The Plataforma Solar de Almeria (PSA) is recognised as a Major European Scientific Installation by the European Commission and is also the largest and most complete R&D centre in the world dedicated to Solar Thermal Concentrating Systems, Solar Desalination and Photochemistry. It is a privileged place for the development, evaluation, demonstration, and transfer of solar concentrating technologies, both for thermal applications and for chemical processes. It offers researchers a location with insolation and climate characteristics similar to those of the developing countries of the equatorial belt with the advantages of owning the largest scientific facilities among European countries. Research activity at PSA has been structured around four R&D Units:

- Solar Concentrating Systems Unit. This unit is devoted to promote and contribute to the development of solar concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes.
- Thermal Storage and Solar Fuels Unit. Its objective is to look for different solutions to make concentrating solar thermal a dispatchable energy supply, either by thermal storage systems and/or solar fuels as hydrogen.
- Solar Desalination Unit. Its objective is new scientific and technological knowledge development in the field of brackish and sea water solar desalination.
- Water Solar Treatment Unit. Exploring the chemical possibilities of solar energy for promoting photochemical processes, mainly in water for treatment and purification applications but also for chemical synthesis and production of photofuels.

The PSA consists of solar concentrating and solar water treatment facilities that are unique in the world due to their variety and size. In the SFERA-III Project we offer access to the following installations:

PSA Solar Furnace (SOLFU)

The PSA Solar furnace installation houses three solar furnaces: two horizontal axis solar furnaces SF60 and SF40 and a vertical axis solar furnace SF5. It is the installation with the highest concentration of the PSA, with peak concentrations range from 3000 to 7000 kW/m^2. The SF60 (the 60 kW power solar furnace) consists essentially of a 130 m^2 flat heliostat and a 100 m^2 surface reflection parabolic concentrator, slats shutter or attenuator, and test table. This SF60 has a peak concentration of 3000 kW/m^2. The SF40 (the 40 kW power solar furnace) consists of a flat heliostat with 100 m^2 reflecting surface, a

Eurodish parabolic concentrator with 56.5 m^2 projecting area, slats shutter or attenuator, and test table with three axis movement, and has a peak concentration of 7000 kW/m^2. The vertical axis solar furnace (SF5) reaches concentrations over 6000 kW/m^2 and operates in a vertical axis, i.e. parabolic concentrator and heliostat are vertically aligned on the optical axis of the paraboloid. Basically consists of a concentrator mirror, placed upside-down with the reflecting surface facing the floor, on a 18 m height metallic tower; in the center of the base of the tower there is a flat heliostat, whose center of rotation is aligned with the optical axis of the concentrator. At the top of the tower, in the test room, and 2 m below the vertex of the concentrator, there is a test table. Finally, under the test table and at floor level of the test room, a louver attenuator is placed, located between heliostat and concentrator. The main advantage of the SF5 is that the focus is arranged in a horizontal plane, so that the samples may be treated on a horizontal surface, just placing them directly in the focus, without a holder, avoiding problems of loss of material by gravity in those tests in which the treatment requires surface melting of the specimens.

Figure 1. **Interior view of the PSA SF60 Solar Furnace in operation (left) and Interior view of the PSA SF5 Solar Furnace (right)**.

Molten Salt Test Loop for Thermal Energy Systems (MOSA)

The Molten Salt Test Loop for Thermal Energy Systems is a replica of a thermal energy storage (TES) system with molten salts and a two-tank configuration. With 40t of molten salts plant, this installation consists basically of two tanks, -one vertical, for hot molten salts, and another horizontal, for cold molten salts-, a thermal oil loop that can be used for heating the salt up to 380°C and cooling it to 290°C, and two flanged sections, where different components for this type of loops (e.g. valves, flow meters, heat trace, pumps…) can be tested.

