues to be a valuable resource for use in characterizing heliostats [Monterreal, 2002], and has continued generating packets in the MATLAB environment for optimization of heliostat fields.

In the field of measurement techniques, a new measurement device for concentrated solar radiation on the aperture plane of a solar receiver using uncooled, fast-response calorimeter bars in combination with CCD-camera video systems has been developed and proven[Ballestrín, 2002].

Finally, it should be mentioned that in 2002, a strong boost was given renovation of existing heliostat field control schemes. In October 2002, a 3-year scientific collaboration agreement was signed with the research group of the Department of Automation, Electronics and Robotics of the University of Almería. This agreement includes the development of a new real-time heliostat field control system to be implemented in the PSA's CESA-1 and CRS fields and the integration in the environments of control, acquisition and evaluation of results in power tower solar receiver tests.

Parabolic-Trough Collector Technology

Parabolic-trough collectors (PTC) are linear-focus concentrating solar devices that convert direct solar radiation into thermal energy and are ideal for working in the 150°C-400°C-temperature range. Thanks to concentration of the direct solar radiation incident on the aperture plane of the collector, the temperature of the working fluid is efficiently raised to around 400°C. Such temperatures make PTC ideal for integration in a large number of industrial processes in the mid-temperature range.

A PTC is basically made up of a parabolic-trough-shaped mirror that reflects direct solar radiation concentrating it on a receiver tube located in the focal line of the parabola. This concentrated radiation heats the fluid that circulates through the tube, thus transforming the solar radiation into thermal energy in the form of the sensible heat of the fluid [Zarza, 2001]. Figure 38 shows a PTC and how it works.

The PSA has a complete parabolic-trough collector technology R&D program aimed at developing a new generation of PTC solar thermal power plants with three main points:

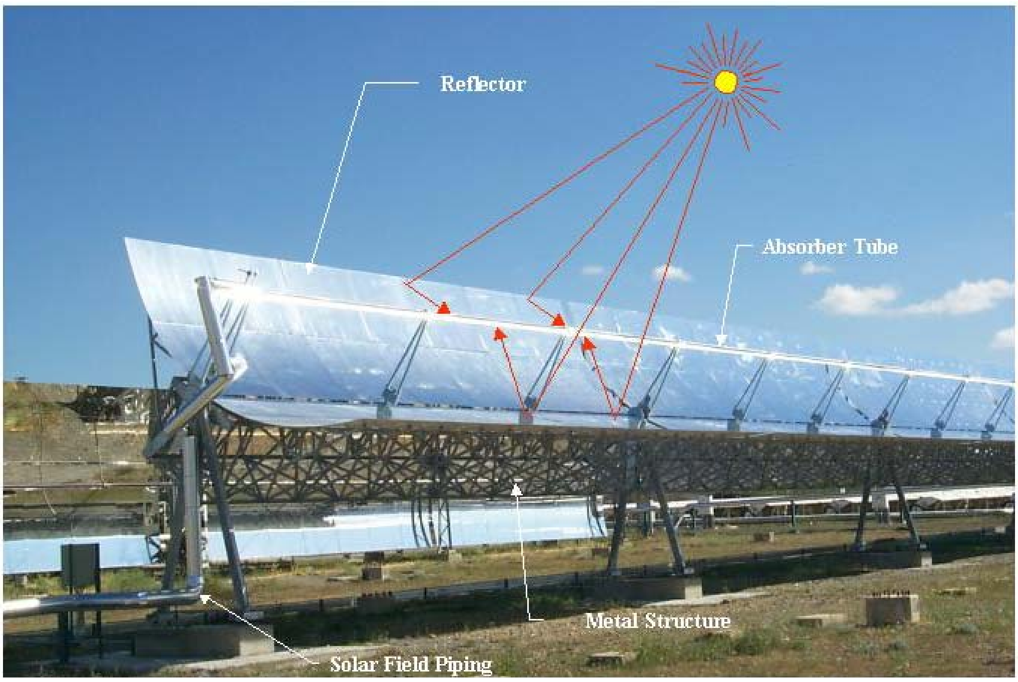


Figure 38. The parabolic-trough collector principle

1) Development and implementation of improved components for parabolic-trough collectors (new absorbers, mirrors, lighter-weight structure designs, new solar tracking systems, etc.).
2) Development of the direct steam generation (DSG) technology to eliminate the thermal oil which is currently used in this type of solar thermal plants as a heat transfer medium between the solar collector field and the power block.
3) Overall optimization of plant design (improvement of the solar system connection to the power block; reduction and improvement of O&M, etc.).

Given the complexity and reach of each one of these three points, the activities developed by CIEMAT in this R&D program are distributed among various projects, each of which has its own group of partners. The final result pursued in this R&D program is a 26% reduction in the cost of electricity generated by this type of solar thermal plants. Furthermore, a series of interesting byproducts may be obtained, as for example: selective mirrors for photovoltaic energy, anti-diffusion coatings, colored glass for buildings, etc.

The improvements in parabolic-trough collector components and the direct steam generation process can be applied not only to electricity generation, but also to any other industrial thermal energy application in the mid-temperature range (150ºC – 400ºC).

The 2002 CIEMAT parabolic-trough collector technology activities were carried out within four projects, EUROTROUGH-II, DISS-Phase I, INDITEP and PREDINCER. The most relevant results obtained in these four projects are described below:

EUROTROUGH-II PROJECT

The final *EUROTROUGH* objective was a European parabolic trough collector structure design, ideal not only for electricity generation in solar thermal plants, but also for delivering energy to any industrial process with a thermal demand between 150º and 400ºC. This collector design will cover some of the most important current requirements for marketing parabolic-trough solar collector systems.

The first phase of the EUROTROUGH project, which began in August 1998, lasted 30 months. A consortium of European companies and research centers, (ABENGOA, CIEMAT, DLR, FICHTNER, PILKSOLAR, SBP y CRES), with the financial assistance of the European Commission under the JOULE program, undertook the design of the new parabolic-trough collector. During that first phase, the new collector prototype was designed, fabricated and installed at the PSA. The second phase of the project, which began in October 2000 and was completed in December 2002, has the objective of improving on the first design and experimentally evaluating it at the PSA. He implementation of the improvements to the first prototype was finished in May 2002, and the rest of the year was devoted to thermal, mechanical and optical evaluation of the improved prototype, called the ET-II. In the last quarter of 2002, the PSA began the design of a new electromechanical solar-tracking system for parabolic troughs. This new system will solve a problem that has been rather frequent in parabolic trough collectors, the impossibility of directly coupling the angle coder of the solar-tracking system to the collector's mechanical rotation axis.

During the first semester of 2002, the work performed by the CIEMAT at the PSA in the EUROTROUGH-II project was related to the installation of the improvements made in the collector design, in which it collaborated in the electrical and electronic part of assembly. During the second semester of the year, the PSA carried out the operation and maintenance of the improved collector prototype (ET-II design) for its optical, thermal and mechanical evaluation. The results of that evaluation have demonstrated improvement in collector optical and thermal performance with regard to the LS3 design used by LUZ in the most recent SEGS plants. It also verified the structural rigidity of the ET-II design which will allow lengths of up to 150 m compared to the 100 m of the LS3.

Figure 39. View of the EUROTROUGH prototype collector installed at the PSA

In 2002, the PSA continued improving the solar tracking system installed on the EUROTROUGH collector, and was able to replace the angle coder originally used to measure the position of the collector rotation axis with a new electromagnetic system that solves the problem of direct coupling of the angular encoder to the collector's mechanical rotation axis. With the improvements to the solar tracking system, collector rotation continues to be kept precise while at the same time facilitating mechanical system assembly. Figure 39 above shows a view of the EUROTROUGH-II collector installed and evaluated at the PSA in 2002.

The PSA also continued studying the stress produced in the glass mirror supports used for the LS-3-type parabolic trough concentrators in 2002. To do this, strain gages were installed on all the supports of one of the new ET-II collector mirrors, and stress induced by wind loads on the glass was measured so that the mirror supports can be improved and reduce the current percentage of breakage in commercial solar plants.

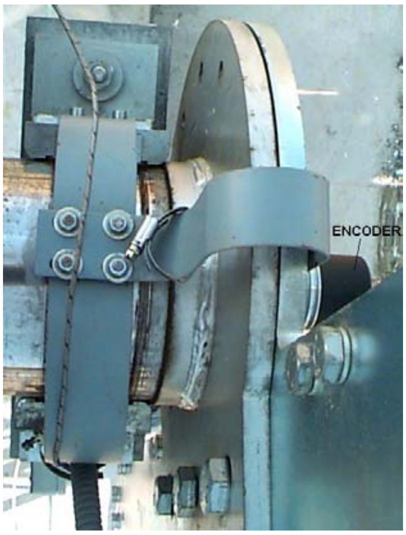


Figure 40. View of the coupling of one of the coders in the system developed by CIEMAT to measure slight deformations in parabolic trough collectors

Another of the activities carried out by the CIEMAT at the PSA in the ET-II project in 2002 was the enlargement of the system designed during the first phase of the project to detect slight deformations in the collector structure. It was found during the tests carried out during 2002 that the high resolution of this system (> 0.04 mrad) and the impossibility of coupling the coders directly to the collector rotation axis were impediments to measurements stability, these problems may be solved soon by using magnetic devices similar to those used by the PSA in the new solar tracking system. Figure 40 shows the coupling of one of the high-resolution coders that make up the deformation measurement system. The impossibility of direct hookup requires them to be coupled with metal brackets and elastic connections which makes deformation measurements oscillate.

DISS PROJECT PHASE II

The main purpose of this project is to develop the direct steam generation technology (known as DSG), by which high-pressure high-temperature steam is produced right in the parabolic-trough collector absorber tubes and allows the thermal oil traditionally used as the working fluid in solar collectors of this type to be eliminated. The DISS-Phase II project began in December 1998 and although the contract signed for its development by the European Commission and the partners (CIEMAT, Abengoa, DLR, ENDESA, IBERDROLA, Flabeg Solar Internacional and ZSW) ended officially in December 2001, CIEMAT continued with project activities in 2002. In the first quarter of 2002, the project final report, describing in detail the activities performed and the results obtained, was prepared and published by CIEMAT in a book entitled "Project DISS-phase II: Final Report" (ISBN: 84-7834-427-6). The experimental DISS plant also continued to be operated, experimental data obtained during testing in 1999-2001 was evaluated and control experiments were continued, evaluating different control algorithms in the DGS solar field of the DISS plant.

Another of the activities carried out by the PSA in 2002 was the development of several simulation models of the experimental DISS plant, both under stationary and transitory conditions. The models developed allow plant behavior to be predicted under different operating conditions. One of the applications of the models developed is finding out the steam title at different points along the collector row. Figure 41 below shows a comparison of experimental data and data provided by the SIMDISS simulation program, for a day on which the plant was operated at 100 bar (10 MPa). As may be observed in the figure, the experimental results agree very well with the simulation program.

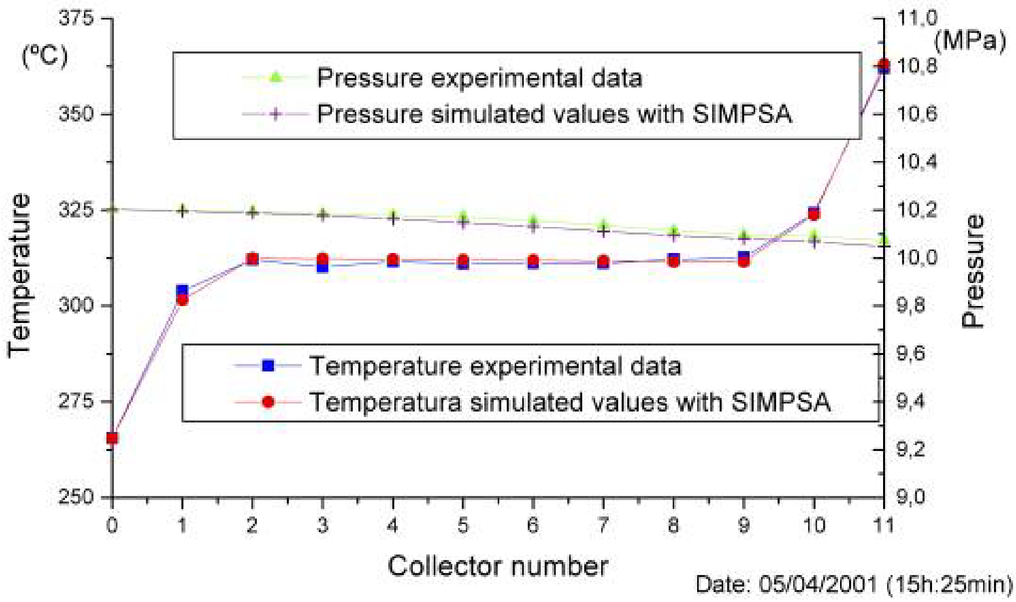


Figure 41. Comparison of the real experimental data and the results provided by the SIMDISS simulation program for the solar field of the DISS plant, for a working pressure of 100 bar (10 MPa).

