Plataforma Solar de Almería

ANNUAL REPORT 2007

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MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

ÍNDICE

Message from the Director

Diego Martínez Plaza

The new regulatory Framework defined by Royal Decree 661/2007 of May 25, 2007 (BOE nº 126, of May 26, 2007) for the sale of electricity generated by solar thermal power plants meant a new boost for the promotion of this type of plants in Spain.

This caused frenetic promotional activity which at the end of 2007 led to almost 4 GW_e total power of plants that had requested to be included in the Special Regime, of which almost 2 GW_e already have a connection to the distribution grid.

The interest of industry in the applications that we develop at our center is stronger all the time; we are receiving an enormous number of visits from businesses in Spain and abroad that want to know more about the technology and cooperation agreements are being signed with important industrial groups.

Research activity in the **Solar Concentrating Systems Unit** continues working on the Direct Steam Generation (DSG) Technology through two parallel processes. The first, from the viewpoint of research, has to do with clearing up the last technological unknown of the DSG process, thermal storage. For this, the PSA is participating in the European DISTOR Project. The second process has more to do with the technology development and demonstration, and consists of promoting an industrial consortium which will build and operate a commercial 3-MW_e solar power plant based on the DSG technology on the PSA's grounds.

On the other hand, innovative working fluids for parabolic-trough collectors are being studied experimentally, evaluating their behaviour under a diversity of real operating conditions and analyzing their advantages and disadvantages compared to fluids currently in use. To achieve this goal, a new parabolic-trough test loop has been erected.

In tower technology, we are working with companies promoting the first generation of commercial central receiver solar thermal power plants, such as PS10 (with Abengoa Solar, already in operation) and Solar Tres/Gemasolar (with SENER, in promotion).

Another important event that took place in 2007 was the creation of a new SolarPACES (Solar Power and Chemical Energy Systems) task, which under the formal name of "Solar Energy & Water Processes and Applications" is going to be devoted to concentrating, publicizing and promoting research and demonstration related to the application of solar energy to water processes and technologies. This new task, called "SolarPACES Task VI", is led by the head of the **Environmental Applications of Solar Energy Unit**, and will initially last 5 years from its official starting date of January 1, 2008.

Training and dissemination continue firmly on course, as we are aware that we cannot neglect our obligation to inform society about the existence of this renewable energy option. Educational Agreements are maintained with many universities and research centers all over the world, and we also take part in courses and training activities of various types. Worthy of special mention are the "Master's in Solar Energy" which is being given at the CIESOL, mixed UAL-CIEMAT center, which is now being given for the third time in Academic 2208-2009.

As always, I do not want to finish without a word of thanks for the support given us by the CIEMAT Directorate and the dedication and professionalism of all the PSA staff.

Diego Martínez Plaza
Director of Plataforma Solar de Almería

1 General Presentation

1.1 The PSA as a large solar installation: general information

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

The following goals inspire its research activities:

- Contribute to establishing a sustainable clean world energy supply.
- Contribute to the conservation of European energy resources and protection

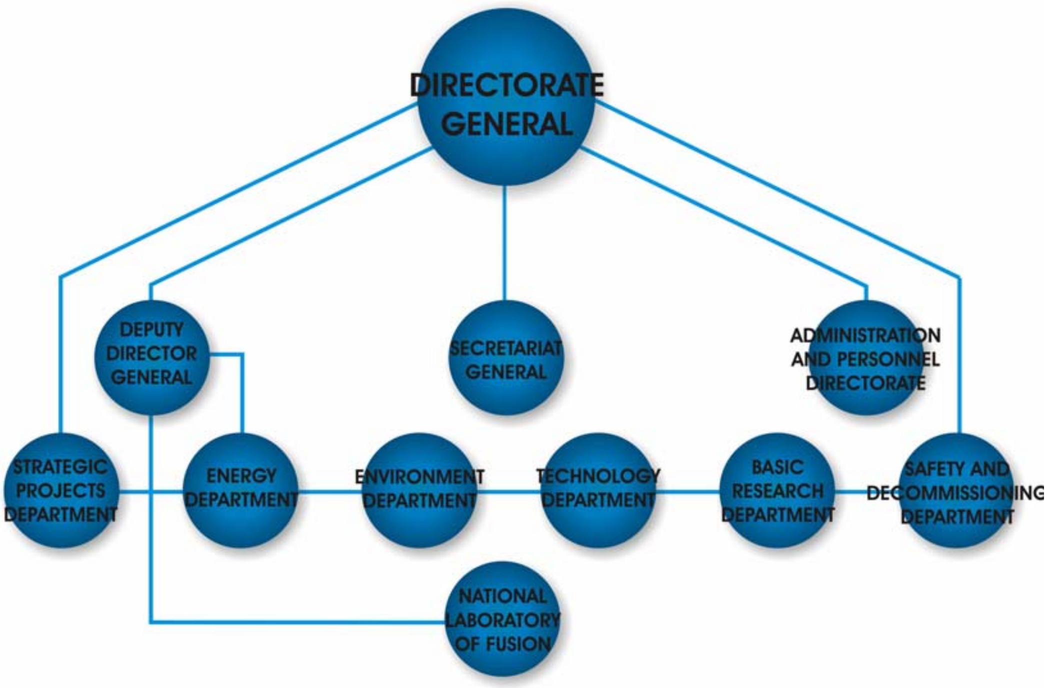

Figure 1.1. Integration of the PSA in the CIEMAT organization

of its climate and environment.

- Promote the market introduction of solar thermal technologies and those derived from solar chemical processes.
- Contribute to the development of a competitive Spanish solar thermal export industry.
- Reinforce cooperation between business and scientific institutions in the field of research, development, demonstration and marketing of solar thermal technologies.
- Strengthen cost-reducing technological innovations contributing to increased market acceptance of solar thermal technologies.
- Promote North-South technological cooperation, especially in the Mediterranean Area.
- Assist industry in identifying solar thermal market opportunities.

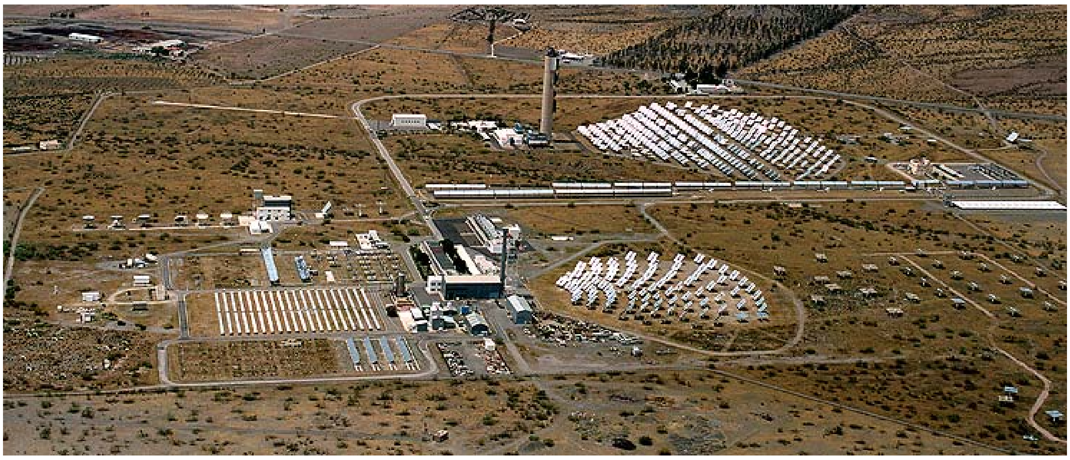

Figure 1.2. Aerial view of the Plataforma Solar de Almería

1.2 Functional Structure

In 2007, research activity at the Plataforma Solar de Almería was structured around two R&D Units:

- Solar Concentrating Systems Unit
- Environmental Applications of Solar Energy and Characterization of the Solar Resource Unit

The first is devoted to developing new and better ways to produce solar thermal electricity and the second to exploring the chemical possibilities of solar energy, especially its potential for water detoxification, desalination and disinfection.

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

These units are largely self-sufficient in the execution of their budget, planning, scientific goals and technical resource management. Nevertheless, the two R&D units share many PSA resources, services and infrastructures, so they stay in fluid communication with the Management Unit, which coordinates technical and administrative support services. For its part, the Office of the Director must make sure that the supporting capacities, infrastructures and human resources are efficiently distributed. It is also the Office of the Director that channels demands to the various general support units located at the CIEMAT's main offices in Madrid.

1.3 Human and Economic Resources

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 118 persons that as of December 2007 made up the permanent staff lending its services to the Plataforma Solar. In addition to this staff, there is a significant flow of personnel in the form of visiting researchers, fellowships and grants handled by the Office of the Director.

Of the 118 persons who work daily for the PSA, 58 are CIEMAT personnel, 21 of whom are located in the main offices in Madrid.

In addition, the 12 persons who make up the DLR permanent delegation as a consequence of its current commitments to the Spanish-German Agreement also make an important contribution.

The rest of the personnel are made up of a no less important group given the center's characteristics. These are the personnel working for service contractors in operation, maintenance and cleaning in the various different facilities. Of these 32 persons, 14 work in operation and 18 in maintenance. The auxiliary services contract accounts for 8 administrative personnel and secretaries, 2 IT technicians and 5 security guards.

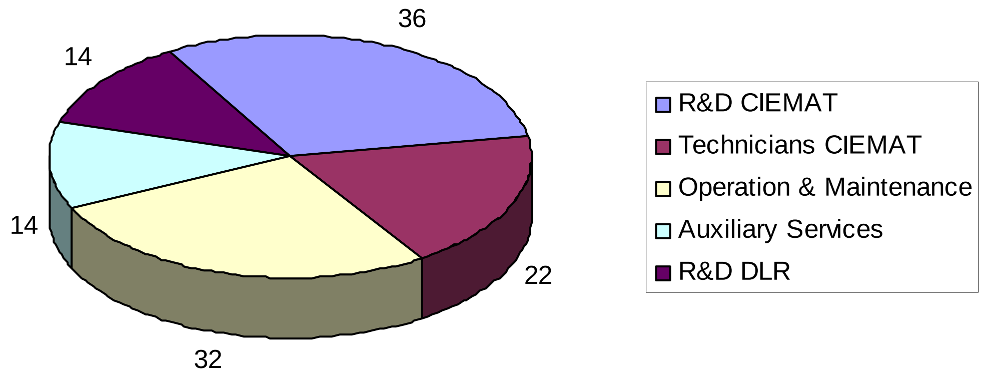

Figure 1.3. Distribution of PSA permanent personnel as of December 2007

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

The PSA budget has an upward trend, in large part due to higher revenues. Income from the European Commission has been an outstanding contribution of our longstanding partner DLR. A good number of the new joint projects proposed to the EC have allowed the DLR to continue at the PSA in a new relationship based on specific projects, and the fruit of this success is the relevance of the German delegation at the PSA.

The significantly increased number of projects financed by the National Plan for R&D reflects a growing decision for renewable energies and in particular, for solar concentrating technologies.

The PSA budget in 2007 reached 9.63 million Euros (not including R&D personnel). The CIEMAT contribution was increased in order to undertake the activities approved for this year in the Plan for PSA Infrastructure Improvement. This plan is devoted to major improvements necessary in the main infrastructure, building, heliostat fields, etc.

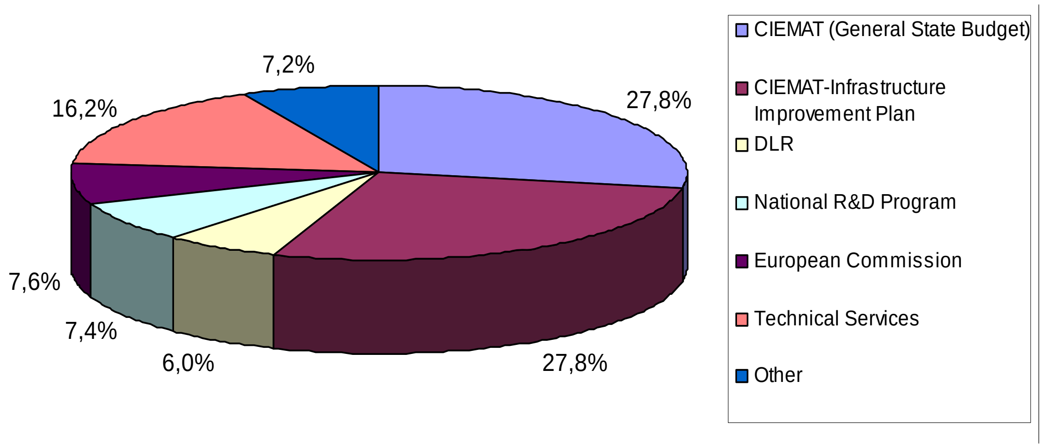

Figure 1.4. Distribution of PSA Income in 2007

1.4 *Scope of collaboration*

As mentioned above, the PSA since 1987 has been the subject of a Spanish-German Cooperation Agreement between the CIEMAT and the DLR (German Aerospace Research Center), commonly known as the CHA. At the present time, scientific relations and cooperation commitments are governed by Annex V of this Agreement, which includes the commitment to maintain a permanent DLR delegation at the PSA from 2006 and 2008.

In all, the scope of collaboration in which the PSA moves is remarkably wide. In the international sphere, the PSA actively participates in the International Energy Agency 'SolarPACES' (Solar Power and Chemical Energy) Program, where information is exchanged and costs are shared with similar centers in the other member countries (USA, Mexico, Italy, Germany, France, Switzerland, European Commission, South Africa, Israel, Algeria and Egypt).

Moreover, the PSA-CIEMAT is a member of the 'Alliance of European Laboratories on Solar Thermal Concentrating Systems' (SolLAB). This virtual laboratory is made up of the main European concentrating solar energy research institutes, that is, PROMES-CNRS in Odeillo (France), the DLR Solar Energy Division in Cologne (Germany), the Renewable Energies Laboratory of the Federal Institute of Technology in Zurich (Switzerland), the Renewable Energies Laboratory of the Federal Institute of Technology in Zurich (Switzerland) and the CIEMAT itself. The agreement was signed in October 2004 and the coordinated tasks have begun to give fruit, especially in the fields of flux and temperature measurement and Ph.D. student education. The 'Paul Scherrer Institute" in Switzerland formalized its membership in 'SolLAB' in 2006.

In training activities, there is an agreement with the University of Almería (UAL) for managing joint fellowships and educational agreements for receiving students from universities around the world.

In fact, this long-lasting collaboration with the UAL has recently been enlarged and consolidated with the creation of the 'CIEMAT-UAL Mixed Center for Solar Energy Research' called 'CIESOL'.

Apart from the joint projects carried out in several fields of science, this year, the 2nd CIESOL Master's Degree in Solar Energy was given. This one-year Master's degree is listed in the Univ. of Almería's coursework catalog.

Figure 1.5. Photo of the 'CIESOL' Bldg.

From the moment of its conception, this Master's Degree was intended to make the best use possible of PSA-CIEMAT availability. It was therefore decided that the scope should be solar-only, not delving into other sources of renewable energy, although it does touch on all the possible applications of solar energy, from its use in greenhouses to high-temperature applications in solar furnaces, and photovoltaics to hydrogen production.

Apart from all these institutional cooperation programs, it should be pointed out that each of the two R&D Units keeps up a stable range of collaboration, including national and international universities, SME and large companies.

Among the universities, we could mention the large volume of joint activities with the UAL (CIESOL), Seville, La Laguna and the UNED.

Collaboration is also intense with important Spanish companies especially interested in solar thermal electricity technology development and commercialization, for example, IBERDROLA, ABENGOA Solar, GAMESA, SENER, ENDESA, ACCIONA and ECOSYSTEM.

In the international sphere, assiduous collaboration with such research centers as the 'Fraunhofer Institute for Solar Energy Systems' and the ZSW in Germany, and the Weizmann Institute of Science' (Israel) should be mentioned. We also collaborate with companies like 'FLABEG Solar', FICHTNER and 'Schlaich, Bergermann und Partner' in Germany and ORMAT (Israel).

New lines of research in 'Solar Fuels and Process Heat' have given rise to new cooperation with the Institute of Ceramic Technology of Castellón, the Venezuelan company 'Petroleos de Venezuela, S.A.', the ENEA in Italy and the CEA in France.

Very recently, ambitious lines of collaboration have been launched with Maghreb countries, specifically, in agreements signed with the Moroccan CNRST and the NEAL (New Energy Algeria) in Algeria.

There is also more and more collaboration with local entities, for example DERETIL, CAJAMAR and COEXPHAL.

In Central and South America there ìs stable collaboration with the Centro de Investigaciones Eléctricas and the Univ. Nacional Autónoma of México and the National Atomic Energy Commission of Argentina.

1.5 Training activities

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

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with the annual agreement with the University of Almería (UAL)
- Management of traineeship grants associated with an annual agreement with the UAL Mediterranean Foundation.
- European funded 'Leonardo da Vinci' grants, for students from other countries, mainly German.
- Management of miscellaneous specific educational cooperation agreements with other entities for sending students to the PSA.

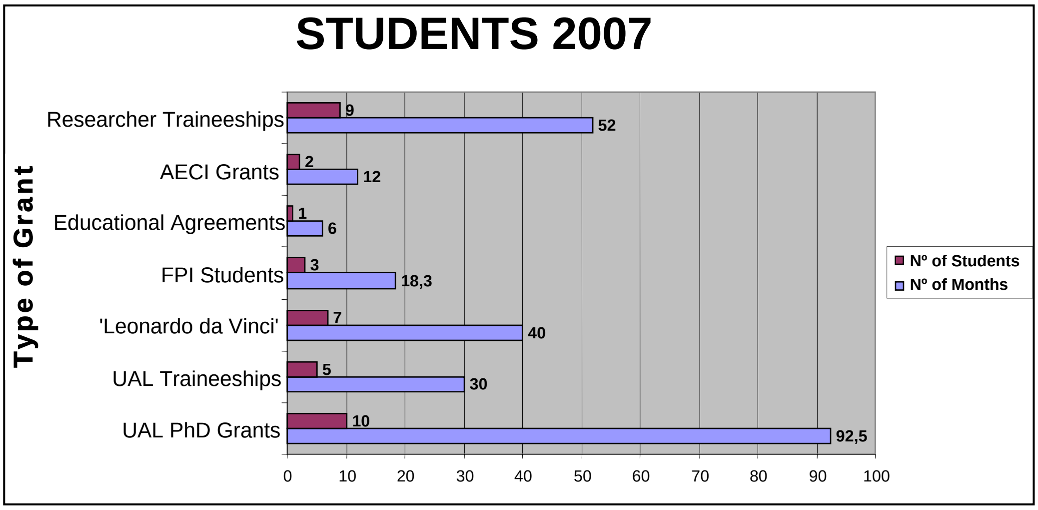

Figure 1.6. Students 2007

Founding in 2004 of the virtual European solar laboratory 'SolLAB', has opened new possibilities for scientific development of researchers in training at the PSA. One of the first joint activities initiated by SolLAB was an annual seminar for Ph.D. students from the four different institutions. This year, from September 11th-13th, thirty Ph.D. students attended the seminar organized by the PROMES-CNRS at its Solar Laboratory in Odeillo (France).

1.6 PSA National Access Activities

In 2005, the National Plan for R&D started a new line of activity for promoting Spain's Unique Large Science and Technology Infrastructures (ICTS). This line, managed by the Ministry of Science and Education's General Directorate for Science and Technology Policy, annually announces the ICTS programs, consisting of two clearly differentiated sections, one called 'Aid for Improvement' and the other 'Offers for Access'. The offer for access is designed to optimize the use of ICTS by paying for access by researchers from other institutions.

Figure 1.7. Ph.D. students who attended the seminar held in Odeillo

This access is given based on annual public announcements that must be issued by the PSA. An 'External Experts Committee' then evaluates the proposals received for their scientific quality and assigns 'user time' to those selected.

The PSA announcements in this national access and improvement program had a very successful response in 2005, 2006 and 2007, and it is currently offering access for 2009.

In 2007, 16 researchers benefited from this program, enjoying a total of 55 weeks of free access to the various PSA test facilities.

Information on the current offer for access to the PSA may be found on our website at:

http://www.psa.es/webesp/projects/acceso_nacional/index.php

2 Facilities and infrastructure

2.1 General Description of the PSA

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

The PSA is an experimental facility with climate 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 large scientific installations in the most advanced European countries, making it a privileged site for evaluation, demonstration and transfer of solar technologies.

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

- CESA-1 and SSPS-CRS central receiver systems, 7 and 2.7 MW_{th} respectively
- SSPS-DCS 1.2-MW_{th} parabolic-trough collector system, with associated thermal storage system and water desalination plant
- DISS 1.8-MW_{th} test loop, an excellent experimental system for two-phase flow and direct steam generation for electricity production research
- HTF test loop, a complete oil circuit for evaluation of new parabolic-trough collector components

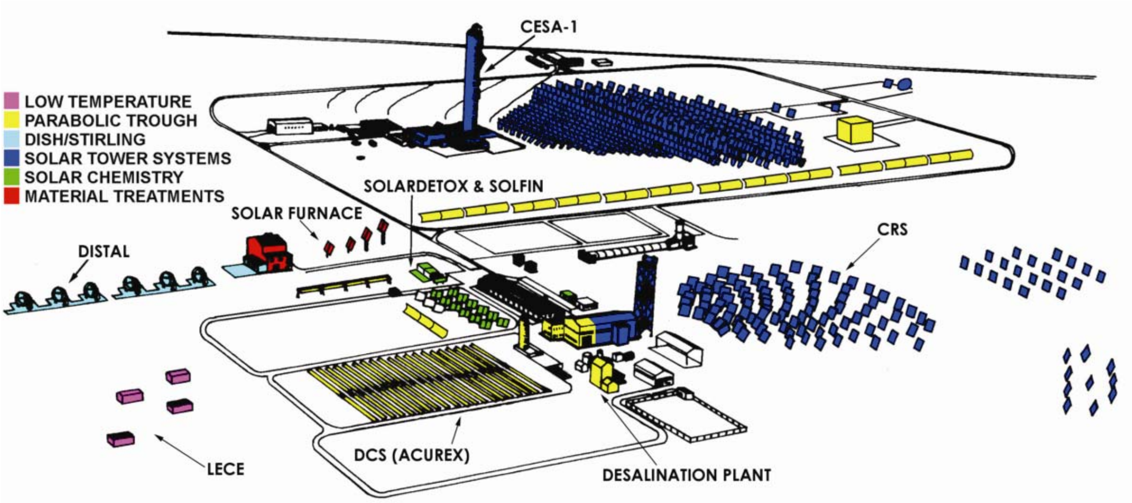

Figure 2.1. Location of the main PSA test facilities

- The FRESDEMO "linear Fresnel" technology loop.
- The parabolic-trough collector system called the "Innovative Fluids Test Loop"
- 6-unit DISTAL dish/Stirling facility.
- A 60-kW_t solar furnace for thermal materials treatments.
- A solar chemistry facility for solar detoxification applications consisting of a parabolic-trough loop with two-axis tracking and three CPC photo-reactors for different types of trials.
- Laboratorio de Ensayo Energético de Componentes de la Edificación (Laboratory for Energy Testing of Building Components) (LECE).
- The ARFRISOL Building, an integral part of the "Unique Project Strategy" of the same name, which is a container-demonstrator for advanced energy savings and efficiency technologies in building.
- Meteorological station forming part of the "Baseline Surface Radiation Network" (BSRN).

2.2 Central Receiver Facilities: CESA-1 and CRS

The PSA has two exceptional facilities for the testing and validation of central receiver technology components and applications. The CRS and CESA-1 enable projects to be undertaken and technologies validated in the hundreds-of-kilowatt range. They are outdoor laboratories specially conditioned for scaling and qualifying systems prior to commercial demonstration.

2.2.1 7-MW_t CESA-I Facility

The CESA-I project, was promoted by the Spanish Ministry of Industry and Energy and inaugurated in May 1983 to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-1 does not produce electricity, but is a very flexible facility operated for testing subsystems and components such as heliostats, solar receivers, thermal storage, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It is

Figure 2.2. The CESA-I facility seen from the East with heliostat rows focusing on the medium-height test level (60 m.)

also used for other applications that require high photon concentrations on relatively large surfaces, such as in chemical or high-temperature processes, surface treatment of materials or astrophysics experiments.

Direct solar radiation is collected by the facility's 330 x 250-m south-facing field of 300 39.6-m^2 heliostats distributed in 16 rows. The heliostats have a nominal mean 90% reflectivity, the solar tracking error on each axis is 1.2 mrad and the reflected beam image quality is 3 mrad. The CESA-1 facility has the most extensive experience in glass-metal heliostats in the world, with first generation units manufactured by SENER and CASA as well as second generation units with reflective facets by ASINEL and third generation facets and prototypes developed by CIEMAT and SOLUCAR. In spite of its over 20 years of age, the heliostat field is in optimum working condition due to a strategic program of continual mirror-facet replacement and drive mechanism maintenance. To the north of the field are two additional areas used as test platforms for new heliostat prototypes, one located 380 m from the tower and the other 500 away from it. 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 and 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 cavity adapted for use as a solar furnace for materials testing at 45 m, which has been used very successfully in reproducing the heat ramp on space shuttles during their reentry into the atmosphere in test pieces of the ceramic shield and also for surface treatment of steels and other metal compounds.
- A cavity with a calorimetry test bed for pressurized volumetric receivers at 60 m. At the present time this cavity houses the SOLGATE project infrastructure, which includes three volumetric receivers with a total incident power of nearly 1 MW, 250-kW solarized turbine, and corresponding electric generator, air loop, heat rejection system and thermal shield.
- The 2.5-MW TSA volumetric receiver test facility at the top of the tower 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 Rankin cycle designed to operate with 520ºC 100-bar superheated steam

2.2.2 The 2.7-MW_{th} SSPS-CRS Facility

The SSPS-CRS plant was inaugurated as part of the International Energy Agency's SSPS project (Small Solar Power Systems) in September 1981. Originally an electricity production demonstration plant, it 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_{th} capacity range. The heliostat field is made up of 91 39.3-m^2 first generation Martin-Marietta units. A second field north of it has 20 52-m^2 and 65-m^2 second generation MBB and Asinel heliostats that can be used as support. The CRS heliostat field has recently been improved with the replacement of all the reflective facets, which now have a lightweight structure and low-iron glass. The most innovative feature are the completely autonomous intelligent heliostat-control units installed in 2003, powered by photovoltaic energy and communicating the entire field by radio by a concept developed and patented by PSA researchers. This first autonomous heliostat field, which does not require the use of channels or cabling, was made possible by financial assistance from the Ministry of Science and Technology's PROFIT program.

Figure 2.3. A CRS field heliostat reflecting on the tower

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 field capacity is 2.7 MW$_{th}$ and peak flux is 2.5 MW/m^2. 99% of the power is collected in a 2.5-m-diameter circumference and 90% in a 1.8-m circumference.

The 43-m-high metal tower has 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 bed for the evaluation of small atmospheric-pressure volumetric receivers. The tower infrastructure is completed with a 600-kg-capacity crane and a 1000-kg-capacity rack elevator.

The test bed consists of an 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. Absorber outlet air is cooled by a water-cooled heat exchanger used for indirect thermal balance. The calorimetric bench has been successfully employed since 1986 with 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.

Figure 2.4. Aerial View of the CRS Facility

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.

2.3 Linear focusing facilities

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 and place the PSA in a privileged worldwide position for research and development of new parabolic-trough collector applications. The main characteristics of these facilities are briefly explained below.

2.3.1 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 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 not only very suitable for the study and development of control schemes, but also for the study and optimization of the operating procedures that must be implemented in direct steam generation solar fields. Other possible applications of this plant are study of the heat transfer coefficients in horizontal tubes through which the two-phase water/steam flow circulates, and testing of components for parabolic-trough solar collector fields with direct steam generation in the absorber tubes.

The DISS plant consists of two subsystems, the solar field of parabolic-trough collectors and the power block. In the solar field, feed water is preheated, evaporated and converted into superheated steam as it circulates

Figure 2.5. View of the DISS plant solar field in operation

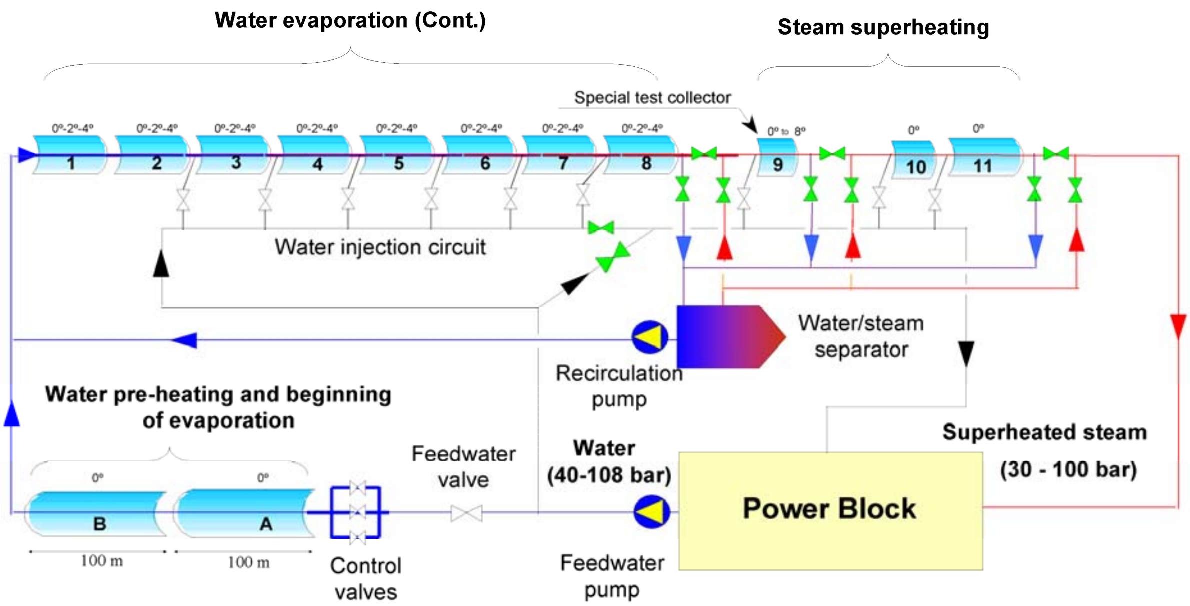

Figure 2.6. Simplified diagram of the PSA DISS plant

through the absorber tubes of a 665-m-long row of parabolic-trough collectors with a total solar collecting surface of 3,838 m^2. The installation of two new collectors in 2003 has increased the nominal superheated steam flow rate that the DISS collector row can produce to 1 kg/s.

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 up to 100 bar pressure as needed (usually at 30, 60 or 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 equipped with all the instrumentation required for complete system monitoring.

Figure 2.6 shows a simplified diagram of the DISS loop in which the solar field is shown as one row of 13 parabolic-trough collectors on 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 flexibility of system operation. The power block consists of water/steam separators, condensers, chemical dosing system, preheaters, deaerators and water pumps.

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

2.3.2 The HTF Test Loop

The, HTF test loop, which was erected in 1997 based on an LS-3 collector, 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 appropriately instrumented for measurement and monitoring.

Figure 2.7. General view of the HTF

The original facility consisted of a closed thermal-oil circuit connected to a solar collector made up of four 12-m-long by 5.7-m-wide LS-3 parabolic-trough modules with a 274-m^2 collecting surface. The thermal oil used in this facility (Syltherm 800) has a maximum working temperature of 420ºC, and a freezing point of –40ºC. The east-west rotating axis of the solar collector increases the number of hours per year in which the angle of incidence of the solar radiation is less than 5º. 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
- Oil circuit sump tank
- Mechanical-draft oil cooler, with air speed control and 400-kW maximum cooling.
- Centrifugal oil pump, with a flow rate of up to 8.3 liters per second
- 40-kW, 3 x 380 V electric oil heater.