Figure 2. **MOlten SAlt test loop for Thermal Energy Systems (MOSA).**

Central Receiver System (CRS)

The Central Receiver System is an outdoor installation specially conditioned for scaling and qualifying systems prior to commercial demonstration. The heliostat field is composed of 92 units, all completely autonomous and powered by photovoltaic energy, with centralized control communicated by radio. Under typical conditions of 950 W/m^2, total field capacity is 2.5 MWth 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 three test platforms, all test levels with access to pressurized air (1.5m^3/min at 7-8 bar), pure nitrogen supplied by two batteries of 23 standard-bottles (50dm3/225bar) each, steam generators with capacity of 20 and 60kg/h of steam, cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from a 8m^3 buffer tank for use in steam generators or directly in the process, and the data network infrastructure consisting of Ethernet cable and optical fibre.

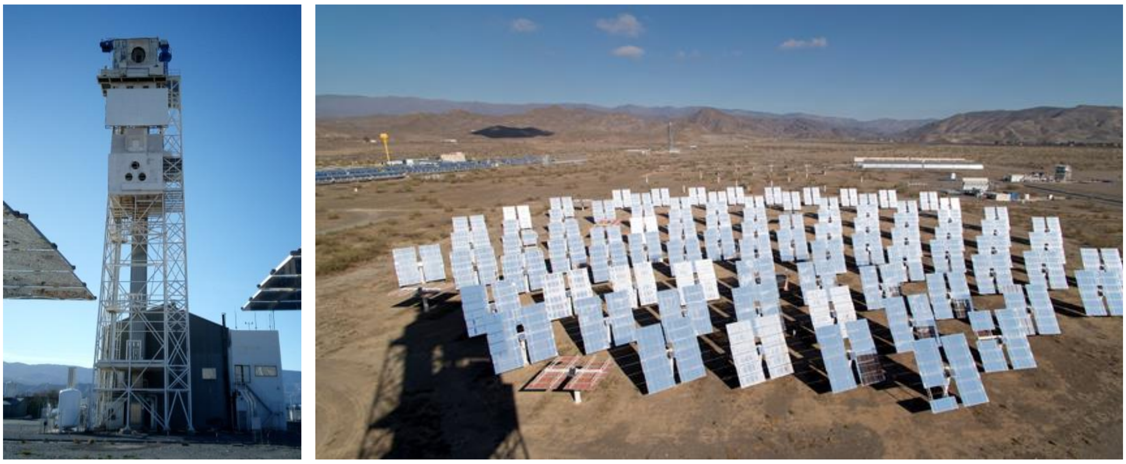

Figure 3. **Central Receiver System (CRS) tower (left) and front view of the CRS tower test bench (right)**.

A hybrid heat flux measurement system to measure the incident solar power that is concentrated by the heliostat field is located at the CRS tower. This method comprises two measurement systems, one direct and the other indirect. The direct measurement system consists of several heat flux sensors with a 6.32 mm front-face diameter and a response time in microseconds. These micro sensors are placed on a moving bar which is mounted in front of the reactor window. The indirect measurement system works optically with a calibrated CCD camera that uses a water-cooled heat flux sensor as a reference for converting grey-scale levels into heat flux values.