With regard to control and regulation, it may be pointed out that the DISS plant solar field control schemes for the Recirculation and Once-Through operating modes have been perfected, achieving stable outlet steam temperature and pressure in the DISS collector row. Figure 42 shows the results obtained on July 17, 2002 when the plant was operating in automatic control from 12:00 p.m. (local time), producing superheated steam at 60ºbar and 350ºC in Once-Through mode. It may be observed in the figure how the steam pressure produced is maintained completely constant, while the temperature only had very minor fluctuations.

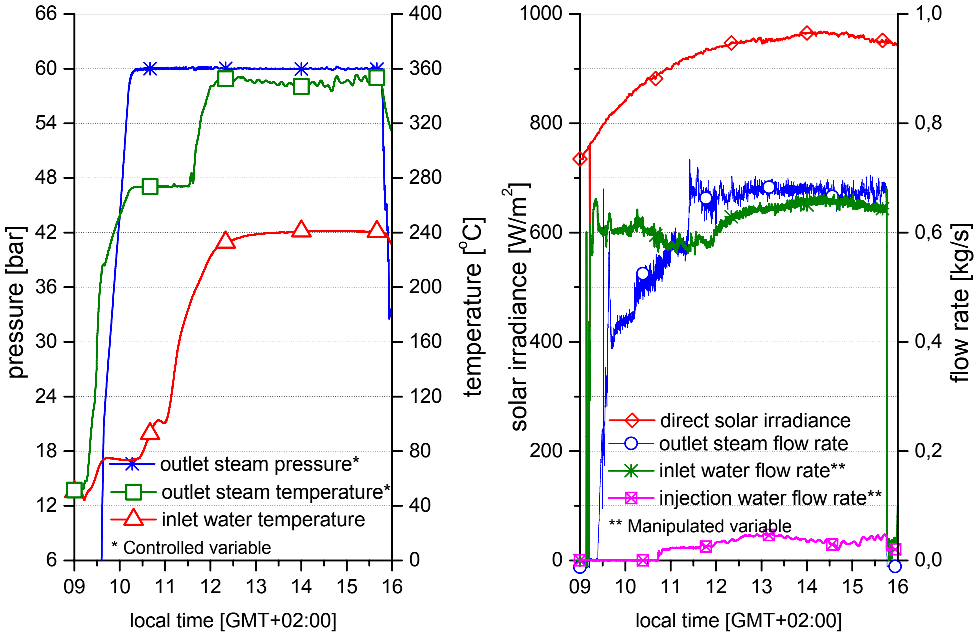


Figure 42. DISS operating data for July 17, 2003, generating superheated steam at 60 bar and 350 ºC.

From January to December 2002, the DISS plant was operated for a total of 965 hours, which allowed experience accumulated up to now in operation and maintenance of parabolic-trough collectors during direct steam generation to be increased significantly. With the hours operated in 2002, a total of 4573 hours have now been accumulated in the DISS plant, providing a good basis for extrapolation to future commercial DSG plants. The Recirculation mode continues to be reconfirmed as the best candidate of the three basic DGS processes (Injection, Once-Through and Recirculation).

With regard to operation and maintenance of the DISS experimental plant, it should also be mentioned the barrier that continues to represent the water recirculation pump. Although the implementation of a lubrication system in pump plunger packing in 2001 improved its operation considerably, the total absence of any cooperation from BW-IP and National Oil-Well, the companies responsible for supply and fabrication of the pump, was a handicap in achieving proper operation of the equipment, since it required costly maintenance. It has therefore been demonstrated that commercial DSG plants cannot use pumps such as the one installed in the DISS plant, and the use of multi-stage centrifugal pumps is recommended instead of piston pumps.

To conclude the description of the activities carried out by the PSA in 2002 in the framework of the DISS II project, the behavioral study of internal capillary coatings in absorber tubes to improve transfer of energy flux applied externally to horizontal tubes under stratified two-phase flow was completed in 2002.

The capillary systems studied were microchannels in the internal tube surface having different configurations and characteristics and porous media, whether as internal coatings or as a mesh or metal screen attached to the inner surface of the pipe. The study performed was divided into a theoretical part, in which existing models and their implications were analyzed, proposing a new formulation for the porous media models and on the other hand, an experimental part, in which, after designing an appropriate experiment to measure the width of the angle of the liquid film developed by the capillary system - responsible for improvement in heat transfer – and a proper tool for the interpretation of the experimental data, around 125 tests were performed with 7 samples. From these results, the theoretical models proposed were verified, proposing and analyzing explanations for the divergence from expected found in experimental behavior. the validity of the theoretical models was demonstrated and the optimum properties for this type of

DSG system were calculated for the parabolic-trough solar collectors most used to generate electricity, the LS3-type or EUROTROUGH collectors.

INDITEP PROJECT

The 36-month INDITEP project officially began on July 1, 2002. It receives financial assistance from the European Commission (contract n° ENK5-CT-2001-00540) and the activities planned under the project constitute the logical technical continuation of DISS project activities. Once the technical feasibility of the direct steam generation (DGS) process had been demonstrated in the DISS project, the next logical step had to be optimization of the process and its essential components at the same time that the detailed design of a first commercial solar thermal power plant with DSG in the solar field could be undertaken.

The INDITEP project has four basic objectives:

1) Detailed design of a first commercial 5-MWe DSG plant
2) Optimization and advanced development of components to make the DSG technology more competitive (compact economical water/steam separators, thermal storage for DSG, etc.)
3) Characterization under real solar conditions of the most important components for DSG solar fields.
4) Socioeconomic study of DSG technology

Most of the Partners in the INDITEP project (IBERDROLA, ABENGOA, CIEMAT, DLR, Flabeg Solar, GAMESA, INITEC, SIEMENS and ZSW) also participated in the DISS project. The participation of the CIEMAT in the INDITEP Project is centered on the following activities:

- Participation in detailed engineering of a 5-MWe DSG plant
- Improvement of the PSA DISS solar field to increase steam production to 1 kg/s.
- Operate and maintain the DISS plant in order to elaborate operation and maintenance procedures for commercial DSG plants, as well as evaluate new water/steam separators, thermal storage systems and new reflectors.
- Improve the PSA DISS solar field regulation and control system
- Analyze stress produced in DISS collector absorber tubes after more than 4000 hours of operation.
- Develop new selective coatings able to support temperatures of up to 550ºC.

In 2002, CIEMAT activities mainly focused on two subjects:

1) Improvement of the PSA DISS plant solar field to increase superheated steam production to 1 kg/s
2) Development of new selective coatings using the Solgel technique.

With regard to improvement of the DISS solar field, in 2002, CIEMAT began to buy the two 100-m long EUROTROUGH collectors that will be added to the existing solar field, increasing its collection area from 2765 m^2 to 3871 m^2. The metal structures were acquired and the instrumentation associated with the two collectors (pressure transmitters, thermocouples and pyranometers were acquired. Figure 43 is a simplified schematic drawing of the enlarged DISS field once the two new collectors, labeled A and B in the figure, have been added at the beginning of the collector row.

In 2002, specific software was developed within the framework of INDITEP for feasibility studies and simulation of the parabolic-trough collector field using the TRNSYS environment. New subroutines and calculation programs have been completed which will be used in 2003 to simulate the annual behavior of the DSG solar field of the 5-MWe commercial DSG solar thermal power plant being designed under the INDITEP project.

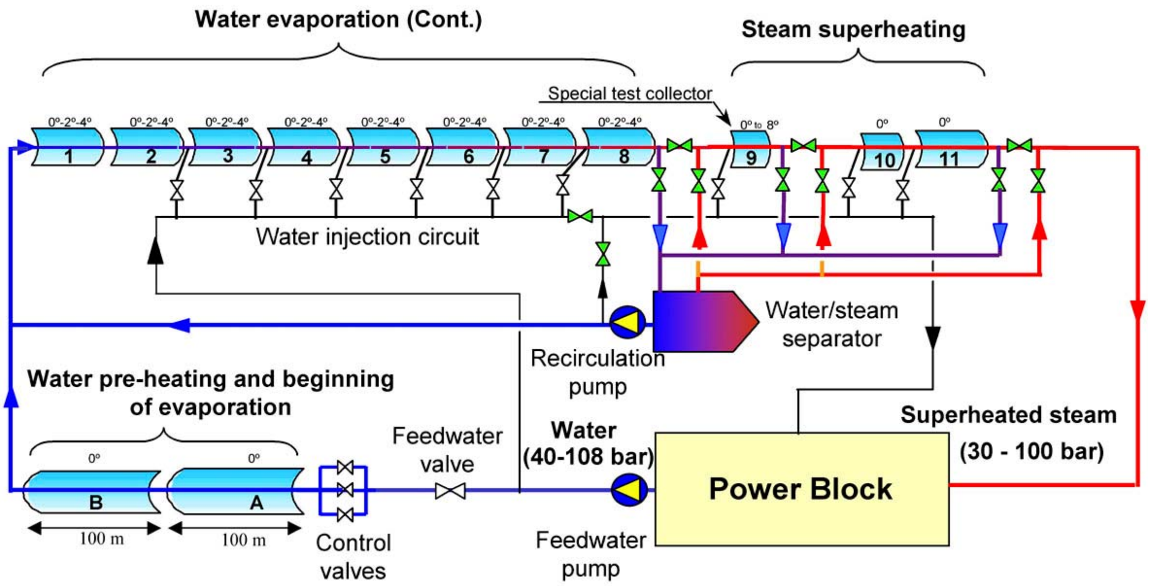


Figure 43. Simplified schematic drawing of the DISS plant solar field after the two new 100-m EUROTROUGH collectors have been added.

Selective Solgel coatings continued to be developed in 2002 with cermet-type coatings for parabolic-trough absorber tubes. Anti-reflective coatings have also been developed for coating the tube glass. A selective absorbent has been obtained on stainless steel with two layers of alumina and platinum cermet having different metal content, an H layer with 40% platinum and an L layer with 20% platinum, on a platinum infrared reflector. The Hemispheric reflectance in the solar spectrum is shown in Figure 44, where it can be seen that a solar absorptance integrated with the spectrum AM1.5 of 0.94 has been achieved and its thermal emissivity at 400°C is 0.12. Its thermal stability in air is over 400°C and tests at 500°C have had promising results.

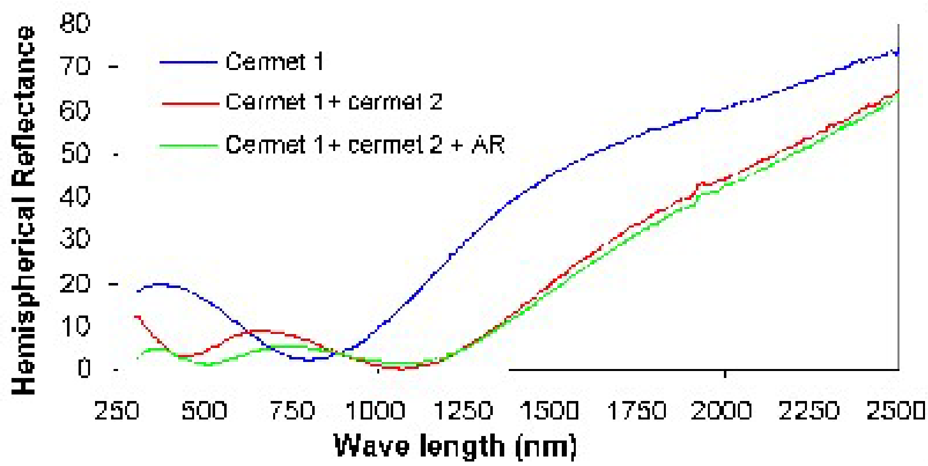


Figure 44. Hemispheric reflectance of the absorbent developed as a function of the number of layers.

The tests carried out in 2002 with antireflective coatings for glass developed by CIEMAT have shown that a solar transmittance of 0.97 was achieved, but that they are slightly hygroscopic at ambient temperatures due to their porosity, which diminishes transmittance to 0.95. It has been demonstrated that water is eliminated and initial transmittance recovered when coated glass temperature is 70°C during operation.

PREDINCER PROJECT

The PREDINCER project is a national R&D project which is partially funded by the Ministry of Science and Technology. In this project, CIEMAT collaborates with the Universities of Almería and Seville to develop and evaluate new control algorithms for solar fields with parabolic trough collectors. This project began in September 2002 and is to last 36 months. Given the date on which this project began, there are still no relevant activities to report in 2002 due to the time necessary in this kind of project for preparing planned activities.

OTHER ACTIVITIES IN 2002

In addition to the activities in the EUROTROUGH, DISS-II and INDITEP projects, the PSA has carried out other activities in 2002 related to parabolic-trough solar collector technology. Two of these activities are particularly outstanding.

- Support and technical consulting for Spanish companies that have shown interest in the parabolic trough collector technology and its commercial applications.
- Preparation and planning of new projects that enable the main lines of work defined by the PSA in the field of parabolic trough collectors to continue. As a consequence of this activity, the PSA participated in several project proposals made in the first announcement of the European Commission 6th Framework Program.