Parallel to the original HTF test loop solar collector is the EUROtrough collector prototype which was installed later. 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 not only apt for solar thermal power plants, but also for other large applications, such as desalination of seawater or industrial process heat in the 150ºC-425ºC range. At the conclusion of the EUROtrough project, the project partners donated this first prototype to CIEMAT for its operation and maintenance, and it now forms part of the PSA parabolic-trough collector facilities, increasing the system's collecting area has to 685 m^2.

2.3.3 Innovative Fluids Test Loop

The parabolic trough technology is currently the most commercially developed for solar thermal power plants with over 2.5 million sq. m of collectors in routine operation and a nominal capacity of 340 MW_e. In spite of its commercial maturity, ways must be found for this technology to reduce costs and increase performance for it to become more competitive with conventional power plants. One of the options for lowering costs and increasing performance is to try and find new collector working fluids. To date three different fluids have been studied experimentally_ oil, water/steam and molten salt.

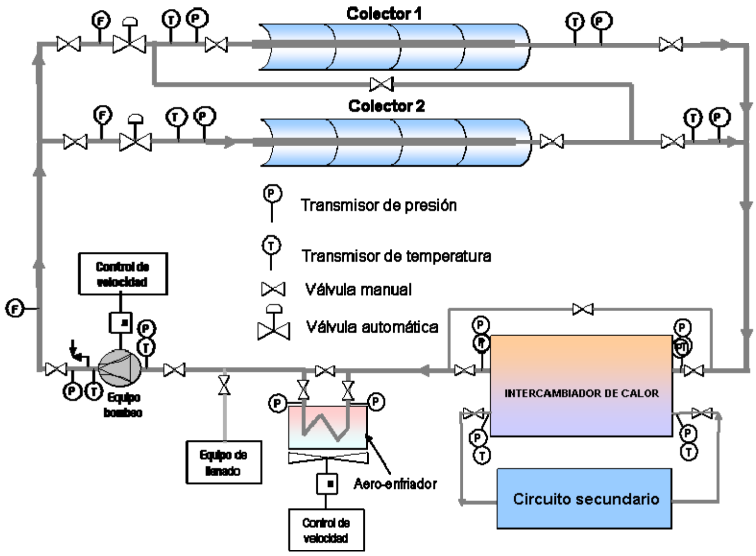

Figure 2.8. Simplified system diagram of the innovative fluids experimental facility.

But there are other possible working fluids that have not been studied experimentally yet. The activities in this project are directed by Prof. Carlo Rubbia.

The purpose of this experimental facility is to study of innovative working fluids in parabolic-trough collectors which have not been studied until now, evaluating their behavior under a diversity of real operating conditions. Figure 2.8 and Figure 2.9 show a simplified system diagram and a photo viewed from the west.

The experimental test loop is located north of the DISS Plant control room. The monitors and central control system for this loop are in the DISS Plant control room. The plant was erected from June 2006 to October 2007, and commissioning activities began immediately thereafter.

The facility, which is prepared to work at pressures and temperatures of up to 100 bar and 400ºC, consists of the following components:

Figure 2.9. View of the innovative fluids test loop in operation.

- Two east-oriented EUROtrough parabolic-trough collectors, each 50 m long with a 274.2-m^2 collector surface. The collectors can be connected in series or in parallel by means of a by-pass.
- An 400-kW air-cooler able to dissipate the thermal energy in the fluid coming from the collectors. It has two 4-kW motorized fans.
- A blower driven by a 15-kW motor which supplies the flow necessary to cool the collectors adequately.
- A data acquisition and control system that allows the temperature, flow rate, pressure, irradiation and humidity in the loop to be completely monitored.
- Automatic control valves that allow precise, safe variation in the collector fluid feed flow rate

2.4 The FRESDEMO Loop

The FRESDEMO loop is a pilot plant for demonstration of the "Fresnel linear" concentration technology.

This plant, which belongs to the "Solar Power Group", a consortium of companies headed by MAN Ferrostaal, is currently under testing and evaluation with the scientific-technical assistance of the PSA.

This 100-m-long, 21-m-wide module has a primary mirror surface of 1,433 m^2, distributed among 1,200 facets mounted on 25 parallel rows spanning the length of the loop.

The collector loop is designed for direct steam generation at a maximum pressure of 100 bar and maximum temperature of 450ºC.

It is presently connected by pipes to the PSA DISS (Direct Solar Steam) loop from where it is supplied with solar steam at different pressures and temperatures for testing in the three work modes: preheating, evaporation and superheating.

This facility was inaugurated on July 9, 2007 and testing is scheduled to end at the end of 2008.

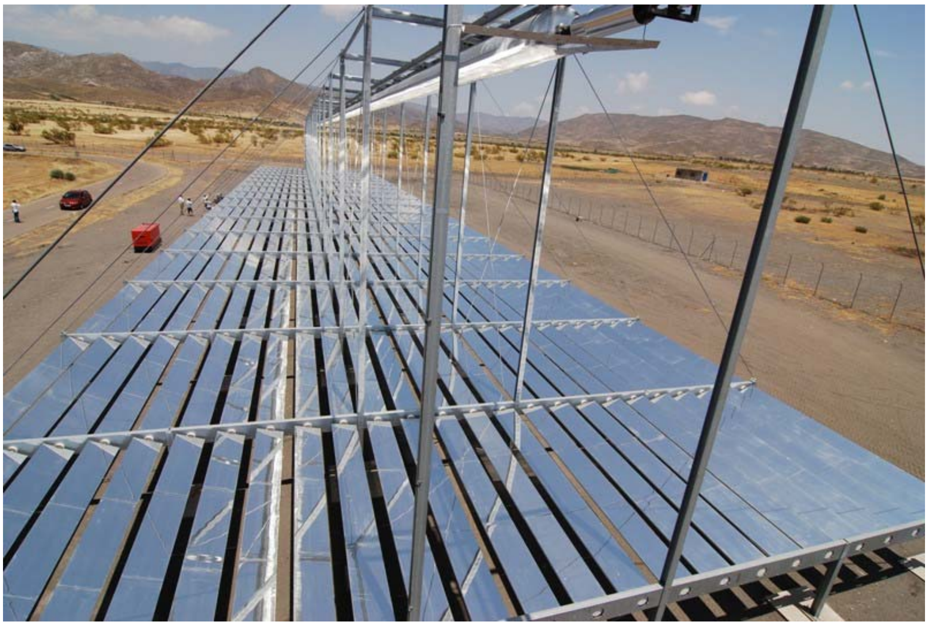

Figure 2.10. Photo of the MAN linear Fresnel demo collector erected on the Plataforma Solar de Almería (PSA).

2.5 Dish/Stirling Systems: DISTAL and EUROdish

2.5.1 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 from sunlight is collected by the parabolic dish and concentrated on its focal zone in a high-performance thermodynamic cycle.

An alternator is connected to the Stirling motor so that the light 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.

2.5.2 DISTAL I

The concentrator prototype made use of 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 2.11. A DISTAL I dish in operation

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.

2.5.3 DISTAL II

The DISTAL II was a first attempt at a system with better features and per-kW_e 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.

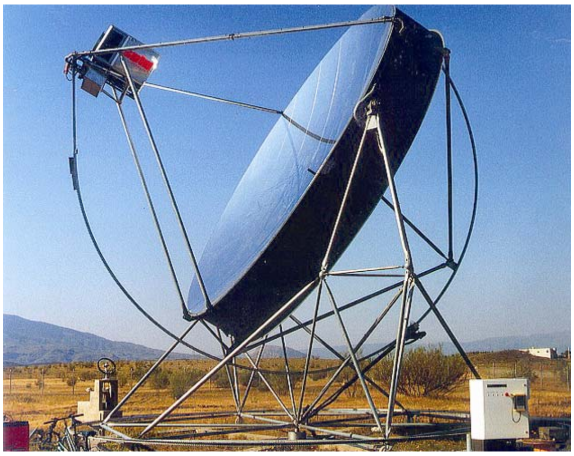

Figure 2.12. DISTAL II unit

2.5.4 EURODISH

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

- 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.
- Develop a new optimized system assembly procedure that uses new specially developed tools.
- Remote control and monitoring over the WWW.
- Improve the Stirling SOLO V161 motor, especially those components used in the receiver cavity.
- Test pre-commercial units as reference systems.

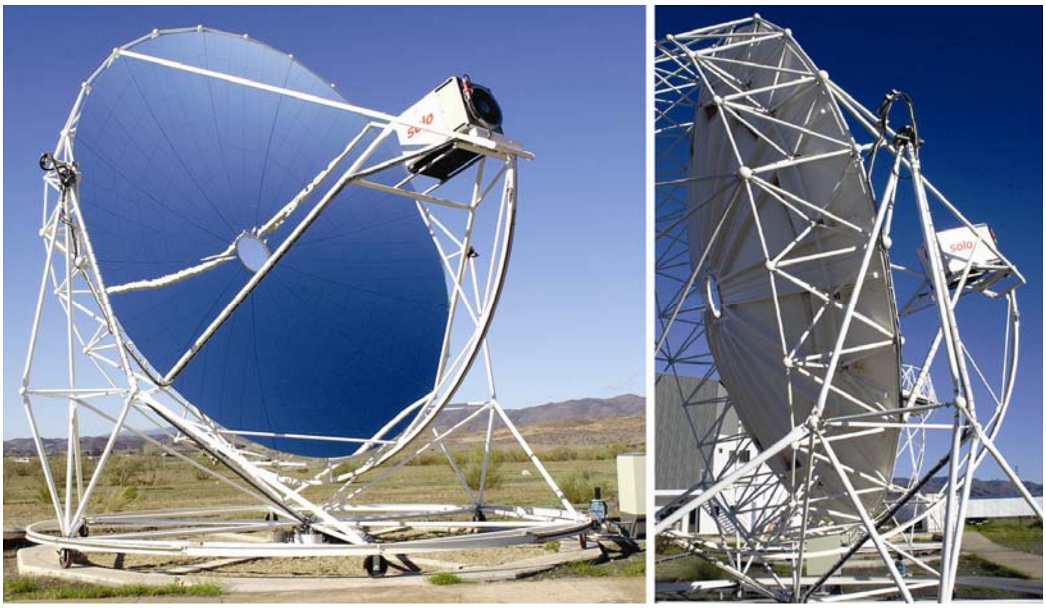

Figure 2.13. Front and back views of the EUROdishes.

2.6 Solar Furnace

2.6.1 General Description and Principles of Operation

Solar furnaces reach concentrations of over 10,000 suns, the highest energy levels achievable in a solar concentrating system. Their main field of application is materials testing, either in ambient conditions, controlled atmosphere or vacuum, or 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 collector 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.

2.6.2 Components

The component that collects the solar radiation and redirects it onto the parabolic concentrator is the heliostat field. The reflective surface of the heliostats is made up of 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.

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.

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 55º angle to the horizontal and 0º when open.

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

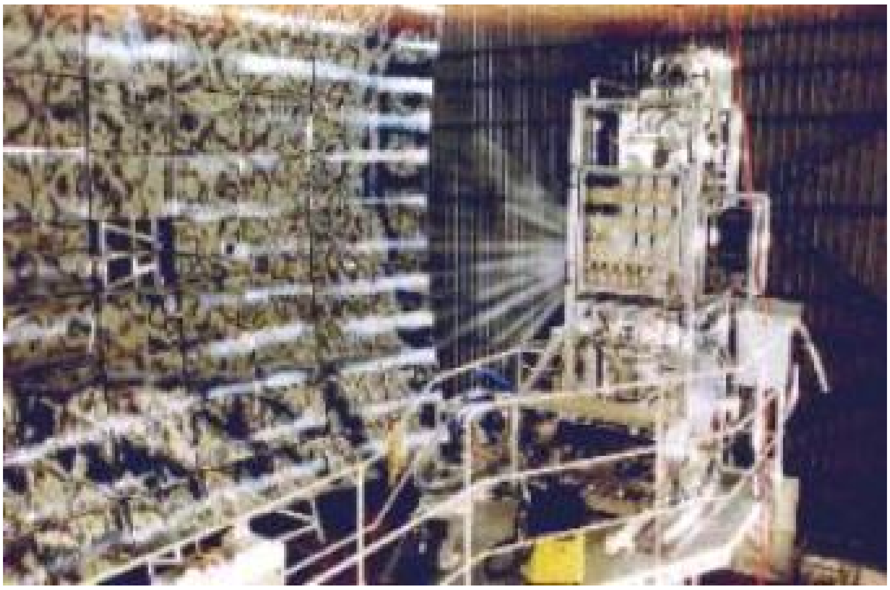

Figure 2.14. Solar Furnace: Concentrator (left) and receiver in operation at the focus (right).

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].

2.6.3 Materials Lab

The Plataforma Solar de Almería, among its other facilities, has a Materials lab devoted mainly to the metallographic preparation and the analysis of test pieces treated with concentrated solar energy.

The Materials lab is located in the PSA Solar Furnace Facility, where most of its equipment is. The lab's equipment is currently is listed below:

- **Leyca DMI 5000 optical Microscope** with Leyca-IM50 image acquisition system and motorized table.
- **Olympus optical Microscope** Union MC 85647.
- **Struers micro durometer** Duramin HMV-2
- **Manual Durometer**
- **Surface Finish Measuring Unit** ZEISS Surfcom 480 with data processor.
- **Grinder** Remet SM1000
- **Automatic cutoff machine** Struers Secotom
- **Manual cutoff machine** Remet TR60
- **Pelleter** Struers Labopres-3
- **Vacuum impregnation unit** Struers Epovac

Figure 2.15. View of the PSA Materiales Lab

- **Polisher** Tegrapol-15 automatic with Tegradoser-5 dosing system
- **Metallographic polisher** 2 plates "LS1/LS2" (Remet)
- **Scale** Mettler E2001/MC max **60Kg**
- **Scale** Mettler Toledo classic max **320g** / min 10mg
- **Ultrasonic bath** Selecta with heater
- **Olympus digital camera** with **reproduction table**

The PSA also has an electronic microscope with the following specifications and installed in its own room, which is shared between the AMES and SCS units.

- **Scanning electronic microscope (SEM) - Hitachi**, model S-3400N II, high/low vacuum, secondary electron image, backscattered electron image, cooling stage and magnification x5 to x 300.000.
- Microanalysis by Quantax 400 Energy dispersive x-ray spectrometer (EDS)

The SEM room also has environmental secondary electron detection (ESED), a **critical point dryer** and **Sputterer**

2.7 Solar Photochemical Facilities

The PTC (Parabolic-Trough Collector) photochemical pilot plant is presently configured in four 128-m^2 parabolic-trough solar collectors with two-axis solar tracking and a concentration factor of 10.5 suns. The 56-mm-diameter absorber tube is made of 2-mm-thick borosilicate glass.

There are several CPC plants installed at the PSA. The oldest (1994) consists of three 3-m^2 modules tilted 37º from the horizon. The total system volume is about 250 L and the absorber tube holds 108 L (illuminated volume). In 2002, a new 15-m^2 collector for experiments of up to 300 L was installed. It also has small twin 3.08-m^2 prototypes with a 40-L total volume, 22 L of which is irradiated, for parallel experiments. Since 2004, a new CPC system, with 50-mm-diameter photoreactor, more suitable for photo-Fenton applications, with tank and recirculation pump (75 L), has been hooked up to a 150-L biological reactor based on fixed biomass on an inert matrix, and 50-L ozonization system with ozone production of up to 15 g O_3/h. All of it is monitored (pH, T, ORP, O_2, flow rate, H_2O_2,0_3) by computer. Furthermore, there

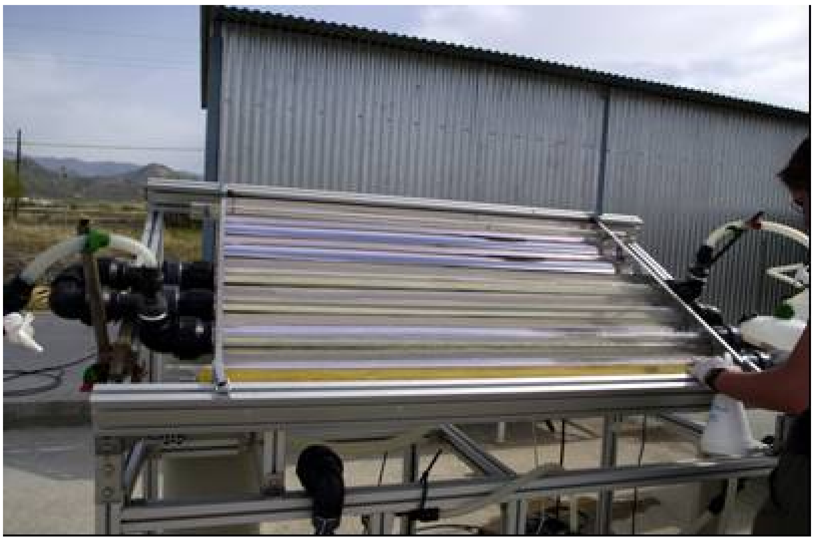

Figure 2.16. Partial view of the solar photochemical facilities. Front of solar CPC collector prototype used for water disinfection.

are also several prototypes for water disinfection applications (Figure 2.16). There are also three ultraviolet and two global solar radiation measurement sensors placed horizontally and tilted 37º (the same angle as the CPCs) to the Earth's surface. All of the data are sent to a computer that stores them for later evaluation of results.

2.8 PSA Analysis Lab

The PSA solar chemistry lab is a 75-M^2 building designed to contain all of the conventional laboratory equipment: work benches, gas extraction hood, storage space for small amounts of chemicals, centralized gas distribution system, UPS, safety systems (extinguishers, shower, eyewash, etc.) precision scales, ultrapure water, ultrasonic bath, thermostatic bath, centrifuge and microcentrifuge, vacuum distillation system, autoclave, 2 laminar flow hoods, incubator for microbiology and many other systems normally used in a chemistry lab. A phase contrast/fluorescence combination microscope is connected to a digital photography system for analysis of our microbiological samples. The following analytical equipment is also available for environmental chemistry: liquid chromatograph (quaternary pump with diode array detector, automatic injection, simultaneous dual column chromatograph and fraction collector kit), gas chromatograph (mass spectrometer) with purge and trap system (analysis of volatile compounds dissolved in water), ion chromatograph configured for isocratic analysis of anions, ion chromatograph configured for gradient analysis of anions and cations, TOC analyzer (with automatic injector), UV-Vis spectrophotometer, turbidimeter, COD, BOD, and automatic shredder. All of these systems are computerized and integrated in a complete information network. In 2006, a Scanning Electron Microscope (SEM) was acquired and installed for solar disinfection test analyses of microbiological samples and catalysts. Equipment for ultra-thin metal coating and a critical-point dryer were also installed for the preparation of these samples. All of the above equipment is located at the Plataforma Solar de Almería Technical Building.

2.9 SOL-14 Solar Thermal Seawater Desalination Plant

This facility is composed of the following subsystems:

- A 14 stage multi-effect distillation plant
- A field of stationary CPC (compound parabolic concentrator) solar collectors
- A solar thermal water storage system
- A double effect (LiBr-H_2O) absorption heat pump
- A water-tube gas boiler

The multi-effect distillation unit is made up of 14 stages or effects, arranged vertically with direct seawater supply to the first effect. At a nominal 8 m^3/h feedwater flow rate, the distillate production is 3 m^3/h, and the thermal consumption of the plant is 190 kWt, with a performance factor (number of kg of distillate produced per 2326 kJ of thermal energy consumed) over 9. The saline concentration of the distillate is around 5 ppm. The nominal temperature gradient between the first cell and the last is 40ºC with a maximum operating temperature of 70ºC in the first cell.

The system heat transfer fluid is water, which is heated as it flows through the solar collectors to the storage system. The hot water from this storage system provides the MED plant with the thermal energy required for its operation. The solar field is composed of 252 stationary solar collectors (CPC Ao Sol 1.12x) with a total surface area of 500 m^2, arranged in four rows of 63 collectors. The maximum working temperature is 100ºC since the collectors are connected to atmospheric pressure storage tanks in an open loop. The thermal storage system consists of two water tanks connected to each other for a total storage capacity of 24 m^3. This volume allows the operation sufficient autonomy for the backup system to reach nominal operating conditions.

The double effect (LiBr-H_2O) absorption heat pump is connected to the last effect of the MED plant. The low-pressure saturated steam (35ºC, 56 mbar) produced in this cell supplies the heat pump evaporator with thermal energy, which would otherwise be discharged to the atmosphere, cutting in half the thermal energy consumption required by a conventional multi-effect distillation process. The fossil backup system is a propane water-tube boiler with a 10-bar saturated steam production capacity of 200 kg/h. This boiler ensures heat pump operating conditions (180ºC, 10 bar), as well as operating the MED plant in the absence of solar radiation.

2.10 Stationary Solar Collector Test Platform

This facility was built in 2002 for the purpose of offering additional services to the scientific research community, among which was the possibility of carrying out energy characterization of the stationary solar collectors, with special emphasis on its possible application to solar desalination processes.

The facility has three independent hydraulic circuits. In the primary fluid circuit (water or water mixed with antifreeze) is heated as it flows through the solar collector, delivering the energy acquired to the water deposited in a storage tank. In the secondary circuit, the water from the tank is pumped to the heat exchanger where its energy is transferred to the tertiary circuit. This heat exchanger simulates the hot water inlet in the first cell of a multi-effect distillation plant. Finally, the water that circulates through the tertiary circuit goes to a cooling tower where the energy from the secondary circuit is discharged into the atmosphere.

Figure 2.17. SOL-14 plant stationary solar collector field (500 m²)

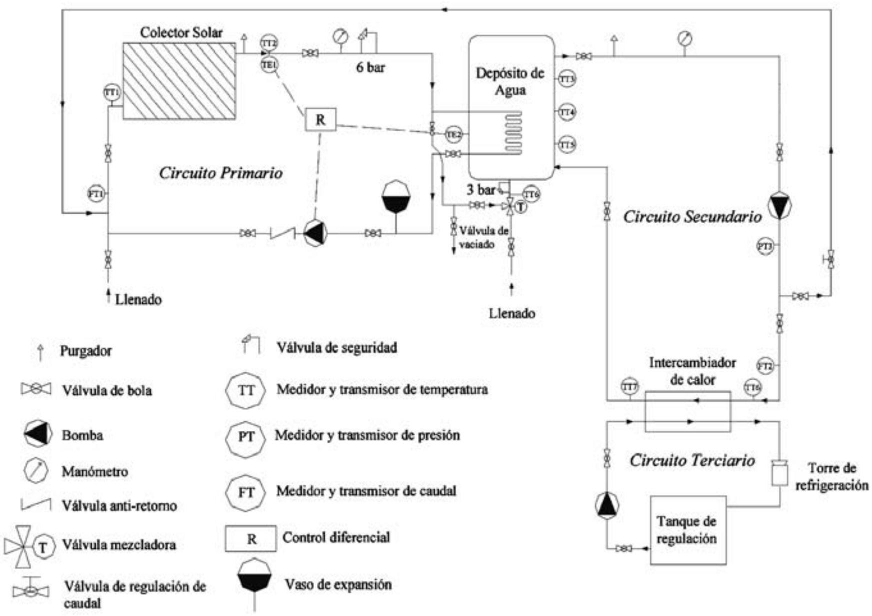

Figure 2.18. General diagram of the stationary solar collector test platform

2.11 Other facilities

2.11.1 PSA Meteorological Station

Figure 2.19. General view of the new PSA radiometric station

The PSA has had a meteorological station since 1988, primarily for measuring integral solar radiation (global, direct and diffuse radiation), but also for other generic weather variables (temperature, wind speed and direction, relative humidity and atmospheric pressure, cumulative precipitation, etc.). The task of entirely remodeling this old station has recently been undertaken. Given the framework in which our facilities work, from the beginning this initiative was intended to comply with the strictest requirements of quality and accuracy in solar radiation measurement. As an overall indication of having reached this goal, the station has been a full member of the World Meteorological Organization's Baseline Surface Radiation Network, whose directives it follows, since October 2005.

Figure 2.20. Spectroradiometer probes for measuring global and diffuse radiation installed in the solar tracker

Figure 2.21. Spectroradiometer detector with three-probe connector switch

In addition to measurement of the meteorological variables mentioned, its most outstanding feature is the measurement of the spectral distribution of solar radiation.

The new radiometric station's equipment may be classified in three basic groups:

1) ***Measurement instruments***. The PSA meteorological station instruments are in the highest range of solar radiation measurement. All the radiation sensors are ventilated and heated, and have a temperature measurement sensor. This equipment provides the best information on solar radiation and more general atmospheric variables, and can be used for filtering input data and validating spectral models. They are used for:
   - Measurement of the terrestrial radiation balance. Incoming and outgoing shortwave and long-wave radiation is measured at 30 m
   - Solar radiation component characterization: (direct and diffuse) and UV
   - Vertical wind profile: wind speed and direction at 2, 10 and 30 m
   - Vertical temperature and humidity profile at 2 and 10 m
   - Miscellaneous weather information: rain gauge, barometer and psychrometer

2) ***The* Spectroradiometer** is so different that it must be considered an independent installation. It is a prototype developed to CIEMAT specifications by *Instrument Systems*. This equipment, based on the SP320D, which incorporates a photomultiplier and a lead sulfur detector, records the spectral distribution of the solar radiation over its whole spectral range (from 200 to 2500 nm), compared to the majority of such equipment which works only for a part of the spectrum (generally visible or ultraviolet). The basic equipment is connected to a switch in such a way that it can work with three alternating probes, which are arranged in a solar tracker to record the global, direct and diffuse solar radiation, respectively. Although it is configurable, the equipment has been programmed to record a spectrum (with an approximate resolution of 2 nm in UV and visible and 10 nm in IR) in about 7 minutes, and changes measurement probes every 10 minutes. This way, there is an hourly database with 2 spectra for each one of the solar radiation variables. Another important difference from the usual solar radiation spectral distribution measurement equipment is that it operates continuously from sunup to sundown.

3) ***The data acquisition system***. The system was developed specifically for this purpose in Visual C++ using IMP cards. Acquisition frequency is 1 s

http://www.psa.es

Figure 2.22. User login for access to solar radiation information.

with 1-minute, hour and daily averaging. The data are stored in a relational database management system, described below, and a series of physical and other filters are applied during acquisition. It is worth mentioning that this data acquisition system is connected to a GPS which also acts as a high-precision time server.

The database. The database was developed in Microsoft SQL Server 2000 and consulting tools were developed in ASP so it would work on the internet. The data base tables are dynamic, making it possible to remove or add sensors to the station without having to modify the table structure. The database size is designed to provide simultaneous access to 10 years of second data and averages of all the variables recorded. This information is currently available on the PSA website. In order to find out the demand for the information, it is necessary to log on for access.

2.11.2 The Spectral Calibration Lab

The need for a calibration laboratory arises from the way in which the Spectroradiometer is designed to operate. This equipment usually works only during specific measurement campaigns, in which case yearly recalibration is recommended. However, this equipment is in constant operation, so on-site calibration is necessary to:

- Minimize loss of data during calibration periods (around 1 month if the equipment must be sent to the manufacturer).
- Be able to increase calibration frequency as needed: every 6 months, quarterly, monthly or even weekly.

The calibration laboratory has been specially designed for calibration over the whole 200 to 2500 nm range.

Figure 2.23. New Spectral Calibration Laboratory adjacent to the CESA-1 building

2.11.3 Energy Testing of Building Components Laboratory (LECE)

The Energy Testing of Building Components Laboratory (LECE) is another of the facilities at the PSA. This laboratory is part of the Bioclimatic Architecture R&D program of CIEMAT's Renewable Energies Department and is managed directly by it. It participates in the PASLINK EEIG, a network of European laboratories with similar characteristics, which is of economic interest. The laboratory consists of four fully instrumented test cells for testing conventional and passive solar building components and, furthermore, makes use of the excellent infrastructure at the PSA for solar applications.

Figure 2.24. Views of the LECE: Cells, reference buildings and solar chimney

The purpose of the LECE is to contribute to the knowledge on the energy quality of building elements through experiments determining the thermal properties of closures, such as the global heat transfer coefficient, the solar gain factor or system response times. It also performs other types of tests among which are important because of the climatic conditions in Spain, with regard to ventilation phenomena. The knowledge of those properties can be used to improve building design for increased energy savings without loss of comfort and predicting their thermal behavior. LE high-precision time server CE activities may be classified as:

- Experimental support for preparation of standards and regulations.
- Experiments in the CIEMAT Bioclimatic Architecture R&D program.
- Collaboration with and services for building materials and component manufacturers.

2.11.4 ARFRISOL Building

The PSA 'ARFRISOL' Building is part of the Unique Strategic Project on Bioclimatic Architecture and Solar Cooling (PSE-ARFRISOL) with partial funding from the Spanish Ministry of Science and Innovation.

The purpose of the PSE-ARFRISOL Project is to demonstrate that it is possible to save from 80 to 90% of conventional energy through proper application of active and passive solar technologies, by adapting building design to its surroundings and climate. There are five buildings in the PSE- ARFRISOL Project, built in different climates within Spanish territory: Almería (2), Madrid, Soria and Asturias.

The PSA building includes the following "active" measures:

- Solar field for sanitary hot water, which is also used for heating through a radiant floor and as a source of energy for an absorption pump for cooling in summer.
- Building-integrated photovoltaics on the façade. This is an experimental system designed to work best on a vertical plane. It supplies 7.5 kW_p for consumption in the building itself.
- Radiant panels open to night sky, for pre-cooling of offices in summer through the radiant floor.

Figure 2.25. ARFRISOL Building

Among the "passive" measures are the following:

- The compact building provides a larger solar collection area in winter and evacuation of energy in summer.
- The characteristics of the shell materials and concrete structure provide the building with strong thermal inertia (capacity for maintaining heat and passing it on or absorbing it from its surroundings).
- A marquee on the south side of the building provides shading in summer and is penetrated by sunlight in winter.
- A double pergola provides shading on the roof and support for the solar installations (solar collectors and radiant panels).
- Ducts to the air treatment units are underground, which previously tempers the air, saving energy.

The PSA ARFRISOL Building was inaugurated on December 13, 2007 and at present is under surveillance by CIEMAT researchers. This stage will be extended to the end of 2010 and data acquired will lead to valuable conclusions on the mass application of the innovative technologies the building incorporates.

3 Solar Concentrating Systems Unit

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3.1 Introduction

The purpose of the Solar Concentrating Systems Unit (USCS) is to promote and contribute to the development of solar radiation concentrating systems, both for power generation and for industrial processes which require solar concentration, whether for medium or high temperatures or high photon flux.

This Unit consists of three R&D Groups:

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

The activities performed in the USCS in 2007 followed four master lines that are defined as goals:

- Develop new solar concentrating system components with an improved quality/price ratio.
- Develop simulation and characterization tools for this type of solar system.
- Encourage and promote vanguard action in solar concentrating technologies, opening the way to medium and technology long-term improvement, and

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- Facilitate development and consolidation of a national solar concentrating system industry through technical-scientific consulting and technology transfer.

The new regulatory framework defined by Royal Decree 661/2007 of May 25, 2007 (BOE nº 126, May 26, 2007) on the sale of electricity generated by solar thermal power plants provided new leverage for the promotion of this type of plant in Spain. The increase it set in the premium for electricity produced by solar thermal power plants, although it left some gaps to be covered in certain details, boosted the interest of business in these plants, and caused frenetic promotional activity. At the end of 2007, the total power of plants applying for inclusion in the Special Regime was nearly 4 GW_e, of which almost 2 GW_e already had a connection to the grid.

This activity led to many requests for PSA Solar Concentrating Systems Unit technical and scientific consulting from many companies in the sector in 2007, which along with R&D projects already underway caused a workload far in excess of the available resources. However, a remarkable effort was made in this Unit to attend to all the companies who requested information, technical support or cooperation. The number of Cooperation Agreements signed and technical services performed are good proof of this.

