PLATAFORMA SOLAR DE ALMERIA (PSA)

DESCRIPTION OF STRATEGIC LINE AND ACTION PLAN 2021-2025

April 2021

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1. DESCRIPTION OF RDI ESTRATEGIC LINE

1.1. NAME OF STRATEGIC LINE

Solar Thermal and Photochemical Technologies

1.2. DESCRIPTION

The Strategic Line of Solar Thermal and Photochemical Technologies is fully associated with the PSA activities and in line with the Strategic Objectives of the currently approved PSA STRATEGIC PLAN as Singular Scientific and Technological Infrastructures (ICTS) of the Spanish ***Ministerio de Ciencia e Innovacion***. Main objectives inspiring the research and technology activities in the PSA are the development of Concentrated Solar Thermal technologies (CST) to produce Solar Thermal Electricity (STE, also known as Concentrated Solar Power or CSP), development of new processes and devices that allow a better use of the solar radiation for other energy applications and environmental protection, specially focused on desalination and water treatment. Therefore, fully allocated in the ambit of renewable energy technologies and applications and highly relevant to potentially and significantly contribute to the clean energy transition in countries and regions with solar energy resources.

The Line is structured into the following seven topics, being the first 3 of them directly related with the corresponding technologies, the last 3 focused on specific applications and the 4th one (Materials) horizontal to all others:

1) **Linear Focusing concentrating technologies**. Unit devoted to testing, evaluation and development of components and applications for linear focusing solar concentrators.
2) **Point Focusing concentrating technologies**. This unit targets are focused in providing technical assessment to the industry stakeholders together with the research and innovation related to power tower technologies such as the measurement of concentrated solar flux, R&D of new fluids and receivers, optical analysis.
3) **Thermal Energy Storage for concentrating solar thermal technologies**. Unit addressing the design, testing and optimization of thermal storage systems for temperatures above 100ºC.
4) **Materials for solar concentration technologies**. Unit addressing the development and testing of new or improved materials for CST solar technologies or their applications, as well as thermal treatment, aging or modification of materials.
5) **Thermochemical Processes to Solar Fuels and Raw Materials Production**. This includes high temperature processes based on concentrated solar energy to hydrogen and other valuable and energy intensive raw materials production.
6) **Solar Thermal Applications.** This Unit is devoted to the development and evaluation of solar thermal technology for industrial process heat applications, including desalination and brine concentration.
7) **Solar Treatment of Water.** Unit focus on exploring the chemical possibilities of solar energy, especially the potential for water decontamination and disinfection and the production of solar fuels by means of photochemical processes.

These R&D Units are largely self-sufficient in the execution of their budget, planning, scientific goals and technical resource management. Nevertheless, the R&D units share many PSA resources, services and infrastructures, so they stay in fluid communication with the PSA Technical Services Unit, which coordinates technical support services. For its part, the Director´s Office and Administration must ensure that the budget capacities, infrastructures and human resources are efficiently distributed. It is also the Director´s Office and Administration that channels demands to the various general services located at the CIEMAT's headquarters in Madrid. Figure 1 shows the current PSA internal structure and organization to provide support to the previously indicated research units and all external ICTS users.

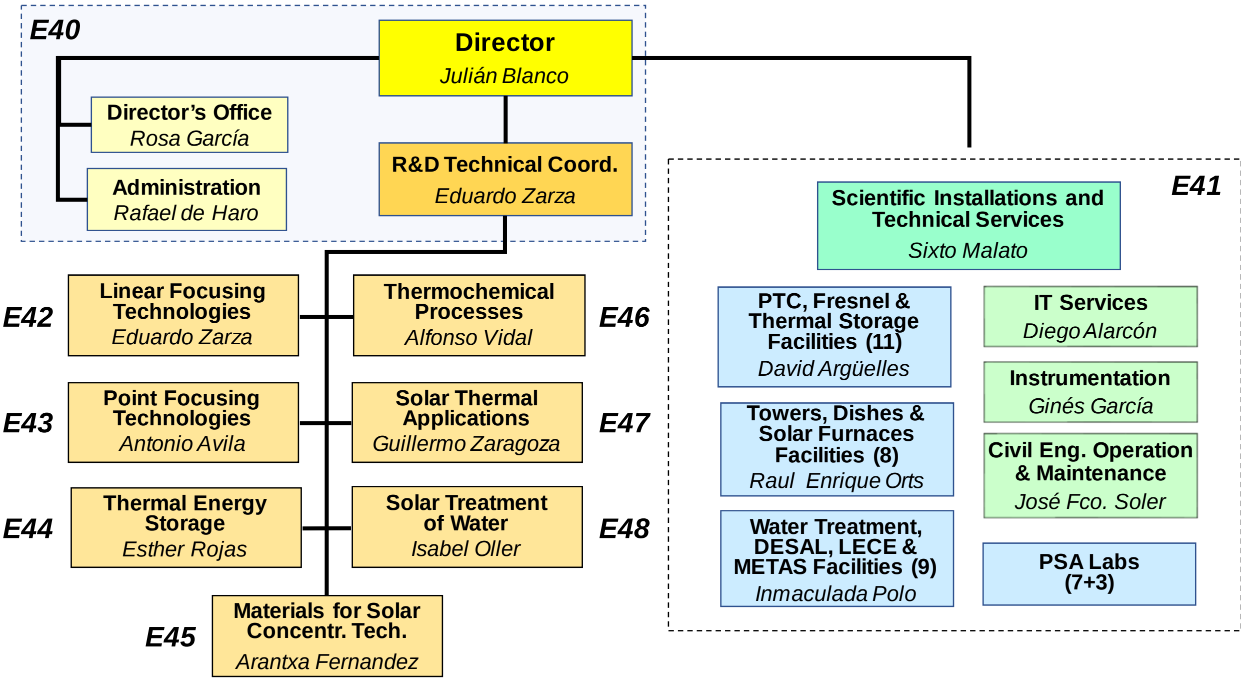


Fig. 1. Updated PSA organisation chart

Among the various services that PSA facilities have, it is worthy to highlight, among others, the followings: Library, Computing, Mechanical workshop, Instrumentation and control, etc.