Solar Chemistry

INTRODUCTION

The general purpose of this PSA activity is to establish the scientific-technical basis for developing the technology necessary to use solar radiation in eminently environmental chemical processes. Among these processes special attention is given those for the destruction of toxic compounds and industrial waste in water and gas using the ultraviolet band of the solar spectrum (solar detoxification), and purification (solar disinfection) and production (solar desalination) of drinking water. More specifically, the project objectives or tasks are:

- Development and optimization of a pre-industrial solar photocatalytic detoxification technology for the efficient treatment of persistent organic water pollutants from industrial chemical processes and from the intensive use of pesticides in agriculture.
- Development and optimization of solar technology (engineering, photoreactor and appropriate monolithic catalyst) for the photocatalytic detoxification of VOCs (Volatile Organic Contaminants) to enable high-performance photocatalytic destruction of persistent volatile and semi-volatile organic compounds in industrial gas emissions.
- Development of the basic technology to disinfect water for human consumption by solar photochemical processes in rural locations in developing countries.
- Development and improvement of the solar seawater desalination technology to reduce solar energy system costs approaching the economic threshold of conventional technologies [Blanco et al., 2002(a)].
- Exploration of the technical and economic feasibility of high-temperature of solar chemistry processes for the production of hydrogen or syngas and other chemical processes with significant potential for application in Spain (thermochemical storage, solar high-temperature treatment and recycling of waste materials, methane reforming, etc.).
- Design, construction and testing of a pilot facility for the above-mentioned developments, in order to obtain basic feasibility data.

In order to achieve these objectives, in 2000, the Department has been actively worked on the following tasks:

3) Solar detoxification of liquid

- Development and evaluation of a pilot plant for the treatment of residue from empty pesticide containers to be recycled, by incorporating a solar photocatalytic system in the process Ministry of Science and Technology (MCYT) Project.
- Development, construction and testing of an industrial water treatment plant for rinse water from pesticide containers used in intensive agriculture in the province of Almería (LIFE Project).
- The Project "Application of photocatalysis to purification of waste effluents from the paper industry. Design of a solar facility for treatment of said effluents". MCYT (Project AMB99-1212-C03-03) has been successfully completed.
- European Access to Large Installations Program "Improving Human Potential" (IHP) in the area of solar photocatalysis.

4) Gas-phase solar detoxification processes

- Photocatalytic destruction of precursory species that generate foul odors in wastewater treatment facilities (MYCT-PROFIT Project).
- Elimination of persistent organic pollutants in gaseous effluents by advanced photooxidation (MCYT Project).
- Development and evaluation of a photocatalytic treatment system for deodorizing and disinfecting indoor air (CAM Project).

5) Solar disinfection of drinking water

- Development of a stand-alone system for disinfection of water for human consumption using solar photochemical processes. Startup of two European INCO international cooperation projects to explore their application in isolated rural regions of Latin America and North Africa, respectively.

6) Solar seawater desalination processes

- Development of an advanced hybrid solar/gas desalination technology based on static solar collectors with zero waste. Design, construction and testing of an experimental pilot plant (European project).
- Development of an advanced hybrid solar/gas desalination technology with static solar collectors (MCYT Project complementing the above.)
- Various activities and cooperation within the European Access to Large Installations program (IHP) in the area of solar desalination.

7) Other solar chemistry environmental processes

- Solar synthesis of fine chemical compounds: selectively catalyzed terminal acetylenes functioning of by coordinating compounds in aqueous medium (MYCT project).
- European Access to Large Installations program (IHP) in the area of solar photocatalytic synthesis of fine chemical compounds.

Among the most outstanding results in the year 2002 are the satisfactory conclusion of two doctoral dissertations in the Solar Chemistry Group, a total of 10 peer-refereed publications in international high-scientific-impact journals, edition of a monographic issue of *Catalysis Today* "Recent developments of Photocatalysis in Iberoamerica" (Vol. 76, 2002), two new patents applied for, renewal at the PSA of solar seawater desalination activities and as a new activity, the startup of solar drinking-water disinfection projects.

The ample intense labor sustained by the Solar Chemistry Group during recent years has been the motive of the high international prestige of its widely-known work. In the following sections the main projects and activities carried out in 2002 are summarized.

TREATMENT OF PAPER MILL WASTE WATER

This project of the Ministry of Science and Technology called, "Application of photocatalysis to the purification of waste effluents from the paper industry. Design of a solar facility for treatment of effluents" (Project: AMB1999-1212-CO3-03), was concluded in 2002. The project was carried out in collaboration with the Autonomous University of Barcelona for the photocatalytic elimination of organic pollutants in the effluents from bleaching paper pulp in order to size a treatment facility for these effluents based on pilot plant testing under sunlight.

The CPC pilot plant employed in this project has been in use at the PSA since 1994. Each of the 6 CPC modules is 1.22 m wide by 1 m long and has an 8.9-m^2 area and a 108-L photoreactor volume (247 L total plant volume). There are 8 parallel 48-mm-diameter CPC reflectors (152 mm wide) with UV-transparent tubes. The aperture angle of the collectors is 60° to normal. The reflective material is aluminum (UV reflectivity: 0.829 at 300 nm, 0.861 at 325 nm, 0.834 at 350 nm and 0.810 at 375 nm) and the absorber tubes are fluorinated polymer (UV transmissivity: 0.735 at 300 nm, 0.765 at 325 nm, 0.780 at 350 nm and 0.822 at 375 nm). The modules are mounted in pairs on a platform tilted 37° to the horizontal (local latitude). The 6 modules are connected in series and the water flows directly from one to the other and finally to a tank. A centrifugal pump returns the water to the collectors [*Malato et al., 2002(b)*].

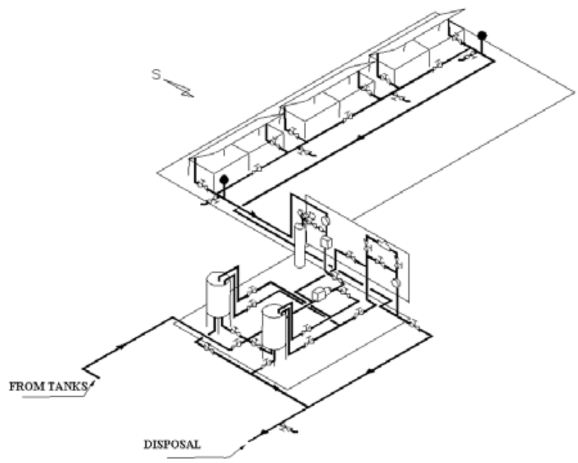


Figure 45. Sketch of the CPC pilot plant used in the experiments with paper mill effluents

Figure 46. General view of the facility at the PSA which was later improved based on these experiments

The experiments for degrading water from paper mill effluents were carried out in this experimental facility. In a first phase, phenol, the main problem compound, was degraded. In these experiments, Degussa P-25 titanium dioxide (200 mg/L) was used with directly applied untreated peroxydisulfate additive. The mixtures of TiO_2 and water were prepared by adding the powder to the experiment tank until a milky suspension was obtained.

In the second phase of the project, tests were carried out under real solar conditions with a sample of water supplied by the CELESA company (Tarragona, Spain). 200 mg/L of TiO_2 were added to the sample waste effluent which was then circulated through the collector. In some tests, peroxydisulfate was also added to favor degradation of the recalcitrant organic compounds present in the sample. The use of this substance has been demonstrated to be highly beneficial for the process.

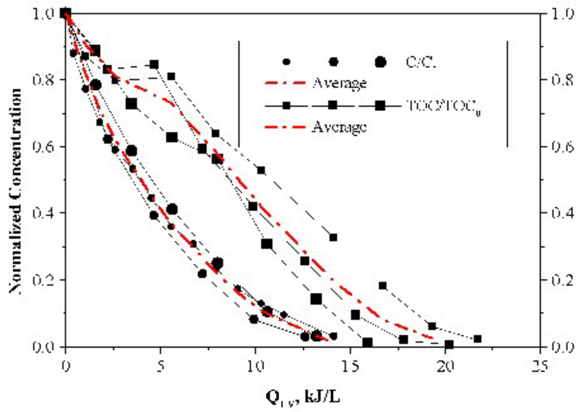


Figure 47. Solar photocatalytic degradation of phenol (C_0 =20 mg/L): evolution of the concentration (C) and Total Organic Carbon (TOC) normalized as a function of accumulated energy. $[TiO_2]$=200 mg/L; pH_0=5

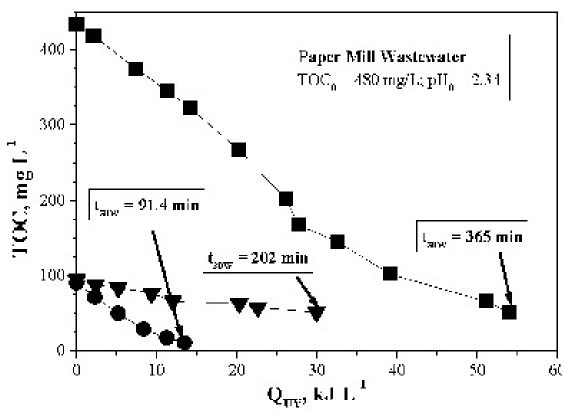


Figure 48. Degradation of TOC in sample from CELESA with regard to Q_{UV} under different conditions: ● Water diluted 5 times. $[S_2O_8^{2-}]_0$ = 15 mM; ■ Undiluted water. $[S_2O_8^{2-}]_0$ = 67 mM; ▼ Water diluted 5 times and TiO_2 alone.

Based on the experiments carried out and the results obtained, the calculation procedure for the size of the solar field necessary to treat the effluent analyzed was as follows:

- Most appropriate photocatalytic process: TiO_2 (200 mg/L) plus $S_2O_8^{2-}$ (50 mM).
- Undiluted effluent with initial TOC concentration of 480 mg/L.
- The treatment is considered complete when TOC is down to 150 mg/L. This merely orientational and is equivalent to degradation at which the effluent becomes biodegradable and can be transferred to conventional biological treatment. Additional specific studies would obviously be necessary to determine the right amount of photocatalytic treatment for effective biodegradability to be attained.
- 10,000 m^3 a year total volume of water to be treated is assumed. If there were a different volume, the resulting factor is simply applied to the size of the solar field.
- Annual solar plant availability of 3,000 hours of operation is assumed.
- Average global UV irradiance (sunrise to sunset) of 18 W m^{-2} is assumed (reasonable in Mediterranean Spain.)
- The average solar energy required to degrade the effluent to the level defined is 32 kJ_{UV} L^{-1} (experimental data).

With the above hypotheses, the calculation of the solar field necessary (CPC photocatalytic reactors) is the following:

$$A_r = \frac{Q_{UV}\ V_t}{T_s\ \overline{UV_G}} = \frac{32\ x\ 10^3\ \ x\ 10000\ x\ 10^3}{3000\ x\ 3600\ x\ 18}\left[\frac{J\ L^{-1}\ L}{s\ W\ m^{-2}}\right] = 1646\ m^2$$

DESIGN AND OPTIMIZATION OF A PILOT PLANT FOR THE INTEGRAL TREATMENT OF PESTICIDE RESIDUES FROM CONTAINERS TO BE RECYCLED.

The project (entitled TREN-AGRO) is financed by the Ministry of Science and Technology (R&D Projects announced in BOE, March 8, 2000, Project PPQ2000-0126-P4-05) and began in November 2001. The Plataforma participates in this project together with the Analytical Chemistry Dept. of the University of Almería (Coordinator), Aragonesas Agro, S.A., Cooperativa de Exportadores de Frutas y Hortalizas de la Provincia de Almería and the Chemical Engineering Dept. of the University of Alcalá.

The work proposed attempts to develop a process for the treatment of residues from pesticide containers after which they can be recycled and reused in other applications in the plastic industry. The process will consist of two basic steps, each consisting of several operations: (i) the containers themselves: shredding, washing, drying and compacting to properly inertize the residues and (ii) the rinse water; physical-chemical treatment with advanced oxidation processes (AOP) that totally eliminates toxic components such as pesticides and their transformation products [*Malato y col., 2002(a),(d); Vidal y col., 2002(a)*].