Along this same line of support to industry, an intensive course on "Solar Concentrating Systems" given in Madrid from November 5th to 15th was received with enthusiasm by all sectors (engineering, builders, equipment manufacturers, research centers) involved in technological and commercial development of solar thermal power plants. This year, the compendium of texts prepared for last year's course was improved, and is now the most complete compendium of such documentation currently available in Spain on solar concentrating systems (design, component development, operation and maintenance, storage, future perspectives, etc.).

The following chapters summarize the most important activities and achievements in the three R&D groups in the Solar Concentrating Unit. The large number of projects in which the Unit participated, continuing the trend of previous years, covers the whole range of solar concentrating systems.

3.2 Medium Concentration Group

As in 2006, the activities carried out by the Medium Concentration Group in 2007 may be grouped in two main categories:

Activities directly related to the DSG technology (Direct Steam Generation), and

New component development activities (selective coatings and antireflective treatments), new parabolic-trough collector designs, and the study of innovative concepts, including working fluids and the solar plant itself.

In addition to the Group's own R&D activities, in 2007, consulting and assistance were provided to a multitude of companies who came to the PSA enquiring about solar thermal power plants with parabolic-trough collectors. A great effort was made along this line to give as many companies as requested it the basic technical information they need to enable them to evaluate the commercial interest of solar thermal power plants within the new legal framework of RD 661/2007, and the technologies available for them.

As in 2006, during the first half of 2007, the Group was greatly encouraged by the interest shown by so many companies in commercializing the parabolic-trough collector technology developed at the PSA during recent years (new selective coatings, new antireflective coatings for glass, etc.). But this interest has only materialized in the signature of specific agreements in 2007, leading us to think about the commercial feasibility of some of these developments. This is not the case of the solar tracking system developed in cooperation with the PSA Technical Office, which is now in an advanced stage of commercialization.

The activities and achievements in the various different projects on which the Solar Concentrating Systems Unit Medium Concentration Group worked in 2007 are described below.

3.2.1 DISTOR

Energy Storage for Direct Steam Solar Power Plants

Participants: DLR (DE), CIEMAT-PSA (ES), Sistemas de Calor (ES), INASMET (ES), IBERINCO (ES), DEFY Systemes (FR), EPSILON Ingénierie (FR), SGL Technologies GMBH (DE), FLAGSOL GMBH (DE), Solucar (ES), ZSW (DE), Weizmann Institute of Science (IL), and the Central Laboratory of Solar Energy and New Energy Sources (BG).

Contact: Javier León, Javier.leon@psa.es

Budget: 3,036,650€. Project partly funded by the EC (Contract SES6-CT-2004-503526)

Duration: February 2004 - October 2007

Background: Direct steam generation in the parabolic-trough collector absorber tubes is a very attractive option for lowering the cost of electricity generated by this type of solar collector. For such solar thermal power plants to be more commercial, they must have storage systems that allow electricity generation to be independent from the hours of sunlight. The thermal storage systems currently available for solar thermal power plants are based on materials that heat up (sensible heat), and do not work in direct steam generation solar systems, so a thermal storage system specific to solar fields with direct steam generation must be developed.

Purpose: Develop a competitive thermal storage system suitable for direct steam generation parabolic-trough collector solar plants. Since most of the thermal energy in steam is released upon condensation, and this is a process which takes place at a constant temperature, storage systems for this type of solar plant must be based on a medium that can absorb heat at a constant temperature, such as the latent heat provided by phase-change materials. Several different options for a phase-change storage system were studied and the best option selected, and in 2007, a prototype storage model with a rated power of 200-kW_t and capacity of 200 kW_h was installed and evaluated at the PSA.

Achievements in 2007: During the first half of 2007, the interface necessary to connect the 100-kWt rated power, 200-kWh capacity phase-change thermal storage module which was built in the DISTOR project to the DISS plant was erected at the PSA. Figure 3.1 below shows a general as-built view of this interface and the storage model.

The thermal storage module was 580 x 596 x 4310 mm, with an inner bundle of 21.3-mm-OD tubes. The module had 3-mm-thick graphite layers in it to favor conductive heat transfer through the tube bundle to the circulating salt and vice versa. For its connection to the DISS plant, the module was installed in a metal container (at the right in Figure 3.1), and the space between the outer walls of the module and the inner walls of the container were filled with thermal insulation to reduce thermal loss during testing. The storage module design parameters were:

- pressure /nominal temperature: 25 bar/220ºC
- nominal water/steam flow rate: 0,083 kg/s

As soon as the phase-change thermal storage module prototype had been connected in July 2007, charge / discharge and behavior testing planned for evaluating the module were begun. In the months of July and August, some adjustments had to be made in the module connection to the DISS plant before the system was ready for operation in September 2007. Thermal charging (melting salt) was done very slowly the first time, in order to avoid stress in the module tube bundle. After the first slow melting of the salt in the module (thermal charging) successive module charging and discharging was done while monitoring all of the process parameters (water/steam flow rates, pressures and temperatures). A large number of thermocouples installed inside the module when it was manufactured allow the temperature profile to be monitored in several different cross-sections during testing.

Project results were presented by the partners at the final meeting of the DISTOR project, held in Seville on October 23, 2007. Although the official date of termination was October 31st, the PSA continued evaluating the storage module prototype until the end of the year, when several additional charge/discharge tests were carried out under real operating conditions.

The technical feasibility of the molten salt thermal storage concept and later heat recovery by crystallization was demonstrated during testing. It was also demonstrated how important tube bundle design is to ensuring heat transfer during charging and discharging. The lower velocity of the working fluid (water) during discharging requires the tube bundles to be sized for the right convective heat transfer coefficient without excessive pressure drops in the tube bundle during charging, when the working fluid (steam) density is lower.

Figure 3.1. General view of the system installed in the PSA DISS plant for evaluation of the phase-change storage module.

Among project activities at the PSA in 2007, the Technology Dissemination Workshop on September 27th, which was attended by representatives of R&D institutions and companies related to solar thermal plants, should also be mentioned. DISTOR project activities and results were presented at this workshop.

Publications: [3.1]

3.2.2 Almería GDV

Pre-commercial solar thermal power plant with direct steam generation

Participants: IBERDROLA, SOLUCAR, SENER, IDAE and CIEMAT-PSA

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

Budget: 20,000,000€.

Duration: January 2006 – December 2008

Background: The experimental results in the DISS (1996-2001) and INDITEP (2002-2005) projects demonstrated the technical feasibility for direct steam generation in horizontal parabolic-trough collector absorber tubes, a process known by its initials, DSG. However, the results in the experimental DSG plant erected at the PSA for the DISS project are insufficient to ensure the technical and commercial feasibility of large DSG plants, as the PSA plant has only got one row of collectors and does not have a turbogenerator to convert the steam produced in the solar field into electricity. Therefore, a DSG plant with several parallel rows of parabolic-trough collectors must be built to experimentally verify that the DSG process is commercially feasible.

Purposes: The purpose of this project is the construction of a 3-MW_e pre-commercial plant with several parallel rows of parabolic-trough collectors connected to a power block where the steam supplied by the solar field is converted into electricity by a steam turbine and electric generator. This plant will allow study of the interaction among the parallel collector rows, as well as the optimum startup and shutdown processes for large commercial DSG plants. Construction of this DSG plant is necessary before large commercial DSG plants can be safely undertaken.

Achievements in 2007: among the activities carried out in 2007, is the definition of the specifications for the three work packages in which the detailed plant engineering was divided, and the offers provided by the partners to develop them were evaluated and awarded. These three work packages are:

1) Solar field,
2) Power block, and
3) General coordination, document Management and integration

The Partners responsible for developing these three packages are: SENER WP1 and IBERDROLA WPs 2 and 3. CIEMAT-PSA will participate in WP1 as a SENER subcontractor.

With the funding originally contributed by the partners, the procedures imposed by current legislation were begun in 2007: Registration in the Special Regime, request for grid connection and construction license, and the corresponding bank guarantees were deposited as required by law.

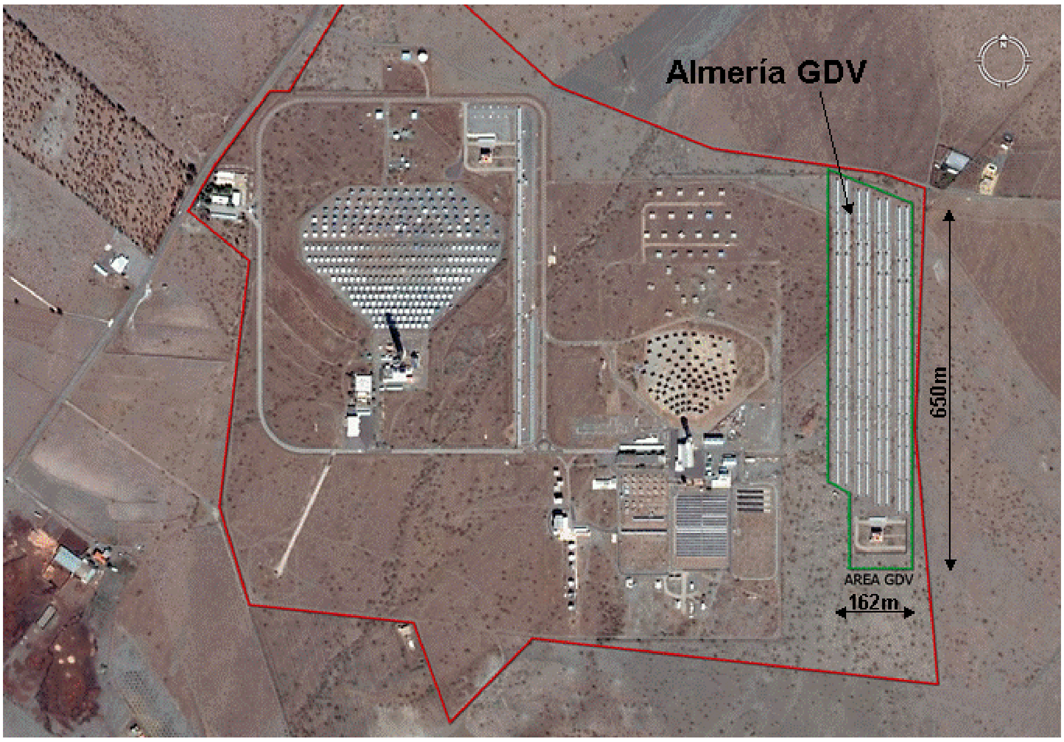


Figure 3.2. View of the planned location of the 3-MW_e GDV plant at the PSA

At the same time, funding was requested of the regional (Agencia Andaluza de Innovación) and national government agencies (CDTI) to relieve the financial load being borne by the partners. The year ended without having received a concrete response from them, although they declared their interest in the project at all times and the desire to assist this technological initiative which would make Spain the world leader in the DSG technology. This situation is causing some concern among the partners, since if they do not receive aid from these public agencies soon, we run the risk of losing a magnificent opportunity for Spain to lead the way in a technology with excellent potential for lowering the cost of electricity generated with solar thermal power plants.

At the end of 2007, it was agreed to revise all of the tenders to update the project budget, since the sharp increase in cost that certain lots have undergone in 2007 (metal structures, turbines, civil engineering work, etc.) forecast a significant increase in the investment required to execute the project.

3.2.3 Low-cost absorber tubes

Participants: CIEMAT-PSA, ABENGOA Solar (ES)

Contact: Angel Morales, angel.morales@ciemat.es

Budget: 750,000 €.

Duration: December 2004 – December 2008

Background: One of the most important elements of the parabolic-trough collector is the absorber tube, since that is where the concentrated solar radiation is converted into thermal energy. Due to its high technology, only two vacuum absorber tube manufacturers, Schott and Solel, currently market this type of solar collector. Because of the scant offer, both the price and the delivery period for these tubes are currently a serious barrier to rapid commercial development of solar thermal power plants with parabolic-trough collectors. Therefore, the development of new absorber tubes with a high quality/price ratio is of interest and very attractive. CIEMAT has been working on the development of anti-reflective (AR) and selective coatings for use on this type of absorber tube, and has already patented several.

Purpose: Develop new absorber tubes for parabolic-trough collectors, both with (for solar thermal power plants) and without vacuum (for moderate working temperatures) based on the Sol-gel technology developed by CIEMAT for selective and anti-reflective (AR) coatings.

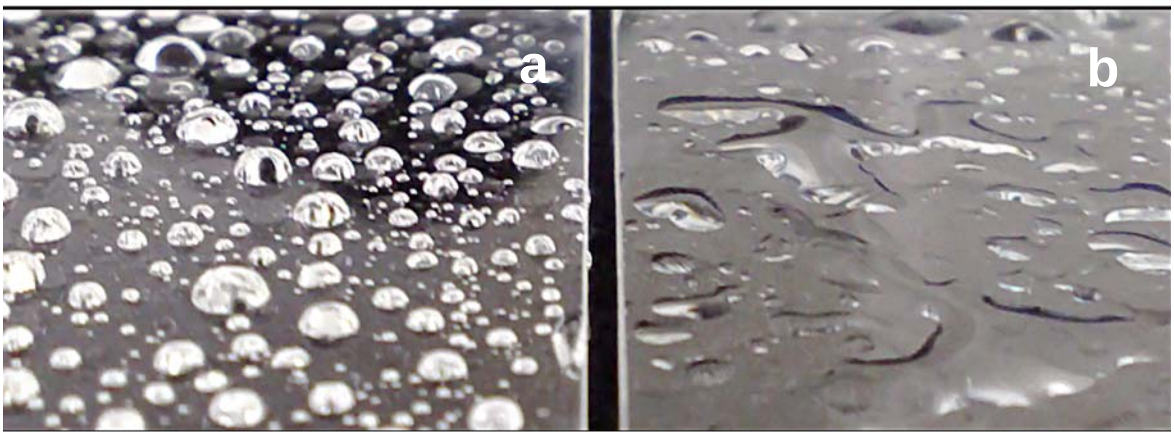
Achievements in 2007: The activities and achievements in this Project in 2007 are described below classified into two areas: AR films for glass and selective absorbers.

AR films for glass covers

In 2007, we continued evaluating and optimizing the durability of antireflective films for their application to borosilicate-glass parabolic-trough collector tubes and solar glass for flat collector covers. Different hydrophobic surface treatments were studied, and solar transmittance of borosilicate-glass samples after exposure to outdoor conditions for over thirteen months was found to be over 0.96. Solar glass with a single coating had a transmittance of 0.945. This difference is because borosilicate glass has a solar transmittance of 0.91 to start with, while for solar glass it is only 0.89.

Thermal treatment conditions for film densification have also been optimized. Temperatures of 500ºC for 15 minutes are enough to achieve AR films with optimal properties. This short thermal treatment time will facilitate transfer of the process to industrial scale, since it considerably shortens the coating preparation time.

Finally, the effect of environmental dirt (pollution, dust, etc.) was studied in samples exposed to outdoor conditions. Solar transmittance diminished between 1% and 3% due to the effect of dirt, which would slightly lower its efficiency.



Photographs by J. Campaña

a) b)

Figure 3.3. Effect of hydrophobic surface treatment.
a) with treatment; b) without treatment.

High-temperature-selective absorbers.

In 2007, the optical properties and durability of the high-temperature-selective absorber were optimized and work was mostly on perfecting a pilot plant for preparing 50-cm-long tubes with the same diameter as the receiver tubes currently used in commercial parabolic-trough collector plants, followed by preliminary tube preparation tests.

The high-temperature-selective absorber has a solar absorptance of 0.96 and thermal emissivity at 400ºC of 0.11 and 0.13 at 500ºC, considerably lower than those of commercial tubes manufactured by Schott and Solel.

Publications: [3.1]

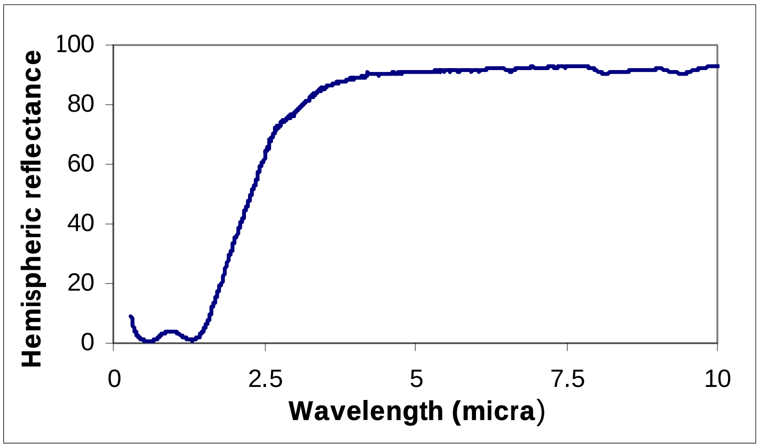


Figure 3.4. Complete spectrum of the selective absorber developed by CIEMAT

3.2.4 Advanced low-temperature absorber coatings

Participants: CIEMAT-PSA (ES), Wagner Solar (ES)

Contact: Angel Morales, angel.morales@ciemat.es

Budget: 161,500 €.

Duration: March 2005 - June 2008

Background: There is currently a wide variety of solar collectors for hot water. Although some of their characteristics are different, all of them have working temperatures clearly below 175ºC. The selective coatings that are usually used on these collectors are economical to manufacture, although their optical and thermal properties are not excellent. Improving the quality of these coatings and their optical properties is of commercial interest only if it can be done without considerably raising the manufacturing cost. CIEMAT-PSA has had long experience in the field of selective coatings for solar absorbers manufactured using the sol-gel technique. This experience can be applied to the development of solar absorbers that have better properties than those currently in use in low-temperature solar collectors, without making their cost prohibitive. Solar collectors that have a better selective coating without significantly increasing their cost will doubtless rank higher in the market.

Purpose: Develop an advanced absorber for solar collectors working at temperatures below 200ºC. The manufacturing process must be an industrial sol-gel technique competitive with currently available low-temperature coatings.

Achievements in 2007: Activities related to preparation of the low-temperature absorber have concentrated on improving the optical properties and durability of the initial 2-layer absorber, $Al/CuMnO_x/SiO_2$, with α_s=0.940 and ε_{100} =0.041. An additional absorbent-protective $CuMnSi_{0.1}O_x$ layer deposited directly on the aluminum substrate (3-layer absorber) has improved the absorptance up to nearly 0.95, with practically the same emittance of ε_{100} =0.044. Durability of both absorbers (2 and 3-layers) was evaluated in thermal stability (200 h/250ºC) and moisture resistance (600 h/40ºC-condensation) tests recommended by the IEA Solar Heating and Cooling Program's Task X for low-temperature solar absorbers. All of the samples analyzed (2 and 3-layer absorbers) passed both the thermal stability and moisture tests with the same or even better results as some commercial absorbers. It should be mentioned that in copper oxide and manganese absorbers, moisture resistance is far more aggressive. This is because the aluminum substrate corrodes, causing the appearance of white pores. The 3-layer absorber had a better appearance after this test because of the additional $CuMnSi_{0.1}O_x$ layer.

3.2.5 FASOL

Design and development of a parabolic-trough thermal collector for process heat

Participants: CIEMAT (ES), Univ. of Almería (ES), Composites y Sol S.L. (ES)

Contact: Aránzazu Fernández, arantxa.fernandez@psa.es

Budget: 225,000€

Duration: October 2007 – May 2010

Background: There is demand for a solar collector for thermal energy temperatures below 250ºC, with a cost/efficiency ratio that makes it competitive and geometry and weight facilitating its integration in industrial, commercial and residential areas. Processes likely to admit a solar thermal energy supply in this temperature range are industrial process heat, heating and cooling of large buildings, such as industrial bays, hospitals, schools, sports facilities, swimming pools, prisons, airports, etc., and other applications, such as water pumping, desalination and detoxification. These applications have a high market potential which has not been exploited to date due to the lack of solar collectors available on the market that work at these temperatures with adequate performance and at an affordable cost.

Purpose: The main purpose of this project is to develop a parabolic-trough collector for temperatures up to 250ºC. To achieve this basic goal, the following specific goals are set:

- Design of a parabolic solar collector with performance, cost, size and weight that will make it a commercially viable technical product.
- Fabrication of a series of prototypes meeting design specifications.
- Develop a set of Tools and facilities for optical and thermal evaluation of this type of solar system.

- Test and evaluate the prototypes manufactured using the tools and facilities developed.
- Determine design and fabrication improvements in the solar collector based on the results of evaluation.

Achievements in 2007: In continuation of CIEMAT activity in this project in previous years, in 2007, a relationship with Composites y Sol S.L. led to the signature of a cooperation agreement for development of parabolic-trough collectors.

The first task carried out in this project in 2007 was the conceptual design of the solar collector, for which the best geometric configuration and associated geometric parameters were determined, taking into account both optical and thermal performance criteria, as well as technical, practical and economic matters; and the definition of the technical requirements for the various components of the solar collector design. During this phase, the Fluent® finite-elements fluid-dynamics simulation code was used to study the thermal behavior of the different geometric configurations and for the analysis of the influence of the process variables.

When the design phase was completed, based on its results and the specifications set in it, during the second half of 2007, construction of a first prototype parabolic-trough solar collector was begun. For this, commercially available materials meeting the technical requirements defined were selected and the collector components for which there was no commercial solution were developed by Composites y Sol S.L. advised by the PSA staff.

In August 2007, evaluation testing of commercial reflector materials was begun by exposing them to outdoor environmental conditions at the PSA. This test, which will last one year, is to determine the best reflector material to use in the solar collector concentrator, as well as the most effective cleaning method.

A code was also written for calculating photogrammetric data, which enables the solar concentrator optical quality to be evaluated. The program, which was written in the Matlab® environment, determines the intercept factor by means of different surface generation techniques based on the coordinates of a set of points and the ray-tracing method. With photogrammetry and these calculations, the optical quality of the concentrator fabricated by Composites y Sol S.L. with composite materials was evaluated with satisfactory results.

Publications: [3.3]

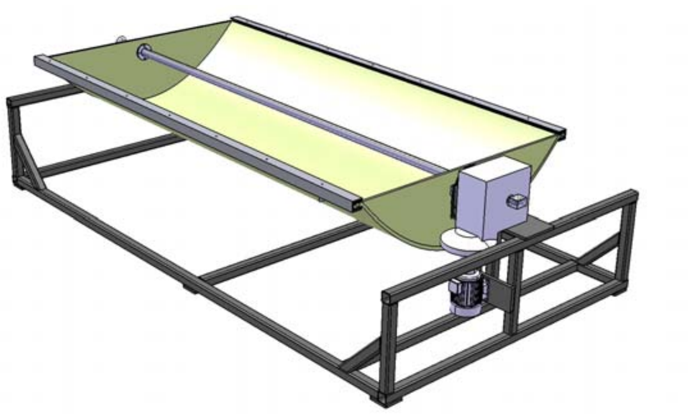


Figure 3.5. Parabolic-trough collector designed

3.2.6 Innovative working fluids for parabolic-trough collectors

Participants: CIEMAT, Polytechnic Univ. of Madrid

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

Budget: 950,000€.

Duration: December 2005 - December 2008

Background: Parabolic-trough collector technology is at the present time the most commercially developed for thermal power plants, with over 2.5 million square meters of collectors and a rated electrical power of 340 MW_e in routine operation. In spite of its commercial maturity, ways must be found for this to reduce the technology's costs and increase its performance to make it competitive with conventional power plants. One option is to find new working fluids for the collectors. To date three different fluids have been studied experimentally, oil, water/steam and molten salt. But others are possible that have not yet been studied experimentally. The activities in this project are directed by Prof. Carlo Rubbia.

Purpose: Experimental study of innovative working fluids for parabolic-trough collectors, evaluating their behavior under real operating conditions and analyzing their advantages and disadvantages compared to those currently in use. The first goal is design and construction of a test loop at the PSA this purpose.

Achievements in 2007: The main activity carried out in 2007 at the PSA in the framework of this project was the construction of the test loop designed in 2006. Commissioning began as soon as the construction stage ended in September 2007. Figure 3.6 below shows the loop during erection.

Construction work on this experimental loop in 2007 included:

Figure 3.6. View of the experimental loop to study innovative working fluids for parabolic-trough collectors during erection at the PSA in 2007

- Pipe fitting and x-ray weld inspection
- Installation of the high-voltage power supply, uninterrupted power supply, and compressed air for regulating valve control.
- Installation of all of the loop instrumentation (flow meters, thermocouples, pressure transmitters and solar radiation sensors)
- Installation of the data acquisition and control system and general electric box.
- Assembly of all of the main equipment, except for the two parabolic-trough collectors, which were erected at the end of 2006.
- Hydraulic pressure testing at 160 bar, following the current standard for pressure facilities.

The main components of the test loop erected in 2007, which can work at temperatures of up to 400ºC and pressures of up to 100 bar, are:

- Two east-west oriented EUROtrough parabolic-trough collectors with a total collector surface of 274.2 m^2 and a length of 50 m, which can be connected in series or in parallel by a by-pass valve.
- A400 kW rated power air cooler
- A blower powered by a 15 kW motor, which blows the working fluid through the pipes.
- A data acquisition and control system for complete monitoring of loop temperature, flow rate, pressure, radiation and moisture.
- Automatic control valves for precise, safe variation of collector input flow.

The basic criterion for this design was highly flexible operation allowing parameters to be easily varied.

Two of the main problems solved during construction and commissioning of the loop in 2007 were drying out the loop completely the hydraulic testing at 160 bar and repairing the defects in water tightness and sealing in the 3” valves installed in the main pipes. In view of the lack of response from the Chinese manufacturer of the valves, they had to be dismounted by the PSA maintenance team and replace the original steel pressure seal with a Spanish one made of graphite and steel.

A special 1-bar pressure blower was necessary to dry out the whole system after the hydraulic tests. After drying, a 3-mbar vacuum was possible in the test loop pipes, which demonstrated total absence of water.

3.2.7 Other activities of the Medium Concentration Group

In addition to the R&D activities described in the paragraphs above, the PSA Solar Concentrating Systems Unit Medium Concentration Group performed other activities, such as:

- Improvement of the parabolic-trough solar thermal power plant modeling and simulation software in the TRNSYS environment for HTF technology, and in Matlab for the DSG technology.
- Evaluation of new parabolic-trough collector designs and components. The confidential nature of this type of work prevents us from providing more specific information on what the PSA did in 2007 in these matters.
- Dissemination of the parabolic-trough collector technology: giving numerous lectures and courses on renewable energies. In this area, the most significant contribution of the Medium Concentrating Group was our participation in the Course on “Concentrating Solar Systems” given in Madrid from November 5 to 15, 2007.

- Advising promoters and engineering firms on the parabolic-trough collector technology: the incentives and premiums established by Royal Decree 661/2007 have increased interest in commercial solar thermal power plants, and the number of companies involved in the promotion of these plants grew in 2007. Since parabolic-trough collectors are the most commercially mature technology for solar thermal power plants, most of the companies are interested in it. As the PSA is the European reference in solar concentrating technologies, almost all these companies come to the PSA at some time for information and advice. Given the logical limitation of available resources in the Medium Concentration Group, it is sometimes impossible to take care of all the requests we receive from both national and foreign companies. But it is our firm intention to continue giving the maximum assistance possible.

3.3 High Concentration Group

After up-scaling and concept demonstration, at the end of 2007, a first Central Receiver System (CRS) plant (11-MW PS10) was in full commercial operation, another two plants were at different stages of progress in Spain and interest in the technology was reactivated due to various international commercial projects. Until the PS10 was commissioned, the solar thermal central receiver plant "learning curve" was based on the testing of more than 10 complete experimental CRS facilities around the world and a wide variety of components (heliostats, receivers, storage devices). The accumulated experience has served to demonstrate the technical feasibility of the concept and its capacity to operate with high incident radiation fluxes (typically between 200 and 1000 kW/m^2), which enables high temperatures (between 250ºC and 1100ºC) and stepped integration in more efficient cycles, from Rankin cycles with saturated steam to Brayton cycles with gas turbines. They have also been demonstrated to easily admit hybrid operation in a wide variety of options and have the potential for generating electricity with high capacity factors with the use of thermal storage, so that at present, systems surpassing 4,500 equivalent hours per year can already be proposed. Predictions for system efficiency, solar-to-electric conversion, are from 20-23% at design point and 15-17% annually.

The high cost of capital is still an obstacle for full use of its commercial potential. The first commercial applications that are starting to be deployed still have installed power costs of 2,500-9,000 €/kW (depending on storage size) and generating costs are around 0.16-0.20 €/kWh. A reduction in the cost of the technology is therefore Essentials to extend the number of commercial applications. Aware of this problem, the PSA, in addition to participating in the first commercial CRT demonstration projects, maintains a permanent line of R&D concentrated on the technological development of components and systems to lower the costs and improve their efficiency.

In 2007, in addition to the activities common to the USCS, to improve its own capacity for R&D and 3rd-party technology training, the High Solar Concentration Group (HSCG) has carried out three basic types of activity:

- Collaboration in system development, which with the present commercial deployment of these technologies could be understood as accompanying companies that are promoting the first generation of commercial central receiver solar thermal power plants, such as PS10 (with Solucar-Abengoa) or Solar Tres/Gemasolar (with SENER).

- Participation in component development for Central Receiver technology through initiative or collaboration in national (like AVANSOL) or international (like SOLHYCO) projects.
- Improvement of the experimental capacity and quality procedures (such as radiometry laboratory and accelerated solar weathering facility)

3.3.1 SOLAR TRES

15 MW_e Molten Salt Solar Thermal Power Demonstration Plant

Participants: SENER Ingeniería y Sistemas, S.A. (ES), GHER,S.A. (ES), CIEMAT-PSA (ES), Compagnie de Saint Gobain, S.A. (FR), SIEMENS Aktiengesellschaft (DE)

Contacts: Javier Viñals (javier.vinals@sener.es), Juan Ignacio Burgaleta (ignacio.burgaleta@sener.es); Félix M. Téllez (felix.tellez@ciemat.es)

Funding: CEC- DG TREN (ENERGIE Program, Ref.:NNE5/369/2001): 5 M€

Duration: December 2002-December 2008

Background: The Project accumulates the experience of the former Solar Two project, but also has design innovations which have come out of work performed together by SENER and the CIEMAT as well as the technical conditions imposed by Spanish legislation on solar thermal power. The initial Solar Tres project was predesigned to meet the requisites of the Spanish legal framework in 2000. During the development of the project, national legislation on renewable energies underwent some changes, and there were also some changes in partners, which led to reorientation of the project and the promoting consortium. Finally, in 2005, the team was consolidated in an entirely European consortium led by SENER. At the same time, SENER and CIEMAT signed an agreement for the development and evaluation of new heliostat and molten salt receiver concepts and a prototype with better thermal perform-

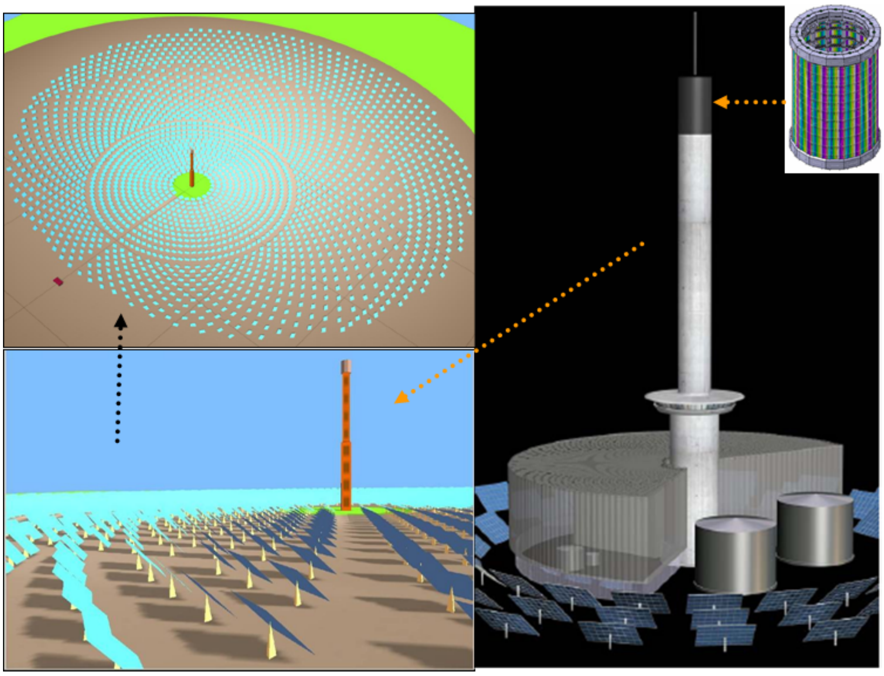


Figure 3.7. Predesign views of the Solar Tres plant

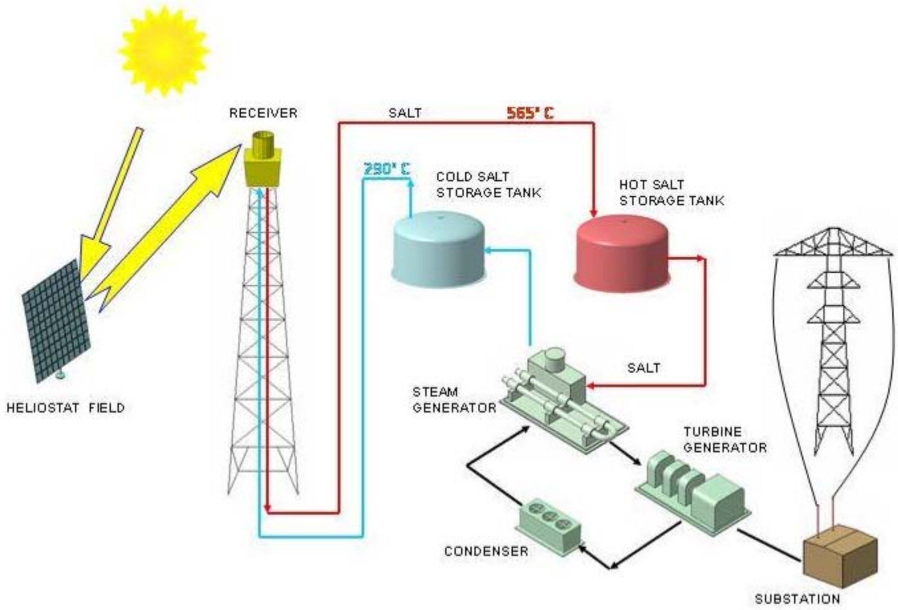


Figure 3.8. Diagram of the Solar Tres/Gemasolar Plant

ance, able to operate at higher flux without compromising its durability (see project below).