1.3. GENERAL OBJETIVES

1.3.1. Scientific Objectives

The main objective of ongoing research in the field of the Strategic Line is the achievement of performance improvement and cost reduction, associated to three specific challenges: i) Investment cost reduction; ii) Operation & maintenance cost reduction; iii) Efficiency increase. Development of new applications for these technologies is also within the objectives of this Strategic Line. More specifically, the scientific and technological objectives of the line, grouped and associated to the 7 previously indicated topics, are summarized as follow (see also Fig. 1):

a) Linear Focusing concentrating technologies (E42)

- Advanced heat transfer fluids with lower environmental footprint for working temperatures higher than 450ºC
- Cheaper collector designs and innovative plant configurations achieving better use of solar energy resource and technologies
- More efficient, cost-effective and reliable receiver tubes and flexible connections
- Higher degree of automation of plant control by condition monitoring and artificial intelligence
- New applications for linear focusing concentrating technologies

b) Point Focusing Solar Thermal Technologies (E43)

- Receivers for mean solar fluxes >1MW/m2
- Receiver thermal efficiencies higher than 85% for temperatures above 600°C
- New innovative working fluids with operating temperatures above 600°C for Rankine cycles, and above 750°C for unfired Brayton cycles.
- Self-calibrating and cheaper heliostats, below 90 EUR/m2 (installed).

- High precision heliostat field and automated control for long focal distance and/or high temperature applications up to 1200°C.
- Innovative plant configurations achieving better use of solar energy resource and technologies.
- High degree of automation of condition monitoring of all relevant plant parameters to optimize O&M, including virtualization of plants, augmented reality and remote supervision.
- Provide solutions for onsite measurements to characterize the total solar receiver's surface in terms of temperature and concentrated solar irradiance, and solar radiation extinction within the solar field.
- New applications for point focus solar thermal technologies

c) Thermal Energy Storage for concentrating solar thermal technologies (E44)

- Feasibility of materials for thermal storage systems
- Testing and characterization of prototypes, components and equipment for thermal storage systems
- Design and optimization of thermal storage system following an holistic approach
- Integration of thermal storage systems in different applications

d) Materials for solar concentrating technologies (E45)

- Development and testing of advanced materials and coatings for CST technologies (primary and secondary reflectors, absorbers, receiver covers, receiver particles, etc.) for increased robustness, efficiency and long-term durability under operating conditions in harsh climates or environments.
- Development and standardization of suitable methodologies for the optical characterization and lifetime prediction of materials for CST technologies.
- Development and testing of cost-effective cleaning methods to reduce the water consumption in the O&M activities.
- Usage of CST technologies for materials' treatment, including thermal treatment, synthesis, characterization, aging and processing of materials at high temperature, by surface or volume treatment (with solar receiver's or reactors).
- Development and testing of nanostructured materials to enhance thermal conductivity.
- Development of catalysers for electrochemical and solar thermal applications to produce fuels (hydrogen, ethanol, methanol…).

e) Thermochemical processes to solar fuels and raw materials production (E46)

- Solar-to-fuel conversion efficiencies ≥ 15 %, with the integration of heat recovery.
- Proof-of-concept operation of solar fuels production reactors, comparable to "traditional" chemical industrial plant operation.
- Development of components for high solar concentration, especially those with a significant impact on the performance of the technology (solar receivers, secondary concentrators, windows, etc.).
- Use of materials that do not exhibit toxicity and/or corrosion issues especially under the extreme conditions that many thermochemical cycles require.
- 1 MW scale demonstrator with at least 1000 hours of operation time.
- Explore custom-made solar fields options capable of achieving the high temperatures required on high-efficiency receivers/reactors.
- Integration of receiver/reactor concepts to the requirements of industrial processes, such as lime, aluminum, etc.

f) Solar process heat applications (E47)

- Advanced solutions to reduce energy consumption, operation and maintenance costs of solar thermal applications.
- Autonomous and smart small solar fields e.g. fail detection software, active & predictive management of the solar plant.
- Development of software tools for predictive design and test a solar plant in an industrial environment.
- Hybridization by integrating power generation from the produced industrial heat or from waste heat.
- Improved efficiency of solar fields for low temperature heat applications.
- Design and implementation of solar thermal separation solutions for desalination, water treatment, brine concentration and product recovery.
- Integration of desalination technologies in concentrated solar power plants for water and power cogeneration.

g) <u>Solar treatment of water (E48)</u>

- Design, improvement and optimization of solar photo-reactors.
- Technologies at the edge of the knowledge based on a combination of reductive and oxidative photochemical processes for the elimination of particularly complex and persistent contaminants.
- Combination of advanced solar photo-oxidation processes with other innovative technologies for decontamination and disinfection of all kinds of wastewater for reusing purposes (own industrial processes or crops irrigation).
- Production of fuels and artificial photosynthesis by solar photocatalysis.
- Residues valorisation. Combination of separation technologies and solar processes to achieve the recovery of nutrients from wastewaters for their subsequent use in agricultural activities.
- Comprehensive systems analysis. Techno-economic assessment and Life cycle analysis for new developed technologies and /or applications.

1.3.2. Other Objectives

- To provide support to the national and international CST/STE industry and water treatment related companies and public/private R+D entities.
  - Submission of proposals to include specific topics related to CST and photochemical technologies in the work plan of the European Framework Programmes
  - Joining efforts with other national and international R+D centres and entities to increase the presence of the CST technologies in the national Energy programmes prepared by European countries
- Promoting technological innovations aimed at reducing costs that contribute to increasing the efficiency of solar thermal and photochemical technologies.
- To increase the awareness and knowledge of CST/STE and photochemical technologies and applications.
- Strengthening the cooperation between the business sector and scientific institutions in the field of research, development and demonstration of technologies related to the concentration of solar radiation and water treatment.
- Performing studies to show the usefulness of CST technologies to achieve a decarbonized energy market. Environmental life cycle assessment of the solar process and comparison to the standard technology.
- Improve and expand the services that ICTS-PSA offers to the national and international scientific community as well as to technology-based companies.
- Promoting the introduction in the market of solar thermal technologies and those derived from thermochemical and photochemical solar processes.

- Participation in courses, seminars, workshops and other dissemination events to promote CST and thermochemical and photochemical technologies.
- Contribution to national and international standardization of CST/STE technologies. More specifically, participation in the National Committee AEN-CTN206 and in the international standardization committees IEC-TC117 and related ISO working groups.
- To maintain the leadership and coordination of major European initiatives (EERA JP-CSP, EU-SOLARIS, Water Europe, etc.) related to CST.
- Training of researchers, engineers and technicians in solar thermal technologies and water treatment so as to increase high HR training in the Spanish labour market.
- Formation of PhD specialised in solar thermal technologies and water treatment.
- Promoting technological cooperation North-South, especially in the Mediterranean area and Latin American.