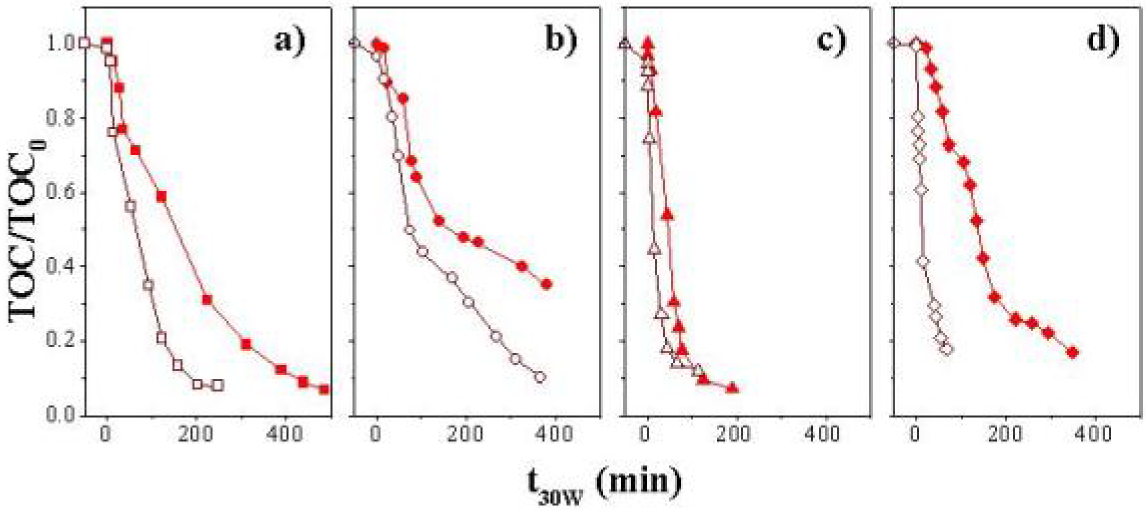


Figure 49. Mineralization of Imidacloprid (A), Methomyl (B), Diuron (C) And Formetanate (D). Tio$_2$ (200 Mg/L): Solid symbols. Photo-Fenton (0.05 Mm Fe): Open symbols.

In 2002, it was demonstrated that photocatalysis both with TiO_2 and by photo-Fenton are feasible treatments for purifying and detoxifying water polluted by pesticides. In this study, the feasibility of both processes was demonstrated under solar radiation at pilot plant scale [*Malato y col., 2002(c)*]. In fact, it was attempted to demonstrate that control of different AOPs is not a trivial matter [*Parra y col., 2002; Rodríguez y col., 2002*]. The proper evaluation of any AOP, applied to the treatment of waste water, must not include only a study of the disappearance of the original compound. A complete study of the degree of mineralization of the substance in question as well as its degradation products (DPs) generated during the process with an integral parameter such as the TOC is always necessary. Furthermore, knowledge of the evolution of the wastewater toxicity, evaluated by a battery of bioassays, is fundamental [*Fernández-Alba y col., 2002*]. The application of advanced analytical techniques, such as liquid and gas chromatography coupled to mass spectrometry, gas chromatography with atomic emissions detector and bioassays of acute toxicity are decisive for evaluating the overall effectiveness of the degradation processes and assuring that the final discharge is innocuous.

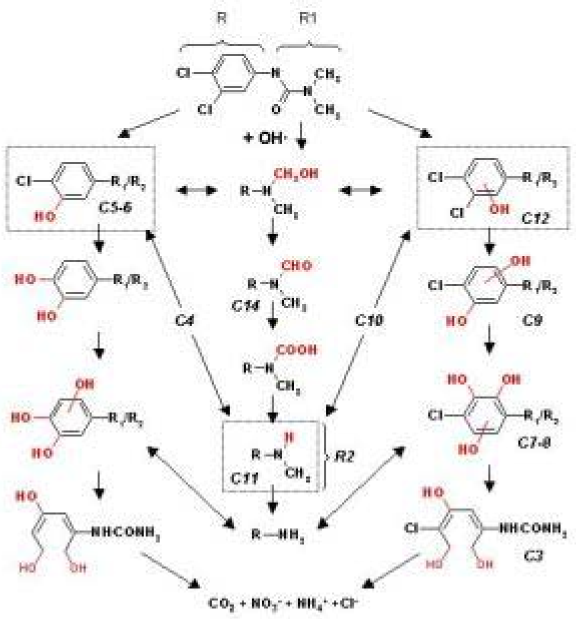


Figure 50. Solar photocatalytic degradation path proposed for diuron with TiO$_2$ and photo-Fenton.

The photo-Fenton process has been shown to be more efficient than TiO_2, not only for degradation of the pesticides, but also for mineralization of TOC and reduction of toxicity [*Mézcua y col., 2002(a),(b)*]. The degradation products identified by GC-MS, GC-AED and LC-MS during both treatments are similar, although in different proportions, because in both processes, the •OH radicals are the main path of attack on the organic molecules. The proportion in which the DPs are detected is different due mainly to the reaction rate [*Malato y col., 2002(f)*]. Thus, as there are different reaction rates, the DPs are generated and disappear in different proportions during the two treatments. However, the DPs or mixtures of them that are generated during the photocatalytic degradation processes may be more toxic than the original components. This clearly demonstrates the need to perform batteries of bioassays in order to obtain conclusive results. The use of biotoxicity evaluation techniques can also help reduce treatment cost since it is unnecessary to completely demineralize the pollutants. It is enough to reduce their toxicity below limits compatible with the environment or other simpler treatments (for example, biological) [*Malato y col., 2002(e)*].

The final goal of the project is to design, build and optimize a pilot plant in 2003 which includes the quality controls (product and environmental) necessary to transform the plastic containers with pesticide residues into plastic free of pesticides and usable for other applications.

ACCESS TO THE PSA AS A LARGE EUROPEAN SCIENTIFIC FACILITY

The European Project "Trans-national Access to the Plataforma Solar de Almería: the European Solar Thermal Test Centre" of the Improving Human Potential Program, began on February 1, 2000 and will last until the end of 2002. This project consists of making the Plataforma Solar de Almería available to different European research groups for performing tests related to Solar Energy with the advice and collaboration of PSA's scientific staff. In this project, solar photochemistry activity is one of the most successful areas, with a fruitful scientific production [*Augugliaro y col., 2002(a),(b),(c),(d); Catastini y col., 2002; Kositzi y col., 2002; Mailhot y col., 2002; Nguyen Dinh y col., 2002; Robert y col., 2002(a),(b); Salud y col., 2002; Sarria y col., 2002*] which has allowed the Solar Chemistry team to become a reference point in Europe. In fact, in 2002, 12 European groups were received at the PSA in 7 test periods (4 in the DETOX facility and 3 in the SOLFIN facility), very similar to the activity during 2001. Such activity is expected to continue to be the same or even more intense, in coming years. The tests carried out in 2002 in photocatalytic detoxification, basically addressing decontamination of water, were the following:

1) Viostamp S.A.-Thessaloniki Dyeing Mills S.A., / Lab. Phys. Chem.-Univ. of Thessaloniki (Greece). *Photocatalytic treatment of effluents containing dyes*. Reduction of the organic content of the aqueous effluents from the textile dyeing mills by homogeneous photocatalysis (photo-Fenton) and heterogeneous (TiO_2) was studied. Two different TiO_2 were studied as well as the effect of oxidants such as H_2O_2 and $Na_2S_2O_8$. The TiO_2/H_2O_2 system was demonstrated to be most efficient for heterogeneous photocatalysis. 70% of the Chemical Oxygen Demand (COD) and all of the color from textile (cotton) water were eliminated. In any case, homogeneous photocatalysis was the most effective, since more than 90% of the TOC was eliminated.

2) Lab. Photocatalyse, Catalyse and Environment-E. Centrale de Lyon / AHLSTROM PAPER GROUP (France). *Efficiency study of photocatalyst supported on fiber: application to the elimination of dyes*. Different amounts of Millennium anatase PC50 and PC500 titania photocatalyst were fixed on paper support prepared from synthetic fiber by the Ahlstrom company. Different pollutants, such as formetanate (pesticide), methylene blue (model dye) remazol and amaranth (azoic dyes), dissolved in water were treated with this new catalyst installed in a cascade STEP reactor (see Annual Report 2001). This system was compared to Millennium catalysts suspended in water at 0.5 g/L in CPC photoreactors [*Herrmann y col., 2002*]. The effi-

ciency of both systems was very similar in treatment of formetanate, but results with the suspended catalyst were better for dye treatment (Figure 51).

3) <u>Environmental Biotechnology Department, Silesian University of Technology, Poland / Laboratoire de Chimie et Applications (EA 3471), Universite de Metz, France.</u> *Photo-catalytic degradation of organic compounds from lixiviants in garbage dumps.* Humic acids are generated in large amounts in old and abandoned garbage dumps. Their degradation with TiO_2 (P-25) was tested and more than 85% of COD and color were removed. Furthermore, biodegradability was demonstrated to have increased during the photocatalytic treatment.

4) <u>Vienna Univ. of Agricultural Sciences, IWGA-SIG / Vienna Univ. of Agricultural Sciences, IBF, Austria.</u> *Photo-Fenton treatment of commercial pesticides and 4-nonylphenol*. Mixtures of nine commercial pesticides (10-60 mg/L de TOC) were tested with photo-Fenton in parabolic trough collectors (Helioman) and 85% degradation of TOC was obtained. The COD and BOD5 (biological oxygen demand at 5 days) measurements demonstrated that biodegradability had increased from 15% to 37% of COD. Furthermore, it was shown that 4-nonylphenol (endocrine disrupting chemical) could be degraded by two orders of magnitude with both photo-Fenton and TiO_2, the first of the two being the more effective treatment.

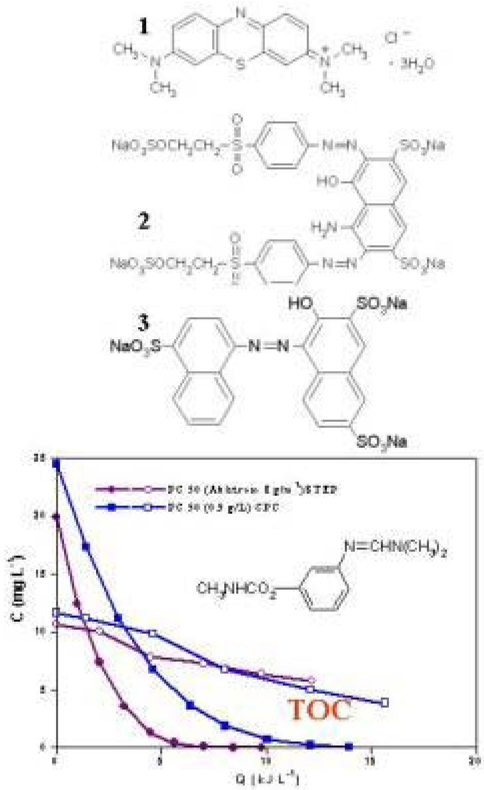


Figure 51. Structure of dyes (1 methylene blue, 2 remazol, 3 amaranth) tested in STEP and comparison of STEP and CPC in formetanate degradation.

Testing in 2002 in the SOLFIN facility, basically devoted to the synthesis of compounds using the sun as the radiation source, was as follows:

1) <u>Faculty of Chemistry, A. Mickiewicz University, Poznan, Poland.</u> *Photoproduction of hydrogen from a water-methanol mixture with modified titanium.* Three series of tests for generation of hydrogen from water in the presence of methanol with platinized titanium-yttrium catalysts under artificial and natural light. In the experiments carried out under solar radiation, an increase in sedimentation of the catalyst was observed, producing decrease in generation of hydrogen, regardless of the type of reactor or titanium used. The best results were obtained for the catalysts that contained 0.3% platinum, while an increase in the Y_2O_3 concentration led to decreased total activity.

2) <u>Dipartimento di Ingegneria dell'Università di Bergamo/ Dipartimento di Chimica, Chimica-Fisica e dei Materiali "Giulio Natta", Milan, Italy.</u> Photochemical synthesis of azahelicenes and useful precursors for synthesis. Several different photochemical reactions were carried out to synthesize mono and diaza-helicene compounds and achieve cyclation of a derived styryl, precursor of the synthesis of these aza-helicenes. The formation of aza-helicenes was rather successful, however, only trans-cis isomerization could be attained. It was verified that solar photoreactors could be used at above-laboratory scale and with natural radiation to derive large quantities of styryls and, thereby, a substantial amount of aza-helicene compounds.

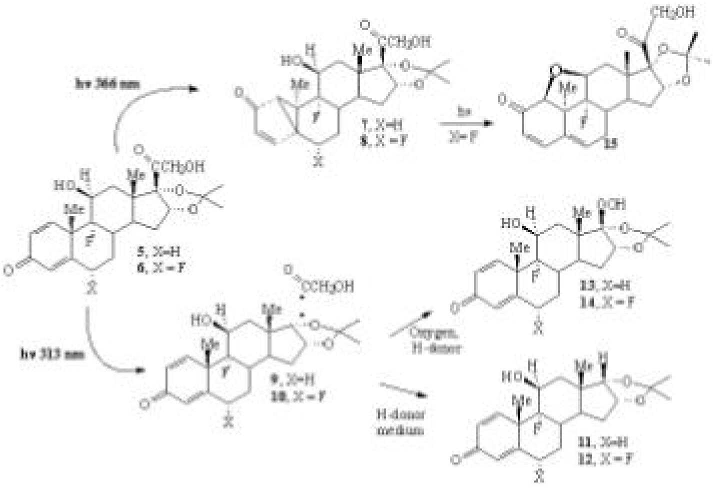


Figure 52. Photochemical transformation of a glucocorticosteroid depending on λ irradiation.