Purposes: The purpose of the SOLAR TRES project is to build and operate a 17-MW commercial-scale demonstration solar thermal power plant with heliostat field, tower and molten salt thermal storage system. As allowed by recent Spanish law (RD 661/07), the facility will have up to 15% natural gas or LPG, which, which along with the molten salt heat transfer fluid and thermal storage, will make it possible to generate 105 million kWh/year. This electricity will be delivered entirely to the grid under the Special Regime for Electricity Generation established by the above-mentioned decree.

Achievements in 2007: SENER and the CIEMAT undertook "validation" of the Solar Tres receiver design, a task important to the progress of the Project, through the construction and evaluation of a prototype panel receiver with their own funding (65% SENER, 35% CIEMAT), and in October 2007, after successful experimental validation, the prototype receiver and salt loop, SENER decided to promote the plant that is now called GEMASOLAR. By that time they had already done the permitting and financing necessary for the special regime, and they had begun the environmental impact studies on the site chosen. In 2007, detailed engineering of the main components was completed: Heliostat, receiver, and thermal storage system (SENER), turbine selection (Siemens), electrical tracing, instrumentation and definition of the civil engineering work (SENER), selection of mirrors for heliostat (Saint Govain).

Publication: [3.4]

3.3.2 Development of amolten salt receiver for a solar thermal power plant

Participants: SENER Ingeniería y Sistemas, S.A. (ES), PSA-CIEMAT (ES); [2 CIEMAT Divisions participate in this project: a) PSA-CIEMAT, b) CIEMAT- Structural Materials Division].

Contacts: Juan Ignacio Burgaleta (ignacio.burgaleta@sener.es);
Félix M. Téllez (felix.tellez@ciemat.es) (HSCG)

Funding: Budget 7 M€, of which SENER provides 4 M€, the CIEMAT provides 2 M€ and the CDTI-PIIC provides 1 M€.

Duration: November 17, 2005 to December 31, 2007 (Extended to December 2008)

Background: In 2004-2005, Boeing withdrew its offer to build the Solar Tres receiver, compromising continuation of the project in the absence of an alternative commercial offer. In view of this situation, SENER decided to undertake the engineering and development of the molten salt receiver for Solar Tres on its own. Nevertheless, in order to reduce the development risk, it requested CIEMAT assistance in sharing in the design and validation of a tube salt receiver, including design, building and testing a receiver panel prior to the fabrication of the Solar tres receiver, which will consist of 16 such panels. In the second half of 2005, SENER and CIEMAT signed a collaboration agreement for receiver technology validation (with SENER-CIEMAT technology) and definition of operating and control strategies to be applied in solar thermal power plants (starting with Solar Tres).

At the beginning of 2007, the CDTI approved inclusion of this Salt Receiver Development project for its support as a Subsidized Industrial Research Project to last until December 2008, which will increase the Solar Tres/Gemasolar plant receiver's reliability and reduce its design risks.

Purpose: i) Reduce the risk associated with the first own development of a molten-salt central-receiver solar thermal power plant technology, ii) Experimental validation of the Solar Tres receiver design, iii) Review of the selection of materials and geometries to extend the lifetime expectancy of the receiver. The equipment developed for the experiment is almost the complete system, lacking only the turbine and generator. It includes the 4-MW thermal receiver subsystem, 18-ton molten salt storage tank, 1-MWh evaporator, air con-

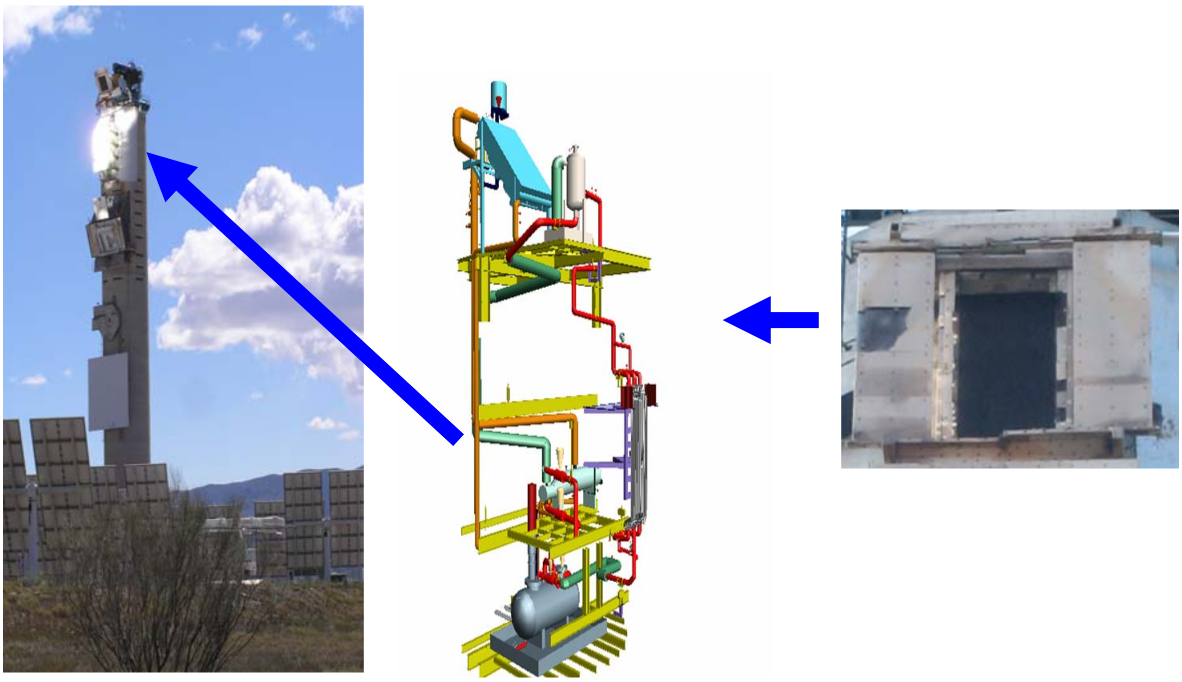


Figure 3.9. Salt Receiver Panel Receptor during testing at the 70-m level of the CESA-1 Tower; diagram of the experimental device and front view of the Reciever Panel with side shields.

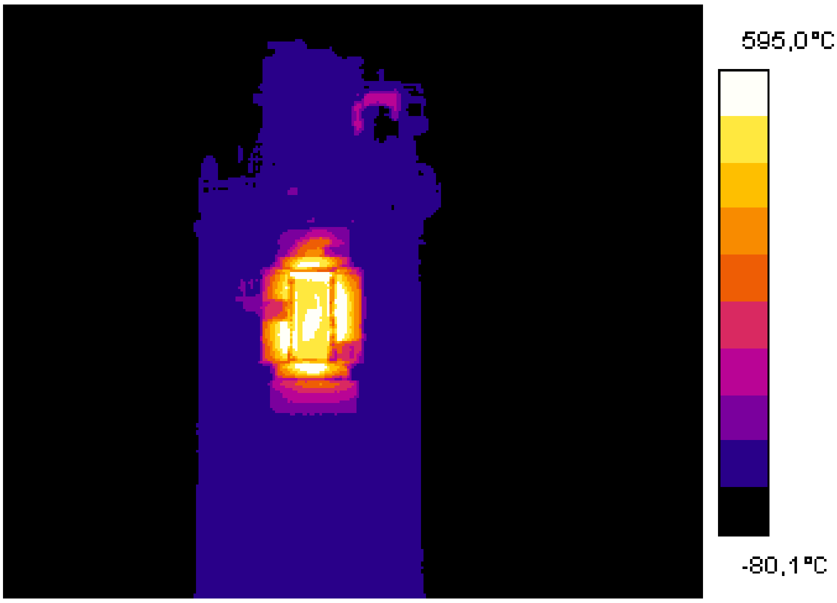


Figure 3.10. Infrared image of the salt receiver panel in the CESA-1 Tower during the first tests.

denser, electrical tracing system, tubing, control and measurement system equipped with about 400 sensors.

Achievements in 2007: In February 2007, the molten salt solar receiver panel test plan began. By the end of July 2007, around 27 days of concentrated high-flux solar radiation testing had been completed, covering the most relevant part of the test plan, and reaching an incident flux of 1000 kW/m^2 with a 20% salt flow.

SENER and CIEMAT then proceeded to evaluate the results, which led to final verification of the design expectations for reliability and efficiency, in September 2007. After a meeting where evaluation results were shared and SENER's go ahead for promotion of the Gemasolar plant, the salt loop/receiver panel test plan continued in order to increase confidence in component operability and reliability. This campaign, thanks to CDTI_PIIC funding, was extended to the end of 2008, allowing the conditions the modules or receiver panels in the circular Gemasolar plant receiver will undergo to be simulated.

Testing has been continued to determine residual impurities in the salt mixtures from different suppliers to determine which ones produce the least corrosion in the receiver tubes and piping.

Publication: [3.5]

3.3.3 PS10

10 MW Solar Thermal Power Plant for Southern Spain

Participants: SOLUCAR (ES) Coordinator, CIEMAT (ES), DLR (DE), Fichtner (DE).

Contacts: Valerio Fernández (valerio.fernandez@pssm.abengoa.com); Félix M. Téllez (felix.tellez@ciemat.es)

Funding: Subsidies of 5 M€ from the European Commission CEC-DG TREN ENERGIE Program (Ref. NNE5-1999-00356) and 1.2 M€ from the Andalusian Regional Govt.

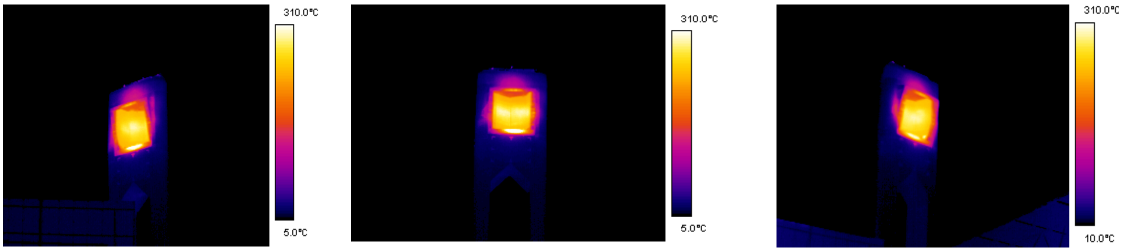


Figure 3.11. Infrared measurement, PS10 receiver during commissioning from three different field observation points.

Duration: July 2001-July 2004 (CIEMAT participation extended by Cooperation Agreement to plant commissioning: March 2007).

Background: The PS10 Project, begun in 1999, has had a long history to date and awakens many expectations in the solar community, as it is the first commercial solar tower initiative inside and outside of Spain. For the PSA, the PS10 project is of enormous importance as the obligatory reference that focuses research and technology development and channels feedback from industry, in this case the SOLUCAR company, and a public research organism like the CIEMAT, for definition of joint development strategies for heliostats, advanced concentrators, solar receivers, software codes and tools and thermal storage, all subjects which have generated projects funded by the Ministry of Education and Science PROFIT Program.

Purpose: The main purpose of the PS10 Project (Planta Solar 10) is to design, build and operate a commercial solar thermal power plant with tower and heliostat field system having a rated gross power of 11 MW. This plant has been installed in the municipal limits of Sanlúcar la Mayor in the Province of Seville and is expected to be inaugurated in March 2007.

Achievements in 2007: In 2007 occasional support continues as questions by the PS-10 operating team arise.

Publications: [3.6]

3.3.4 AVANSOL

Advanced volumetric absorbers for high-concentrating solar technologies

Participants: Solucar, Coordinator; Fundación INASMET, Univ. Seville and CIEMAT [three Divisions: a) CIEMAT-PSA, b) CIEMAT- Fusion Materials. National Fusion Laboratory; c) CIEMAT- Structural Materials Division].

Contacts: Cristina Montero (cristina.montero@solucarrd.abengoa.com); Félix M. Téllez (felix.tellez@ciemat.es)

Funding: PROFIT, (CIT-120000-2005-49): 513 k€

Duration: October 30, 2005 – October 30, 2007 (extended to June 2008)

Background: After experiments with about thirty different-sized volumetric receiver prototypes, there are still matters pending that are crucial to the development and industrial application of this type of receiver: i) Durability of materials; ii) Efficiencies observed in volumetric receivers up to now are far from expected performances, the apparent temperatures are similar to maximums and thermal behavior does not adequately reproduce theoretical models; iii) determination of optimum pretreatment techniques of porous materials such as "blackening" for operation at high fluxes and high temperatures; iv) Search for new materials and geometric structures which would allow low-cost thermal performance; v) Scale-up of receiver sizes to around 50 MW_{th} or higher.

Purpose: The AVANSOL project attempts to respond to two main uncertainties in air-receiver technologies: 1) Durability of the volumetric receiver under real operating conditions, and 2) Optimum selection of absorber material and porous geometry. An advanced metal volumetric absorber and another ceramic one (with higher efficiencies, durability and lower-cost) for high-temperature applications between 600 and 800ºC (metal) and between 800 and 1000ºC (the ceramic absorber prototype) were developed to do this.

Achievements in 2007: In 2007, a series of samples of porous ceramic structures were made at the University of Seville and the INASMET Company, to test the adaptability of a variety of porous structure manufacturing methods to the requirement for gradual porosity of volumetric receivers. Many of these test pieces were tested under thermal shock and cycled with very high solar flux thanks to French acceptance of the proposal for testing in the CNRS furnace in Odeillo.

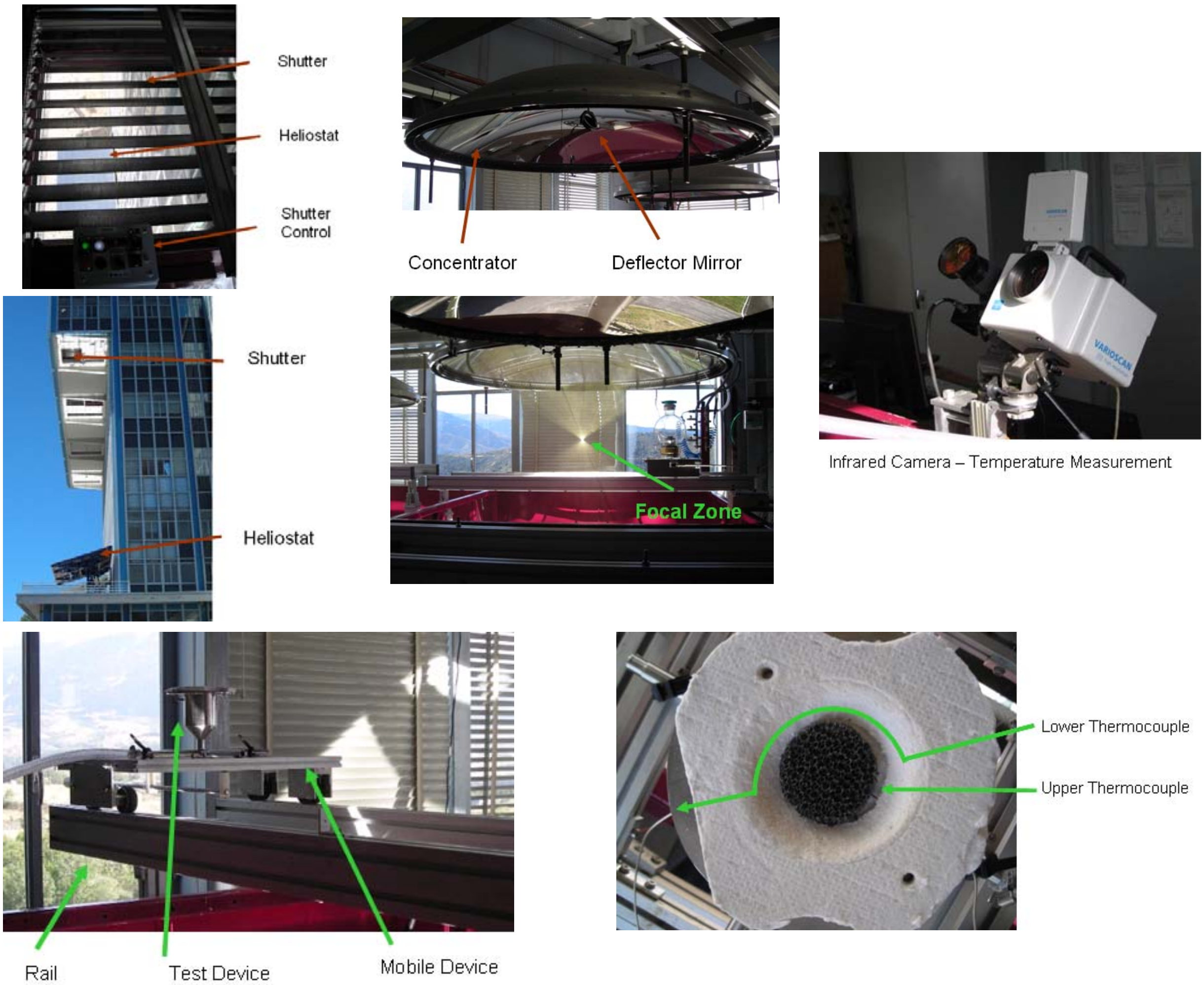


Figure 3.12. Experimental setup of AVANSOL test pieces in the CNRS-Odeillo-France de probetas AVANSOL en horno solar del CNRS-Odeillo-Francia

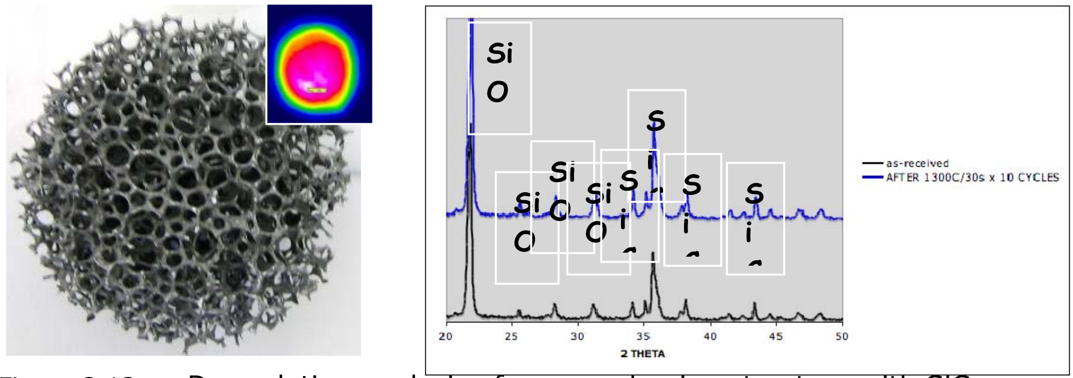


Figure 3.13. Degradation analysis of porous alumina structure with SiC coating at 1300ºC after cycling under flux of 3000 kW/m^2

Furthermore, new experimental capacities partly funded by this project were installed and characterized: i) 4000 W lamp for lab tests between 100 and 1500 kW/m^2; ii) optical bench for measuring reflectivity and directional transmissivity of porous absorbers; iii) device for testing solar thermal cycling to be installed in a parabolic dish at the Plataforma Solar de Almería; iv) acquisition and adjustment of Vickers and Knoop (Leco mod LV-700) hardness tester; v) acquisition and adjustment of thermogravimetric and thermobalance analysis system.

Publications: [3.7]-[3.9]

Figure 3.14. Position of the metal sample in the focal zone

3.3.5 SolHyCo

SOLar HYbrid power and COgeneration plants

Participants: DLR (D, coordinator), TURBEC (IT), CIEMAT (ES), CEA (FR), Ormat (IL), Abengoa (ES), FTF (DE), Sonatrach (DZ), GEA (PL), Vitalux (BR), and the IIE (MX)

Contact: Peter Heller (peter.heller@dlr.de); Thörsten Denk (thorsten.denk@psa.es)

Funding: European Commission 6th Framework Program (Contract 019830)

Duration: January 1, 2006 to June 30, 2009

Background: This project is the heir to the successful REFOS, Solgate and HST projects that developed pressurized receiver solutions for integrating solar heat in gas cycles or combined cycles and demonstrated their capacity to produce electricity in hybrid schemes (with conventional fuel backup) in a 250 kW_e system. This type of solar-hybrid system combines solar energy and fossil fuels, but they are only 100% sustainable if they use biofuels.

Purpose: The main purpose of SolHyCo is to develop a very high-efficiency solar-hybrid microturbine for generation of both electricity and heat, working with concentrated solar radiation and biofuels, and making it a completely renewable system. Another purpose of the project is study of market introduction in sunny countries, in particular, Algeria, Brazil and Mexico.

At the Plataforma Solar, solar testing will be done in two stages in the CESA-1 Tower. The first will be in 2008 with the 250-kW turbine from the Israeli Ormat company on the 60-m level (Figure 3.15), which was already operated very successfully in the SOLGATE Project. This turbine will be fed by three pressurized air receivers (one tube receiver and two volumetric) with a total thermal power of 1 MW. The kerosene used in Solgate has been replaced by a 100% biological diesel fuel (biodiesel).

The second stage will be in the same place in 2009 with a Italian/Swiss Turbec turbine which has an electrical power of 100 kW. A new type of pressurized air receiver is being developed for this turbine based on the tube concept, but with high-technology "multilayer pipes". These pipes have three layers, the outer one of high-temperature steel, the middle one copper for better heat distribution around the circumference of the pipe, and the inner one steel again, but very thin, for mechanical stabilization of the copper layer.

Achievements in 2007: In 2007, the turbine and the receivers were prepared for solar testing. Because of the long time it had been without operating, many defects were found in the system which delayed startup considerably. After the manufacturer had checked over the metering valve and made the modifications necessary for use with biodiesel, the turbine was finally started up. With the turbine running, vibration measurements were made to diagnose any imbalance. The results were within tolerance.

Afterwards, the receiver system could be checked over. Both quartz windows were disassembled for thorough cleaning of the crystal, some mirrors were repaired, and the secondary concentrator water-cooling system, which

Figure 3.15. Ormat Turbine on the 60-m level of the CESA-1 Tower

was rather badly damaged, was repaired and improved with an automatic water circuit filling system, which replaces amounts lost.

The last job was to install another tank for startup which runs on kerosene. In principle there are no basic problems for starting up with biodiesel, but it would require, on one hand, an in-depth revision of the turbine control system and on the other, modification of several fuel feed system components to resist the more aggressive atmosphere of biodiesel for at least one year. The new system (Figure 3.16) includes a second line, that goes from a new little 40-m tank about 10 m above the turbine to the receiver room where a remotely controlled three-way valve supplies one fuel or the other. The strategy is to start up with kerosene, wait connection to the grid, and then change over as quickly as possible to biodiesel and begin with solar energy. When the turbine is shut down, the procedure is reversed, but with the additional need to leave the system running on kerosene for about 15 minutes to ensure that the volume between the three-way valve and the combustion chamber has completely filled with kerosene. This procedure consumes about 25 liters of kerosene. Apart from this, two remotely controlled valves were also installed so the operator could cut off the fuel flow in case of emergency. There were only two manual valves for this before.

Solar testing finally began in March 2008 and is scheduled to finish at the end of September. The main goals are calibration of the air mass flow measured with two new measurement systems and accumulation of around 100 solar test hours to gather as much system durability information as possible.

Publication: [3.10]

Figure 3.16. New biodiesel operation installations

3.3.6 MEPSOCON

Measurement of concentrated solar power in central receiver power plants and radiometry lab

Participants: CIEMAT

Contact: Jesús Ballestrín (jesus.ballestrin@psa.es)

Funding: 2002 National R&D Plan. Industrial Production Program. Ministry of Science and Technology (Reference DPI2003-03788)

Duration: December 2003 and after

Background: The PSA Radiometry Lab came out of the need to verify measurement of important radiometric magnitudes associated with solar concentration. These magnitudes are solar irradiance ("flux" in solar concentrating language) and material surface temperatures (IR detection).

Several different systems are used to measure high solar irradiance on large surfaces at the PSA. In these systems, the basic element is the radiometer, the proper use and deployment of which depend on the measurement of the concentrated solar radiation incident on the aperture of the solar receivers. The measurement of this magnitude is basic to determining the efficiency of the receiver prototypes evaluated at the PSA and defining future central receiver solar plants.

During the execution of the MEPSOCON (**ME**dida de **P**otencia **SO**lar **CON**centrada en plantas eléctricas de receptor central, Reference DPI2003-03788), a procedure for calibrating radiometers for high solar irradiance was defined and put into use. Up to that time, there was no established procedure for calibrating these sensors. A systematic error was also found en the measurement of high solar radiation. Calibration of high solar irradiance radiometers is a normal practice in this radiometry laboratory, and provides service to national and international companies and institutions: Solucar, CENIM, DLR, CIEMAT, etc.

A black body can be used as a reference source of thermal radiation for calibration of IR devices (infrared cameras and pyrometers) that use thermal radiation to find the temperature of a surface. It is also used as an irradiance reference for calibrating radiometers.

Purpose: i) Define a sensor calibration procedure (calorimeters or fluxmeters) for measuring concentrated solar flux (in the 100-1000 kW/m^2 range). ii) Model and design a new calorimeter correcting the deficiencies of those

Figure 3.17. Radiometry Lab

Figure 3.18. Calibration of the laboratory IR detector

currently in use; iii) Integrate existing concentrated solar radiation power measuring systems used for evaluating solar receivers to make measurement of this magnitude redundant and ensure validity.

Achievements in 2007: This laboratory is currently in operation and providing service to CIEMAT and other national and foreign entities. These services are:

- Calibration of high solar irradiance radiometers
- Calibration of IR sensors for temperature measurement

A Black box can be used a reference source of thermal radiation and for calibration of IR devices (infrared cameras and pyrometers) that use thermal radiation to determine the temperature on a surface. It is also used as an irradiance reference for calibrating radiometers.

The Radiometry Lab has two black boxes as references for calibrating IR sensors for temperature measurement. The MIKRON M330 black box can provide any temperature between 300 and 1700ºC with a ±0.25% accuracy and a resolution of 1ºC. Its emissivity is 0.995 in a 25-mm diameter aperture. Both have an integral PID control system and the temperature is checked by a high-precision platinum thermocouple. It is intended to cover the low-temperature range (-20ºC – 150ºC) with a black box of similar characteristics in brief.

The most promising lines of research propose using infrared sensors that work in shortwave spectral ranges containing the atmospheric absorption bands for H_20 and CO^2 for detecting the radiation on a hot surface without any distortion by the reflected solar radiation, even through quartz (Fig. 12). Great advances have been made in this direction this year.

Publications: [3.11][3.12]

3.4 Solar Fuels and Solarization of Industrial Processes

Solar fuel production, mainly hydrogen, as well as integration of solar concentrating Technologies in industrial processes that need to adapt the process for integrating the solar contribution in the most endothermal stages, are the main goals of the Solar Fuels and Solarization of Industrial Processes Group.

In the first case related to solar fuels, the greatest effort, without doubt, is concentrated on thermochemical production of hydrogen. The interested awakened by hydrogen as the energy vector in the transportation industry and the doubtless attraction that its clean production from solar energy, make it at the PSA the centre of attention, adapting high-temperature concentrating solar technologies to application to mass production of hydrogen. This activity falls under a European project (HYDROSOL-II) the PROFIT program (SOLTER-H), a project funded by the Madrid Regional Research program (PHISICO2) and a project with significant industrial support from the Venezuelan company Petróleos de Venezuela (SYNPET). These technology development projects are supplemented by active participation in forums and associations of major impact such as the SUSHYPRO initiative in collaboration with R&D centers in France, Germany and Italy, and another international network called THESIS sponsored by the International Partnership for the Hydrogen Economy (IPHE). Furthermore, the CIEMAT has begun procedures for joining the EU 7^{th} Framework Program's Joint Undertaking for Fuel Cells and Hydrogen. Application of solar concentrating technologies to industrial processes and certain high-temperature heat process is another field of enormous importance which the PSA is channeling through the SOLARPRO project, the purpose of which is, in cooperation with Spanish universities and research centers, demonstrate the technological feasibility of the use of solar thermal energy as a power supply system in industrial processes having high temperature as their common denominator.

3.4.1 Hydrogen production

Just as their European, American and Japanese counterparts, the CIEMAT, as a national energy research laboratory, is carrying out its own hydrogen technology program. Hydrogen production is part of this program, with impacting weight and goals. In spite of all the uncertainties and challenges posed by the so-called hydrogen economy, it is clear that public research promotional programs are providing more and more significant support to hydrogen. CIEMAT's main goal in this field is research and development of efficient, competitive hydrogen production technologies leading to implantation of the hydrogen economy in the Spanish transportation and stationary consumption sectors, from native energy resources. The PSA is the main instrument for developing hydrogen production processes using the plentiful solar resources available in our country and the excellent knowledge of solar concentrating technologies applicable to reactors operating at temperatures over 1000ºC. The lines of activity are in two concrete fields of action (see Figure 3.19).

- Development of fossil-fuel decarbonization processes and technologies and their revaluation through solar gasification, with special attention to low-quality carbonaceous materials.
- Demonstrate pre-commercial technical and economic feasibility through the use of thermochemical cycles with concentrated solar energy.

These R&D lines are supplemented by participation in international forums and working groups such IPHE and SUSHYPRO and also by feasibility studies and roadmaps like INNOHYP.