1.4. RELEVANCE, ALIGNMENT AND STRATEGIC ORIENTATION

The Strategic Line, focused on the development of technological solutions that help to tackle global challenges and achieving Sustainable Development Goals, has a very high relevance either from the technical or the economic point of view. With regard to the technical potential of concentrated solar technologies to electricity generation, according to IEA, commercial STE plants produced 15,6 TWh in 2019 and the organization forecasts a worldwide contribution, in the Sustainable Development Scenario, of 53,8 TWh in 2025 and 183,8 TWh in 2030[1], with around 60 GW of installed power. However, the technical potential of CST is much higher if we also add the capability of providing thermal energy for industrial heat applications. The yearly world thermal energy consumption of the industrial sector is higher than 23.600 TWh, and a significant portion of this energy consumption can be delivered with CST technologies[2]. Thanks to the thermal storage capability, the power generated by CST power plants is fully dispatchable and, therefore, these plants can perform the role of baseload and also making possible the penetration of very high rates of renewable electricity in sunny countries (complementing the non-dispatchable technologies like PV and Wind). Another important technical factor that could strongly promote the deployment of CST technology for electricity production in scenarios close to 100% of renewable energy generation, is the necessity of a specific amount of synchronous electricity generation to guarantee system inertia levels above the current critical ones and, as a consequence, sufficient grid stability. Advances in electronics and converters will certainly reduce the current inertia levels limit[3].

With regard to the economic potential point of view of STE, recent estimations provide LCOE values starting from 142 USD/MWh in current CST project development in China (the country with the highest activity in this technology in 2019) at locations with DNI above 1,800 kWh/m2/yr[4]. Lowest bidding price for dispatchable STE reaches 73 USD/MWh (DEWA project case in Dubai). Up to 2019, around 80% of all worldwide commercial deployment of CST technologies has been made by European companies. Assuming a conservative 50% share in the future developments up to 2030 and the previous estimation of 60 GW worldwide installed to that year, a business market of around 100 billion Euros (considering an average investment of 3-3.5 million Euros per nominal installed MW) to the European CST industry, is estimated. Besides, it should be noticed that electricity generation by CST technology with thermal energy storage can be more competitive when the comprehensive net costs of these plants are

[1] International Energy Agency. "Concentrating Solar Power tracking report" (https://www.iea.org/reports/concentrating-solar-power-csp). June 2020.

[2] Solar Payback project. "Solar heat for industry" (https://www.solar-payback.com/wp-content/uploads/2020/06/Solar-Heat-for-Industry-Solar-Payback-April-2017.pdf).

[3] S.C. Johnson, J.D. Rhodes, M.E. Webber, "Understanding the impact of non-synchronous wind and solar generation on grid stability and identifying mitigation pathways". Applied Energy, 262, 114492, 2020.

[4] J. Ji, H. Tang, P. Jin, "Economic potential to develop concentrating solar power in China: A provincial assessment". Renewable and Sustainable Energy Reviews, 114, 109279, 2019.

compared to other renewable energy sources[5]. Typically, in today competitive power markets, the value of energy is determined in advance taking into account that real-time energy imbalances, mainly as a consequence of load forecast errors. The addition of variable wind and solar production to these markets may increase the quantity of balancing energy transacted in real-time providing more value to operational flexibility. This is why the energy storage development will be the key element which will probably determine the final contribution of different generation technologies to the grid systems. And this is a unique advantage of CST enabling dispatchable power supply on demand thanks to the integration of low-cost thermal energy storage. CST is perfectly suited for the delivery of power during the evening, night and morning when PV cannot deliver (much) power. Current cost for thermal storage systems in CST plants is around 40 €/kWh[6], being in the case of batteries around 350-450 USD/kWh[7].

Environmental applications are another relevant area of the Strategic Line. As both global energy consumption and concern over environmental contamination continue to increase, it is imperative to develop renewable energy resources that neither rely on fossil fuels nor emit carbon dioxide. Solar energy has attracted much interest as one such sustainable, clean energy source. Among the various approaches to solar energy conversion, solar-driven photo-processes is one of the most promising ways to convert solar energy into valuable products. The use of direct radiation can render process technologies more efficient, as it also may affect the quality of the conversion process under study. The most prominent examples are water desalination[8] and wastewater treatment[9]. But also many synthesis processes could benefit from the direct use of solar radiation as artificial photosynthesis. The era of apparently plentiful and cheap resources is ending: raw materials, water, air, biodiversity and terrestrial and aquatic ecosystems are all under pressure. Among those resources, water is fundamental to human health, food security or sustainable development. However, freshwater resources are under increasing stress due to climate change, pollution, overexploitation and increasing competition between different end-users. To mitigate the problem of water scarcity, wastewater reuse and desalination by solar energy are an opportunity that needs to be properly integrated in the water cycle. Therefore, the use of solar thermal technologies for the reuse of water and the extraction and valorisation of substances is important to support water circular economy. Furthermore, since irrigation stands out as one of the most established applications of new sources of water, PSA's strategy contributes to food security and sustainable agriculture, addressing the water-energy-food nexus in regions with water scarcity and abundance of solar radiation.

The alignment of the strategic orientation of the line with national and international challenges and research plans is also excellent. On one hand, defined research topics (PSA Research Units) are fully coincident with the existing Sub-Programmes of the European Energy Research Alliance (EERA) Joint Program on Concentrated Solar Power (JP-CSP), organization coordinated from the PSA. On the other hand, the research objectives of the Strategic Line are also fully aligned with the ones defined by the Strategic Energy Technologies Plan (SET-Plan) of the European Commission, allocating CST/STE within the group of key European renewable technologies. The SET-Plan also promoted and officially approved the CSP Implementation Plan (CSP-IP). Working Group (IWG) of the CSP-IP, chaired from Spain. Additionally, PSA strategic research topics and objectives are well in concordance with the outcome and finally approved Strategic Research and Innovation Agenda (SRIA) of the Clean Energy Transition Partnership

[5] "The Economic and Reliability Benefits of CSP with Thermal Energy Storage: Literature Review and Research Needs". CSP Alliance Report, 2014.

[6] L. Crespo, "The double role of CSP plants on the future Electrical Systems", presented in the WBG Conference Concentrating Solar for Power and Heat, April 2020.