3) Department of Organic Chemistry, University of Pavia, Italy. *Solar-induced Photoreactivity of drugs*. Reactivity to natural UVA-UVB radiation of photo-sensitive drugs belonging to the fluoroquinolones, glucocorticosteroids, solar creams and nitrophenyl dihydropyridines. The tests with solar creams used both micellar SDS and aqueous solutions. From the results obtained it was concluded that the drugs investigated were strongly degraded by exposure to sunlight for a few minutes to several hours.

SELECTIVE CATALYZED FUNCTIONALIZATION OF TERMINAL ACETYLENES BY COORDINATING COMPOUNDS IN AQUEOUS MEDIA.

The project, which is financed by the Spanish Ministry of Science and Technology (P2000-1301), began in December 2000 and the groups that participate in it are the Plataforma Solar de Almería, the Dept. of Inorganic Chemistry of the University of Almería (coordinator), DLR-PSA and the Department of Organic Chemistry of the University of La Laguna.

Biphasic homogeneous catalysis (aqueous/organic) would be the solution for many of the traditional problems in catalysis in homogeneous media, without loss of any of its advantages. The processes are equally selective, but as the catalyst is dissolved in water and the reaction products are soluble in organic phase or insoluble in water, they are easily separable, and the catalyst is reusable. On the other hand, unsaturated carbenes are important intermediates that can act as catalysts forming C-C bonds.

One of the objectives of this project is the study of the chemical and catalytic properties of the vinyl and allenylidene compounds soluble in water, the acceptor and donor atom and tensoactive properties of which make them optimum catalysts in two-phase systems. Another objective proposed has been the use of solar radiation as a source of energy in synthetic reactions. For it, new systems have been developed [*Romerosa et al., 2002*] that require the optimization of all the parameters so that the two-phase catalysis solar energy system is a selective, economical and ecological system.

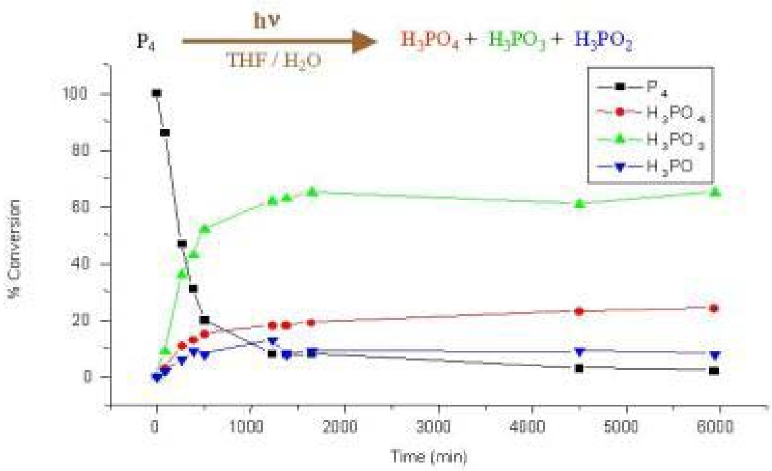


Figure 53. Formation of phosphoric acid derivatives, H_3PO_3, H_3PO_2 y H_3PO_4 from solar radiation of a P_4 solution.

For example, one of the processes carried out has been the catalyzed transesterification with vinyl ester RU(II) coordination complexes substituted to form organic, acetal and aldehyde compounds [*Mañas y col., 2002(a)*].

Development of a system for synthesis of inorganic compounds such as phosphoric acid derivatives using solar energy has also been investigated [*Mañas y col., 2002(b)*].

SOLAR PHOTOCATALYTIC DISINFECTION OF WATER

Disinfection is a crucial process for the environmental industry. It should be recalled that water is the main vector of transmission of disease to humans and as a result, the quality of water is an absolutely primary necessity. During the first 75 years of the 20th century, almost the only water purification treatments were chemical flocculation, filtration in granular media and chlorination. Chlorine is the chemical most commonly used for water disinfection because of its ability to inactivate bacteria and viruses. However, in the last 20 years we have been witness to a radical change in the water industry, which as begun to consider other "alternative" treatments to those used traditionally. One of the reasons for it is the fact that it has recently been demonstrated that in the presence of organic impurities in water, chlorine can generate undesirable sub-products such as trihalomethanes and other carcinogenic compounds.

Membrane filtration technologies (micro, ultra and nanofiltration and reverse osmosis) are used more and more, even though it is rather more expensive. Irradiation with ultraviolet light (UV, 254 nm), although it is a compact and economically competitive technique, is entering only slowly, since it has no oxidative ability (simultaneous control of color, taste and odor such as chlorine and ozone do). Furthermore, there is still insufficient information on the dosage necessary for the destruction of many microorganisms and natural light cannot be used. Ozone (with or without hydrogen peroxide or additional UV light) and other advanced oxidation treatments that are based on the generation of OH radicals, may present problems of toxicity during operation, high cost, design optimization and formation of secondary products that endanger human health. One example of this is the formation of bromide ions in the case of water rich in bromine.

In this context, photocatalysis as a method of disinfection is still a basically unexplored process. However, the bactericide effect of TiO_2 has been demonstrated with several microorganisms, including *Escherichia Coli*, *Lactobacillus Streptococcus* and others. This effect is associated with the division of the cell wall by photocatalytically induced surface oxidation, resulting in the disintegration of the cell. The disinfection of viruses, such as Phage MS2 and poliovirus 1 may be found in the literature. One of the worst problems in all these methods is the lack of any residual capacity of disinfection when the treatment is finished, so the microorganisms can reproduce again afterward. By contrast, the simultaneous presence of microorganisms and organic compounds in the media can make photocatalysis still more effective due to the formation of radicals of these compounds that are also bactericide. The figure presents a simplified drawing of the processes that could take place if water contaminated by microbial and organic pollutants is treated photocatalytically. A realistic application should include preliminary photocatalytic treatment to partially disinfect the water to reduce the level of organic pollutants, followed by limited chlorination to

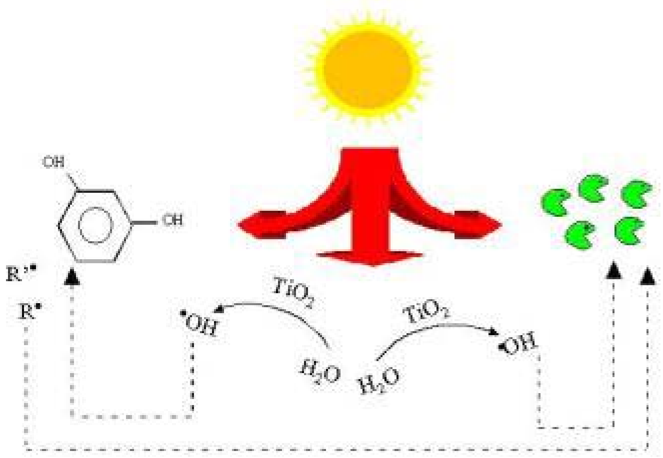


Figure 54. Simultaneous photocatalytic disinfection and decontamination.

maintain disinfection in the distribution mains and avoid formation of undesirable secondary products.

As water resources become fewer and both industrial and sanitary demand greater, the need for innovative, competitive water disinfection treatments is also greater, with a clear potential for photocatalytic processes based on sunlight. Therefore, the Plataforma Solar proposed a project called "Cost effective solar photocatalytic technology to water decontamination and disinfection in rural areas of developing countries" (SOLWATER) to the European Commission (DG Research, Confirming the International Role of Community Research for Development), which has now been approved and work began in November 2002. The PSA Solar Chemistry Group is the coordinator of this project with European (ECOSYSTEM-Spain, AOSOL-Portugal, COMPLUTENSE UNIVERSITY OF MADRID-Spain, NATIONAL TECHNICAL UNIV. OF ATHENS-Greece, FEDERAL POLYTECHNIC SCHOOL OF LAUSANNE-Switzerland) and South American (MEXICAN INSTITUTE OF WATER TECHNOLOGY, NATIONAL ATOMIC ENERGY COMMISSION-Argentina, NATIONAL UNIVERSITY OF ENGINEERING-Peru, TINEP-Mexico) participation.

ENVIRONMENTAL COLLECTING AND RECYCLING OF PLASTIC PESTICIDE BOTTLES USING SOLAR PHOTOCATALYSIS

This project focuses on the problems originating in intensive greenhouse agriculture, a sector which has been growing exponentially in recent years in the Mediterranean Basin. At the present time there are more than 200,000 hectares of greenhouses, most of them in EU countries. This type of agriculture requires up to 200 times more pesticides than conventional growing methods and the resulting environmental problems are one of the major disadvantages of this sector's growth.

One of these problems is the uncontrolled dumping of the used plastic pesticide bottles, which usually retain small amounts of residue in them. This originates serious risk of contaminating soil and underground water. The solution is the selective collection of these bottles for recycling. But before the plastic can be recycled, it must be washed, and the water used for it becomes contaminated with the pesticides. This water must be treated before it can be disloadd. Therefore, the development of a simple, clean, on-site water-treatment process is necessary. At the present time such a technology does not exist. That is why the ALBAIDA company, with the collaboration of CIEMAT, presented a project entitled "Environmental Collection and Recycling of Plastic Pesticide Bottles using Advance Oxidation Process Driven by Solar Energy" to the European LIFE-ENVIRONMENT, which has been approved and began in October 2001. At this time, the CIEMAT is assisting the ALBAIDA company in the final design of the solar detoxification plant to be installed in the plastic pesticide container processing and recycling complex [*Blanco y col., 2002(b),(c),(d)*].

This 30-month project is divided in five phases, each with its own specific objective. Each one has been designed to approach all aspects related to proper recycling of plastic bottles containing toxic chemicals. The first part of the Project (Work packages 1 and 2) are focused on developing a method for collecting the bottles. An appropriate container has been selected and their geographic distribution organized, basically placing them near agricultural cooperatives in the province of Almería. Different aspects related to their collection (numbers of bottles per container and day, amount of residue per bottle, type of plastic, etc.) have been determined by placing some test containers at strategic points. Moreover, the recycling plant has been designed and is final site based on the logistics of collection. The second phase (Work package 3) includes the construction of a small pilot plant for to-scale testing of all the parameters involved in recycling. The plastic collected in some of the containers will be transported and treated to evaluate any possible problems on a small scale in order to optimize the entire process as closely as possible. The third phase (Work package 4) will consist of the design, construction and operation of the complete industrial-scale system taking into consideration all the findings obtained in the previous phases. The selective collection, transport, recycling and rinse-

Figure 55. Beginning construction of the pesticide container recycling plant in La Mojonera (Almería)

water decontamination will be permanently set up. Furthermore, the versatility of the process will be studied for use in other places and/or applications.

In 2002 the permits and licenses of the environmental authorities were obtained and the first stone was laid in the municipal limits of La Mojonera (see Figure 55). Afterwards, the pilot plant will be erected. This will be the prior necessary step before beginning construction of the definitive plant. The project will conclude with the edition and distribution of information brochures for growers showing how it will avoid the damage to the environment caused by uncontrolled dumping.

GAS-PHASE DESTRUCTION OF ORGANIC POLLUTANTS

Eliminating H_2S from air

The "Photocatalytic Destruction precursors and generators of foul odors in waste water treatment facilities" project (Project financed by the MCYT- PROFIT: FIT-140100-2001-158 and 2002-84) completed in December 2002. The CIEMAT Department of Renewable Energies collaborated in this project together wit the ICP-CSIC and Aguas de Murcia S.A. It studied for the first time in Spain, the application of solar radiation on a catalyst for the destruction of noxious gases from treatment plants, basically hydrogen sulfide. The study of photocatalytic activity is divided into two stages:

- Testing of photocatalysts under controlled laboratory conditions.
- Construction of the first photoreactor prototype and proposal for testing under real conditions.

In conclusion, effective destruction of H_2S is observed during the first few minutes which slowly diminishes over time, leading us to think about catalysts washing processes.

PHOTOCATALYTIC TREATMENT OF DIOXINS AND FURANES

The project "Elimination of persistent organic pollutants in gaseous effluents by advanced photooxidation" (FOTOCOP), financed by the Spanish Ministry of Science and Technology with an external contribution to CIEMAT of 55,000 Euros, was begun in 2002.

The main goal of this project is the development, erection and testing under pilot plant conditions of a first photocatalytic reactor which alone or associated with a conventional adsorption system, can destroy persistent organic compounds (POCs), such as dioxins and furanes found in exhaust gas from waste incineration systems. During the development of the project, the following partial objectives are expected to be achieved:

1) Preparation and characterization of different monolithic catalysts – with either massic incorporation or impregnation of the titanium dioxide – for highly efficient catalytic and/or photocatalytic oxidation of dioxins and furanes without formation of any secondary products.

2) Preparation and characterization of different supports impregnated with titanium dioxide by different techniques, such as surface deposition (coating) and sol-gel, as an alternative to monolithic catalysts.

3) Determine on laboratory scale the photocatalytic activity of the different impregnated supports.

4) Modulate the airflow through the channels that comprise the monolith. Measure intrinsic reaction rates experimentally and propose kinetic models based on the corresponding degradation mechanisms.