3.4.2 INNOHYP

Innovative High-Temperature Routes for Hydrogen Production: Roadmap for thermochemical hydrogen production

Participants: CEA (FR) coordinador, CIEMAT (ES), Empresarios Agrupados (ES), ENEA (IT), DLR (DE), Universidad de Sheffield (UK), JRC-Petten (EU), CSIRO (AU).

Contacts: François Le Naour, francois.le-naour@cea.fr
Manuel Romero, manuel.romero@ciemat.es

Funding: Cofunded by EC. Total budget: 617 k€. CIEMAT: 55 k€.

Duration: 1 September 2004 – 31 December 2006

Background: The accelerated development of the so-called hydrogen economy inevitably goes through progress in innovative technologies for its mass production without polluting emissions and at competitive prices. The use of thermochemical cycles that achieve thermal water splitting based on consecutive redox stages is extraordinarily attractive, but requires the use of clean, renewable energy sources, such as solar energy. The number of thermochemical cycles analyzed in the literature is enormous, but most of the options have only been studied theoretically or in the laboratory at most. The interest in a roadmap in the subject is to compile available information on the various processes and propose master lines of joint action in Europe.

Purpose: The INNOHYP-CA (Innovative high temperature routes for Hydrogen Production – Coordinated Action) Project is a Coordinated Action funded by the European Commission under its 6th Framework Program, the purpose of which is to review the state-of-the-art of innovative processes for mass thermochemical production of hydrogen with no CO_2 emissions [3.29].

Achievements in 2007: The project began in September 2004 and the final report was presented to the European Commission in 2007. A summary of its results were presented at a Seminar that took place in Brussels on November 29, 2006. The compilation of the state-of-the-art offers a selection of promising processes under three categories (see 0). The roadmap includes parallel

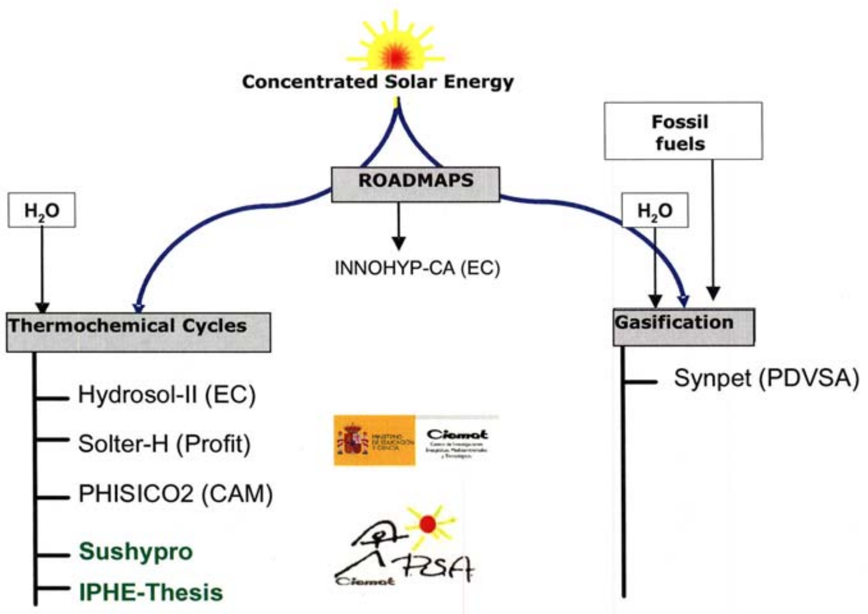
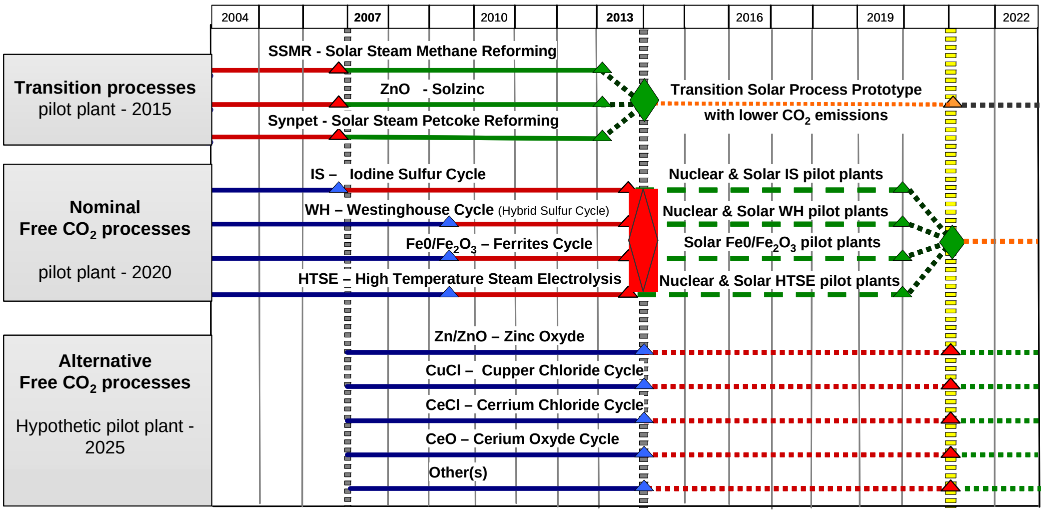


Figure 3.19. Lines of activity and projects in thermochemical hydrogen production at the PSA



(Source: INNOHYP)

Figure 3.20. Main hydrogen high-temperature thermal production processes retained for development for a future hydrogen economy

development of horizontal R&D activities in materials and component development, such as high-temperature heat-exchangers and test beds.

Publication: [3.29]

3.4.3 SYNPET
Solar gasification of petcoke

Participants: Petróleos de Venezuela (PDVSA), the Instituto Tecnológico de Zurich (ETH) and the CIEMAT.

Contacts: Juan Carlos de Jesús, dejesusjc@pdvsa.com
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding: Project financed by the Partners, with majority share by PDVSA. Total budget: 6,950 k$. CIEMAT Budget: 1,940 k$.

Duration: 1 September 2002 – 31 December 2008

Background: The solar gasification of carbonaceous materials is of great interest in the transition to the hydrogen economy. In conventional industrial gasification, the energy required to heat the reagents and the reaction heat is supplied by burning a large amount of raw material, whether directly by internal combustion, or indirectly by external combustion. Internal combustion, as applied to self-heating reactors, leads to polluting product gases, while external combustion, as applied in allothermal reactors, has lower thermal performance due to the irreversibilities associated with indirect heat transfer. Alternatively, the advantages of supplying solar energy for heat processes are multiplied by three: 1) the calorific value of the raw material is increased; 2) product gas is not contaminated by combustion subproducts, and 3) emission of pollutants into the environment is avoided. Furthermore, direct irradiation of the reagents provides a very efficient heat transfer medium directly in the chemical reaction zone where the energy source is needed, avoiding the limitations imposed by heat exchangers. The solar gasification of coke without combustion may be represented in a simplified form by the reaction:

$$CH_xO_y + (1-y)H_2O = \left(\frac{x}{2}+1-y\right)H_2 + CO \qquad (1)$$

The gasification of 1 mol of C requires another 1 mol C in energy supply. So replacement of the fossil energy supply by solar reduces CO_2 emissions by about 50%.

Purpose: The main purpose of the SYNPET Project is to develop a specific project for solar gasification of coke and waste from processing extra-heavy crude oil from the Orinoco Oil Belt. The specific work packages are to find the thermodynamic and kinetic parameters for the associated reactions, select particle sizes and contact times, design of a solar reactor with quartz window, and scale up and test a 500-kW facility located at the top of the CRS tower at the PSA.

Achievements in 2007: In 2007, the SYNPET Project culminated the design and construction of the main components of the 500-kW installation, with assembly and commissioning scheduled for 2008 in the CRS tower. Project equipment installation was carried out by SENER, taking into account both technical and safety requirements associated with a high-temperature syngas production facility. The size of the plant made it necessary to have information on applicable safety legislation (R.D. 681/03 [ATEX Directive]) as a first step to updating the area classification. As shown in Figure 1, the facility makes use of Levels 41 and 31.66 of the CRS tower. The reactor and coke (slurry) feed system are on Level 41, and hanging over them, the heat exchanger, which cools the reactor exhaust gas before it goes to the flame. The separator and electrical steam generator for the gasification process are on Level 31.66. By the end of 2007, most of the main components had been

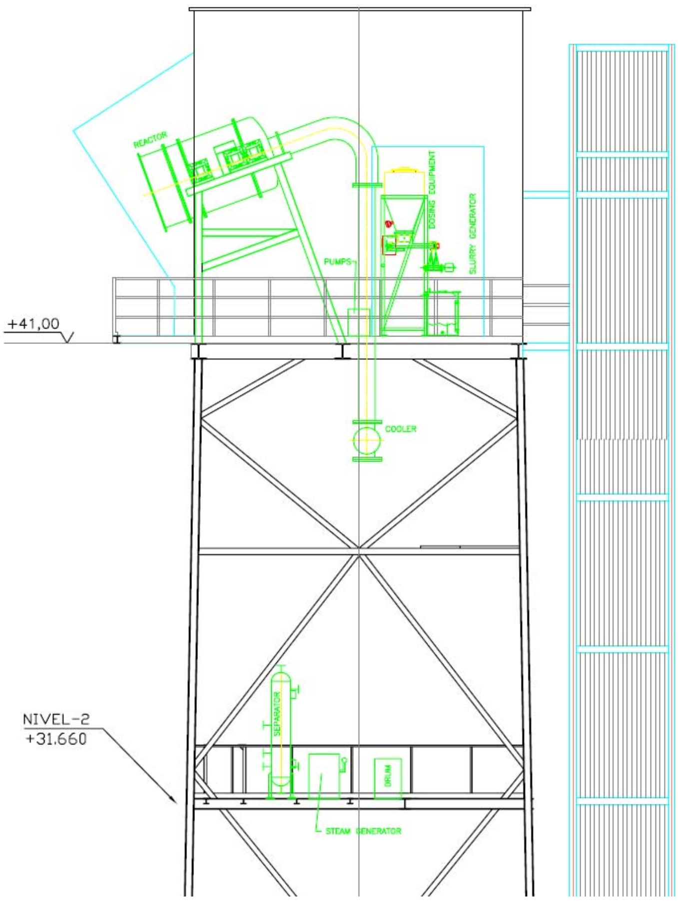


Figure 3.21. Implantación de la instalación SYNPET-500 en la torre CRS de la PSA.

supplied or were being manufactured (reactor, reactor window, support structure steam generator, feed pumps and system and flame), with the heat exchanger and control system remaining pending execution for the first half of 2008.

Facility up-scaling from the small 5-kW reactor tested in Zurich with petcoke [3.14] and carbonaceous waste products [3.15] meant complete revision of the feed system, the reactor's inner thermal insulation system arrangement, the quartz window design and also heat rejection in the outlet gases. The SYNPET-500 facility therefore makes use of construction and engineering solutions nearer to a real production plant, adapted solar energy as the main power source. The process proposed in the SYNPET project was patented in the U.S. on February 13, 2007 [3.16]. The solar reactor patent application was published in May 2007 prior to granting [3.17], which has already been communicated, and is now being issued.

The pilot-scale results from 2006 were determinant fro the selection of the type of reactor to use for the process. The results show that the use of direct absorption receivers allows a gas with no CO_2 emissions to be produced at lower temperatures. To explain this behavior, it is hypothesized that direct irradiation of the reagents provides an effective way to transfer heat directly at the reaction site, improving kinetics and eliminating the limitations of heat exchange.

The direct absorption receiver was manufactured this year according to the ETH design. This reactor was conceived in several different segments to allow easy assembly on the CRS tower (Figure 3.22). The reactor is S30815 (ASTM)/1.4835 (EN) refractory steel, which allows it to be operated at high temperatures, although it is also insulated with a ceramic coating (89 to 95% Al_2O_3) which extends the material lifetime.

Publications: [3.14] - [3.17]

Figure 3.22. SYNPET solar receiver parts with ceramic insulation

3.4.4 Proyecto SolterH

Generación de hidrógeno a partir de energía solar térmica de alta temperatura. Proyecto PROFIT.

Participants: Hynergreen and CIEMAT.

Contacts: Victoria Gallardo; victoria.gallardo@hynergreen.abengoa.com
Alfonso Vidal, Alfonso.vidal@ciemat.es

Funding: Cooperative project funded by the Spanish Ministry of Education and Science PROFIT program. Total budget: 987 €. CIEMAT budget not incluiding personnel: 286 k€.

Duration: January 1, 2004 –December 31, 2008

Background: Great confidence has been placed in thermochemical cycles as the mid-to-long-range solution for clean mass production of solar H_2. Thermochemical cycles have the great advantage of splitting the water molecule in several stages, generating H_2/O_2 in different stages, thereby favoring their separation and avoiding recombination at the same time as the operating temperature is reduced to a more acceptable level where it can be reached with current solar concentrating system designs used for electricity production. Thermochemical cycles based on ferrites lower the process temperature considerably, as in the following example which employs zinc ferrites:

$$ZnFe_2O_4 \xrightarrow{1800K} ZnO + ZnO + \tfrac{2}{3}Fe_3O_4 + \tfrac{1}{6}O_2$$

$$H_2O + 3ZnO + 2Fe_3O_4 \xrightarrow{1000K} H_2 + 3ZnFe_2O_4$$

Although use of nuclear energy in thermochemical processes is limited to temperatures of around 900ºC, this does not happen with solar energy. Solar concentrating technologies can achieve fluxes of over 5 MW/m^2 and temperatures above 2000K at a reasonable cost.

Iron-based mixed oxides can lower the temperature significantly because the hydrogen generating stage is based on the artificial creation of gaps in the oxide structure, increasing its attraction to this material. Therefore, the SolterH project concentrates on developing technologies based on the use of mixed ferrites as ideal candidates for thermochemical hydrogen production.

Purpose: The main purpose of the SolterH Project is to demonstrate the usefulness of the combination renewable energy and hydrogen vector, specifically of solar thermal energy, and its use for clean, renewable hydrogen production based on the use of an unlimited, plentiful resource, the sun. Therefore, the final goal of this project is the design, development and evaluation of a system able to produce hydrogen from high-temperature solar thermal energy, with an important milestone at the end of the project which is testing of a 5-kW reactor in the PSA solar furnace. To this, the first stage of the project in 2004/2005 studied and revised the different possibilities in view of the technical and economic feasibility criteria, evaluating the advantages and disadvantages of each. The cycle based on mixed oxides (ferrites) has all of the qualities for being an ideal cycle, that is, simplicity and relatively high temperatures, although it has the drawback of an absence of reliable operating data. In 2006, the second stage of the project proceeded to validate the results in a laboratory installation and with materials synthesized by the CSIC Instituto de Catálisis y Petroleoquímica.

Achievements in 2007: Preparation and characterization of alternative materials (synthesized mixed ferrites), so this research has been supplemented with developments under the PHISICO2 Project which is summarized further below. Mixed ferrites were characterized by size, shape, specific surface measurement, elemental composition, thermal behavior, etc. In the study directed at materials preparation, two types of materials were used: doped manganese ferrites and commercial ferrites. X-ray diffractograms of samples after the activation stages and hydrolysis show that the sample doped with Ni spinel maintains this structure for two process stages. This material therefore was selected as the candidate for later cycling experiments.

Table 3.1. Results of the first cycles with 0.25Ni sample

Cycle nº	O_2 (mmol / g ferrita)	H_2 (mmol / g ferrita)	Performance hydrolysis (%) [a]
1	0.46	0.06	7
2	0.22	0.04	9

[a] performance = (mol H_2) / (2 mol O_2)

Table 3.1 shows the results of the first two cycles with the $Ni_{0.25}Mn_{0.75}Fe_2O_4$ ferrite. This production of oxygen and hydrogen would eventually lead to the complete deactivation of the cycle, so the efficiency of the hydrolysis stage must be increased for a long-term cyclable process, either by modifying the base material, or varying the reaction conditions.

Samples have also been acquired of commercial ferrites for their evaluation as candidates for their use in thermochemical cycles with a view to scaling up to the solar reactor, as well as to compare their activity with the samples from the laboratory. Sigma-Aldrich provided ferrites of Ni, Cu, Zn, Ni-Zn and Cu-Zn. The samples were tested in cooperation with the PHISICO2 Project.

Finally, this year, the Plataforma Solar hydrogen production facility was perfected, also using existing structure, valves, measurement and control equipment, etc.

3.4.5 PHISICO2

Clean Production of Hydrogen: CO_2 Emission-Free Alternatives.

Participants: Rey Juan Carlos University, CSIC, INTA, REPSOL, HYNERGREEN and CIEMAT.

Contact: David Serrano; david.serrano@urjc.es
Fernando Fresno; fernando.fresno@ciemat.es

Funding: Cooperative Project funded by the 4th PRICIT-Madrid Regional Plan Science and Technology. Total Budget: 1,000 k€. CIEMAT Budget not including personnel: 240 k€.

Duration: January 1, 2006 –December 31, 2009

Background: This Project is basically to coordinate and distribute the research capabilities and efforts of various different research groups from different institutions (URJC, CSIC, CIEMAT, e INTA) with regard to the study and development of clean hydrogen production processes, that is, CO_2 emission-free using renewable energies as the primary source of energy for its generation. There are also two companies in the power sector (REPSOL YPF and HYNERGREEN) in the project, which have shown interest in participating actively in the project and following up on results. It should be mentioned that

CIEMAT participation includes not only the PSA, but also the Chemistry Division and the Fusion Materials Laboratory. The hydrogen production processes in this project are photoelectrolysis of water, thermochemical cycles and decarbonization of natural gas. In addition to contributing to the scientific and technology development of these alternatives, it is intended to evaluate its medium-to-long-term technical and economic feasibility, as well as its ability to reduce CO_2 emissions over more conventional hydrogen production systems, such as gasification and steam reforming.

<u>Purpose</u>: The basic purpose of the project is to study the different clean hydrogen production processes and advance in solving the technological and economic limitations it currently presents. The alternatives included in this project are characterized by avoiding formation of CO_2 as a co-product of hydrogen and using renewable energy sources in the formation and release of hydrogen.

1) Hydrogen production from water by photodecomposition
2) Hydrogen production from water by solar thermal processes based on thermochemical cycles
3) Hydrogen production from natural gas by catalytic decarbonization
4) Comparative analysis of the possibilities posed

<u>Achievements in 2007</u>: In 2007, the study of thermochemical cycles for solar hydrogen production from water concentrated on the use of mixed iron oxides (ferrites) using three types of materials, doped manganese ferrites, Zn ferrites and commercial ferrites.

a) Manganese ferrites: Manganese ferrites were doped with 25 atomic percent of Co, Ni or Cu, and in addition to the Mn ferrite, $MnFe_2O_4$, by a process based on the Pechini method, which consists of making metal chelates with citric acid and later polyesterification of these chelates with ethylene glycol to form a resin, which is calcinated to produce the final oxides. The materials acquired were analyzed by ICP-AES, which showed a final composition essentially coinciding with the theoretical. Structural characterization was done by X-ray diffraction, which showed that the only sample in which only the ferrite with a spinel structure appears is the one doped with Ni, while in the case of the manganese ferrite the Fe_2O_3 and Mn_2O_3 phases also appear and in the ones doped with Co and CU, Fe_2O_3 appears along with the ferrite. Keeping this result in mind, a different method of $MnFe_2O_4$ synthesis was tested to achieve pure phases in the cases where the Pechini method produced a mixture. This method consisted of calcinating the precourser made from precipitation of sulfates in the corresponding metals in an inert atmosphere. The preliminary result of $MnFe_2O_4$ synthesis with this method led to the formation of only the desired phase.

   As a preliminary test of the behavior of the oxides produced, thermogravimetric analyses (TGA) were performed on them in an inert atmosphere, simulating the thermochemical cycle activation phase. The TGA curves showed how all the materials lose weight during thermal treatment at ambient temperature. In an experiment combining a gas chromatograph of thermoscale outlet gases, it was found that this weight loss corresponds to the evolution of sample oxygen. It was also observed that the temperature at which the different oxides undergo this weight loss varies, as does its magnitude, and that the undoped manganese ferrite is the one with the greatest weight loss, and therefore, a priori, the one which has the best H_2 production capacity. The introduction of dopants in the manganese ferrite caused lower weight losses and less activation of temperature, which, on one hand, would lead to less hydrogen production, but on the other, would lower the system power demand.

Once the materials had been characterized, hydrogen was produced in the laboratory by the thermochemical cycle mentioned above. The tests were done in a fixed bed reactor fed with argon as the drag gas, with the possibility of using dry gas for the activation phase and gas saturated in steam for hydrolysis. Detection and quantification of outlet gases were done by gas chromatography. The test bed was assembled and put into service in 2007. During the activation phase, the amount of oxygen released was found to be in agreement with the weight loss observed in the thermogravimetric analyses. In the hydrolysis phase, however, the amount of hydrogen produced was not as expected based on activation results, and the most hydrogen was produced with the manganese ferrite doped with nickel, with 7% performance in the first cycle with respect to the water molecule disassociation stechiometry. This material was therefore selected as the candidate for later cycling experiments and testing the influence of different reaction parameters. With a view to increasing this performance, experiments were done using the ferrite doped with nickel but at a lower argon feed flow rate. In these experiments there was 16% more hydrolysis of activated material at lower flow rates of 25 cm^3/min, which shows that the process is limited by diffusion.

b) Zinc ferrites: the activation stage of two zinc ferrites supplied by the ICP-CSIC Group, found by direct co-precipitation and calcination at 700 and 850ºC, respectively, was tested. In both cases, the formation of a metal coating was observed at the reactor outlet, which, when analyzed by XRD was confirmed to be metal zinc. This shows partial decomposition of the ferrite. The interest of this system is that this decomposition occurs at a lower temperature than reported in the literature, as well as the possibility of limiting this decomposition to the formation of non-volatile species, which would eliminate the need for a quenching stage, and the consequent energy savings.

c) Commercial ferrites: Samples of ferrites available on the market were acquired for their evaluation as candidates for use in thermochemical cycles with a view to up-scaling to a solar reactor. These samples have different compositions: $NiFe_2O_4$, $Ni0.5Zn0.5Fe_2O_4$, $CuFe_2O_4$, $Cu0.5Zn0.5Fe_2O_4$ and $ZnFe_2O_4$ X-ray diffraction confirmed that all of them had a spinel structure. Up to now thermocycle tests have been performed on $NiFe_2O_4$ and $CuFe_2O_4$ ferrites. A large amount of oxygen was produced in the activation stage of the second of these, however it did not correspond to the formation of hydrogen in hydrolysis, probably due to the disappearance of the spinel phase and the formation of phases in which the reaction with water is not thermodynamically favored. The sample of $NiFe_2O_4$, on the other hand did lead to formation of hydrogen in the second stage of the cycle, with a better performance than that found with the Systems mentioned above (26% con 25 cm^3/min de Ar).

An important milestone in 2007 was the design and construction of a fixed-focus solar dish, a complete innovation especially appropriate for high-temperature chemical testing, which will be used in 2008 for testing hydrogen production from ferrites. The Concentrating System consists of a set of concentric reflector rings, on the same plane, which focus solar radiation by their double reflection. Each of these rings is made of two truncated conical surfaces joined in a V-shape. When the collector is turned toward the Sun, the

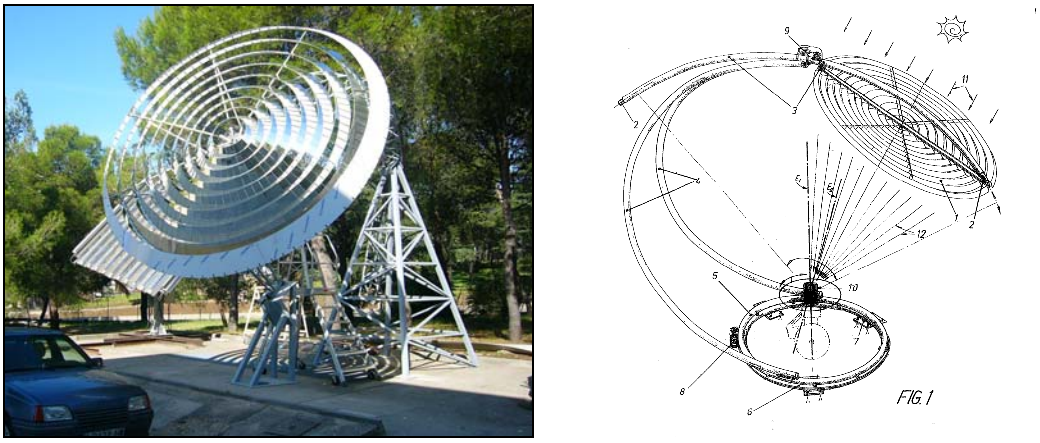


Figure 3.23. 7-m^2 2500x double-reflection fixed-focus solar dish developed under the PHISICO2 project for testing hydrogen production with mixed ferrites.

incident radiation is reflected by one of the truncated-conical surfaces facing the Sun onto the next truncated-conical surface further out, which reflects it again, redirecting onto the focus. As the reflection is on ruled surfaces, concentration is not punctual, but by a multitude of linear concentrations delimited in a small area. This double-reflection design minimizes the intercept losses between adjacent planes typical of any stepped reflection concentrator. The concentration device has an installed reflective surface of 7 m2 provides solar concentration of 2,500x.

Advances have also been made in the definition of the most appropriate solar reactor configuration. Both reaction (activation and hydrolysis) qualification tests allowed long reactor residence times to be set. The most versatile option in terms of contact times was based on the use of a reactor with a cavity geometry and quartz window working in batch mode. The reactor is rotary to provide good distribution of ferrite particles on the cavity walls.

Publications: [3.18] - [3.21]

3.4.6 Hydrosol-II

Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants.

Participants: APTL (GR) DLR (DE), CIEMAT (ES), STC (DK), Johnson Matthey (RU).

Contacts: Christos Agrafiotis; chrisagr@cperi.certh.gr
Antonio López; antonio.lopez@psa.es

Funding: Cooperative project funded by the EU 4th Framework. Total budget: 4.230 k€. CIEMAT budget: 647 k€.

Duration: December 1, 2005–December 1, 2009

Background: Solar thermochemical hydrogen production faces the huge challenge of scaling up the solar concentrating technologies and reactor capabilities to operate at powers of several MW. Doubtless, it will be the central receiver technology, or tower-heliostat field, the only one that can be adapted for this use. There are currently developments with volumetric receivers that operate at temperatures above 1000ºC, many of them tested jointly by DLR and CIEMAT at the PSA facilities. The motivation for the Hydrosol-II project is the confidence in being able to transfer the accumulated experience in developing materials and systems with catalytic matrices using SiC with monolithic channels that were validated successfully during the SOLAIR project [3.22]. The impregnation of these ceramic matrices with mixed ferrites would allow the volumetric receiver/reactor concept to be used for hydrogen production. The possibility of using this monolithic reactor with the ferrite fixed to a substrate facilitates in large part the separation of oxygen and hydrogen on performing the alternating charge/discharge stages.

Purpose: The second stage of this project (Hydrosol-II) began in November of 2005. Its purpose is to demonstrate H_2 production from mixed Zn ferrites impregnated on SiC ceramic matrices in a 100 kW reactor at the Plataforma Solar de Almería. The endothermal stage is performed with solar illumination, so the high flux focus of solar radiation generated by a field of heliostats moves alternately from some matrices to others to allow for the later H_2 discharge stage.

Achievements in 2007: In 2007, work at the PSA concentrated on mounting and commissioning the 100-kW HYDROSOL-II Facility on the 25-m level of the PSA CRS tower. The facility incorporates a system enclosure and test-bench support structure, as well as the corresponding supply manifolds, cabling, auxiliary gas and steam generator. The test bench includes a dual system with two reactors as shown in Figure 3.24. In order to be able to achieve the regeneration and dissociation conditions simultaneously, it was necessary to optimize the separation between the two apertures. The most unfavorable conditions are given when one of the reactors is in the heating phase (500 kW/m^2) and the other in dissociation (110 kW/m^2). A separation of 1.3 m was found to be enough to keep the operation of the two reactors separate [3.23].

Figure 3.24. Side view of the Hydrosol-II facility located in the PSA CRS Tower.

The preparation of the Hydrosol-II facility was preceded by intense work by the entire consortium in developing the best solution for the material and beehive matrix to use, as well as in developing a suitable reactor and control system. In 2007, 147x147x60 ReSiC ceramic support blocks with 90 cpsi (cells per square inch) manufactured by the Danish company, STC, were tested in Almería. Later 90 cpsi SiSiC blocks impregnated with mixed ferrites by Johnson Matthey were installed. Impregnation was done using 10 kg of redox material (Zn,Fe)O synthesized by the SHS method in Greece by APTL and then ground to a characteristic diameter of d_{90} < 10 µm, to ensure strong adhesion to the SiSiC. At the end of 2007, intensive work was done to have the final solar reactor and absorbers ready by the beginning of 2008. Official inauguration of the facility is scheduled for March 2008.

Publications: [3.22], [3.23]

3.4.7 SolarPRO II

Development of preindustrial prototypes for generating high-temperature solar process heat: Testing and characterization of their application to production processes and waste elimination.

Participants: CIEMAT, Univer. Seville, Instituto de Tecnología Cerámica, Polytechnic Univ. of Catalonia, Centro Nacional de Investigaciones Metalúrgicas -CSIC

Contact: Diego Martínez, diego.martinez@psa.es;
Inmaculada Cañadas, i.canadas@psa.es

Funding: Project funded by the Spanish Ministry of Science and Technology, under the National RD&I Plan (2004-2007). Total budget: 35.04 k€. CIEMAT budget: 7.26 k€.

Duration: 1 October 2006 – 30 September 2007

Background: Solar thermal energy is the renewable energy which, because of its characteristics, must take on a relevant role in industry, because it can provide, directly or through its transfer to a fluid or an absorptive material, the thermal energy necessary for many industrial processes, and can supply solar process heat at different temperature levels.

Industrial processes which generally require the most power are those which take place at high temperatures. For the future implantation of concentrating solar thermal technology in industrial processes, there must be a strong boost in research and the technological feasibility of each particular process must be demonstrated, adjusting the design and production parameters.

Purpose: The purpose of "SolarPRO" is to demonstrate the technological feasibility of the use of solar thermal energy as an energy supply system in different industrial processes having high temperature as their common denominator. The processes studied in this project are classified into two basic groups:

- Industrial production
- Waste treatment

From which the following processes have been selected:

Table 3.2. First processes selected

Typical processes in the ceramic industry		
Drying of raw pieces	100ºC < T < 200ºC	Drying chamber with volumetric receiver
Third firing for certain types of decoration	800ºC < T < 900ºC	Baking chamber with volumetric receiver
Baking ceramic tiles	850ºC < T < 1150ºC	Baking chamber with volumetric receiver
Powder metallurgical processes		
Metal sintering processes	T~ 1000ºC	Controlled atmosphere chamber
Waste treatment		
Processes for eliminating heavy metals from polluted soils	T< 630ºC	Solar rotary furnace
Materials treatments		
Tempering, treatment of ferrous and non-ferrous materials for aging and degradation	T < 900ºC	Solar fluidized bed furnace

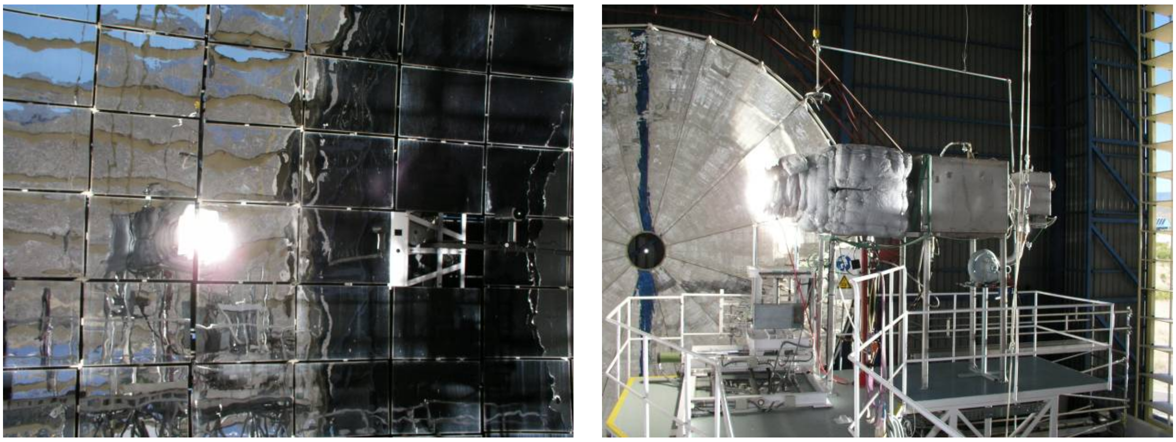


Figure 3.25. Processing plant in operation in the PSA Solar Furnace

Achievements in 2007: In SolarPRO I three different innovative reactors were were designed and built at the same time, based on different technologies, and in addition to different prototypes and test devices for specific applications. Their own data acquisition and control programs were also developed, the facility was improved and enlarged, and the different reactors were characterized and put into operation, and tested for each of the processes studied in "SolarPRO".