[7] M. Mehos, C. Turchi, J. Vidal, M. Wagner, Z. Ma, C. Ho, W. Kolb, C. Andraka, A. Kruizenga, "Concentrating Solar Power Gen3 Demonstration Roadmap". National Renewable Energy Laboratory - Sandia National Labs, 2017.

[8] Dao, V.-D., Vu, N.H., Yun, S. "Recent advances and challenges for solar-driven water evaporation system toward applications". Nano Energy, 68, 104324, 2020.

[9] Pesqueira, J.F.J.R., Pereira, M.F.R., Silva, A.M.T. "Environmental impact assessment of advanced urban wastewater treatment technologies for the removal of priority substances and contaminants of emerging concern: A review". Journal of Cleaner Production, 261, 121078, 2020.

(CETP), an important European initiative to boost and accelerate the energy transition in a coordinated action among European countries and the European Commission. Finally, PSA strategic research topics and objectives are also well aligned with ESTELA (European Solar Thermal Electricity Association) and PROTERMOLAR (Spanish Association to the promotion of Concentrated Solar Thermal Industry) research priorities thanks to the fluent and constant existing relationship. The strategic vision of the line in terms of water treatment is completely aligned with the Joint Programming Initiative (Water JPI) on "Water challenges for a changing world" aiming to tackle the ambitious grand challenge of "Achieving sustainable water systems for a sustainable economy in Europe and abroad". Research activities defined in some of the units at PSA are focused on the same challenges described and considered in the strategic plan of Water Europe, a member-based multi-stakeholder platform; the EC recognized voice and promoter of water-related innovation and RTD in Europe. Within this European Organization, PSA is leading the working group "Renewable Energy Desalination" and co-leading the working group "Contaminants of Emerging Concern".

In addition, scientific and development interests of solar water treatment are also aligned with those of the Mediterranean Basin Countries within the frame of PRIMA – Partnership for Research and Innovation in the Mediterranean Area and ENI CBCMED initiative (the largest Cross-Border Cooperation initiative implemented by the EU under the European Neighbourhood Instrument). Special emphasis is given in attaining inclusive, healthy and prosperous Mediterranean societies through innovative solutions in agro-food and water systems, contributing to the sustainable use of natural resources, economic growth and stability. In this sense, some of the research activities of this line comply with the main requirements of The Food and Agriculture Organization (FAO) of United Nations, for attaining one of their main goals focused on achieving food security for all. The Strategic Line is also adjacent to Water Europe vision of building a water-smart society since PSA is actively participating in the platform and leading Working Groups.

PSA research topics and activities are also well aligned with Work Programmes Horizon 2020, Green Deal and Horizon Europe, as well as the national Spanish Official R&D programmes and periodic calls, being possible to allocate in such Work Programmes the majority of indicated research topics.

1.5. JUSTIFICATION OF RESEARCH AREA RELEVANCE TO CIEMAT

In 1981, the International Energy Agency started in Tabernas (Almeria) the project SSPS (Small Solar Power Systems) with strong involvement of Spain and later evolving to the current PSA, today the largest and most important worldwide scientific centre to the research, development and testing of Solar Thermal & Photochemical technologies and its applications. Since the very beginning, PSA was linked to and owned by CIEMAT. Since CIEMAT is the Spanish avant-garde institution in the field of Energy and Environment and taking into account the relevance of renewable energies to fight against the climate change, the relevance of this Strategic Line for CIEMAT is evident. Currently (December 2020) the global number of commercial STE projects in operation is 115, totalling 6397 MW of nominal installed power. From these amounts, 71 of such project (50 of them in Spain) has been built by Spanish Engineering companies and with Spanish technology. These 71 projects totalize today 4681 MW, which means 73% of worldwide installed power, being this fact the clearest demonstration of current Spanish leadership in CST/STE technologies. The PSA played a major role in the past to make possible the previously indicated figures, firstly by promoting the needed knowledge transfers to these companies to make possible the initial projects in Spain and, secondly, supporting and collaborating with many of these companies, either national or international, in specific technological developments.

Current CST/STE commercial deployment in Spain is 2,3 GW, expecting to be increased with an additional 5 GW by 2030, as indicated within the Integrated National Energy and Climate Plan 2021-2030 (*Plan Nacional Integrado de Energía y Clima*, PNIEC). Internal PSA prospects and simulations also indicate that a minimum of 20 GW of STE installed power will be needed in Spain by 2050 to achieve the zero GHG emissions within the Spanish power sector. Global prospect deployment is obviously much higher. To this end, further cost reduction will be needed, goal only possible to be achieved through performance improvement of the technology and, as consequence, fully justifying the necessity of corresponding research activities.

The PSA consists of unique solar thermal and solar photo-processes experimental facilities in the world, due to the variety and size thereof, and thus it attracts organizations from all over the world which desires to test new prototypes and develop new processes before implementing them in a commercial scale. Therefore, PSA contributes to establishing a sustainable clean world energy supply, conservation of European energy resources and protection of its climate and environment, market introduction of solar thermal technologies, the development of a competitive Spanish solar thermal export industry, reinforce cooperation between business and scientific institutions in these fields, strengthen cost-reducing technological innovations contributing to increased market acceptance of solar technologies, promote North-South technological cooperation, especially in the Mediterranean Area and Iberoamerican Community, assist industry in identifying solar thermal and solar photochemical market opportunities. In addition, PSA activities are successfully contributing to the achievement of 4 (out of 17) United Nations Sustainable Development goals: clean water and sanitation, affordable and clean energy, climate action and sustainable cities & communities.

In summary, PSA is a unique and among the best of the World R&D infrastructures in renewable energy, leading Spanish public system of science and technology in solar energy applications and an essential laboratory to consolidate Spanish industrial players with worldwide competitiveness while providing opportunities for disruptive technologies and new systems adapted for suitable integration into the European energy sector and within the strategy of accelerating clean energy innovation. As consequence, the relevance to CIEMAT of this Strategic Line, considering the existing research potential and available PSA infrastructures, is therefore very high.