5) Model the area radiated in the interior of the monoliths, calculating the radiation flux densities on the surface of the canals and optimizing the design parameters, mainly leading to making better use of the solar radiation .

6) Improve the sampling method for analysis of dioxins and furanes before and after photocatalytic treatment.

Figure 56. In addition to the monolithic ceramic catalysts traditionally tested by our research group in gas phase, new supports such as the one shown here are being assessed for photocatalytic use.

7) Develop a low-cost photoreactor prototype based on an optimized collector plane that uses solar radiation and UV lamps simultaneously to study the possibility of working continuously day and night.

8) Determine, the efficiency of this collector photoreactor in the destruction of gaseous effluents from a pilot plant under real solar conditions, key parameters that control it and importance of the displacement reagents and reaction agents, such as O_3 and H_2O_2.

Deodorizing and disinfecting air in interiors

This new project entitled, "Development and evaluation of a photocatalytic treatment system for deodorization and disinfection of air in the interiors of buildings", financed by the Regional Government of Madrid (CAM) with an non-CIEMAT budget of 39,000 Euros, also began this year. The specific objectives are the following:

1) Study of VOC concentrations in two model environments: hospitals and office buildings.

2) Study of the microbial load, saprophytes or pathogens, etc. in those environments.

3) Develop a modular reactor design able to treat a gas stream containing VOCs identified as problematic. Also test their efficiency in treating colonies in order to extrapolate to pathogenic colonies.

Figure 57. Growth of Aspergillus sp. and Penicillium in a Petri dish

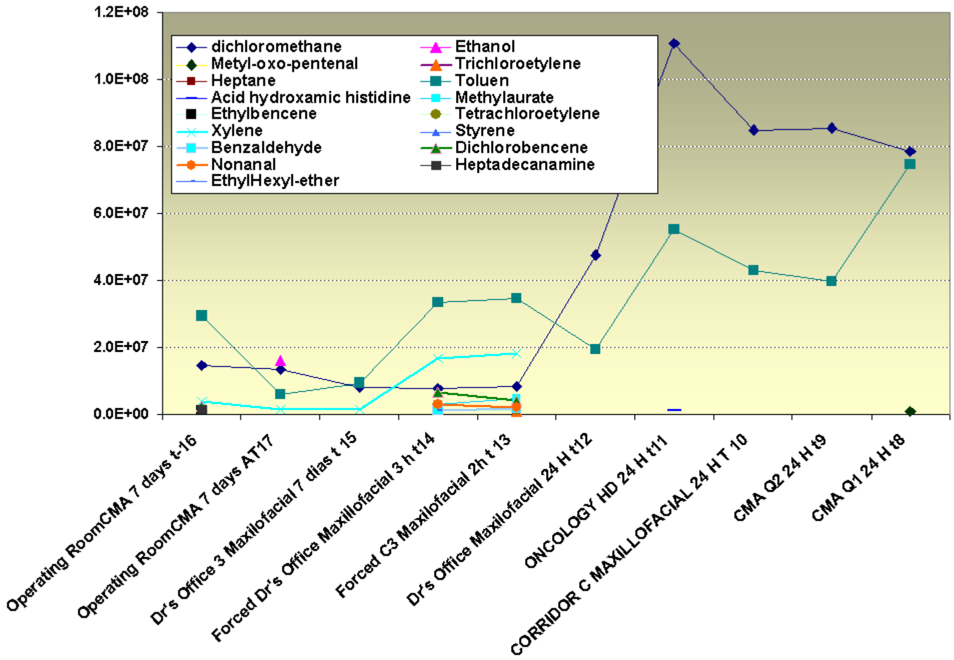


Figure 58. VOCs determined by GC-MS in different hospital environments.

4) Develop a TiO_2 waveguide impregnation procedure (optic fiber or similar) that allows the efficiency of these systems either alone or in combination with monolithic catalysts to be evaluated when these fibers are incorporated along their parallel channels.

5) Determine the influence of key parameters in the reaction chemistry. Residence time, photonic flux concentration and importance of displacement reagents such as H_2O and CO_2.

SOLAR DESALINATION OF SEAWATER

At the present time, in the PSA Solar Chemistry Area, two solar seawater desalination research projects are underway, one European (AQUASOL Project: Enhanced Zero Disload Seawater Desalination Using Advanced Hybrid Solar Technology) and another national (SOLARDESAL Project: Advanced Hybrid Solar- Gas Desalination Technology with Static Solar Collectors).

The participants in the SOLARDESAL Project are: CIEMAT (coordinator), University of la Laguna, INABENSA and ECOSYSTEM. The 3-year project began in November 2001.

The participants in the AQUASOL Project are: CIEMAT (coordinator) INABENSA (Spain), Ao Sol Energias Renováveis (Portugal), National Technical University of Athens (Greece), INETI (Portugal), Cajamar (Spain), Hellenic Saltworks (Greece), Comunidad de Regantes Las Cuatro Vegas de Almería (Spain) and Weir-Entropie (France). The duration of this project is four years, divided in two phases: a first research phase lasting two-and-a-half years and a second demonstration phase lasting a year and a half. Formal project startup was in March 2002.

The objective that both of these projects have in common is the development of a hybrid solar/gas seawater desalination technology using a multi-effect distillation (MED) system which complies with the principles of energy efficiency, low cost and zero disload.

The AQUASOL project in particular focuses on the technological development of three basic aspects:

6) Incorporation of a hybrid solar/gas energy supply source based on high-efficiency, low-cost compound parabolic solar collectors (CPC).

7) Development of a double-effect absorption heat pump (LiBr/H_2O) optimized for the MED process that will enable energy consumption to be halved.

8) Reduction to zero of any kind of disload from the distillation process by recovering the salt from the brine.

In 2002, the main activities carried out were related to establishing the conditions (operating specifications and techniques) of the different subsystems that make up the desalination system to be implemented in the AQUASOL Project (See figure).

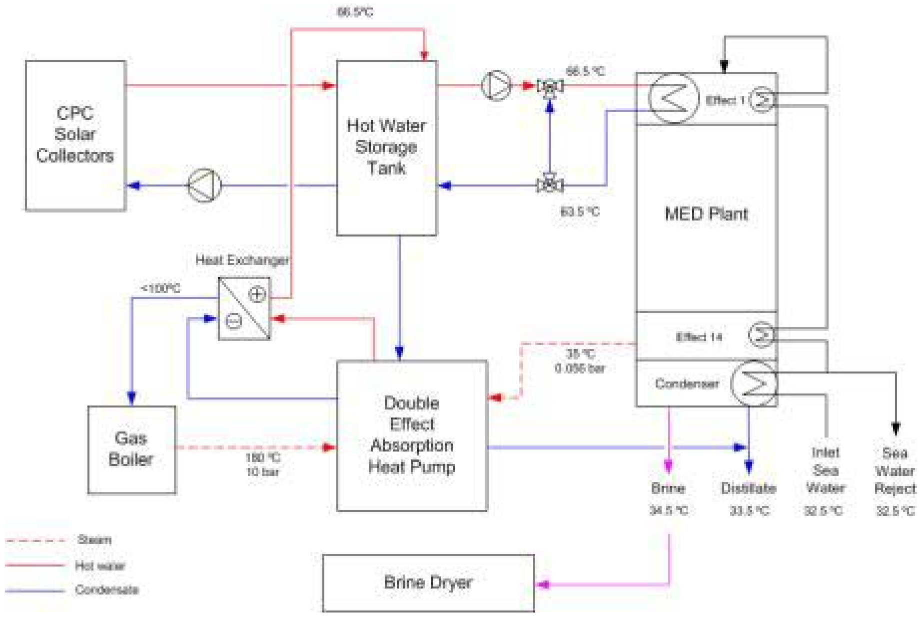


Figure 59. Final desalination system configuration to be implemented in the AQUASOL Project

The first effect of the MED plant is fed hot water at 66.5°C directly from the storage tank, which is in turn fed either by the solar collector field, or by the double-effect absorption heat pump. Operation at those temperatures presents two clear advantages: in the first place, the danger of incrustations in the distillation plant heat exchangers is considerably reduced, reducing consumption of chemical additives; in the second place, the energy efficiency of the static solar collectors increase the less the difference between fluid and ambient temperatures is.

Due to the maximum temperature limitation that can be obtained with standard CPC solar collectors, the only possibility of operating the double-effect heat pump is to use high-temperature high-pressure steam (180°C, 10 bar) from the gas boiler. Therefore, the plant performance factor (kg distillate/2300 kJ energy contributed to the process) oscillates between 10 (solar-only mode) and 20 (gas-only mode) [*Alarcón y col., 2002*]. One of the aspects to be studied in the project is a hybrid operation mode in which the heat pump can be operated at partial loads (20%-100%) in combination with a complementary contribution from the solar field.

In so far as post treatment of the saline effluent produced by the distillation process is concerned, research has led to the conclusion that it is impossible to obtain salt directly by a completely passive solar device. Therefore, the functional specifications of the advanced solar dryer to be designed have been reformulated with the new goal of increasing the concentration in the inlet brine up to the saturation point of calcium carbonate (16BE, Baumé scale). This concentration would be sent to conventional salt evaporation pools where the standard process for obtaining salt is followed. Simulations have demon-

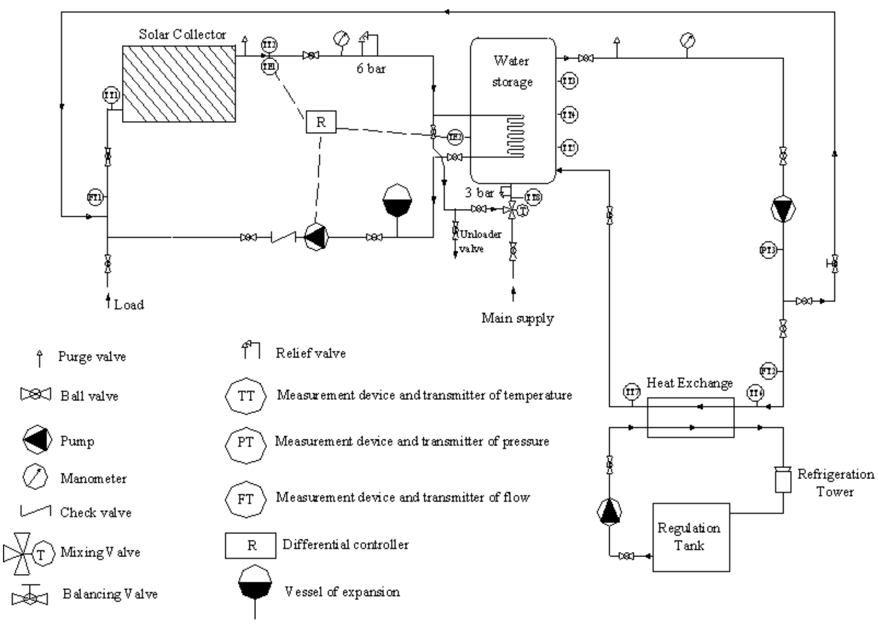


Figure 60. General schematic diagram of the static solar collector test bed

strated an increase up to a factor of 9 in performance with the solar dryer proposed in comparison to the process carried out in a conventional salt plant.

In 2002, desalination activities were also included in the European program "Improvement of Human Potential for Research". In order to offer additional services to the research community, a static solar collector test bed was erected and started up for determining their efficiency curves in desalination applications (See figure). This facility has three independent hydraulic loops: In the primary loop, the fluid (water or mixture of water and antifreeze) is heated as it goes through the solar collector delivering the energy acquired to the water deposited in a storage tank. In the secondary loop, the water from the tank is pumped to a heat exchanger where its energy is transferred to a third loop, simulating the inlet of the first effect of an MED plant. Finally, the water that circulates through the third circuit is pumped to a cooling tower, where the energy from the secondary loop is dissipated into the ambient.

Figure 61. View of the static solar collector test bed (top)

Figure 62. PSA 14-effect multi-effect distillation plant (left)

SOLAR ENERGY STORAGE PROCESSES

In recent years, several international efforts have been made in both thermochemical and photochemical solar energy storage. Thermochemical conversion of solar energy into chemical energy is a thermodynamically efficient process allowing transport of solar energy. In these processes, the direct thermal decomposition of ZnO provides an attractive possibility for solar energy concentrating systems.

$$ZnO + C \rightarrow Zn + CO \qquad (T > 1400^{o}C)$$

The solar energy stored in the condensation phase can be used to produce electricity in a Zn/air or hydrogen fuel cell by hydrolysis in the presence of steam; in both cases ZnO is regenerated and reused.

With regard to photochemistry processes, the application of photocatalysis to selectively promote CO_2 reduction represents a very attractive path for development of systems for the sustainable production of organic chemistry compounds, fuels and materials [*Vidal y col., 2002(b)*]. These processes avoid the use of conventional fossil fuels and as a consequence, the addition of more CO_2 to the atmosphere.

Training and Access

The objectives of this project may be considered to be among the priority activities of CIEMAT itself. **Participation in access programs** contributes to dissemination of the possible applications of solar thermal energy among the international scientific community, so that an ever-greater number of research groups dedicate their time and resources to exploring this option.