In 2007, under SolarPRO II, these reactors were successfully improved, further approaching the preindustrial goals of the project.

The current state of the art of the processes studied in SolarPRO is therefore the following:

Ceramic processes: A processing plant with an open volumetric receiver has been developed for drying and baking of ceramic tiles. To improve the current solar processing plant prototype, in 2007, modifications and improvements were made in the first prototype, and then it was recharacterized, confirming that it generated process heat at temperatures over 1100ºC. Once characterized, drying and baking of ceramic tiles, as well as third firing were tested.

The main milestones reached were:

- Reach continuous generation of process heat in air up to temperatures over 1100ºC
- Demonstrate the feasibility of the ceramic drying process
- Demonstrate the feasibility of the low (850ºC) and medium-temperature baking (T> 1050ºC), and third firing of pieces at temperatures between 700 and 900ºC

Waste treatments: Testing of thermal desorption of polluted soils in the fluidized bed reactor demonstrated homogeneous sample treatment.

Powder metallurgy: Metals were sintered in a controlled atmosphere reactor, at process heat temperatures of over 800ºC in air and in different gases. Under the SolarPRO II Project, in a two-month test campaign in cooperation with the Univ. of Seville, aluminum and brass test pieces with different compositions and preparation methods were sintered, with satisfactory results for aluminum (650º) and brass (810ºC).

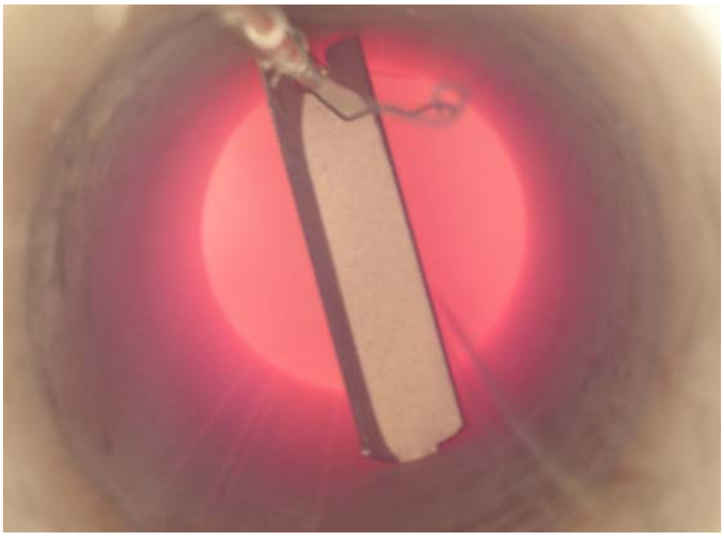


Figure 3.26. Interior of solar fluidized bed

Materials treatment: A fluidized bed heated by solar energy was widely used throughout SolarPRO II, for several different materials treatments and characterization of the reactor in February, July and October 2007, and for thermal treatment of aluminum and steel test pieces. Aluminum was solutionized (550ºC), several different types of carbon steel (C50) were treated, tools (95MnWcr%) were austenized (850ºC) and quenched in water and oil forming martensite, tempered (650ºC) and normalized.

Therefore, SolarPRO:

- Demonstrated the technological feasibility of using solar thermal energy as an energy supply system in high-temperature industrial processes
- Developed three different innovative reactor prototypes based on different technologies that generate solar high-temperature process heat
- SolarPRO II improved the three innovative prototypes developed in the previous stage of the project based on different technologies, with different temperatures and working conditions, supplied with concentrated solar energy. These improvements have made it possible for us to advance in our

Figure 3.27. Fluidized bed reactor in operation in the PSA Solar Furnace

knowledge of the reactors and the technology and on this basis design better future pre-industrial-scale reactors.
- Identified potential new processes that could work on solar energy
- Gained sufficient experience and knowledge to approach a second pre-industrial stage of the project.

In addition, two cooperation agreements for developing new processes and reactors for concentrated solar energy materials treatment were signed.

- Specific Cooperation Agreement between the CIEMAT and the Centro Nacional de Investigaciones Metalúrgicas (CENIM) entitled "Thermal treatment of metals with concentrated solar energy and characterization of solar concentrators" (2006-2008).
- Specific Cooperation Agreement between the CIEMAT and the Polytechnic University of Madrid entitled "Feasibility study of the use of concentrated solar radiation for the manufacture of aluminum foam" (2005-2009)

Publications: [3.24] - [3.28]

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4 Environmental Applications of Solar Energy and Evaluation of the Solar Resource Unit

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4.1 Introduction

2007 was a year of continuation and consolidation in the various activities that configure the Environmental Applications of Solar Energy and Evaluation of the Solar Resource Unit, and which encompass the following lines of research:

- Solar water detoxification and disinfection
- Solar air detoxification
- Solar seawater and saltwater desalination
- Characterization and measurement of solar radiation

These activities also define the four groups which provide the Unit's content. Good proof of the consolidation shown in these activities is the fact that in 2007, the Unit 6 new projects (2 European and 2 Ministry RD&I projects, one PROFIT project and one CENIT project). All of these projects are directly related to the main activities of the abovementioned groups.

As of December 31, 2007, the staff was made up of 23 people (the same number as last year) as follows: 6 permanent researchers, 6 contract researchers, 8 Ph.D. research students (3 of them not Spanish) and 3 laboratory technicians. The researchers in the "Characterization and Measurement of Solar Radiation" and "Solar Air Detoxification" groups are located at the CIEMAT Madrid facilities, while the other two are at the PSA. From a budgetary point of view of, the Unit's income (as defined in fiscal 2007) increased by over 30% above the year before to 638,000€.

In 2007 there was also a noticeable increase along the same line as in previous years, in the interest of many companies and other research entities in the development of processes and technologies related to solar energy in general and environmental applications in particular. To demonstrate this interest, in 2007 the IrSOLav Company (Research and Advanced Solar Resources, S.L., http://irsolav.com/) was created as spin-off from the "Characterization and Measurement of Solar Radiation" in response to the strong demand for data related to the estimation and analysis of the solar resource at potential sites as well as research, consulting, promotion, advising and training in related activities.

Another outstanding thing that also took place in 2007 was the creation of a new IEA-SolarPACES (Solar Power and Chemical Energy Systems) task which, under the name of "Solar Energy & Water Processes and Applications", is going to concentrate, disseminate and promote activities in research and demonstration related to solar energy applied to water technologies and processes. This new task (SolarPACES Task VI), and is led by the Head of the CIEMAT Environmental Applications Unit (which coordinates it), and will last for at least five years beginning January 1, 2008.

Among the activities to be carried out in it, in addition to water desalination, detoxification and disinfection are integration of water desalination in solar power plants, an activity referred to by its acronym: CSP+D. Because of the solar power plant construction boom and also because where there are high radiation levels justifying the installation of this type of plant, water resources are usually a problem, it makes sense to propose the use of solar energy not just for power production, but also for water supply. In view of the potential application and strong interest this activity could attract in many countries, it is entirely possible that it could end up becoming a new Unit area.

The main activities carried out in 2007 in each of the different groups and lines of research and technological development discussed above are described below.

4.2 Water Detoxification and Disinfection Group

Recent concern for pollution and other environmental matters have led to a search for new and more efficient methods for eliminating water pollution. Among them, the use of solar radiation as a resource for developing physical and chemical processes appears today to be a promising treatment method for toxic pollution and water disinfection.

In 2007, a total of 4 European projects were worked on (6th European Commission Framework Program), plus another three National RD&I Plan projects and the national Access to Large Scientific Installations Plan, because of its scientific and economic importance, could be considered as having a weight equivalent to several national projects. It should also be pointed out that among these, the TRAGUA project, under the Ingenio 20010 Program(CONSOLIDER) is an MEC excellence project. A detailed description of each is given on the following pages. In 2007, a total of 12 researchers from other research centers and universities in Spain, Portugal, Argentina, Ireland, Greece and South Africa were guest researchers collaborating with our group.

In view of the importance this group gives publication of project results in high-impact journals, it should be remarked that 25 articles were published in 2007. Three of these are especially relevant because they are state-of-the-art reviews. Furthermore, scientific activity is also recognized by the following work: 6 Ph.D. theses underway, 2 books, 2 book chapters and 13 communications (6 of them oral or invited) at 4 international congresses.

Publications: [4.7][4.11][4.34]

4.2.1 FOTOBIOX

Development of a combined oxidation (solar photocatalysis and biological oxidation) system for treatment of water effluents polluted by non-biodegradable pesticides.

http://www.psa.es/webesp/projects/fotobiox/index.html

Participants: CIEMAT-PSA (coordinator) Chemical Engineering Dept./Univ. Almería; Textile Engineering Dept./ Polytechnic Univ. Valencia;.

Contact: Dr. Sixto Malato, sixto.malato@psa.es

Funding: National RD&I Plan, MEC. CIEMAT Budget: 80 K€ + 1 FPI Ph.D. Research Grant.

Duration: October 2006 – September 2009

Background: Design of combined for solar photochemical and biological reactors for water treatment.

Purpose: The goals were:

1) Study photocatalytic detoxification of pesticide mixtures using experimental design and modeling techniques.
2) Study pollutant degradation routes, influence of intermediates formed during detoxification, and increase in biodegradability of the water treated.
3) Study the toxicity of other pollutants present in waste water along with the pesticides and their influence on photodegradation.
4) Design of a specific biological treatment system based on microorganisms adapted to the chemical nature of the pollutants pretreated by photocatalysis.
5) Design and construction of an integrated photocatalysis-biological pilot plant
6) Evaluation of system operability and economics.

Achievements in 2007: In 2007, the goals planned were achieved, undertaking mainly tasks related to goals 1, 2 and 3.

An increase in photo-Fenton treatment efficiency with Fe concentration (both Fe^{2+} and Fe^{3+}) was demonstrated, and 20 mg/L was found to be the best concentration. No significant differences were observed between Fe^{2+} and Fe^{3+}, although consumption of H_2O_2 was higher with Fe^{3+}. Demonstrated degradation of the active ingredients in the pesticides was shown to be stronger with Fe^{2+}. This effect became more noticeable the higher the concentration of Fe was. The comparison of photo-Fenton and Fenton showed that the

Photo-Fenton treatment is more effective than Fenton for degrading the commercial pesticide mixture.

Toxicity and biodegradability studies of the mixtures of pure pesticides pretreated by photo-Fenton were done to optimize the process variables not only to reduce TOC, but to reduce toxicity (measured using luminescent bacteria) of the effluent using this parameter as the basis for comparison of results. It was also intended to reduce biodegradability. It is hoped to find relevant information for pinpointing the moment when the water becomes biodegradable. Figure 4.1 shows an example of this strategy, demonstrating that the samples with a steep drop in toxicity, coinciding with the disappearance of the original pesticide (between t_{30W} 160 and 200 min), are those with good results in the Zahn Wellens test.

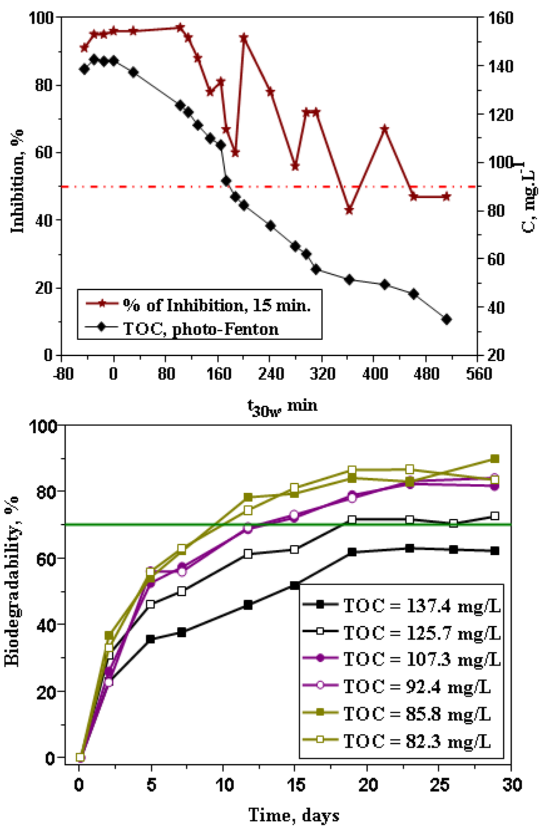

Figure 4.1. Toxicity (top) biodegradability (bottom) of mixtures of pure pesticides pretreated by photo-Fenton. The samples selected for biodegradability are shown in the figure at the top.

Publications:
[4.3][4.4][4.6][4.8][4.15][4.38][4.42][4.46][4.48]

4.2.2 PhotoNanoTech

Photozyme nanoparticle applications for water purification, textile finishing, photodynamic biomineralization and biomaterials coating

Participants: Sofia Univ. (coord., BLG), Bulgaria; CIEMAT-PSA (ES), Polytechnic. Univ. Cataluña (ES), Univ. Minho (PT), Univ. Kaiserslautern (DE), Univ. Torino (IT), Specialni polimeri Ltd. (BG), Tinfer (ES), Colorcenter (ES), Tecnologie Biomediche (IT), Inotex spol s r.o. (Rep. CH) and Perca Ltd. (BG).

Contact: Dr. S. Malato, sixto.malato@psa.es

Funding: EC, 6th FP. Nano-biotechnologies: Using nature as model for new nanotechnology-based processes; 1,720 k€. CIEMAT Budget: 350 K€.

Duration: April 2007-March 2010

Background: This project plans such interesting innovations as materials coatings for use in medicine to enable compatibility with cells and tissues by the addition of specific photozymes to minimize rejection, modify tissues by adding specific photozymes to imitate the behavior of chlorophyll in plants (selective adsorption of photons of certain solar spectrum wavelengths) to improve whiteness, brightness, color and tone, modify tissues to enable self-cleaning exclusively by exposure to solar radiation, take advantage of the antenna effect for decontamination and disinfection of water and, above all, of soils, and materials that favor photodynamic biomineralization to improve regeneration of bones and even bone implants.

Purposes: The PhotoNanoTEch project is intended to develop new "photozymes", amphiphilic copolymers containing comonomers with chromophoric Groups) using zwitterionic comonomers, and demonstrate their potential for innovation in the following applications: (IT) solar photocatalytic treatment and disinfection of polluted water; (ii) treatment of whiteners in the textile industry; (iii) development of biomineralization processes and (iv) development of new biomedical coating materials with no inflammatory response. The last three photozyme applications are completely innovative and have not been explored up to now.

Achievements in 2007: The first experiments performed with the photozymes synthesized in the Coordinator's (Univ. Sofia) laboratory were:

- Poly(SSA-co-NVC)
- Poly(SSA-co-St-co-NIm)
- P(SSA-VBC-RB)

The poly photozymes (SSA-co-NVC) and (SSA-co-St-co-NIm) are not suitable for decontamination. Light absorption by Photozyme P(SSA-VBC-RB) is suitable for use with sunlight (absorbs Light up to 600 nm), but is unstable

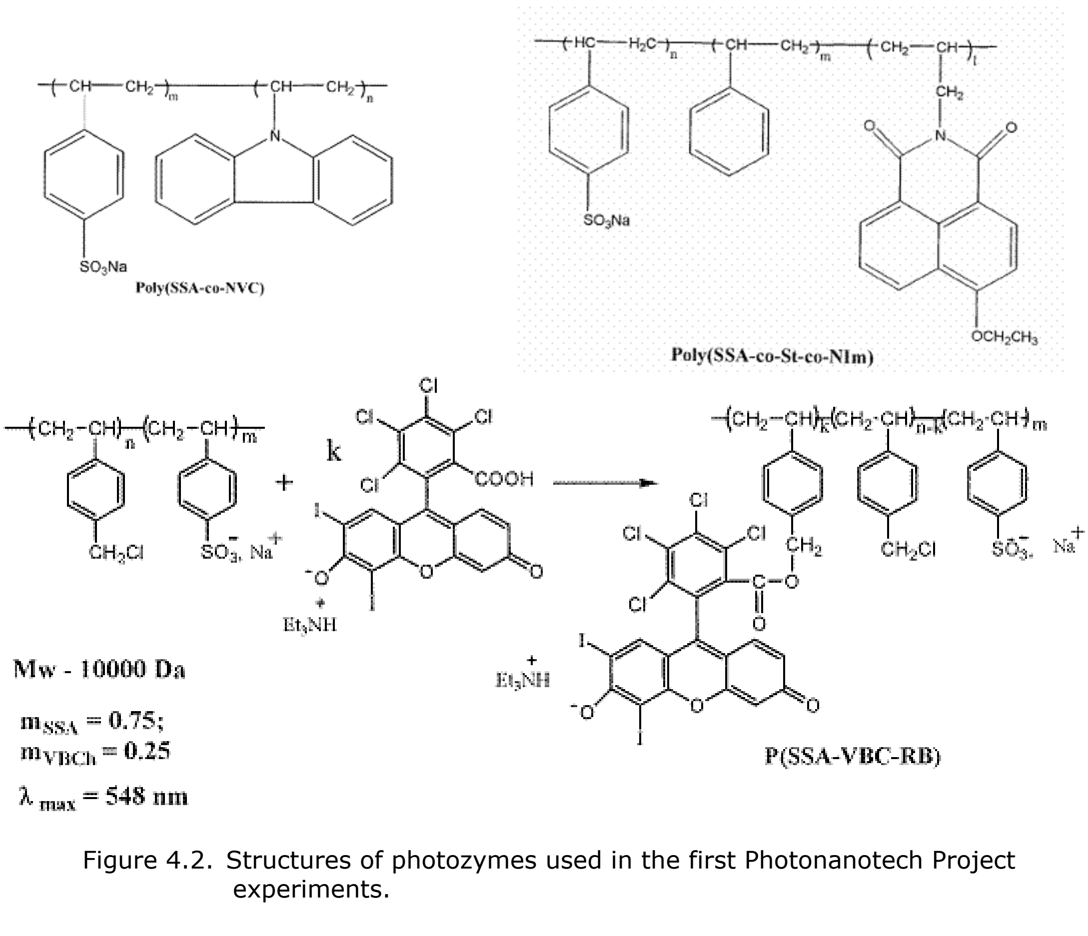

Figure 4.2. Structures of photozymes used in the first Photonanotech Project experiments.

under illumination, and is lost alter 5 hours of illumination, whether with natural pH or pH10 (50% conversion in 5 hours). It should be mentioned that phenol is a model compound used in photocatalysis, which is easily photodegraded and mineralized. Although Photozyme P(SSA-VBC-RB) adequately overlaps the solar spectrum, photozymes to be developed in this project should be stable under illumination.

4.2.3 INNOWATECH

Innovative and integrated technologies for the treatment of industrial wastewater. http://www.innowatech.org

Participants: CNR - Istituto di Ricerca Sulle Acque (IT), Aachen Univ. Technol. (DE), Tech. Univ. Delft (NL), Swedish Env. Res. Inst. Ltd (SE), Cranfield Univ. (UK), Swiss Fed. Inst. Tech. (CH), CIEMAT-PSA (ES), Norw. Inst. Wat. Res. (N), SolSep BV (NL), Bayer MaterialScience AG (DE), ITT Wedeco (DE), Austep S.r.l. (IT), Albaida S.A. (ES), AnoxKaldnes (SE), Water Innovate Ltd (UK), DHV (NL), Adv. Wastewater Manag. Centre (Aus).

Contact: Dr. W. Gernjak, wolfgang.gernjak@psa.es
Dr. Antonio López, antonio.lopez@ba.irsa.cnr.it

Funding: 6th FP. Global Change and Ecosystems.; 2.750 k€. CIEMAT Budget: 350 K€.

Duration: November 2006 – October 2009

Motivation: Granulated aerobic biomass, combination of advanced oxidation processes and biological treatment and integration of membrane processes are all considered high-potential innovations for development of industrial process wastewater treatment. These technologies will be applied to different industrial effluents (lixiviates, pharmaceuticals, pesticides, paper industry, etc.).

Purposes: (i) Study and increase the performance of promising options for industrial wastewater treatment, such as, e.g., aerobic granulation, membrane contactors and chemical membrane reactors, (ii) Advance in both fundamental knowledge and technology, (iii) Evaluate economic and ecological sustainability of these technology options, (iv) Develop integrated solutions tailored to the requirements of the final user, valid in different industrial sec-

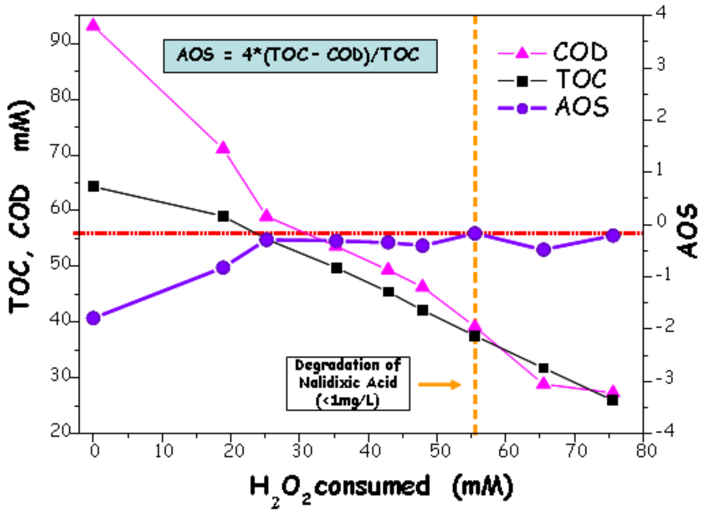

Figure 4.3. TOC, COD and AOS during photo-Fenton treatment of waste water containnig nalidixic acid.

tors and favoring their implementation to increase competitiveness in the EU water industry, (v) Transfer the knowledge developed to potentially interested final users inside and outside the scope of the project.

Achievements in 2007: The PSA, in cooperation with the other partners in WP2, has written a protocol for them all to use in evaluating the tests. The AUSTEP company provided the waste water (form the synthesis of nalidixic acid) for a combined photo-Fenton/biological treatment. This water contains a significant amount of biodegradable compounds. Nalidixic acid was the target to be eliminated in the combined treatment since it is not biodegradable. A combination of solar treatment and fixed bed biomass reactor were used for this. The samples were subjected to a complicated analytical protocol including TOC, COD, Zahn-Wellens, HPLC-UV, acute toxicity with *Daphnia Magnae* and *Vibrio F.*, dissolved iron, H_2O_2 and pH).The best point for discharging into the biological treatment is when the nalidixic acid has been completely degraded. A mixture of five commercial pesticides from ALBAIDA was also tested as the model for real waste water.

Publications: [4.9], [4.10], [4.12]-[4.14], [4.20]-[4.22], [4.24]-[4.28], [4.31], [4.32]

4.2.4 SODISWATER

Solar disinfection of drinking water for developing countries or emergency situations. http://www.rcsi.ie/sodis/

Participants: RCSI (Coord., IR), UU (UK), CSIR (S. Africa), EAWAG (CH), IWSD (Zimb.), CIEMAT-PSA (ES), UI (UK), ICROSS (Kenya), USC (ES).

Contact: Dr. Kevin McGuigan, kmcguigan@rcsi.ie
Dr. Pilar Fernández-Ibáñez, pilar.fernandez@psa.es

Funding: EC, 6th FP. Specific measures in support of international cooperation "INCO". 1,900 k€. CIEMAT Budget: 350 K€.

Duration: September 2006 – August 2009

Background: The main purpose of this Project is to demonstrate that the SODIS technology ("Solar Disinfection) for solar-only disinfection of drinking water is an effective tool against diseases communicated by domestic water (in developing countries) and as an aid in natural disasters. Solar disinfection is a water depollution technique that commonly uses transparent plastic bottles full of water exposed to direct solar radiation for 6-8 hours.

This process reduces the levels of fecal contamination of 1 million bacteria per ml to zero in less than 1.5 hours and is completely effective in treatment of pathogens responsible for such diseases as cholera, dysentery, typhus, giardiasis, salmonellosis, gastroenteritis and poliomyelitis. The only clinical test for this technology to date, carried out in a community in Kenya, has demonstrated that children under 5 years of age who drank SODIS-treated water were 7 times less likely to contract cholera than those who did not. There are no limitations to SODIS applications in high solar radiation areas (e.g. Africa), and its cost is practically nil as the only material required is transparent plastic bottles.

Purpose: The project is basically focused on Sub-Saharan Africa. Its strategic objectives are the following:

- Demonstrate SODIS as a suitable and effective technique for making contaminated water fit for human consumption in small communities in developing countries that do not have easy access to "safe water". Its application is equally effective in natural catastrophes or accidents that place access to drinking water in jeopardy.
- Test and evaluate strategies for changing behavior and spreading information about SODIS as a drinking water treatment technique in zones with different social and cultural profiles.
- Communicate the results of project research to developing countries and victims of catastrophes through international aid organizations, so SODIS is recommended as a quality intervention measure meeting water treatment standards (e.g., filtration, chlorination, desalination, etc.).
- Development of a series of technological improvements in the SODIS process, based on the use of ultraviolet disinfection dose indicators, solar-radiation activated photocatalysts and solar collector modules (CPCs) to be used depending on socio-economic conditions.

The scientific project objectives are: (i) Study the effect of the consumption of water treated with SODIS on health in four African countries; (ii) analyze the relationship between water disinfected by SODIS and certain health markers (morbidity due to diarrhea and dysentery, weight loss, loss of life, growth rates, productivity, etc.); (iii) demonstrate the effectiveness of the SODIS technique on a domestic scale and its acceptance as a disinfection method; (iv) evaluate the effectiveness of SODIS for certain viruses, protozoa, helminthes and bacteria. CIEMAT-PSA will work mainly on the design and construction of a prototype low-cost continuous-flow solar reactor based on the use of CPC solar collectors, design and construction of a batch-type photocatalytic reactor; evaluation of all of the technological improvements related to reactors and radiation sensors und real radiation conditions with suitable model microorganisms (without affecting the environment); making a cost analysis of the technologies proposed for their use in a developing country

Achievements in 2007:In 2007, an experimental work plan was carried out to evaluate the possibilities of up-scaling the SODIS process from a 1 or 2-L treatment volume to several tens of liters (daily residential use scale). Based on previous knowledge of the SODIS process in bottles of water, disinfection experiments were performed using CPC reactors (Figure 4.4) prepared for the purpose with treatment volumes of 2.5 L, 14 L and 70 L.

Figure 4.4. Solar photoreactor prototypes for water disinfection 14 L (a) and 70 L (b).

Different parameters, such as flow rate (Figure 4.6, left), water temperature, solar collector area illuminated (Figure 4.6, right), total volume and post irradiation effects when solar exposure time was limited. It was also demonstrated that the total inactivation process of bacteria in water by SODIS is produced when the system receives a minimum uninterrupted dose of solar energy during the treatment, which is independent of solar irradiance. In the solar ultraviolet range, this dose is 108 kJ/m^2 (30 Wh/m^2) for total inactivation of 106 CFU/ml in 2.5 L of natural well water (turbidity=1-2 NTU) with a 0.2-m^2-aperture CPC collector. This means the system is supplied with 9 kJ/L of energy in the solar UV range (Figure 4.7).

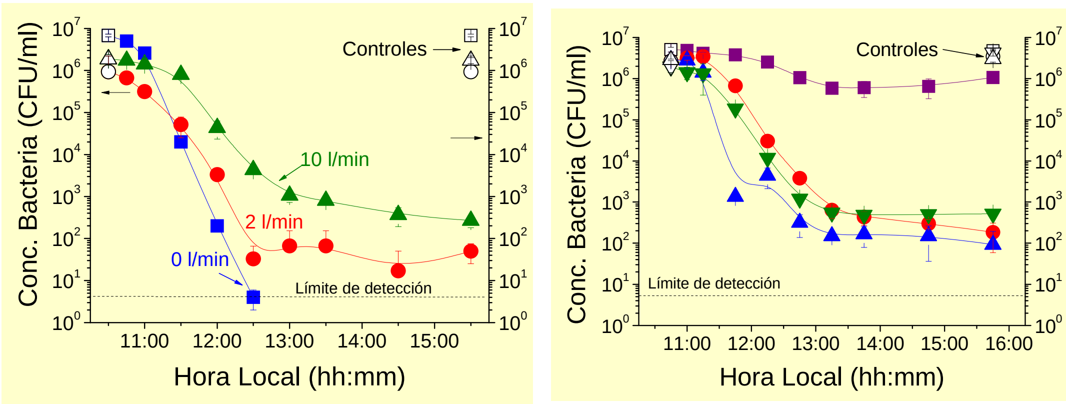

Figure 4.5. Solar *E. coli* inactivación curves in the 2.5-L, 14-L and 70-L CPC reactors at different flow rates: 0 L/min (-■-), 2 L/min (-●-), 10 L/min (-▲-) (izquierda). Solar *E. coli* inactivation curves in the 70-L reactor. Flowrate: 10 L/min; iluminated area: 1 m^2 (-■-), 2 m^2 (-●-), 3 m^2 (-▲), 4 m^2 (-▼-). (right). White symbols correspond to control samples.

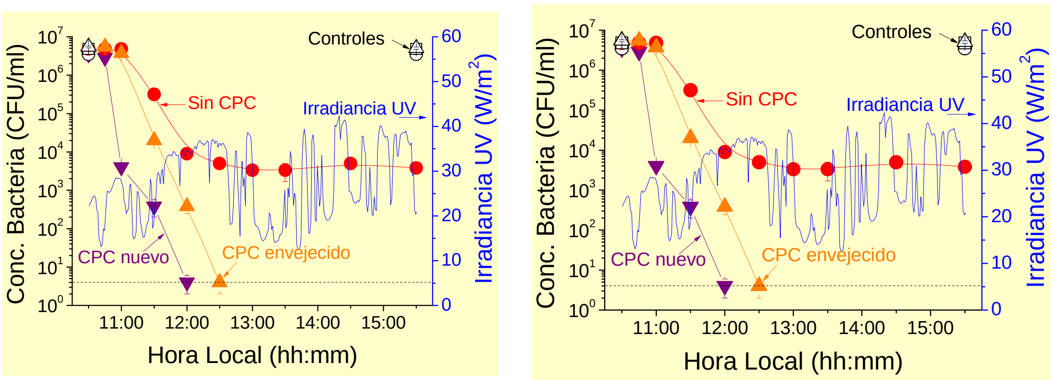

Figure 4.6. Inactivation of *E. coli* K12 under solar radiation on clear days (left) in a tube with CPC (-▼-), without CPC (-●-), PET bottle (-▲-), in the dark (-■-); and on cloudy days (right) in glass tube with new CPC (-▼-), aged CPC (-▲-), with no CPC (-●-). The line corresponds to solar UV irradiance (295-385 nm).