SolWater

SolWater is the biggest European installation dedicated to solar water treatment and disinfection at pilot plant scale. It is composed by several photo-reactors based on Compound Parabolic Collectors (CPC) technology combined or not with other conventional and advanced technologies for achieving the scientific and development goals of wastewater (urban and industrial) treatment/disinfection and reuse in different applications (crops irrigation, industrial processes, etc.). Available solar pilot plants are built by modules which can be connected in series. Each module consists of a number of photo-reactors placed on the focus of an anodized aluminum mirror with CPC shape to optimize solar photons collection in the photo-reactor tube. The modules are place on a platform titled at 37° from the horizontal to maximize the global solar collection of photons through the year. In addition, the pilot plants may be equipped with added systems for different purposes, for example: sedimentation tanks (for catalyst recovery), heating and cooling systems for temperature control during the experiments, coupling with other treatment technologies like bio-treatment, ozonation, etc. A 2 m^2 CPC collector with 10 borosilicate glass tubes (50 mm diameter), illuminated volume of 25 L and a total volume of 40 L is connected to four electrocells for experimental research on electro-photo-Fenton processes for decontamination and disinfection of water. There are also several CPC prototypes for applications of water disinfection. One of these systems consists of two 50 mm outer diameter borosilicate-glass tubes installed in the reflector focus and mounted on a fixed platform tilted 37°. The illuminated collector surface area is 0.42 m^2. The total volume of the system is 14 L and the illuminated volume is 4.7 L. Photo-reactor for solar disinfection 'FITOSOL' consists of two components, a CPC solar reactor (4.5 m^2 of collector surface, 45 L of irradiated volume, and 60 L total) and a pilot post-treatment plant for photocatalyst recovery (100L). The system is equipped with pH and dissolved oxygen online sensors, connected to a controller for automatic data acquisition. In 2016, a new pilot plant with two modules of 2 m^2-collectors with different mirror shape (CPC and U mirror type) has been installed. It is composed by a feeding polypropylene tank of 192 L of total volume and a preparation tank of 92.5 L, connected by gravity to the CPC and U type photoreactors. The last presents 1.98 m^2 of irradiated surface with a recommended operating volume of 53 L. The whole pilot plant is equipped and automatically controlled by a UVA solar sensor. In addition, the pilot plant is equipped with a solar water heating panel which permits to increase the temperature of water prior to discharge it in the photoreactors.

WetOx

WetOx is a new installation based on combinations of high temperature and pressure, various proportions of oxygen and nitrogen, the use of oxidants and different catalysts, for the application of highly powerful oxidant conditions for the treatment of complex wastewaters. The innovative part of this installation lays in its combination with solar energy. The high versatility of this system opens a wide spectrum of applications. The WetOx pilot plant consists of a stainless steel reactor with a total volume of 1000 mL, a magnetic stirrer, a breakup disk, liquid reagents injector prepared to operate under 200 bar and a maximum temperature of 300 °C, thermo-probe, pressure sensor (until 250 bar) and a cooling-heating jacket , all made of stainless steel. The Wet Air Oxidation pilot plant includes an automatic system of control and data acquisition of diverse parameters such as pressure, temperature, reagents dosses and mixture.

Figure 4. **CPC in the Solar Water (SolWat) pilot plant (left) and Wet Air Oxidation (WetOx) pilot plant (right)**.

HyWATOx

The HyWATOx installation is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions. This is the first photo-reactor at pilot plant scale in Europe devoted to the application of this technology for the generation of solar hydrogen. The pilot plant consists on a stainless steel tank with a total volume of 22 L, fitted with gas and liquid inlet and outlet and a sampling port. Two parallel mass flow controllers are used to control the desired N_2 gas flow into the reactor headspace during the filling step.