The results thus favor penetration of the renewable energies in general, and of solar thermal energy in particular, into the industrial and economic structures of society, which is defined as one of the basic objectives of the Department of Renewable Energies.

Another no less important objective of PSA participation in access to large installations programs, is that it contributes to the optimized use of its facilities by taking advantage of otherwise idle periods in which the research infrastructure is not required for PSA projects.

The purpose of these access programs, aimed especially at benefiting young researchers, is usually the transnational movement of researchers and their **training. This is the same principle behind the Plataforma Solar de Almería's own training program**. Around thirty students of different nationalities are admitted to this program each year, thus giving new generations of professionals the experience of the Plataforma Solar in solar thermal technologies accumulated during twenty years of experimentation.

ACTIVITIES WITHIN THE 'IMPROVING HUMAN RESEARCH PROGRAMME'

The 'Improving Human Research Potential' Program (IHP) is a concerted activity of the European Commission Directorate General for Science, Research and Technology Development (DG-RTD). Its main objective is to give the European scientific community an opportunity to use any large research infrastructure, in whatever member country it may be located.

Given that one of the objectives of CIEMAT in general and of the PSA in particular, is to contribute to the dissemination of knowledge of the possible applications of solar thermal energy, this program is an excellent tool for achieving this purpose.

Therefore, the PSA has been participating almost without interruption in the successive research and technology development programs that can generically be called 'Access to Large Scale Installations' promoted by the DG-RTD since 1990.

Participation in the IHP program is for three years from February 2000 to January 2003. The PSA offers eight facilities for access and 68 research groups will have been received in them by the end of the three-year period.

As the first activity of the year, the independent expert User Selection Panel met at CIEMAT-Moncloa on January 29, 2002, selecting a total of 14 research groups from other European countries to be awarded free access to the PSA's test facilities during the year.

For the first time, the annual meeting of new PSA Users was held together with the "Workshop" of the previous year's Users, seeking better use of the event by participants of both. This combined two-day event, which was attended by over 50 researchers, took place in Almería on February 25-26, 2002. The lectures delivered at the Workshop were collected a book published by the CIEMAT.

In June, as stipulated in the contract signed with the DG RTD, a follow-up technical audit was taken by Brussels, in which evaluation was very positive.

On the other hand, the PSA has signed another new contract with the European Commission under this program, with the following main parameters: for 24 months beginning in March 2002, with financing of 517,500 Euros (approx. 86 MPTA) for 48 weeks of access offered.

THE 'EUROCARE' SCIENTIFIC INFRASTRUCTURES NETWORK

In its desire to advance toward the unification of efforts and optimization of resources dedicated to research, the European Commission is promoting a series of infrastructure networks grouped by subject matter. The Psa is part of the 'EuroCARE' network with those centers that study energy.

Apart from the PSA, other members of EuroCARE' are:

- University of Wales-Cardiff (coordinator-United Kingdom)
- ENEL Produzione (Italy)
- International Flame Research Foundation (Netherlands)
- Federation of Aerothermodynamics and Propulsion Studies (France)

Figure 63. IHP Users Meeting at the PSA

- Institute des Materiaux et Procedes (France).

This is also a horizontal IHP program and within it, the tasks are structured around three study panels:

- First: Measurement and diagnostic techniques in high-temperature processes.
- Second: Future research requirements. This is an especially interesting task, since the final document will be sent to the European Commission for its consideration when it is preparing the basic outline of the 6th Framework Program for Community research and technological development.
- Third: Industrial training in the context of large installations.

Semiannual meetings are usually held, although this year, for several reasons, only one was held. This took place at the PSA itself in March.

Figure 64. www.euro-energy.net

The reports corresponding to the first and second study panel meetings were issued in 2001 and the third panel report was issued this year.

It was also agreed to create a web page to publish the contents of those study panel sessions and the opportunities related to access programs of each of the members. The address of this page is www.euro-energy.net.

EuroCARE's 6th Framework Program objective includes the expansion of its activities, by including new members and cooperating in depth on common subjects of research.

TRAINING ACTIVITIES

The European Commission DG RTD's access programs normally have as their argument the transnational mobility of researchers and their training, with special emphasis on young researchers.

This is also the principle governing the **Plataforma Solar's own training program**. Through this program, around thirty students of different nationalities are admitted every year, thus contributing to the transmitting to new generations of graduates, the knowledge on solar thermal technology accumulated at the Plataforma Solar de Almería during twenty years of experimentation.

As our goal within this project, we intend to continue with this activity and even reinforce it if possible. Such training activities are also CIEMAT priorities.

Training program activities consisted of:

- Management of the grants given by annual agreement with the University of Almería (UAL).
- Management of the 'Leonardo da Vinci' agreement grants.
- Management of several specific educational collaboration agreements with other centers to accept students at the PSA: Federal Polytechnic School of Lausanne, University of Bordeaux, etc.

In 2003 it is expected that the agreement with UAL for PSA grant management and also the 'Leonardo da Vinci' program for foreign students will be renewed.

Figure 65. Participants in a course at the PSA

REPRESENTATION OF THE PSA AS LARGE INTERNATIONAL SCIENTIFIC INSTALLATION

This facet of the project is summarized by the participation of the PSA in the events held for "Science and Technology Week 2002". In the first place, the 37,000€ awarded by the FECYT (Fundación Española para la Ciencia y la Tecnología[7]) to finance the cost of these activities, entitled "Almería en Renovable[8]", at the Campus of the University of Almería (UAL) during the week of November 4th-10th, is to be highlighted (Figure 66).

The purpose was to offer the people of Almería in general and the academic community in particular, a perspective of the research and technological development activities in renewable energies and conservation of the environment carried out in the province.

Two centers were involved in putting the action into practice that stand out for their activities related to the study and implantation of renewable technologies, as well as the knowledge and environmental conservation in the province of Almería: the UAL and the Instituto de Estudios Almerienses[9] (IEA).

To carry out the project, the responsibilities for the event were distributed among three partners, who signed a tripartite agreement to that effect. This agreement made the CIEMAT-PSA, which would manage funds awarded by the FECYT, the coordinator mainly responsible for the action.

In so far as the tasks themselves are concerned, the CIEMAT-PSA assumed responsibility for the exhibition space, the UAL was responsible for the lecture series and the IEA was in load of organizing guided tours. Publicity on the various events was done "horizontally", that is, with responsibility shared by all three partners.

[7] Spanish Foundation for Science and Technology
[8] Almería in Renewable
[9] Institute for Almería Studies

Figure 66. Poster "ALMERÍA IN RENEWABLE"

Setting up an Exhibition Space at the University of Almería Campus

Partner responsible: Plataforma Solar de Almería (CIEMAT)

This exhibition space consisted of a 100-m^2 tent with three stands, one for each partner in the initiative, housing informative material on the activities carried out with regard to renewable energies and the environment, posters, brochures, videos, models and technology demonstration units.

An inauguration ceremony was organized to which the media were invited.

It is estimated that around ten thousand students at the campus visited this exhibition space. A series of books were shown at the stand of the Plataforma Solar and a form was available to request free copies. At the conclusion of exhibition, the largest number possible of requests were filled depending on the number of copies available of each title. As a complementary activity, a series of brief technological demonstrations was scheduled, each of which was announced the day before. Among these, the following may be mentioned:

- How the detoxification of waste water by photocatalytic process works
- Environmental control in greenhouses

Figure 67. The PSA's Science Week stand

Lecture Series

Partner responsible: University of Almería

The lecture series took place in the auditorium of the university, two lectures each weekday during the "Week".

The following table gives the final series program:

Date	Time	Title	Lecturer
Nov. 4	6:00 pm	The Plataforma Solar de Almería: Center of European Excellence for Research in Solar Thermal Energy	Mr. Manuel Romero Álvarez, Director of the Plataforma Solar de Almería (PSA)
	7:30 pm	Solar Resources in the Province of Almería.	Mr. Manuel Pérez García, Dept. of Applied Physics, UAL
Nov. 5	6:00 pm	Solar Chemistry Applications to Environmental Problems in the Province of Almería.	Mr. Sixto Malato Rodríguez, Researcher, 'Solar Chemistry' Project at the Plataforma Solar de Almería.
	7:30 pm	Detoxification and reuse of typical waste from intensive agricultural. Water and Plastic.	Mr. Amadeo Rodríguez Fernández-Alba, Dept. of Analytical Chemistry, UAL
Nov. 6	6:00 pm	Potential of bioclimatic architecture in Almería. The example of the MEDUCA Project.	Ms. Rosario Heras Celemín, Head of 'Solar Energy in Building' project at the CIEMAT.
	7:30 pm	Photochemical Activation of phosphated compounds using homogeneous catalysts.	Mr. Antonio Romerosa Nievas, Dept. of Organic Chemistry, UAL
Nov. 7	6:00 pm	Solar Plant Control Systems	Mr. Manuel Berenguel Soria. Dept. of Languages and Computation, UAL
	7:30 pm	Solar Thermal Desalination of Water: the European 'AQUASOL' Project at the Plataforma Solar de Almería	D. Diego César Alarcón Padilla. Investigador del proyecto 'Química Solar' de la Plataforma Solar de Almería.
Nov. 8	6:00 pm	Alternatives for recycling and management of solid agricultural waste.	D. Francisco Camacho Ferre. Dpto. de Producción Vegetal. UAL
	7:30pm	Direct steam generation for power production: The PSA DISS project.	Mr. Eduardo Zarza Moya. Head of the 'Parabolic-Trough Collector Technology' project at the PSA.

An average of thirty persons attended each of the lectures. Attendance certificates were given upon request.

Program of guided tours

Partner responsible: Instituto de Estudios Almerienses

The following all-day bus trip was organized for November 8th for visits to points of interest in the province related to renewable energies and the technology applied to solving environmental problems.

- Plataforma Solar de Almería (Tabernas)
- Wind Farm, Enix

Figure 68. Stand of the Instituto de Estudios Amerienses during Science Week

72 persons in two buses went on the tour. The group was accompanied by a representative of the Instituto de Estudios Almerienses and at each center visited, by a qualified guide for the pertinent explanations.

TESTING IN THE SOLAR FURNACE

In the Solar Furnace in 2002 and in the framework of the European Commission Improving Human Potential (IHP) program, several types of materials tests were performed for two European research groups. Furthermore, a volumetric receiver was tested with different absorbers.

Researchers from the German Aerospace Institute, DLR, together with the German company, Babcock, the Higher Technical Institute of Lisbon, IST, and the Technical University of Riga, RTU, of Latvia, in cooperation with the Materials Group at the PSA, have tested different types of test pieces in the MiniVac (mini vacuum chamber) under atmospheric pressure and in controlled argon and nitrogen atmospheres, on both horizontal and vertical planes. Furthermore, several (receiver) absorbers were tested in the DLR VMR volumetric receiver and sintering tests were begun by the PSA Materials Group on test pieces consisting of copper wires with different sections.

The tests performed for **DLR-Babcock BSH** are for recycling aluminum in the Solar Furnace, which is an innovative technology with great expectations for future development of high-efficiency low-emissions aluminum manufacture and could advantageously replace conventional fossil energies because of the reduction in emission gases, avoiding

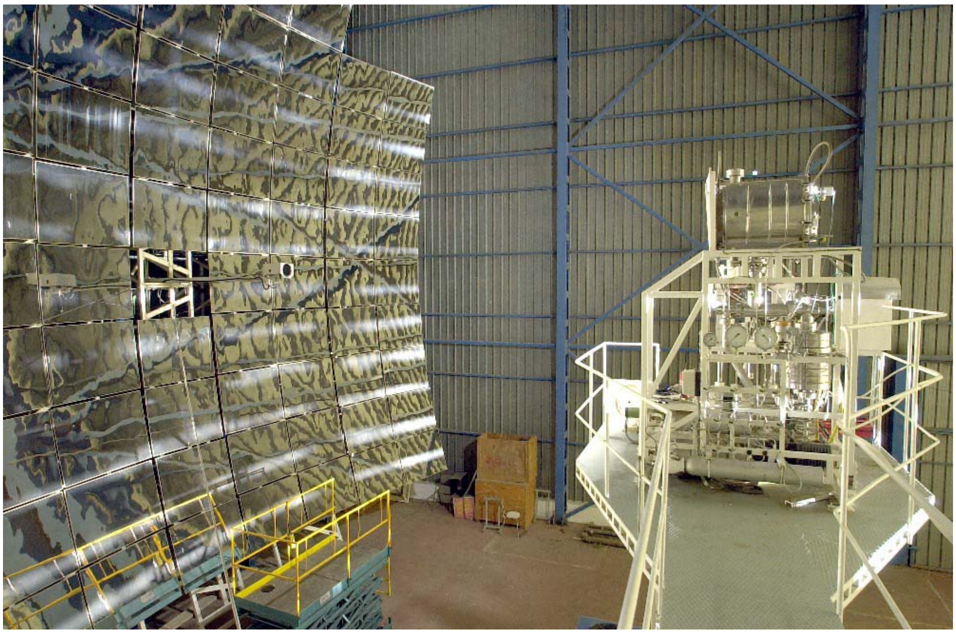


Figure 69. Parabolic concentrator and vacuum chamber

the generation of gases that contribute to creating the greenhouse effect and other pollutants.