2. BACKGROUND AND PREVIOUS EXPERIENCE

2.1. DESCRIPTION OF PREVIOUS R&D ACTIVITIES

- **Linear Focusing concentrating technologies**
  Advanced heat transfer fluids with lower environmental footprint and higher working temperatures have been tested at PSA during the last five years. We have participated in two European projects related to this topic: the SITEF and SIMON projects. Several silicone-based oils have been experimentally tested at the PSA PROMETEO and REPA test facilities to check their durability and suitability to be used in linear focusing concentrators as heat transfer fluid at temperatures higher than 400ºC. We have also tested under real solar conditions new components for parabolic trough collectors (i.e. receiver tubes, ball joints and flex-hoses for receiver tubes). This activity has been mainly performed within the framework of service contracts with the manufacturers or solar thermal power plant operators. We have also participated in consortiums submitting new project proposals for the design of innovative parabolic trough collectors. One of these proposals is still under evaluation, while other was approved and another one was rejected. The Si-Co project funded by CSP ERANET (https://csp-eranet.eu/) will start in May 2021 to develop a new parabolic-trough collector specially designed for silicone-based oils working at 425ºC. It is also worth of mentioning the development of a very innovative design of Linear Fresnel Concentrator, which has been patented and the construction of a first prototype is underway at PSA. This prototype will be completed and evaluated in 2021-22. Concerning new applications for linear focusing concentrators, we have been working in two scientific topics simultaneously:
  - Promotion of solar heat for industrial process (SHIP) applications: we have participated in the European project INSHIP and we are coordinating Subtask B of the new Task 64/IV of SH&C and SolarPACES (http://task64.iea-shc.org), which was launched in January 2020.

- The use of line-focus concentrators to provide thermal energy to innovative processes to produce raw materials with less environmental footprint (i.e. production of NH3 or CH4 by means of catalytic processes using renewable energy). Since we are convinced that this is a promising new field of application for line-focussing technologies, we will keep on paying attention to this topic in next years.

- **Point Focus Solar Thermal Technologies**

  This unit targets are focused in providing technical assessment to the industry stakeholders together with the research and innovation related to power tower technologies. Following these principles, the main R&D activities performed during the last 5 years are:

  - Development, testing and onsite validation of the solar radiation extinction within the solar field.
  - Development, testing and onsite validation of self-calibrating heliostat in order to reduce O&M and costs. Concept patented.
  - Characterization, evaluation, and tests of different morphological absorbers for the open volumetric receiver technology using air as heat transfer fluid.
  - Research on solar components devoted to industrial process applications, including innovative and optimized heliostat designs and volumetric air receivers.
  - Technical assessment of pre-commercial heliostat prototypes.
  - Evaluation of individual components (heliostats, receivers, regenerators, Brayton turbine) and complete systems loops including ad-hoc hot air turbines.
  - Yield analysis and feasibility studies of the different available power tower technologies.
  - Numerical and computational modelling of different components or sub-systems.

- **Thermal Energy Storage for concentrating solar thermal technologies**

  On this topic and according to the already mentioned scientific objectives the R&D activities in the last 5 years can be resumed as:

  - Design and testing of a thermocline storage tank with concrete as structured filler (POLYPHEM project, H2020, 2018-2022)
  - Definition of procedures for studying the feasibility of phase change materials (PCMs) based on the development of predictive models of their useful life time (SFERA-III project, H2020, 2019-2022 & ACES2030 project, Madrid Regional R&D Programme, 2019-2022)
  - Definition and realization of testing of components for nitrate molten salt loops (SFERA-III project, H2020, 2019-2022 & Services and collaboration agreements with manufacturers' components)
  - Simulation and testing of packed bed thermal storages with atmospheric air as heat transfer fluid (ACES2030 project, Madrid Regional R&D Programme, 2019-2022)
  - Studying the use of thermal storage for delaying the exhaust heat of a power block (H2020 WASCOP project, 2016-2019).
  - Feasibility study of liquid crystals as innovative PCMs (DETECSOL project, Spanish National R&D Programme, 2015-2017 & ALCCONES project, Madrid Regional R&D Programme, 2014-2017)
  - Design, testing and optimization of a latent storage system for 140 ºC and 180 ºC, including storage material study (REELCOOP project, FP7, 2013-2017)

- **Materials for solar concentrating technologies**

  On this topic and according to the already mentioned scientific objectives the R&D activities in the last 5 years can be resumed as:

  - Development and testing of selective and non-selective absorbers for tubular or volumetric receivers (DETECSOL, RAISELIFE and NEXTOWER projects).
  - Development of non-selective high-temperature solar absorber for receiver particles (COMPASSCO2 project).
  - Development and testing of antireflective coatings for windows used in point focus receivers (DETECSOL and SOLTERMIN projects).

- Development and testing of optimized antireflective coatings for glass receiver tubes (RAISELIFE project).
- Testing of primary and secondary solar reflectors under several outdoor environments (desert, coast, industrial and urban areas, etc.) as well as accelerated aging conditions to optimize their durability and to develop lifetime prediction models (DETECSOL, INSHIP, RAISELIFE and SOLTERMIN projects).
- Standardization of the methodology to measure optical properties of components for CST technologies (reflectors and absorbers) (Reflectance, Soiling and SFERA-III projects).
- Development and testing of cost-effective cleaning methods to reduce the water consumption of CSP plants in the O&M activities (WASCOP and SOLWARIS projects).
- Accelerated aging of materials for CST technologies (absorbers and secondary reflectors) under high radiation fluxes in solar furnaces (NEXTOWER, RAISELIFE, SFERA-III, SOLTERMIN and HiPIMSOLAR projects).
- Materials treatment under concentrated solar radiation in solar furnaces (SFERA-III project).

- **Thermochemical processes for hydrogen and raw materials production**

In the field of hydrogen production, the Plataforma Solar de Almeria has a large experience in National and International Projects. The Group has participated in more than 10 international projects on solar thermal power production in the last 20 years. The most relevant activities are collected in the following projects: SYNPET project "Solar thermochemical application for production of syngas from heavy crude oil" private initiative whose objective would be to demonstrate the technical feasibility of the solar gasification process with the participation of Eidgenössische Technische Hochschule ETH (Switzerland) and PDVSA (Venezuela) (8 M€); Hydrosol-Beyond project "Thermochemical HYDROgen production in a SOLar structured reactor: facing the challenges and beyond as the first pilot experience in the world for the development of thermochemical cycles at 750 kW size, demonstrating CIEMAT's clear commitment to these technologies. Some National initiatives as the SolH2 project "Hydrogen production using high temperature solar thermal energy (SolH2)" approved within the INNPACTO initiative in collaboration with the company Abengoa Energia, IMDEA Energy and the University of Seville, which proposes the design and evaluation of a 100 kW receiver to carry out water dissociation using commercial ferrites. And finally, the project "Hydrogen Production and Fuel Cells: Development and Applications" (PLE2009-0022) funded by the Subprogramme for the Promotion of international scientific cooperation (FCCI), whose objective was to remodel the existing infrastructure at the PSA to provide a suitable platform for demonstration projects for the clean production of H2.