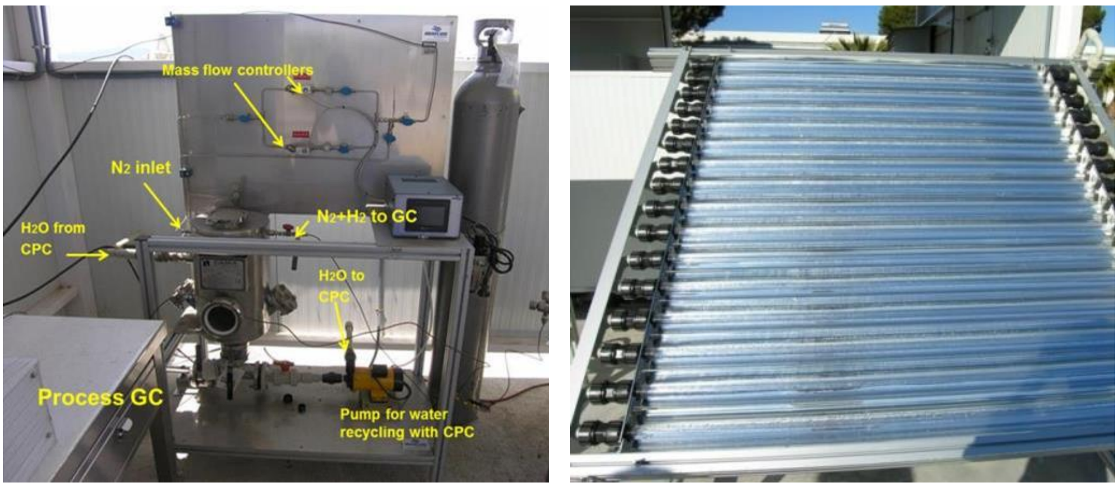

Figure 5. **Solar pilot plant for photocatalytic generation of hydrogen (left) and CPC photo-reactor (right)**.

DESAL

Figure 6. **Solar Multi-Effect Distillation installation (SOL-14)**

The DESAL installation consists of several test-beds and bench-scale units for the experimental assessment of different desalination technologies: **a) Solar Multi-Effect Distillation installation (SOL-14)**: it is composed of a 14-effect vertically-stacked forward-feed MED unit. Working in low-temperature mode (LT-MED at 70ºC) the unit has a nominal fresh water production of 72 m^3/day for a thermal consumption of 200 kW. For low-temperature operation the MED plant is powered by the AQUASOL-II solar field (large-aperture flat-plate) **b) Double-Effect Absorption Heat Pump – MED Plant & NEP CCP Solar Field (DEAHP-MED):** A Double-Effect Absorption Heat Pump (DEAHP) can be coupled to the last effect of the MED unit for low-temperature thermal energy recovery and gives the possibility of working in ABS-MED mode. The DEAHP is able to work in hybrid mode (solar/gas) and has a nominal thermal consumption of 100 kW at180ºC. For solar operation a 230-m^2 of small aperture parabolic trough solar collectors is connected to a steam generator that powers the DEAHP. The solar field is composed of 8 collectors (NEP Solar Polytrough 1200) arranged in four parallel rows with two collectors in series within each row. This solar field has a nominal capacity of 125 kW_{th} (at 200ºC) **c) Test-bed for solar thermal desalination applications (AQUASOL-II)**: The AQUASOL-II solar field is a large-aperture high-efficiency flat plate solar field composed of 60 collectors (Wagner Solar LBM 10HTF) with a total aperture area of 606 m^2 and a total thermal power output of 323 kW_{th}

under nominal conditions (efficiency of 59% for 900 W/m^2 global irradiance and 75ºC as average collector temperature). It consists of 4 loops with 14 large-aperture flat plate collectors each (two rows connected in series per loop with 7 collectors in parallel per row), and one additional smaller loop with 4 collectors connected in parallel, all of them titled 35° south orientation. The