In any case, model conditions of real polluted water were for natural well water (no prior treatment) with inocula of *Escherichia coli* K12 bacteria. All tests were done with real solar radiation. The effect of using CPC collectors [18, 19] was also studied. The improvement with CPC systems in clear-sky and cloudy conditions was evaluated. To do this the 2.5-L system with two different qualities of CPC mirrors, one a new Miro-Sun (Alanod, Germany) and

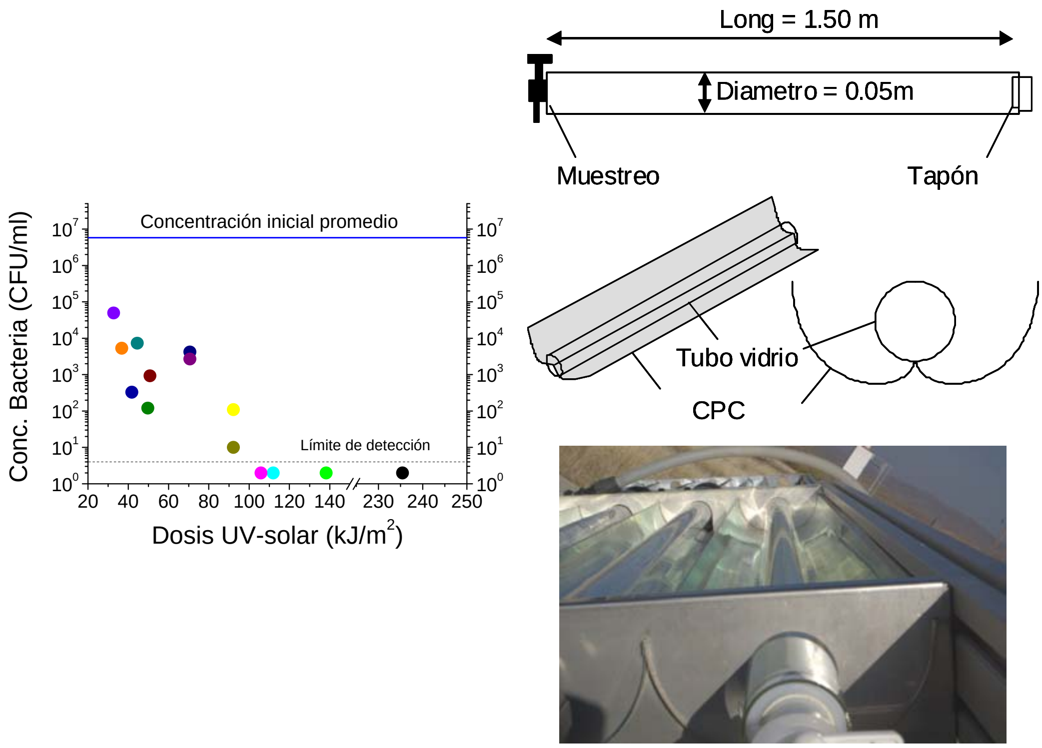

Figure 4.7. Final bacteria concentration compared to the cumulative dose of solar UV radiation during 16 SODIS experiments with exposture times of from 30 minutes to two hours at several different solar irradiances, done in the 2.5-L CPC batch system with no flow (right).

another was used again 320-G (Alanod) after 3 years of use under natural outdoor conditions at the Plataforma Solar de Almería (Figure 4.5).

Publications: [4.2][4.16][4.17][4.43]-[4.45][4.29][4.30][4.35]-[4.37]

4.2.5 FITOSOL

Photocatalytic elimination of plant pathogens in water; application to disinfection and reuse of recirculating hydroponic feed water http://www.psa.es/webeng/projects/fitosol/index.html

Participants: CIEMAT-PSA (coordinator) and Univ. of Almería Vegetal Production Dept.

Contact: Dr. Pilar Fernández-Ibáñez, pilar.fernandez@psa.es

Funding: National RD&I Plan, MEC. CIEMAT Budget: 117 K€ + 1 FPI

Duración: October 2006 – September 2009

Background: The destruction of plant pathogens by solar photocatalytic treatments (using a non-soluble semiconductor, titanium dioxide and photo-Fenton processes), avoiding the use of conventional chemical disinfectants (toxic non-biodegradable) that give the water with the nutritive solution an undesirable level of toxicity. The effectiveness of the photocatalytic treatment will be evaluated using models present in horticulture crops of Southeast Spain: *Pythium aphanidermatum*, which causes root and hypocotyl necrosis, leading to withering of *Cucurbitaceae*, *Phytophthora parasitica*, sp. *radicis-*

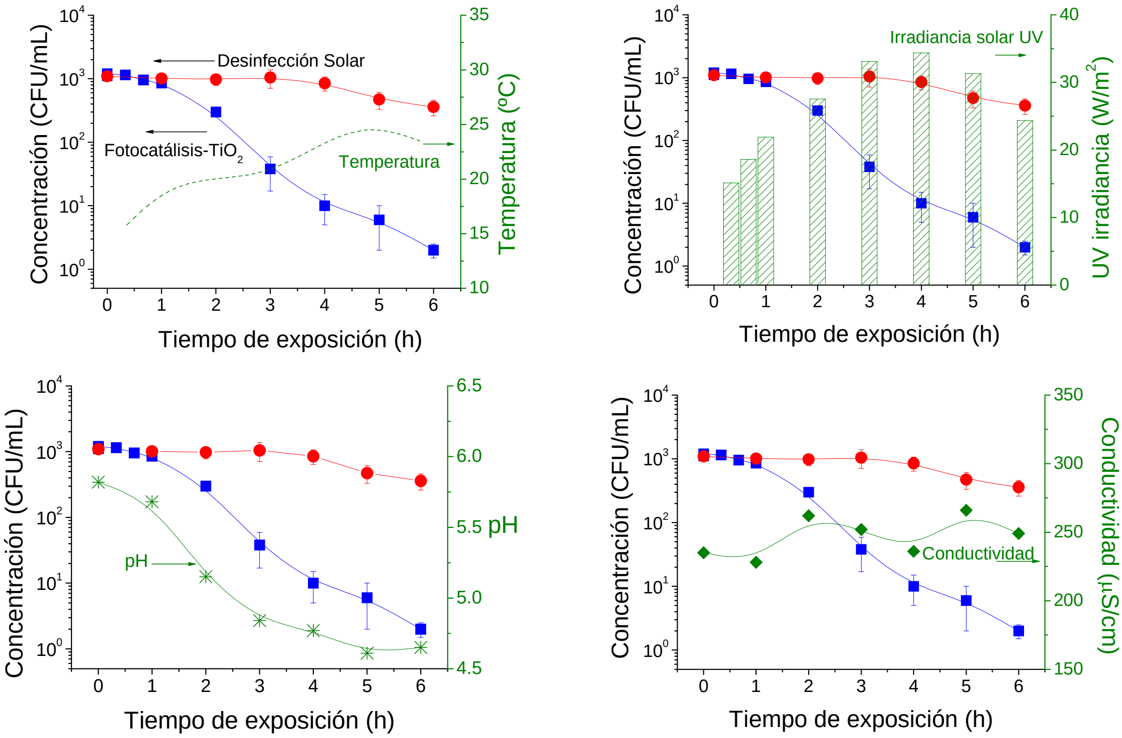

Figure 4.8. Solar photocatalytic disinfection of *F. equiseti* spores. Temperature (a), UVA irradiance (b), pH (c), conductivity (d)

cucumerinum, a fungus not having zoosporangium which causes significant crop losses , and *Olpidium bornovanus*, the vector of MNSV in melon and watermelon.

Purpose:

- Laboratory study of elimination of model plant pathogens in recirculating feed water of soilless crops by solar photocatalysis with TiO_2 (in suspension and immobilized) and with photo-Fenton).
- Design and construction of a pilot solar rector for disinfection of water containing the abovementioned plant pathogens for application to reuse of water used in hydroponic crops.
- Evaluation of photocatalytic water treatment of plant pathogens using model pathogens of the different types commonly found in soilless crops.
- Demonstration of the feasibility of photocatalysis for disinfection of real polluted feed water from hydroponic crops.

Experimental testing of the ability of photocatalysis to disinfect these pathogens is being done in lab-scale and pilot-scale solar reactors at the Plataforma Solar de Almeria. The final stage will be testing in a typical soilless crop with recirculating water at the experimental facilities of the Univ. of Almería.

Achievements in 2007: A series of lab-scale (200 ml) and prototype reactor (14 L) studies were carried out to demonstrate the disinfection ability of titanium dioxide suspensions under real solar radiation. Several different varieties of the pathogenic fungus *Fusarium* were studied. During the tests with *Fusarium equiseti*, pH, conductivity, temperature and UVA irradiance were measured (Figure 4.8). The maximum temperature was 25ºC, which is far below the optimum temperature for growth of *F. equiseti*. UVA irradiance during the first hour of treatment was really low (15-22 W/m^2) and the concentration of

F. equiseti hardly went down with any of the treatments. However, between 1 and 4 hours of treatment, irradiance increased from 22 to 34 W/m^2 resulting in a 2-log decrease with photocatalysis and almost none with solar disinfection. This wide difference in behavior observed between the results with photocatalysis and solar inactivation was especially observed in *F. equiseti*, while the rest of the varieties were sensitive to both treatments, although photocatalysis was more effective in all cases.

The engineering parameters were calculated for the new prototype design to be built in 2008 based on the lab-scale results found and our previous experience in the development of water disinfection reactors.

Publications:[4.1][4.5][4.23].

4.2.6 National PSA Access Plan.

Participants: Autonomous Univ. of Barcelona, Univ. of Barcelona, Univ. Rey Juan Carlos, Univ. Santiago de Compostela

Contact: Dr. Manuel I. Maldonado. mignacio.maldonado@psa.es

Funding: National RD&I Plan, MEC.

Duration: 2005 – 2007

Background: In view of CIEMAT directives to promote knowledge of renewable energies in Spanish society, it has made the PSA facilities and technical scientific staff available to the scientific community through the Spanish Access to Large Scientific Installations Program.

Purpose: The basic purpose is to provide access to the largest number of researchers possible, both Ph.D. students who are researchers in training and senior project researchers under the National Plan. The Water Detoxification and Disinfection Group also intends for this program to the cooperation among Large Spanish Installations, identifying new partners for future projects, making use of ideas brought in by visitors and providing motivation for maintaining and improving the facilities.

Achievements in 2007: Researchers from other large Spanish research installations selected by the external evaluation committee achieved the results summarized below:

Univ. of Santiago de Compostela, Parasitology Laboratory; School of Pharmacy. Researchers: Hipólito Gómez Couso and Elvira Ares Mazás. Test the effect of the SODIS technique on *C. parvum* oocyst viability in drinking water disinfection in PET bottles (similar to those used in third world countries) with different turbidities caused by a real soil matrix (tropical model) under natural solar radiation at the PSA facilities. The improvement in disinfection efficiency in CPC collectors with different concentration factors (1 and 1.89) was evaluated.

Autonomous Univ. of Barcelona. Dept. of Chemistry, Chemistry-Physics Unit. Photocatalysis and Green Chemistry Group. Researchers: Mª José Farré Olalla and José Peral Pérez. Pilot plant degradation of the herbicides diuron (42 mg/L) and linuron (75 mg/L) by combined chemical and biological system. Comparison between pilot-scale and laboratory results. It should be mentioned that this is the first study done at the PSA in which an SBR ("Sequence Batch Reactor") has been used as a biological reactor for the degradation of a photo-treated effluent. A dose of 5 mg/L of iron (II) and 100 mg/L of hydrogen peroxide generate an effluent with BOD5/COD of 0.4 which is potentially biodegradable. Prior lab-scale studies showed that an Fe(II) concentration of 15.9 mg/L and 202 mg/L of peroxide to get the same type of results when the solution is irradiated by a 6-W UVA source. The SBR is fed with the photo-treated solution resulting in complete degradation of intermediates generated in the photochemical stage. COD/TSS ratio of 0.2 was used and it was found that the biomass concentration was stable throughout testing. Figure 4.9 shows the results after biological treatment using 24-hour residence time.

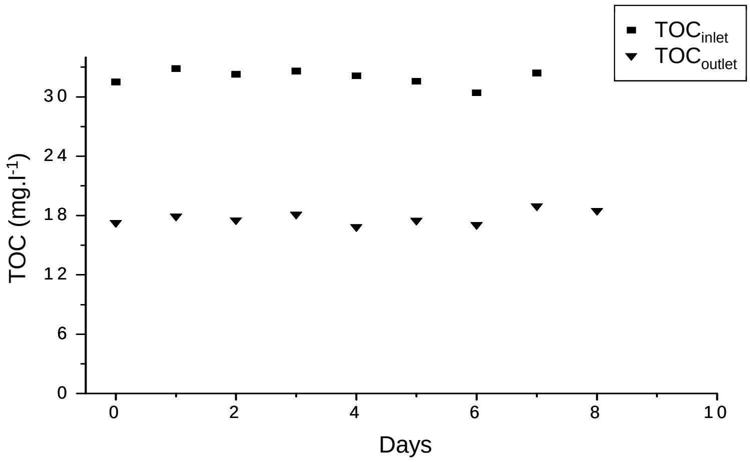

Figure 4.9. Average TOC at inlet and outlet of an SBT fed with a photo-treated solution of diuron and linuron. TRH=24 hours. TSS=0.2 g/L.

Univ. of Barcelona. Dept. Chemical Engineering. Advanced Oxidation Processes Research Group. Researcher: Fabiola Méndez Arriaga. This project undertakes the study of elimination of the aqueous pharmaceutical pollutant, ibuprofen, by an advanced oxidation process, heterogeneous photocatalysis. Degradation of ibuprofen was directly proportional to the concentration of catalyst employed. 50% of elimination of TOC was in 350, 550 and 850 min using 1000, 500 and 100 mg/L of catalyst. The degradation rate increases as the initial concentration of the compound is lowered and the presence of hydrogen peroxide accelerates degradation of ibuprofen as well as mineralization. However, the addition of peroxydisulfate does not improve the compound degradation rate due to the immediate change in solution pH. Due to the compound's pKa, pH below 4.9 precipitates it. To study the possibility of combining chemical and biological treatments and detoxification of the treated water, an experiment was done with 200 mg/L of ibuprofen, and BOD was monitored throughout the reaction. Ibuprofen is toxic and non-biodegradable. The BOD of the original compound in solution was below 1 mg/L. Therefore, all of the samples used to measure the BOD were taken after the complete disappearance of the original compound. Figure 4.10 shows the AOS (average oxygen state), for the BOD_5/COD and IBP/IBPo ratios over TOF/TOCo and illumination time. As observed, compound biodegradability increases with treatment time. It may be concluded that partial mineralization of ibuprofen by photocatalysis produces a solution which is potentially treatable in a biological treatment stage.

Univ. Rey Juan Carlos, Chemical and Environmental Engineering Group. Researchers: Carlos Sordo Olivé and Javier Marugán Aguado. Study of the photocatalytic activity of photocatalysts developed at the Univ. Rey Juan Carlos in disinfection processes using sunlight. The purpose was to make a study of the

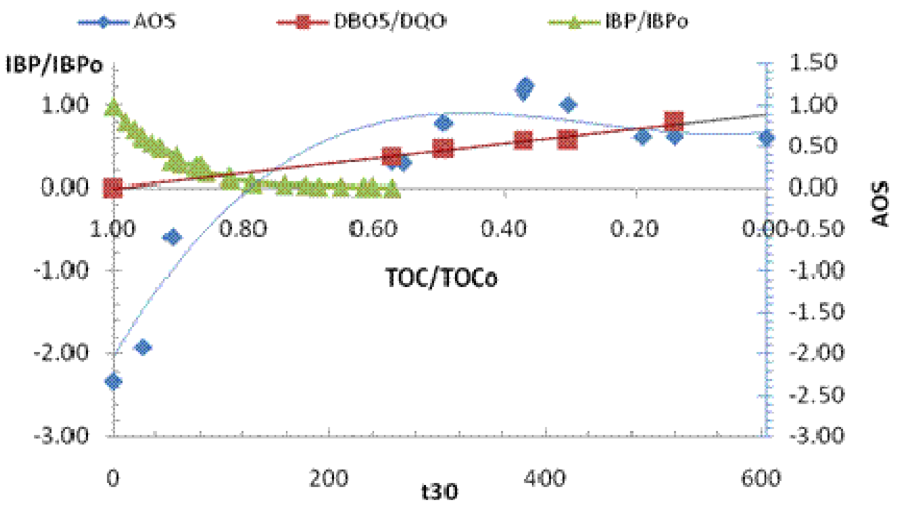

Figure 4.10. AOS (Average Oxygen State) profile, for BOD_5/COD and IBP/IBPo ratios over TOC/TOCo and normalized time.

disinfection of *E. coli* in a CPC solar collector plant using two heterogeneous photocatalysis systems, one in which TiO_2 is supported on the reactor walls and the other in which it is supported on a fixed bed of Raschig rings. Evaluation of the photocatalytic activity of the systems used was done with a solution of methylene blue. It was observed that inactivation of *E. coli* caused by solar energy on the supported TiO_2 heterogeneous catalyst on the glass reactor wall is no better than with solar energy only (SODIS), while disinfection on the supported catalyst on the fixed bed is better than if only solar energy is used (SODIS).

4.3 Air Detoxification Group

The main purpose of this group is to develop efficient air pollution treatment systems using preferentially solar radiation as the energy source. Although adsorbents and combustion catalysts have been also used for this purpose, Group activities are mainly focused on the development of photocatalysts for air purification. Within this field, one of the major priorities is the design of more efficient supported photocatalysts. A significant effort has also been devoted to the abatement of volatile organic compounds (VOCs) and inorganic toxic and malodorous molecules like H_2S. In addition, inactivation of airborne microorganisms is a new challenging niche for the application of this technology, which is gaining noticeably in relevance. In brief, the development of this technology is aimed at providing solutions for the problems of industrial facility and workshop emissions and indoor air quality.

4.3.1 Development of alternative methods for the preparation for high-efficiency photocatalytic materials

Participants: CIEMAT (PSA) and ICP-CSIC (Spain).

Contact: Dr. B. Sánchez; benigno.sanchez@ciemat.es

Funding: MCYT Spanish Ministry of Science and Technology. Total project funding: 75 k€ (Jan. 2005 – Dec. 2007).

Background: Application of photocatalysis to the treatment of gas-phase emissions requires fixation of TiO_2 on a support to avoid this photoactive material being washed away by the effluent. At the same time, the substrate must have an open structure allowing the gas to get through, and ideally must be transparent in the UVA range to strengthen the use of available light. Finally, it would also be desirable for the intrinsic photoactivity to be increased to augment the technology’s treatment capacity. There is therefore an obvious demand for new photoactive materials improving the features of current materials.

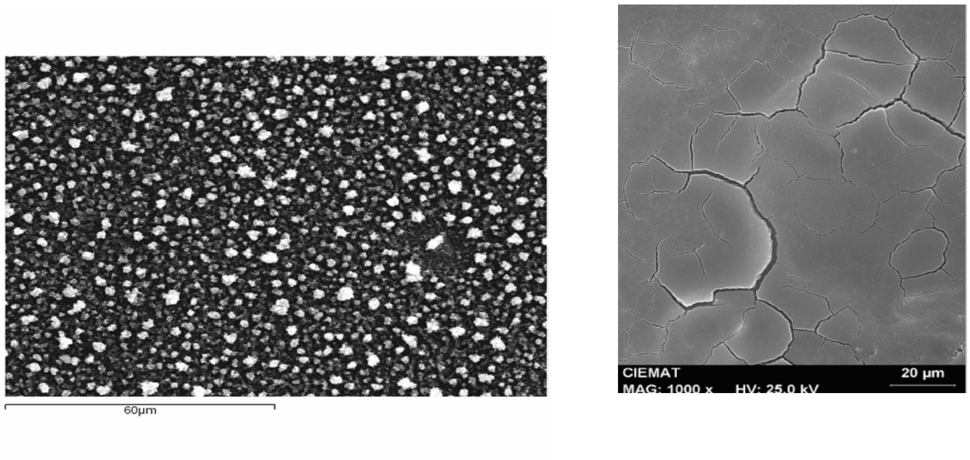

Figure 4.11. SEM micrograghs showing the morphology of A) a TiO_2 coating deposited on OCT by electrospray, and B) TiO_2 film deposited on magnesium silicate.

Objective: The main CIEMAT activity basically concentrated on finding materials coated with TiO_2 for direct use in photocatalytic treatment of gas. Both non-porous supports and supports transparent to radiation, such as borosilicate glass, organic polymers (PET, Cellulose acetate, etc.) and porous substrates opaque to light (sepiolite plate calcinated at different temperatures, prepared by the ICP-CSIC) were used for this purpose. The TiO_2 deposited was used in the form of commercial anatase large-surface powders, and sam-

Figure 4.12. Compound parabolic collector for tests under solar radiation, located on the roof of the buildiing (CIEMAT).

ples prepared in the laboratory by sol-gel methods. Mixed materials prepared by sol-gel methods that combine ZrO_2 and SnO_2 in addition to TiO_2 were also tested and the preparation of TiO_2 doped with Pt has been approached.

Achievements in 2007: During this project, a large number of supports and chemical modifications of TiO_2 were tested. Among them, the good results found with magnesium silicate ceramic supports coated with TiO_2 in the CIEMAT laboratory should be mentioned. These materials are highly photoactive and at the same time are able to improve the selectivity of products to total mineralization. The properties of the organic polymer monoliths coated with TiO_2 are also of great interest, as they are highly active even without thermal treatment to improve their crystallization.

Finally, the good results with photocatalytic degradation of trichloroethylene gas in a compound parabolic collector (CPC) using real solar radiation as the activation source. These results are very promising, since the provide evidence of the feasibility of this solar technology for treating gas effluents.

Publication: [4.52]

4.3.2 DETOX-H_2S

Development of a new system for the elimination of air borne toxic and corrosive compounds generated in sewage treatment plants

Participants: CIEMAT, ICP-CSIC, ICV-CSIC and UNED (Spain); UENF (Brasil); USACH (Chile) and University of Wisconsin (USA).

Contact: Dr. B. Sánchez; benigno.sanchez@ciemat.es

Funding: CAM funded project, cost shared: 700 k€

Duration: January 2006 - December 2009

Background: Emissions into the atmosphere by wastewater treatment plants consisting mostly of sulfurated and nitrogenated compounds also generate foul odors, important environmental problems and equipment corrosion. Therefore, this problem, which may negatively affect both public health and facility maintenance, has to be controlled

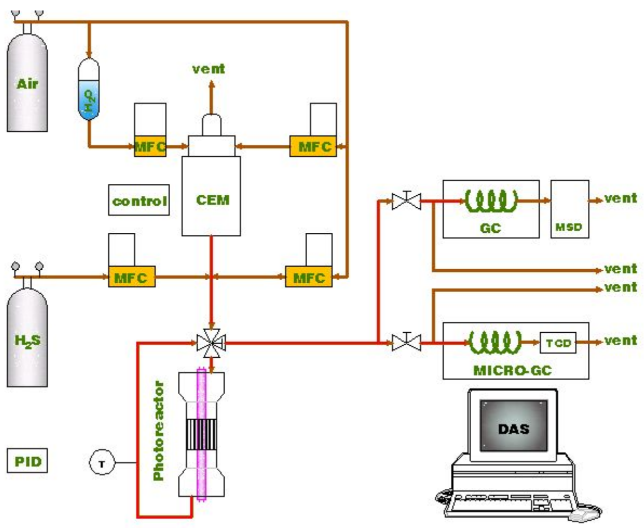

Figure 4.13. Schematic diagram of the reaction used for testing photocatalytic efficiency in degradation of H_2S

Objectives: The priority goal of the DETOX_H2S program is the development and optimization of a stand-alone photocatalytic system or combined with selective adsorbents as an effective method for controlling gas emissions of wastewater treatment plants.

The predicted results are:

1) Development of a photocatalytic treatment activated by solar radiation and/or UVA lamps, which demonstrates its operability working under real process conditions. This activity is carried out entirely by the CIEMAT.
2) Development of an adsorption treatment system to retain and/or treat the same flow rates under the same processing conditions.

It is intended to design a new mixed photocatalysis-adsorption system based on both systems which reinforces the activity of either separately. With the achievement of these goals, the volume of other chemical reagents used to control these emissions should be drastically reduced, providing a safer atmosphere in the workplace and surrounding area.

Achievements in 2007: The CIEMAT Environmental Applications of Solar Radiation to Air Group studied the efficiency of photocatalysts prepared for elimination of hydrogen sulfate, according to their composition and density, time used and operating variables (flow rate, moisture, concentration, temperature), as well as generation of subproducts, the loss of activity over time and regeneration by rinsing with water. During this period, we also worked on the synthesis and characterization of TiO_2 nanocrystalline sol-gel coatings, to improve its characteristics and adapt it to increase its efficiency in treatment of H_2S. In this sense, it is important to emphasize the good results found with the sols prepared by the ICV-CSIC based on controlled hydrolysis of titanium isoproxide with the complexing agent, acetylacetone using polyethylene glycol (PEG) to increase porosity. A significant effort was also made to determine the resistance to aging by solar radiation of the photoactive coatings deposited on polymeric supports. These high-performance materials are especially promising for such applications since they are available in monolithic shapes that make it easier for the gas to go through; they are light and economical. However, in the long term they are damaged by radiation so studies have been made in weathering chambers and exposure to real sunlight. The results found show that the polymer is slowly photo-oxidized depending basically on the nature of the support. Polyethylene terephthalate (PET) is damaged by

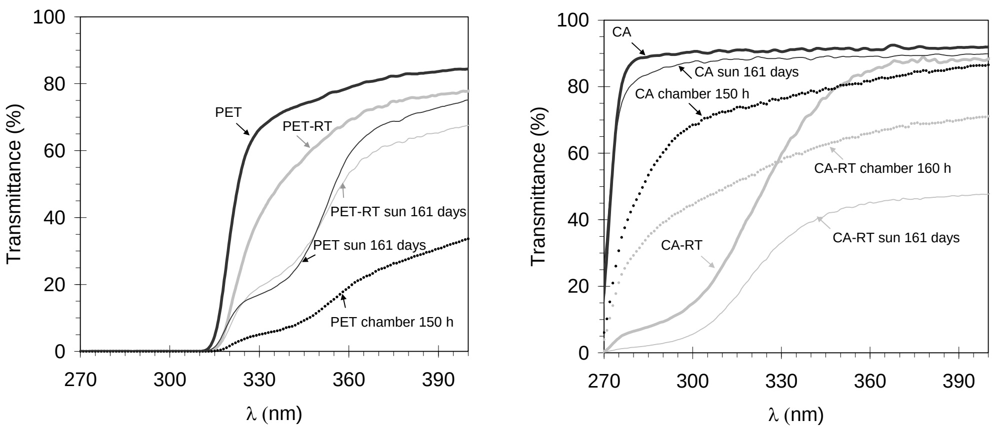

Figure 4.14. Aging of PET (left) and AC (right) and effect of the TiO_2 coating. Transmittance of the uncoated (black) or coated (grey) polymers, fresh (thick), after 161 days of sun exposure in Madrid, May-September 2006 (thin) and after 160 hours of accelerated weathering (dashed).

homogeneous photo-oxidation, but cellulose acetate (CA) is affected by the photocatalytic radicals formed in the TiO_2 film. It is predictable that the results found in this research will lead to strategies for improving the durability of these photocatalysts. On the other hand, in collaboration with the UENF, we are working with TiO_2 supported on mesoporous MCM-41 modified by Cr and Ce. The results wit these catalysts show that they are active in the elimination of H_2S when illuminated with visible light, which provides a way for improving the use of sunlight by this detoxification technology.

Publications:[4.51]-[4.52]

4.3.3 TRAGUA

Treatment and reuse of waste water for sustainable management

Participants: CIEMAT, UAH, UCM, UAM, CIESOL and up to 25 different research groups

Contact: Dr. B. Sánchez; benigno.sanchez@ciemat.es

Funding: MEC CONSOLIDER-INGENIO Project, cost shared: 700 k€

Duration: January 2006 - December 2009

Background: The reuse of waste water generated in wastewater treatment plants (WWTPs) is a key goal for a country like Spain which must face a continual water deficit, which is especially dramatic in the regions most influenced by the Mediterranean. However, the generalized use of this resource requires health guarantees to be established to make the reuse of the water is a safe and acceptable option. These considerations are reflected in the new Royal Decree 1620/2007 on reuse of treated water. In this sense, the main goals of the TRAGUA project is to evaluate the microbiological quality of the treated water, determine the presence of emerging micropollutants, and establish effective, economically feasible methods for increasing the quality of this resource and widening the possibilities for its use.

Purpose: The work of the CIEMAT Environmental Applications of Solar Radiation to Air Group, as an integral part of the intensive treatment of waste water, is to evaluate the use of solar photocatalysis based on the use of TiO_2 for the disinfection and elimination of emerging micropollutants in CPC pilot plants (39 liter volume). This work is done in close coordination with the CIESOL Group, which will develop an analytical methodology suitable for determining the presence of non-biodegradable trace pollutants which are not eliminated by biological treatment in WWTPs.

Achievements in 2007: During this first year, the group has participated in the preparation of the database of the status of water treatment in Spain by collecting data and making the sheets for the provinces of Cadiz and Seville. All in all, basic information has been collected from 55 WWTPs in Seville and 84 in Cadiz.

The following facilities have been prepared to evaluate the photo-efficiency of the various photocatalysts:

Twin prototypes composed of three CPC models arranged in series, with a 3.08-m^2 irradiated surface. The CPC reflector is made of highly anodized aluminum. Each 8-tube module is mounted on a frame of galvanized sheet metal, the support structure is tilted at the same angle as the latitude of the site (37º) (Figure 4.15). The three modules are connected in series and the

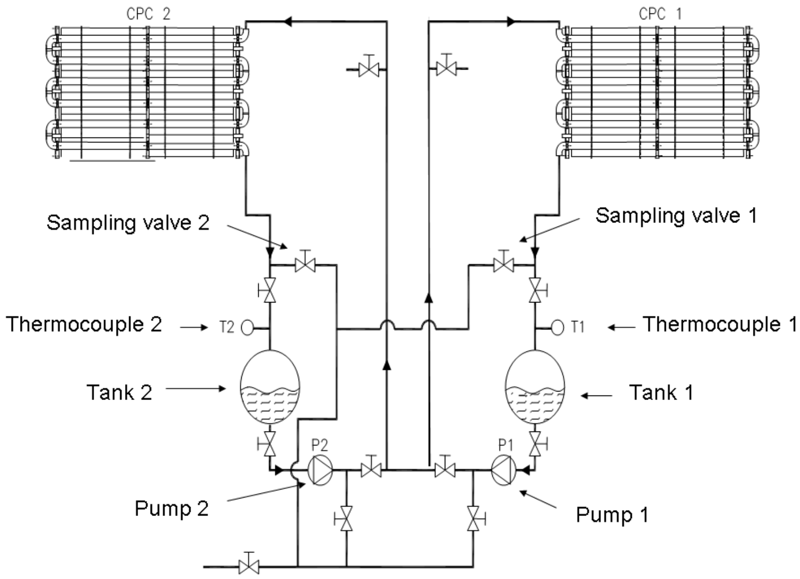

Figure 4.15. Flow diagram of the twin CPC solar photoreactors adapted for supported TiO_2 testing at the PSA.

working fluid circulates directly from one to the other and ends up in a 10-L spherical borosilicate-glass recirculation tank. A centrifugal pump (PAN WORLD, Model: NH-100 PX, 100 W) returns the fluid to the concentrators at a flow rate of 20 L/min, in discontinuous operation. The fluid passes in turbulent flow (Reynolds of about 17000) through irradiated glass tubes and opaque HDPE (high-density polyethylene) tubes.