- **Solar process heat applications**

R&D activities performed within the last 5 years can be summarized as follow:

- Application of solar thermal energy to high capacity distillation processes, with special emphasis on the multi-effect distillation process (LT-MED, TVC-MED, ABS-MED).
- Application of solar thermal energy to low capacity distillation processes, with special emphasis on membrane distillation (MD) and direct osmosis (FO) processes.
- Cogeneration of water and electricity in solar thermal power plants (CSP + D).
- Electricity generation through saline gradient processes regenerated with solar thermal energy: reverse electrodialysis (RED) and pressure delayed osmosis (PRO).
- Application of solar thermal energy to separation processes for the concentration of brines and the treatment of industrial effluents.
- Dynamic modelling, process optimization and advanced control strategies in solar thermal applications.

- **Solar treatment of water**

The Solar Treatment of Water Research Unit (SWT) at PSA (CIEMAT) is focused on R+D+I activities based on the use of solar radiation for photochemical processes at room temperature, the integration of technologies for industrial and urban wastewater treatment and disinfection for reusing purposes as well as production of hydrogen and other photo-fuels. A more specific description of the research lines is detailed below:

- Improvement and optimization of solar photo-reactors, both for applications of decontamination, disinfection and photocatalytic production of fuels for different types of wastewater and geographic locations.
- New technologies based on a combination of reductive and oxidative processes in a heterogeneous phase for the elimination of particularly complex and resistant pollutants.
- Combination of advanced oxidation processes with other innovative technologies for treatment, disinfection and reuse (irrigation and industrial processes) of all types of wastewater.
- Production of fuels and artificial photosynthesis by solar photocatalysis. Use of solar radiation to promote photocatalytic reactions with the aim of producing hydrogen from water or fuels from CO2.
- Recovery of waste. Application of membrane technologies and innovative crystallization processes to achieve the recovery of nutrients such as phosphate, nitrate, ammonium, etc., for their subsequent use in agricultural activities.
- Comprehensive systems analysis. Assessment of the environmental burdens associated with the new technologies developed, identifying and quantifying both the use of matter and energy and the emissions to the environment, to determine the impact of this use of resources and those emissions.

2.2. CURRENT AVAILABLE RESOURCES

2.2.1. Research Units

- **Linear Focusing concentrating technologies**

  This PSA R+D Unit is composed by seven researchers, one laboratory assistant and one doctoral student, and it is devoted to the two technologies of line-focus solar collectors: parabolic-trough collectors and linear Fresnel collectors. Activities performed by this Unit cover all the topics related to these technologies. These topics can be grouped in four categories: a) technology improvements, b) technology applications, c) scientific and technical support to the industry involved in these technologies, and d) dissemination and training. The facilities used by this Unit comprise large outdoor facilities at PSA (HTF test loop, TCP-100 test facility, DISS, PROMETEO, FRESDEMO, the Innovative Fluids Test Loop, KONTAS, REPA test bench and PTTL) and the STRLab laboratory, which is devoted to receiver tubes evaluation. The scientific objectives of this Unit are listed in paragraph a) of section 1.3.1. It is worthwhile to mention the strong collaboration with the industrial sector, collaborating not only in the development of new components, but also in the development of new commercial applications for line focusing solar technologies. This Unit also provides a significant scientific and technological support to the industrial sector, helping them solve problems in commercial plants. A quite noticeable effort is also devoted to training and the dissemination of the concentrating solar thermal technologies because "Society will difficulty support something they are unware of". So, members of this Unit participate in several Master courses and in seminars and workshops related to renewable energies in general, thus promoting the knowledge about concentrating solar thermal energy technologies in general and their applications. This Unit also has a significant contribution in the development of new standards for concentrating solar thermal systems, participating in the national standardization committee AEN/CTN206-SC117 and in the international committee IEC/TC17, which Secretariat is undertaken by a member of this Unit since 2019.

- **Point Focus Solar Thermal Technologies**

The point focus solar thermal unit is concerned with the development and deployment of the technology following two different and complementary perspectives; on the one hand, sharing an unambiguous commitment with Spanish industrial sector to promote the knowledge, development and commercial implementation of the different technology sub-systems, and on the other hand, facing the new scientific and technological challenges such as the measurement of concentrated solar flux, R&D of new fluids and receivers and, optical analysis in order to improve solar field efficiency and O&M among others. In this framework, during the last 5-years, E43 has already proved its commitment with industrial partners with the characterization and assessment of several heliostat prototypes (Sophia, Photon, Solarblue), technology transfer to the industry (BCB company) of self-developed system for the measurement of solar extinction due to the atmospheric effects, and contacting local glass companies to analyse the feasibility of adapting current production lines to innovative heliostat designs. Furthermore, there is a sustained interest in the volumetric receiver technology within the H2020 CAPTURE and NEXTOWER projects, with the aim of developing improved morphological configurations to operate beyond the limit of actual commercial power tower plants (600°C) together with the necessity of coupling the air technology to more efficient thermodynamic cycles, but also to thermal processes that requires such high temperatures. Simultaneously, due to the wide expertise within the unit in heliostat technology, new designs for self-calibrating heliostats have been successfully patented.

- **Thermal Energy Storage for concentrating solar thermal technologies**
  This research topic comprises the following CIEMAT's research groups, integrated in two different departments, Technology and Energy.
    - Thermal Energy Storage Unit (PSA, Department of Energy). Its main expertise is on the development, optimization and integration of thermal energy storage systems for concentrating solar power plants, but also deals with managing thermal heat flows in industrial applications of other energy storage systems where thermal storage can play an important role (like adiabatic CAES, for example)
    - Chemistry Division (Department of Technology). Its main expertise is on the chemical synthesis of transition metals oxides, including doped ones, and their characterization for thermochemical storage. Its contribution to this topic is on the characterization of materials to study their feasibility as storage media

- **Materials for concentrating solar thermal technologies**
  Unit addressing the development and testing of new and/or improved materials and coatings for CST technologies, including the development and standardization of suitable methodologies for its optical characterization and lifetime prediction, as well as the usage of CST technologies for materials treatment, including thermal treatment, synthesis, characterization, aging, processing and modification.