flexibility of the solar field allows the operation of each loop independently, through their own valves and pumping system, each loop being connected to an individual heat exchanger where a user can connect its own thermal desalination mode for testing purposes under real climatic conditions. **d) Test-bed for solar membrane distillation applications at pilot-scale (PILOT-MD)**: It is composed of two solar fields of flat-plate collectors available: one of 20 m^2 with two parallel rows of five collectors in series (Solaris CP1 Nova, by Solaris, Spain), and another of 40 m^2 with four large-aperture collectors in parallel (LBM 10HTF, by Wagner Solar, Spain). The test-beds allow for a stationary heat supply using the thermal heat storage or for direct supply of solar energy without buffering. The installation is fully automated and monitored (temperatures and flows) and allows for heat flow regulation. The maximum thermal power is 7 kW_{th} in one case and 14 kW_{th} in the other, and hot water can be supplied with temperature up to about 90ºC. The installation currently operates with Membrane Distillation modules and has a wide range of different commercial and pre-commercial units from several manufacturers. **e) Bench-Scale Units for MD & FO Applications (LAB-MEM)**: The *bench-scale unit for testing membranes on isobaric MD* consists of a test-bed with a small plate and frame module that can be used for evaluating direct-contact, air-gap or permeate-gap membrane distillation. The module is made of polypropylene and designed so that the membrane can be replaced very easily. The module has a condensation plate on the cold side to operate on air-gap configuration, but it can be closed at the bottom to operate on permeate-gap keeping the distillate inside the gap or spared to operate on direct-contact mode. The effective membrane surface is 250 cm^2. The installation has two separate hydraulic circuits, one on the hot side and another on the cold side. On the hot side, there is a tank of 80 L equipped with an electric heater (3 kW) controlled by a thermostat (90ºC maximum), and circulation is made from the storage and the feed side of the module by a centrifugal pump. On the cold side there is a chiller (800 W at 20ºC) controlled by temperature and water is circulated between a cold storage of 80 L and the module. The circuit is heat insulated and fully monitored for temperature, flow rate and pressure sensors, connected to a SCADA system. The *bench-scale unit for flat sheet membrane distillation testing* is a high precision laboratory grade research equipment designed for testing fundamental and feasibility test trials on membrane distillation. It possesses the following unique features that are essential for representative and scalable results: 1) Cell format with representative flow distribution. The cell size is sufficient for flow distribution and regime to be applicable to full scale MD technology. 2) Adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VMD, VAGMD). 3) Temperature precision of 0.5°C. 4) Driving force temperature difference controllable. 5) Fully automated control system and large range of possible parameter settings by touch screen PLC. 6) Practical A4 format for membrane and condenser foil materials. The *bench-scale unit for 2-stage forward osmosis and pressure-retarded osmosis* consists of a test-bed with two small plate and frame modules of forward osmosis (FO) which can be connected in series or in parallel. There is, therefore, one pump for the draw solution and two for the feed solution, each with variable flow and flow-rate measurements. The hydraulic circuit has been modified so that the modules can be operated in pressure retarded osmosis (PRO) mode. For that purpose, steel pipes and a high-pressure pump (3 L/min; up to 17 bar) are installed in the draw side, and cells with operational pressure up to 15 bar are used. The cells have each a total effective membrane area of 100 cm^2, and hydraulic channels in zig-zag 4 mm wide and 2 mm deep. The system uses one container for the draw solution and two for the feed solutions, each placed on a balance in order to measure changes in the mass flow rates of the draw solution and the feed solution of each cell. The containers have an automatic dosing system to keep the salinities constant. The system has two conductivity meters for low salinity and one for high salinity, as well as pressure gauges in each line and temperature readings.

Figure 7. **Internal (left) and external (right) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility.**

Services offered by the infrastructure

- The **SOLFU** installation is very suitable for **Surface Treatments of Material**, since metallic and ceramic samples can be treated at very high temperatures with great accuracy. The treatments can be carried out in air, vacuum or in controlled atmosphere conditions, inside different vacuum chambers available. Some of the thermal treatments that can be carried out are: quenching, sintering, nitrurization, carburization, foaming, coatings, sintering of nanostructured materials, etc. The SOLFU installation is also very suitable for **Volumetric Absorbers Tests**, since these absorbers can be tested at high temperatures, with very good control of both, temperatures and air flow, in particular in the high flux focus of the PSA SF60 solar furnace. Various configurations are ready for the porous absorber materials to be tested. Finally, the SOLFU installation is suitable for **Accelerated Aging – Durability Tests**, since metallic and ceramic samples can be treated at very high temperatures, and cycles can be performed very precisely. The tests can be carried out in air, vacuum or in controlled atmosphere conditions. Several tests campaigns have been carried out in the last years on this topic.

- **MOSA** is hosting visitor who wants to **Characterize Components and Equipment for molten salts loops**, i.e. to test small hydraulic components and equipment, such as valves and pressure transducers to be placed in molten solar salt loops in order to verify their feasibility. Since MOSA is a replica of a thermal energy storage system with molten salts and two-tank configuration, it can be used to **Validate any Simulation Model** used to predict the behaviour of such type of thermal storage systems. Additionally in the labs associated to MOSA it is possible to study the **Feasibility of Materials for Sensible and Latent Thermal Storage Systems**, i.e. validation of a storage material for a certain application by testing it under different temperature conditions and environments according to an accelerated ageing test plan at the devices of the thermal storage laboratory. Such study allows predicting and ensuring the long-term performance of the storage material under service condition. It can be applied to materials for either sensible or latent storage systems.