The project consists of two parts. The first is a feasibility study on solar thermal treatment of aluminum scrap in the PSA Solar Furnace. The MiniVac was used as the receiver for high-temperature treatment of different types of aluminum scrap. Although the first idea was to treat the aluminum inside the MiniVac in an inert atmosphere – where oxidation losses are reduced in test pieces – but in the end the tests were performed at atmospheric pressure under ambient conditions.

The second part of the project consisted of preparing for the development, manufacture and operation of a solar thermal aluminum recycling demonstration plant using as the central element a rotary furnace with hybrid heating.

Several tests were carried out for DLR-Babcock on small pieces of sheet aluminum at between 500° and 600°C for ten minutes.

The testing performed for the **Riga Technical University (RTU)** addressed research on ceramic nanomaterials based on silicon nitride, silicon carbon nitride with different amounts of alumina and yttrium and in sialons. The nanocomposites Si_3N_4-Y_2O_3-Al_2O_3 and dopants Si_3N_4-SiC, TiN were prepared by plasma chemical synthesis from metal powders (Si, Ti) and oxides (Y_20_3, Al_2O_3).

Production of nanostructured materials demands the development of new nonconventional sintering methods such as spark sintering, microwave and plasma sintering, to which sintering in a solar furnace may be added.

The test pieces were produced by hot pressing at up to 1800°C in a nitrogen atmosphere at the Austrian Research Center (ARC-Seibersdorf). Si_3N_4-$^6Y_2O_3$-$^3Al_2O_3$ beta-sialon, aluminum oxide and titanium oxide nanostructured composite pellets were sintered in the Solar Furnace at different temperatures and heating times in a nitrogen atmosphere.

The sinterability of the composites was compared to that of industrial silicon nitride with oxide additives. The samples had previously been pressed and pre-sintered in a nitrogen atmosphere.

Three test campaigns were performed with a large number of tests carried out at temperatures between 800° and 1750°C and test times ranging from 15 minutes to 2 hours.

In 2002, several tests were performed for the **Higher Technical Institute of Lisbon (IST)** with W+aCx test pieces at different stoichiometries x = 1.5, 2.5 and 5 to sinter wolfram carbides and carbon nitrides.

The samples prepared from W and carbon metal powders were mixed homogeneously and later compacted at a pressure of 40 MPa in 10-mm-diameter by 5-mm-high pellets.

For treatment, the pellets prepared in this way were placed in a graphite crucible and put into the MiniVac in horizontal position in such a way that the samples treated were on the vertical plane where the solar furnace reaches maximum thermal flux. During the tests, the chamber was made inert by an argon stream at 1.4 bar and the samples exposed to the furnace's high flux were heated to 1650ºC in 5 minutes, maintaining this temperature for 30 minutes.

Three tests were carried out with these W+aCx test pieces, so that different samples of Si and metals in the "d" transition group – except for Hf – were subjected to thermal treatment in the Solar Furnace in the 2001 test campaign.

The **PSA Materials Group** is also developing its own line of researched based on concentrated solar sintering.

Sintering is one of the oldest metal and ceramic fabrication methods. Today it is commonly used to obtain solid forms from metal powders, ceramics and, most recently, some polymers. This process is usually accompanied by an increase in conductivity, mechanical resistance, ductility and, in many cases, density. It is believed that there is no field or industrial sector in which sintered products are not used since among the advantages of this procedure is the possibility of obtaining a product with a homogeneity and dimensional precision superior to that obtained with other techniques and at a lower cost. Sintering makes more efficient use of the prime materials, pollutes less and sometimes constitutes the only feasible way to manufacture a given piece.

The energy necessary for sintering, although less than in other production processes, is still high, so that is of great interest to study the use of a renewable energy source, such as solar thermal energy, that allows this process to be the most environmentally correct.

The particular conditions of sintering metal particles, which must be done at high temperatures and in controlled atmospheres or in a vacuum, may be obtained in solar furnaces since these facilities, in addition to reaching very high energy concentrations and

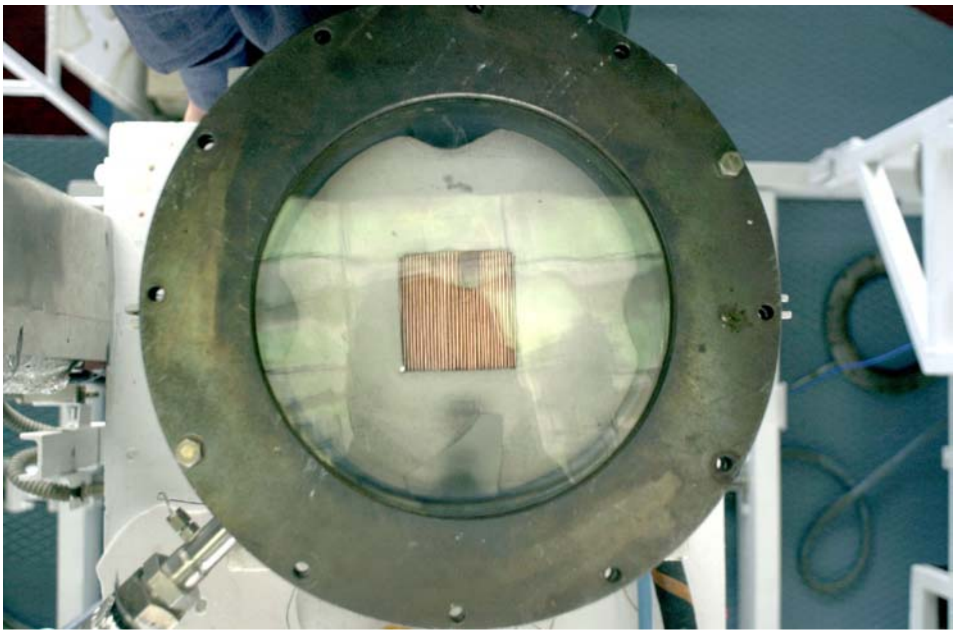


Figure 70. Copper test piece in the MiniVac vacuum chamber

temperatures, admit the use of vacuum chambers and gas preparation systems.

In the Plataforma Solar de Almería Solar Furnace, there have been several sintering test campaigns in which different experimental devices have been configured to evaluate process feasibility. In 2002, to facilitate understanding of the phenomena that take place during sintering, test pieces made of highly pure copper wire were tested in about a dozen tests in reduction atmosphere at temperatures between 850 and 1050ºC and varying exposure times of between 1 and 3 hours.

In later analysis, the pieces tested showed development of well-defined necks and reduced porosity, characteristics typical of sintering, demonstrating the feasibility of sintering copper in solar furnaces.

DISTAL FACILITY TEST ACTIVITIES

As in the Solar Furnace, the facility devoted to testing and evaluation of parabolic disk and Stirling motor systems – DISTAL – is under this project because most of its activities are related to users from outside CIEMAT.

The DISTAL facility also receives research groups from outside under the IHP program. Specifically, this year it has collaborated with researchers from the Department of Transportation Phenomena and Applied Thermodynamics at the Technical University of Crete (Greece). Personnel from this department visited the facility for several weeks, familiarizing themselves with daily operation of the units and assisting in the preparation of an operations manual for it.

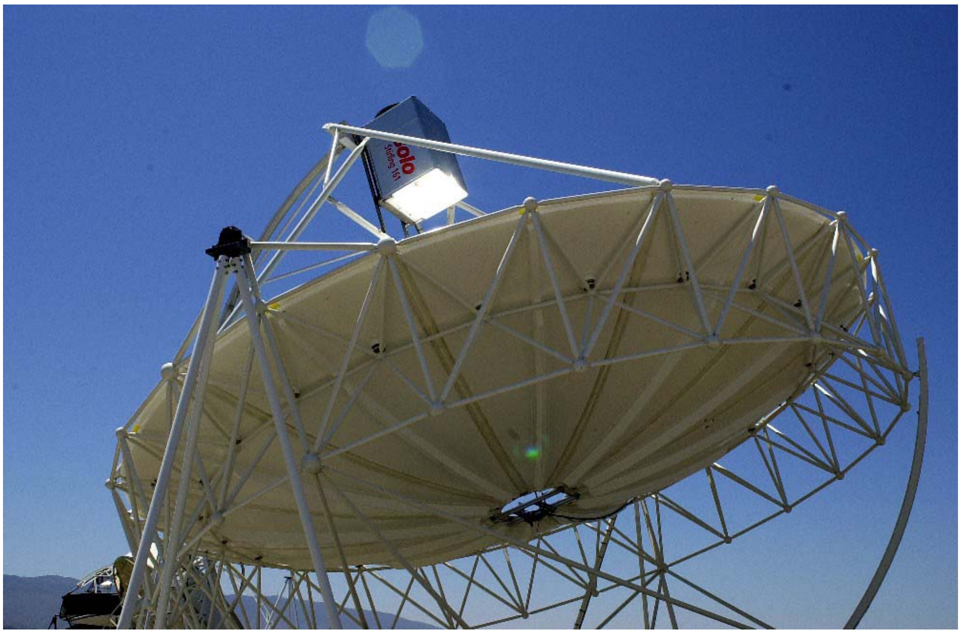


Figure 71. EURODISH parabolic dish system

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List of Acronyms....

ABB	Asea Brown Boveri AG
AICIA	Asociación de Investigación y Cooperación Industrial de Andalucía
AOP	Advanced oxidation process
ARC	Centro Austríaco de Investigación (Seibersdorf)
BOD	Biological oxygen demand
BOD5	Biological oxygen demand at 5 days
CAM	Regional Government of Madrid
CESA-1	Central Eléctrico Solar Almería-1
CG-MS	chromatography mass spectrometer
CIEMAT-DER	Centro de Investigaciones Medio Ambientales y Tecnológicos – Dept. of Renewable Energies
CNRS	National Center for Scientific Research (F)
COD	Chemical oxygen demand
CPC	Compound Parabolic Collector
CRES	Center for Renewable Energy Resources (Gr)
CRS	Central Receiver System
CSIC	Consejo Superior de Investigaciones Científicas
CYTED	Iberoamerican Program for Science and Technology for Development
DCS	Distributed Collector System
DEAHP	Double-effect absorption heat pump
DG RTD	Directorate General for Research and Technology Development (EC)
DG TREN	Directorate General of Transport and Energy
DISS	Direct solar steam
DISTAL	Dish Stirling Test Facility Almería
DLR	Deutsche Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Agency)
DP	Degradation product
DSG	Direct steam generation

EC	European Commission
EHN	Swiss Federal Institute of Technology
ERDF	European Regional Development Fund
ET-II	Eurotrough II
FECYT	Spanish Foundation for Science and Technology
FID	Flame ionization detector
GC-AED	Gas chromatography with atomic emissions detector
GC-MS	Gas chromatograph coupled to mass spectrometry
HDPE	high-density polyethylene
IEA	Institute of Almería Studies
IEA	International Energy Agency
IHP	Improving Human Potential
INABENSA	Instalaciones INABENSA, S.A. (E)
INCO	Cooperation with Third Countries and International Organizations
INETI	National Institute of Engineering and Industrial Technology (P)
IST	Higher Technical Institute of Lisbon (P)
LC-GC	Liquid chromatography, gas chromatography
LC-MS	Liquid chromatography coupled to mass spectrometry
LECE	Energy Testing of Building Components Laboratory
LS-3	"Luz System 3" parabolic trough collectors
MCYT	Ministry of Science and Technology
MED	Multi-effect Desalination
MCYT	Spanish Ministry of Science and Technology
PAR	photosynthetically active radiation
PCHA	First autonomous heliostat field Phase I
POC	persistent organic compound
PS-10	10-MW Solar Thermal Power Plant for Southern Spain
PSA	Plataforma Solar de Almería
PTC	Parabolic trough collector
RTU	Riga Technical University
SBP	Schlaich Bergermann und Partner
SDS	Sodium dodecyl sulfate
SEGS	Solar Electric Generating Systems
SOLAIR	Receptor Solar Volumétrico de Aire Avanzado para Plantas Comerciales de Torre Central
SOLAUT	Solar Thermal Electricity Generation with Autonomous Modules
SOLGATE	Solar Hybrid Gas Turbine Electric Power System
SOLFIN	Solar Synthesis of Fine Chemicals

SOLUCAR	Solúcar Energía, SA
SSPS	Small Solar Power Systems
TCD	Thermal conductivity detector
TOC	Total organic carbon
TRNSYS	Transient Energy System Simulation Tool
TSA	Programa de Tecnología de Receptor Solar de Aire
UAL	University of Almería
UNAM-CIE	Universidad Nacional Autónoma de México - Centro de Investigación en Energía
UNED	National University for Long-Distance Education
UVA	Ultraviolet A
UVB	Ultraviolet B
VMR	DLR Volumetric Receiver
VOC	Volatile organic compounds
ZSW	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

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