- **Thermochemical processes for hydrogen and raw materials production**
  The Thermochemical Processes to Solar Fuels and Raw Materials Production Unit involves high temperature processes based on concentrated solar energy to produce hydrogen and other valuable and energy intensive material (Al, cement, etc). The mission is to contribute to the integration of CSP through cost-effective solutions supporting the decarbonisation of all main energy sectors, including industrial process heat applications and transport.

- **Solar process heat applications**
  The main objective of the Solar Thermal Applications Unit is the generation of new scientific and technological knowledge in the field of thermal applications of solar energy, seeking approaches that take into account the circular economy and the water-energy-food nexus. For example, desalination and brine treatment towards resource recovery.

- **<u>Solar treatment of water</u>**

  The unit of Solar Treatment of Water (STW) was born in 2012, from the Environmental Applications of Solar Energy unit, as a consequence of the strategic plan of CIEMAT to encourage the research activities and applications of solar photochemistry carried out at PSA. The main objective of the Solar Treatment of Water Research Unit is the use of solar energy for promoting photochemical processes, mainly in water for treatment and purification applications but also for chemical synthesis and production of photo-fuels. The knowledge of this group on solar photochemical systems and processes at pilot and pre-industrial scale is backed by 25 years of research activity and contracts with related companies. STW is a National and European reference pioneer in Spain and keeps a consolidated national leadership. The research unit has participated and lead more than 25 EU and 10 national projects since 1997 mainly focused on the development of solar technologies for water treatment and disinfection. The Facilities are extremely well equipped and are among the best in the world in the field of advanced oxidation processes (AOPs) and integration of solar and conventional water treatment technologies at pilot and laboratory scale. STW is pioneer in the application of advanced analytical techniques (chemical and microbiological) for the evaluation of the efficiency of such processes.

2.2.2. Human Resources

The following tables (1 and 2) shows the distribution of human resources among the different PSA units (see Fig. 1, describing the internal structure of PSA and associated CIEMAT functional codes of existing units, E40 to E48). Total number of persons working within PSA is 119, being 49 of them (41% of total) externally subcontracted and providing, among others, support to the operation and maintenance of the research infrastructures and laboratories described within the posterior section 2.2.3, and formally associated to the unit E41 (PSA Scientific Installations and Technical Services).

Table 1. Total human resources associated to PSA, by contractual category and internal CIEMAT organizational codes (2021)

TOTAL PSA	E40	E41	E4 2	E43	E44	E45	E46	E47	E48	Total
Senior official staff	3	1	2	2	2	2	3	3		**18**
Other permanent staff	3	2	1	3		1				**10**
Temporary	3	4	4	2	2	3	1	6	6	**31**
Pre-Doctorals			1	2		2		2	4	**11**
Externally contrated		49								**49**
TOTAL	**9**	**56**	**8**	**9**	**4**	**8**	**4**	**11**	**10**	**119**

And Table 2 shows the distribution of personal fully or specifically devoted to scientific research activities. It should be noticed that, excluding pre-doctoral contracts, the current percentage of temporary personnel is 52% (25 out of total 48). As additional information, the number of scientific personnel with PhD degree is 32, being 16 engineers and technicians (fully devoted and collaborating in research activities). Total CIEMAT contracted people is 70, being the number of women 28 (40% of previous figure).

Table 2. PSA human resources specifically devoted to research activities (2021)

RESEARCHERS	E4	E41	E42	E4	E44	E4	E46	E47	E48	Total

	0			3		5				
Senior official staff	3	1	2	2	2	2	3	3		**18**
Other permanent staff			1	3		1				**5**
Temporary	1		4	2	2	3	1	6	6	**25**
Pre-Doctorals			1	2		2		2	4	**11**
TOTAL	**4**	**1**	**8**	**9**	**4**	**8**	**4**	**11**	**10**	**59**

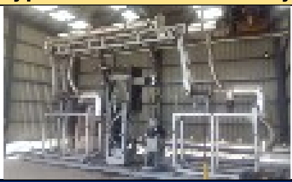
2.2.3. Facilities and laboratories

The PSA consists of unique portfolio of experimental research facilities which, due to its variety and size, attracts organizations from all over the world desiring to test new prototypes and/or develop new processes or test new materials before implementing them in a commercial scale. The following table lists all the test facilities located in the PSA research centre.

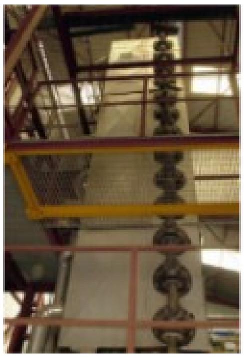
Table 3. PSA Facilities (see also Figure 2 with indication of physical location)

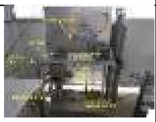
Type and Name of Facility	Brief Description
A) Parabolic Trough Collectors (PTC)	
A1.- DISS 	A Direct Steam Generation (DSG) test loop (N-S oriented) of 2.5 MWth for experimenting with DSG of high-pressure and temp. (up to 100 bar/500°C, flow rate of 1 kg/s) steam in PTC absorber tubes. It consists of two subsystems, the solar PTC field (5,300 m^2 and 1,000-m long) and the balance of plant (BOP). The solar field can be configured for: a) Recirculation (perfectly differentiated evaporation and superheating zones), b) Once-Through (the intermediate water-steam separator and the recirculation pump located in the solar field are not used) and, c) Injection mode (feed water is injected in different points along the collector row).
A2.- HTF 	Large-size PTC test loop (E-W oriented) 3x275 kW_{th} for characterization of solar components: new trough designs, mirrors, absorber tubes, ball-joints, flex-hoses, solar tracking systems, etc. Thermal oil Syltherm 800® is used in this facility (max. working temp. of 420°C and a freezing point of -40°C). Main activities at the HTF test loop are related to study the optical and thermal performance of complete parabolic-trough collectors (optical efficiency, IAM coefficient, and global efficiency/heat losses) and receiver tubes.
A3.- PROMETEO 	East-West oriented test loop that allows the qualification of all collector components and complete collectors of a length of up to 100 m, i.e. structures, reflectors, receivers from 70 to 90 mm and movable joints. It enables sun tracking covering all solar radiation incidence angles in one day thanks to its orientation. The collector modules are connected to the balance of plant (BOP) in parallel or in series configuration using the ad hoc set valve. A pump circulates silicone heat transfer fluid (SHTF) with a mass flow similar to that of PTC commercial power plants
A4.- PTTL 	Large test facility implemented in a 420mx180m plot of the PSA and composed of two solar fields: a) the North one (E-W orientation) is designed to install complete PTCs with a maximum unit length of 180 m; it has an oil pump (75 m^3/h) provided with speed control and a 1.5 MW_{th} oil cooler refrigerated by air; b) the South field (N-S orientation) is designed to install complete loops of PTCs (i.e. several collectors connected in series), with a maximum length of 640 m; additionally, it has