- The **CRS** tower allows **Thermal and Thermodynamic characterization of prototype Reactors for Central Receiver on Tower Technologies under real operating conditions**: Selection of the operating parameters depending on the required power, flux (from 50 kW/m^2 to 2500 kW/m^2) and mechanical boundary conditions for the prototype testing. On the other hand, this CRS tower can be used for the **Qualification of Solar Driven Processes**: Test design and evaluation of the endothermal processes under pilot scale operating conditions, and the **Qualification of Solar Hydrogen Production Process under realistic conditions**, which involves: Preliminary simulation of the system using ray-tracing approach (commercial software). Design/ Set up of test bench. Test operation, Data collection, Data processing end evaluation reporting. Furthermore, the installation is equipped with a large quantity of auxiliary devices that allow the execution of a wide range of tests in the field of solar thermal chemistry.

- **SolWater** is the biggest European installation dedicated to **Solar photocatalytic treatment and disinfection of urban and industrial wastewaters** at pilot plant scale.

- **WetOx** is a new installation based on combinations of high temperature and pressure, various proportions of oxygen and nitrogen, the use of oxidants and different catalysts, for the application of highly powerful oxidant conditions for the **treatment of complex wastewaters**. The innovative part of this installation lays in its combination with solar energy.

- The **HyWATOx** installation is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions and the generation of solar hydrogen. The high versatility of this system opens a wide spectrum of applications for the **simultaneous solar hydrogen production and wastewater treatment**.

- The **DESAL** installation offers the following services: a) **SOL-14** installation allows to carry out **experimental model (stationary and dynamic) validation of MED processes**. First effect of the MED plant works with hot water instead of saturated steam, which allows to establish different temperature levels for the top brine temperature (TBT) as well as the final condenser temperature. The installation also permits to perform research in new materials for the heat exchange surfaces required in the MED process. The connection between solar field, thermal storage and MED plant is regulated through a fully-controllable system of valves which also lets to carry out research tasks in automatic control. b) **DEAHP-MED** installation offers full flexibility for operation of a coupled MED-DEAHP system at different temperatures, allowing **simulation model validation and research in control algorithms** for the different existing flow regulation devices. The DEAHP can be powered by solar thermal energy coming from a 230-m^2 small-aperture parabolic trough solar field (NEPSOLAR 1200) or from a propane gas-boiler (saturated steam at 180°C, 10 bar abs. c) **AQUASOL-II** solar field flexibility offers to the research community the possibility of coupling it with any low-temperature thermal desalination system (60-90°C) for **testing purposes under real climatic conditions**. The AQUASOL-II installation also offers the service of **automatic control development and testing for static collector solar fields and dynamic modelling**. d) **PILOT-MD** is designed for **evaluating solar thermal membrane distillation (MD) prototypes at pilot scale**. The researchers can assess the performance of their own MD modules, model validation of the existing MD modules at PSA and research in automatic control of solar MD processes. e) **LAB-MEM**: The PSA desalination laboratory is equipped with three bench-scale units for the **testing of membrane distillation (MD) process** that allow to the researchers to test different types of membranes adjusting the MD channel configuration to all channel variants (air-gap, permeate-gap, direct-contact) as well as testing them at atmospheric pressure or working with vacuum. Temperature precision of 0.5°C and driving force temperature difference controllable make these bench-scale unit a very valuable tool for model validation and experimental assessment of the membrane behaviour under different conditions of the saline solution. The bench-scale unit with 2-stage **forward osmosis (FO)** and **pressure-retarded osmosis (PRO)** is equipped with two small plate and frame modules of FO which can be connected in series or in parallel. The hydraulic circuit can be modified so that the modules can be operated in PRO mode. With this installation the researchers are able to carry out **assessment of new FO membranes, and model development of this kind of technology** due to the full control of temperatures and flows within the experimental installation.