Each of the spherical tanks also has a glass cover for inserting components required during the test, such as reagents, gas (air, oxygen, inert gas, etc.), a pH electrode, or anything else. Furthermore, two thermocouples have been installed in the inlet manifolds of both tanks (PT-100, Philips, Digital-280), showing the temperature inside the photoreactors at all times.

4.4 Solar Desalination Group

Seawater desalination is one of the possible Solutions to the sever water shortage problem our planet is going to undergo in the first half of this Century, a problem that is not exclusive to developing countries, as persistent seasonal droughts are more and more common in some regions of developed countries.

In spite of all of the advances made in the last decades, seawater desalination technologies continue being intensive fossil-fuel consumers. In the current global setting, with growing price instability in the oil market and the environmental demands of the Kyoto Protocol, sustainability of desalination depends inevitably on improving the efficiency of the technical processes involved, as well as the use of renewable energy resources.

In 2007, two new research projects were begun (POWERSOL and MEDIODIA Projects), and the membrane-distillation pilot module test plant for were completed under the MEDESOL Project.

Under the National Plan for Access to the Plataforma Solar de Almería, several research groups from different Spanish universities have had the opportunity to use the PSA desalination facilities as guest researchers.

4.4.1 POWERSOL

Generation of mechanical energy based on solar thermal engines. http://www.psa.es/projects/powersol

Participants: CIEMAT-PSA (Coord., ES), Univ. de La Laguna (ES), IDMEC (PT), AOSOL (PT), ETH (SW), ECOSYSTEM (ES), INETI (PT), ENIT (TN), PHOCHEM (EG), LOTUS (EG), AES (TN), LENREZA (DZ), Univ. Seville (Coord., ES)

Contacto: Dr. J. Blanco, julian.blanco@psa.es
Dra. L. García, lourdesg@esi.us.es

Funding: FP6-2004-INCO-MPC-3. Topic: B.1.5 – Renewable Energy: Cost-effective renewable energies for Mediterranean specific needs; 1.050 k€.

Duration: January 2007 – December 2009

Background: The absence of an electrical distribution grid and/or drinking water shortage are limiting factors in the social and economic development of many regions in the Mediterranean area where solar resources are plentiful. Therefore, the use of solar technologies offers an opportunity to supply these basic needs while developing the community. Solar thermal power generation has been developed in the range of tens of MW (SEGS plants, USA). However, many applications to remote areas, such as pumping for irrigation, heating and cooling, rural electrification, etc., only require tens of kW. Furthermore, in remote areas, such systems must be simple and robust, easy to control and operate and not require qualified labor.

Purpose: The main purpose of the POWERSOL Project is to develop a mechanical-energy generation technology based on solar thermal energy which is also low-cost and environmentally-friendly, and which is optimized for the supply of the basic needs of rural or small communities.

Achievements in 2007: At the beginning of the project, extensive bibliography was compiled on solar thermal engines, low and medium-temperature solar thermal collectors, and thermodynamic cycles and working fluids proposed in the scientific literature or commercially installed.

Three different maximal temperature ranges were considered: 80-90ºC (Cycle 1), 150ºC (Cycle 2) and 250-300ºC (Cycle 3), and thermodynamic

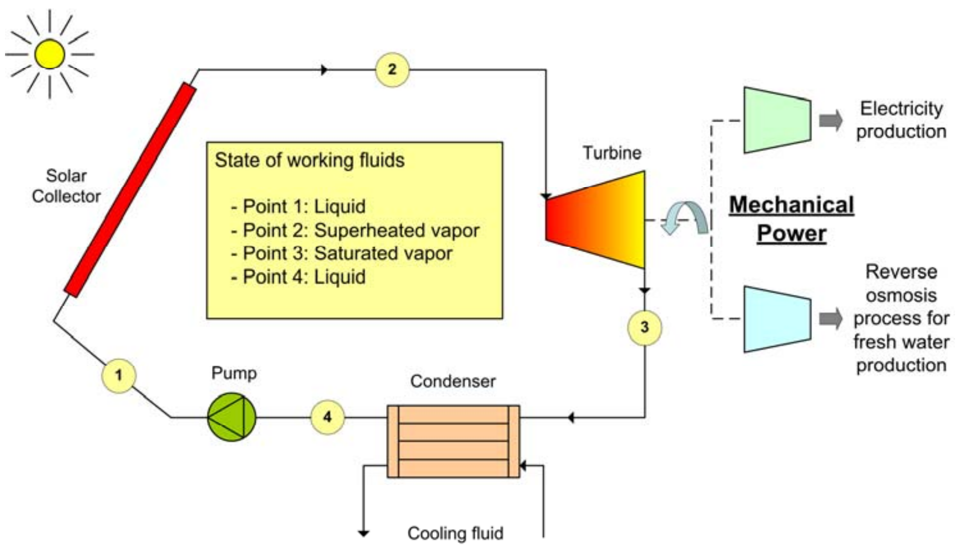

Figure 4.16. Diagrama conceptual de sistema POWERSOL

simulation was performed to determine the most suitable working fluids for each of the cycles.

In 2007, design was begun of three solar thermal collectors for use in the cycles mentioned above. An advanced flat-plate solar collector will be used for Cycle 1, while for Cycle 2, a CPC solar collector will be designed. For Cycle 3, it was decided to design and install a linear Fresnel concentrator.

In 2007, design of an organic 5-kW_e Rankin cycle pilot plant to be connected to the SSPS parabolic-trough collector field was begun. Installation of this plant is scheduled for the early months of 2009 and will be used for experiments in ORC cycles in the range of 160ºC to 250ºC.

Publication: [4.49]

4.4.2 MEDESOL

Seawater desalination by solar membrane distillation systems.

http://www.psa.es/webeng/projects/medesol/index.html

http://www.innowatech.org/

Participants: CIEMAT-PSA (ES, Coord.), Univ. de La Laguna (ES), Acciona Infraestructuras S.A. (ES), Aguas de las Cuencas Mediterraneas, S.A. (ES), AOSOL (PT), Univ. Stuttgart (DE), Tinep S.A. de C.V. (MX), Centro de Investigación de Energía – Univ. Nacional Autónoma de México (MX), Kunglika Tekniska Högskolan Stockholm (SW), Scarab Development AB (SW), Iberinsa S.A. (ES).

Contact: Dr. J. Blanco, julian.blanco@psa.es
Dr. W. Gernjak, wolfgang.gernjak@psa.es

Funding: VI-FP. Global Change and Ecosystems.; 1.375k€. Presupuesto CIEMAT: 417K€.

Duration: Octubre 2006 – Septiembre 2009

Background: Development of membrane distillation processes in which the energy is supplied by low-temperature (60-100 ºC) solar collectors. This very innovative process has a high potential for application, especially for small-to-

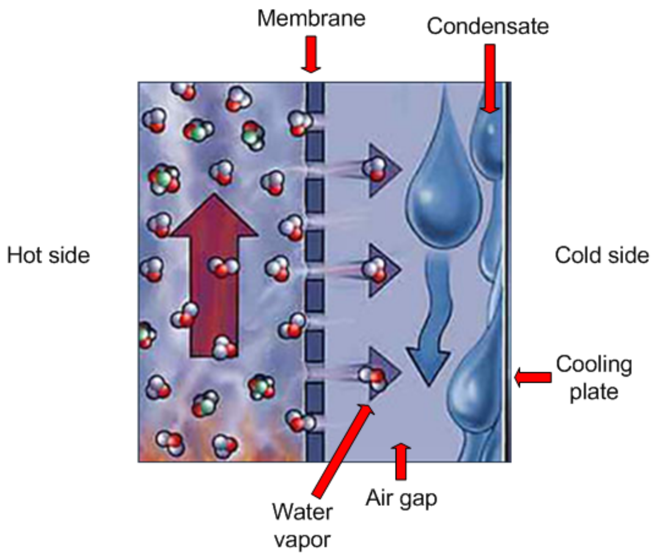

Figure 4.17. Principle of membrane distillation (courtesy of Xzero, Sweden)

Figure 4.18. General view of the MEDESOL-I pilot plant (left); Detail of three membrane distillation modules (right.)

medium capacity units (0.1 – 50 m^3/day). Its main characteristics are its robustness and simplicity, which make it ideal for, geographically isolated, self-sufficient systems. The principle is shown in Figure 4.17. Steam penetrates a hydrophobic membrane due to the difference in steam pressure on either side of the membrane. This steam pressure difference is generated by keeping different temperature levels on either side. This way, the steam goes through the membrane from the hot side to the cold side, where it is condensed and collected as highly pure distillate.

Purpose: (i) Investigate membrane distillation and increase system efficiency, (ii) develop efficient heat recovery system concepts, (iii) develop and/or improve system components, as for example improved solar collector and a heat exchanger which minimizes fouling through innovative surface treatments, (iv) develop a system with a capacity of several cubic meters per day, (v) development of a self-sufficient system with hundreds of liters daily capacity.

Achievements in 2007: During the first half of 2007, the main task in the project was to develop technical components. Several project partners have developed: (i) a CPC solar collector specifically designed for membrane distillation process temperatures (70-100ºC), (ii) develop fouling-resistant surfaces, which have been implemented on titanium heat-exchanger plates installed in the pilot plant now under testing at the Plataforma Solar de Almería.

In the second half of the year, the MEDESOL-1 membrane distillation pilot plant was designed and installed. Its basic characteristics are described in the PSA infrastructure Section 2 of this report on Installations and Infrastructures. The plant is scheduled for commissioning in the first half of 2008.

4.4.3 OSMOSOL

Desalination by reverse osmosis with solar thermal energy. http://www.psa.es/projects/osmosol

Participants: Univ. de la Laguna (Coord., ES), CIEMAT-PSA (ES), Univ. Rovira i Virgili - CREVER (ES)

Contact: Dr. J. Blanco, julian.blanco@psa.es
Dra. L. García, lourdesg@esi.us.es

Funding: Ministry of Education and Science (National Scientific Research Plan, Technological Development and Innovation, 2004-2007); 70 k€ (CIEMAT).

Duration: December 2005 – December 2008

Background: Desalination consumes a large amount of energy, which for reverse osmosis of seawater is about 3.5 kWh/m^3. Keeping in mind the 2 10^6 m^3/day produced in Spain, it is undoubtedly necessary to develop sustainable and economically feasible desalination technologies. Today's solar reverse-osmosis plants are based on photovoltaic technology. The use of solar thermal energy in this promise will make better use of the solar resource and lower environmental impact by eliminating the problems of waste involved in the use of batteries required by photovoltaics.

Purpose: The main purpose of the OSMOSOL project is to develop an innovative technology based on the application of solar thermal energy to reverse osmosis desalination which also fulfils the principles of environmental sustainability and economic feasibility. To do this, the thermal energy is collected and concentrated by a solar device to feed a thermodynamic cycle based on a fluid that evaporates at relatively low temperatures and that, connected to turbine-compressor, makes it possible to directly transform the thermal energy into mechanical energy required for osmosis.

Achievements in 2007: This year we collaborated in the design of a stationary CPC solar collector for use in organic Rankin cycles at a temperature of around 90ºC, with efficiencies of about 50% and at a cost of 300-350€/m^2.

Several latest-generation Ao Sol CPC 1.15x collectors have been installed in the stationary solar collector field of the SOL-14 Plant (described in Section 2.10 of this report), in order to study the behavior of the new materials employed in their construction for the same range of temperatures as the prototype OSMOSOL collector. None of the problems found in the previous CPC 1.12x collectors appeared.

Several different types of advanced solar collectors were also simulated to determine their annual solar fraction and the efficiency of a hybrid system of reverse osmosis desalination connected to organic Rankin cycles for production of mechanical energy.

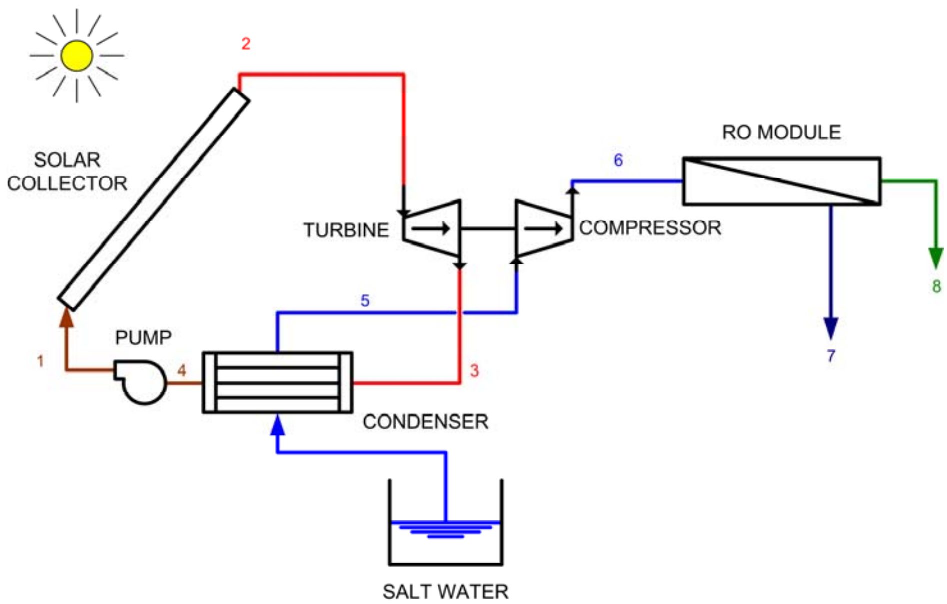

Figure 4.19. Generic reverse osmosis system connected to a solar engine

4.4.4 DEREDES

Development of desalination using renewable energies. http://www.befesa-cta.es/deredes/

Participants: Befesa Construcción y Tecnología Ambiental (Coord., ES), Instituto Tecnológico de Canarias, S.A. (ES), CIEMAT-PSA (subcontracted by Befesa) and Univ. La Laguna (subcontracted by Befesa)

Contact: Dr. J. Blanco, julian.blanco@psa.es

Funding: Ministry of Industry, Trade and Tourism (PROFIT); 83 k€ (CIEMAT).

Duration: April 2006 – December 2007

Background: Desalination processes consume appreciable amounts of energy, so their generalized use requires a parallel increase in energy resources, with the consequent increase in environmental impact. In this sense, the implantation of more efficient and sustainable technologies is crucial, and application of renewable energies offers the most obvious alternative for fossil fuel savings and reduction of environmental impact.

Purpose: The general purpose of this project is to stimulate business in the field of desalination using renewable energies, in system design, installation and maintenance, for which the following specific goals are set:

1. Technical and economic comparison of the various technologies.
2. Design of pre-commercial plants for three different scenarios.
3. Identification of organizations and companies who can favor implantation of the desalination technologies with renewable energies.
4. Prepare an R&D strategy for planning continuity of activities undertaken.
5. Dissemination of results

Achievements in 2007: In 2007, the tasks corresponding to Stages 3 (Evaluation of technologies not yet mature. Need for development), 4 (Technical and economic evaluation of technologies now applicable due to their maturity) and 5 (Final selection of technologies and design).

Three scenarios were proposed Stages 4 and 5: Scenario 1 (Technified places with electricity grid and high demand for water), Scenario 2 (Islands with average water demand) and Scenario 3 (isolated coastal and inland zones).

In Stage 4, CIEMAT contributed with a technical and economic analysis of solar MED systems with gas backup (specific and also for electricity/water cogeneration) in Scenario 1. In Scenario 2, this analysis was performed for MED plants with low-temperature solar thermal energy with biodiesel backup and MED plants connected to saline solar ponds. In Scenario 3, CIEMAT analyzed the option of membrane distillation using solar thermal energy.

In Stage 5, CIEMAT made a detailed analysis for connecting a parabolic-trough solar collector field to a 57600 m^3/day MED distillation plant with natural gas backup, leading to a total cost of desalted water of 2.14 EUR/m^3.

4.4.5 MEDIODIA

Multiplication of effort for development, innovation, optimization and design of advanced greenhouses http://www.cenitmediodia.com/

Participants: Repsol YPF, Acciona Solar (CIEMAT-PSA como subcontratado), Ulma Agrícola, Ulma Packaging, Acciona Agua, Ulma Handling Systems, Fundación Cajamar, Agrobio, Biomiva, Grupo AN, Ingeteam

Contact: Dr. J. Blanco, julian.blanco@psa.es

Funding: Ministry of Industry, Commerce and Tourism (CENIT Project);

Duration: January 2007 – December 2010

Background: Intensive agriculture is one of the most significant agricultural sectors. Research and development is therefore necessary to allow Spain to rank in the vanguard of agrofood technology, boosting other industrial activities and services.

Purpose: The general purpose of the project is to make a strategic study in the field of agriculture under plastic which develops a new advanced greenhouse concept, highly automated, efficient in consumption of power and water and that allows diversification of profitable crops any time of the year in different Spanish climates using an integrated production system.

Achievements in 2007: During this time, available solar thermal seawater desalination options and technologies were analyzed for their individual and centralized application to intensive agriculture under plastic.

4.5 Characterization of Solar Radiation

In 2007, activities related to the study and characterization of Solar Radiation concentrated on participation in projects related to:

- Analysis of spectral distribution of solar radiation.
- Treatment of satellite images for calculation of solar radiation

The most relevant action taken in these lines is described below. Publications associated with this activity may be found in Section 4.6 [4.53]-[4.58].

4.5.1 MEDERAS

Measurement of Spectral Distribution of Solar Radiation and Characterization of its Influence on Photovoltaic Generation by Different Technologies

Funding: Cofunded by the National RD&I Plan.

Purpose: The main goals of this project were:

a. Develop automatic filtering and classification methodologies for measured spectra
b. Validate spectral models of global, diffuse and direct normal radiation.
c. Characterization and analysis of the influence of spectral distribution of solar radiation on the various technologies.

d. Estimate atmospheric components based spectral measurements of direct solar irradiance.

As an extension of the work begun in 2006, in 2007, estimation of atmospheric parameters from measurements of spectral irradiance was completed. In particular, work concentrated on estimating the atmospheric turbidity parameters and the ozone column using direct solar spectral irradiance measured with the SP 320 D spectroradiometer from October 2005 to September 2006. Angstrom turbidity values (Figure 4.20) show that turbidity is seasonal, with low turbidity in autumn and winter and occasionally high in spring and summer. Furthermore, days with very high atmospheric turbidity were found to be associated with intrusion of Saharan dust (Figure 4.22).

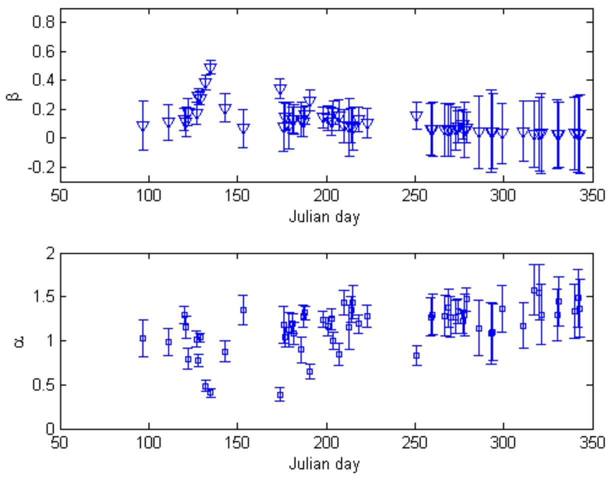

Figure 4.20. Medias diarias de los parámetros de turbiedad de Angstrom

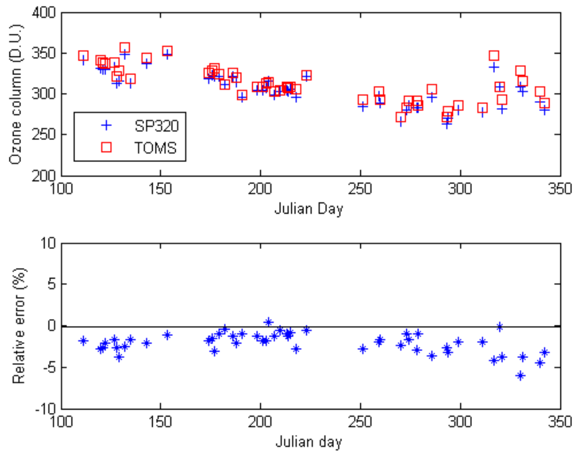

Figure 4.21. Mean daily values of the ozone column compared to satellite estimations

A simple procedure for estimating the ozone column from spectral measurements of direct solar irradiance in the Huggins band was developed. The results for clear days in October 2005 to September 2006 are shown in Figure 4.21, where satellite data are compared with the OMI instrument (TOMS – Total Ozone Mapping Spectrometer) from NASA. There is very good agreement between them with less than 5% errors.

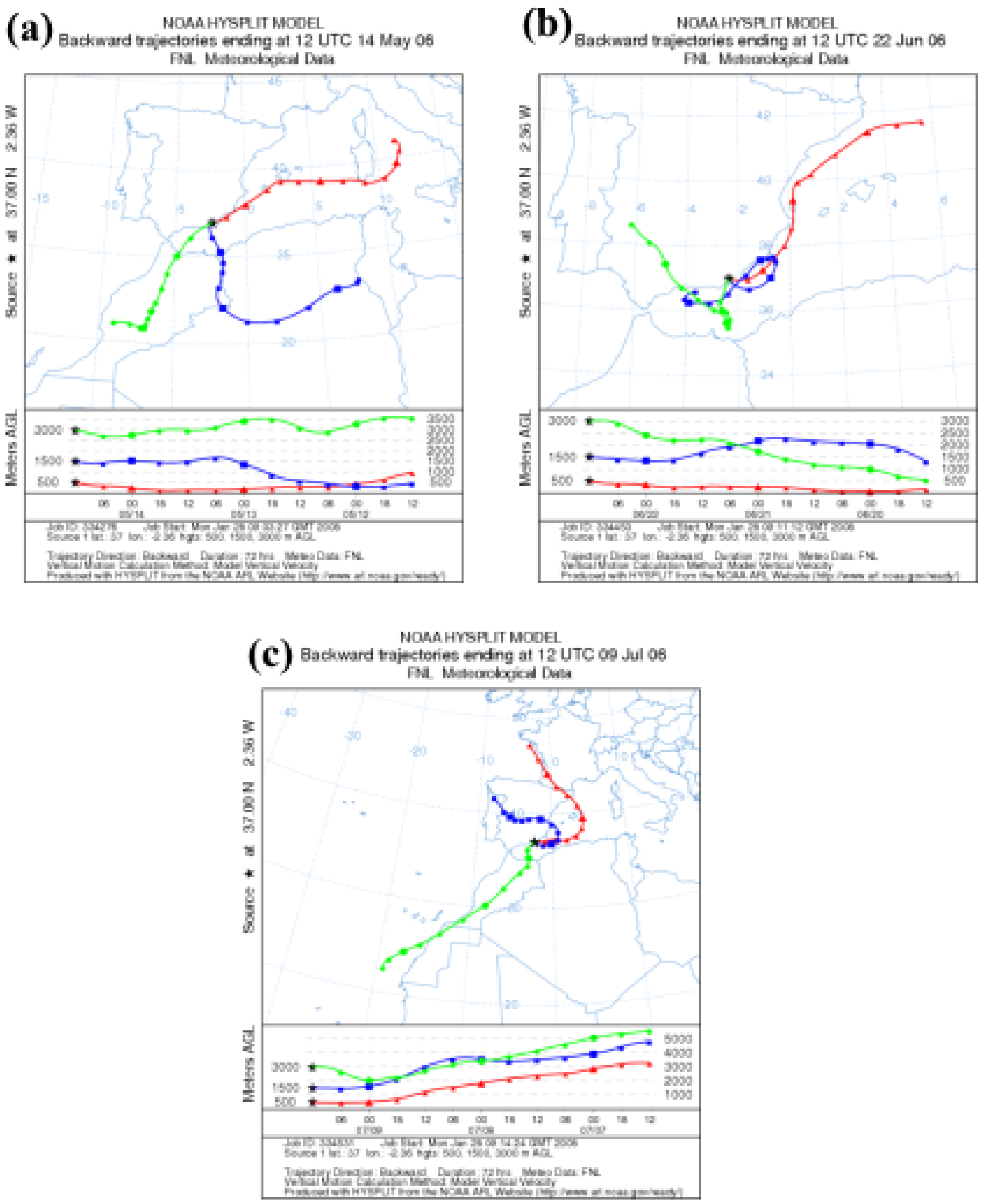

Figure 4.22. Retrotrajectories of air mass estimated with HYSPLIT for says with high atmospheric turbidity.

4.5.2 Projects in Collaboration with Companies Promoting Solar Thermal Power Plants

Since 2005, as fruit of the social and political situation in the Spanish power market, promotion of solar power plants has begun to grow considerably in Spain. To the extent that activity in this sector increases, better knowledge of solar radiation as an energy resource is beginning to have a relevant effect on cost/profit studies done for them, as for any other business activity.

In 2007, numerous contacts were made with companies which finally materialized in technical assistance to several of them and three Cooperation Agreements.

4.5.3 Participation in the SOLAR Tres Project

In the Solar Tres Project, funded by the European Commission, the Solar Radiation Characterization Group cooperated in the complete analysis of the solar resource at the site, employing the 12-year database of satellite images to supply 12 years of hourly global and normal direct irradiation data. Furthermore, a meteorological reference year for the SOLAR Tres site was calculated. In addition, we participated in the review and consulting on the weather station which is now acquiring solar radiation data for the future site of this plant.

4.5.4 MESOR Project

In the second half of 2007, the MESOR (Management and Exploitation of Solar Resources) Project funded by the EC 6th Framework Program was begun. In this project, the most internationally recognized groups in the field of solar resource are collaborating to advance toward the following goals:

- Standardization of uncertainty measurements and comparison of models and methods for estimating solar radiation from satellite images.
- Preparation of a user's guide for solar radiation database treatment and management
- Design and construction of an Internet portal for homogenization and simple distribution of data and products related to knowledge of the solar resource on the terrestrial surface.

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5 Events

Diego Martínez Plaza

2007 saw the inauguration of two new R&D facilities at the Plataforma Solar de Almería, the "research container-demonstrator" of the ARFRISOL Project and the prototype solar collector with "linear Fresnel" geometry, called FRESDEMO.

5.1 Inauguration of the ARFRISOL Bldg.

A new office building for PSA scientific personnel, built as a "research container-demonstrator" as part of the Unique Strategic Project, "ARFRISOL", was inaugurated on December 13th.

Figure 5.1. Uncovering the commemorative plate

The Secretary of State for Universities and Research, Mr. Miguel Ángel Quintanilla Fisac, accompanied by the Director General of CIEMAT, Mr. Juan Antonio Rubio Rodriguez and other personalities, uncovered the commemorative plate on the wall of the entrance to the new building

5.2 Inauguración del lazo FRESDEMO

The FRESDEMO loo pis the property of the "Solar Power Group" company and was installed at the PSA to study its behaviour under real solar operating conditions through the cooperation of the owner with DLR and CIEMAT.

The facility was inaugurated on July 9, with the attendance of the Deputy Director General of CIEMAT, Prof. Dr. Cayetano López, Mr. Michel Möller, Secretary of State of the German Ministry of the Environment (BMU) and Prof. Dr.-Ing. Johann-Dietrich Wörner, President of the DLR Board of Directors.

Figure 5.2. Official welcome by the Deputy Directory General of CIEMAT

Figure 5.3. View of the FRESDEMO loop at the PSA

6 List of Acronyms

AMES ..... Environmental Applications of Solar Energy Unit (PSA)
AOP .... Advanced oxidation process
AOS .... Average oxygen state
AR .... Anti-reflective

BG .... Bulgaria
BMU ...... German Ministry for the Environment and Nuclear Safety
BOD....... biological oxygen demand
BSRN ..... Baseline Surface Radiation Network

CA .... cellulose acetate
CAM....... Caja de Ahorros del Mediterráneo
CDTI ...... Centre for the Development of Industrial Technology
CEA .... Atomic Energy Commission (FR)
CEDER ... Centro de Energías Renovables - CIEMAT
CFU .... Colony forming units
CHA .... Spanish German Agreement
CIEMAT .. Centro de Investigaciones Energéticas Medioambientales y Tecnológicas
CIESOL .. CIEMAT-UAL Mixed Center for Solar Energy Research'
CNRST ... National Center for Scientific and Technical Research (MA)
CNRS-PROMES . Centre National de la Recherche Scientifique – Processes, Materials and Solar Energy Laboratory
COD ...... chemical oxygen demand
CPC .... Compound parabolic concentrator
Cpsi .... cells per square inch
CREVER.. Centre of Technological Innovation in Heat Upgrading and Refrig-

eration - University Rovira i Virgili (ES)

CRS ...... Central Receiver System

CRT....... central receiver technology

CSIC ..... Consejo Superior de Investigaciones Científicas

CSIR ..... Council for Scientific and Industrial Research (Za)

CSIRO ... Commonwealth Scientific and Research Organization (AU)

DE .... Germany

DER ...... Renewable Energies Dept. (CIEMAT)

DISS ..... Direct Solar Steam

DK .... Denmark

DLR....... Deutsches Zentrum für Luft- und Raumfahrt e.V. (DE)

DZ .... Algeria

EAWAG.. Swiss Federal Institute of Aquatic Science

EC .... European Commission

EEIG ..... European Economic Interest Grouping

ENEA..... Agency for New Technology, Energy and the Environment (IT)

ERDF..... European Regional Development Fund

ETHZ..... Federal Polytechnic Institute of Zurich (CH)

ES......... Spain

EU .... European Union

FP......... EC Framework program

FPI........ Ph.D. research fellowship (Formación de Personal Investigadora)

FR......... France

GPS ...... global positioning system

GR .... Greece

HSCG .... High Solar Concentration Group

ICP-AES. inductively coupled plasma atomic emission spectroscopy

ICP-CSIC Instituto de Catálisis y Petroleoquímica -CSIC

ICROSS . International Community for Relief of Starvation and Suffering

ICV-CSIC Instituto de Cerámica y Vidrio - CSIC

IL .... Israel

IMP........ information module profile
INCO ..... Programme for RTD Cooperation with third countries and international organisations
INETI..... Instituto Nacional de Engenharia (PT)
INTA....A Instituto Nacional de Técnica Aeroespacial (ES)
IPHE...... International Partnership for the Hydrogen Economy
IT.......... Italy

JRC........ Joint Research Centre (EU)

LECE...... Laboratory for Energy Testing of Building Components
LPG .... Liquid petroleum gas

MA .... Morocco
MCYT..... Spanish Ministry of Science and Technology
MEC....... Spanish Ministry of Education and Science
MED ...... Multi-effect desalination
MNSV..... melon necrotic spot virus

NEAL ..... New Energy Algeria
NTU....... Nephelometric Turbidity Units

ORP....... oxidation reduction potential

PDVSA ... Petróleos de Venezuela, S.A.
PEG .... polyethylene glycol
PET........ polyethylene terephthalate
PL ....
PSA .... Plataforma Solar de Almería
PTC .... Parabolic-trough collector

RCSI...... Royal College of Surgeons in Ireland
RU......... Russia

SBR .... Sequence Batch Reactor
SEM....... Scanning electron microscope

SME ...... Small and medium enterprises

SODIS ... Solar disinfection

SolLab ... Alliance of European Laboratories on Solar Thermal Concentrating Systems

SSPS ..... Small Solar Power Systems Project

TOC ...... total organic carbon

TSS....... total suspended solids

UAL....... Univ. Almería

UL......... University of London (UK)

UNED .... National Univ. for Distance Education (ES)

UENF..... Universidade Estadual do Norte Fluminense (Br)

UPS....... uninterrupted power system

URJC ..... Univ. Rey Juan Carlos

USACH .. Univ. Santiago de Chile

USC ...... Univ. Santiago de Compostela

UU .... Univ. Ulster

UV .... Ultraviolet

VOCs..... volatile organic compounds

WP........ Work package

WWTP ... Wastewater treatment plant

XRD ...... X-ray diffraction

ZA .... South Africa

ZSW Zentrum für Sonnenenergie und Wasserstoff Forschung (DE)

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