Type and Name of Facility	Brief Description
	an oil pump (125 m^3/h) provided with speed control and a 4 MW_{th} oil cooler refrigerated by air. Up to four complete loops can be installed in parallel. The facility is also suitable to install big-size PTC prototypes.
A5.- NEP 	125 kW test loop of small-sized PTC collectors (Polytrough 1200). It has a production of 15.8 kW per module (0.55 kW/m^2) under nominal conditions, with a mean collector temperature of 200 ºC, and an efficiency over 55% in the range of 120-220 ºC (for 1000 W/m^2 of direct normal irradiance). The field is configured in 8 collectors placed in 4 parallel rows, with two collectors in series in each row. Thermal oil temperature can reach 220 ºC, so different schemes for making use of the thermal energy for polygeneration can be evaluated.
A6.- IFL 	Innovative Fluids Test Loop (pressurized gases) in PTCs (E-W orientation) to study the use of pressurized gases as heat transfer fluid in PTCs, evaluating their behaviour under a diversity of real operating conditions, and designed to work at conditions up to 100 bar and 500°C. It is composed by: a) Two East-West-oriented Euro-Trough PTC, each 50 m long with a 274.2 m^2 collector surface, connected in series; b) A 400 kW air-cooler with two 4 kW motorized fans to thermal energy removal from the fluid; c) A 15 kW blower to provide the needed gas flow rate at the receiver tubes.
A7.- TCP100 	2.3-MWth PTC facility with a thermocline storage tank with 115 m^3 of Santotherm-55 oil specially designed to perform studies related to control systems for parabolic trough solar fields. The facility is composed of six TCP 100 PTCs, installed in three parallel loops with two collectors in series within each loop (N-S oriented). Two collector loops are provided with a solar tracking system developed by PSA, while the third loop is provided with a commercial solar tracking system for comparison. Each collector is composed of eight PT modules with a total length of 100 m and a parabola width of 5.77 m (545 m^2 of total solar collecting surface).
B) Linear Fresnel Collector (LFC)	
B1.- FRESDEMO 	Linear Fresnel technology test loop 800 KW_{th} of 100 m long, 21 m wide module has a primary mirror surface of 1,433 m^2, distributed among 1,200 facets mounted in 25 parallel rows spanning the length of the loop. This collector loop is designed for direct steam generation at a maximum pressure of 100 bar and max. temp. of 450º
C) Other Parabolic Trough facilities	
C1.- KONTAS 	Rotary test bench for parabolic trough collectors and components, under a constant 0º incidence angle of the solar radiation. It allows the qualification of complete modules of a length of up to 20 m. (structures, reflectors, receivers and flexible joints). It enables for 2-axis tracking (test bench platform over a circular rail) at any desired angle of incidence of the solar radiation. It is equipped with high precision instrumentation and controls for precise, quick and automated measurements. The collector module is also connected to a heating and cooling unit on the platform.
C2.- REPAs	Accelerated full lifecycle tests of Rotation and Expansion Performing Assemblies for PTC systems. This test bench is divided into two functional sections, the kinematics unit (to hold and move the pieces REPAs to be tested), and the balance of plant unit (for supplying the conditioned heat transfer fluid). The balance of plant unit is composed of a variable speed pump which circulates the HTF through with an

Type and Name of Facility	Brief Description
	adapted collar type electrical heater. The kinematics unit is prepared to accommodate test samples (ball joints and flexible hoses) with varying and adjustable geometries and for different PTC designs.
D) Thermal Energy Storage	
D1.- MOSA 	Molten Salt Test Loop for Thermal Energy Systems. This facility is composed of, on one hand, an outdoor test loop, which is a replica of a commercial thermal energy storage system with 40 tons of nitrate molten salts and a two-tank configuration, and, on the other hand, an indoor test bench, named BES-II, which is used for testing small molten salt hydraulic components (valves, pressure transducers, etc.). MOSA is the largest facility worldwide similar to a commercial two-tank molten salt storage system on a reduced scale so everything related to this type of systems can be tested in this facility in a relevant and extrapolated scale.
E) Central Receiver Systems (CRS)	
E1.- CESA-1 	6 MWth CRS. Solar field: 330 x 250 m south-facing field of 300 39.6 m^2 heliostats distributed in 16 rows; tower: 84 m high with four different levels to accommodate receivers and a big with target square to heliostat canting and adjustment. Typical peak flux of 3.3 MW/m^2 with an irradiance of 950 W/m^2 (99% of the power is focused on a 4 m diameter circle and 90% in a 2.8 m circle). It is a very flexible facility for testing components such as heliostats, solar receivers, thermal storage, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It can be also used for other applications requiring high photon concentrations on relatively large surfaces, such as in chemical or high-temperature processes, surface treatment of materials or astrophysics experiments.
E2.- SSPS-CRS 	2.5 MWth CRS facility. South part of the solar field is composed by 91 (39.3 m^2) heliostats and the North part of the solar field has 20 (52 m^2 and 65 m^2) heliostats with an average nominal reflectivity of 90%. The solar tracking error is 1.2 mrad per axis and the optical reflected beam quality is 3 mrad. Under 950 W/m^2 of solar irradiation, total field power is 2.5 MWth with 2.5 MW/m^2 of peak flux. 99% of the power is collected in a 2.5 m diameter circumference and 90% in a 1.8 m circumference. Tower: 43 m high metal structure with 3 test platforms. Two first located at 26 and 28 m and for testing new receivers for thermochemical applications and a third test platform. Third one at the top of the tower with crane and calorimetric test bed for small atmospheric-pressure volumetric receivers evaluation, and solar reactors for hydrogen production.
E3.- AORA SOLAR 	35m tall tower facility with a pressurized volumetric receiver (porcupine type receiver) installed on it, to heat up air at 15 bar pressure at nominal temperature of 800ºC; coupled to a 100 kWe solarized gas turbine. The 880 m^2 solar field is composed by 55 heliostats of 16m^2 reflecting surface each of them. Hot air from the turbine exhaust can be used also for cogeneration and/or poli-generation: extra 175 kWth power air is available for driving thermal processes at medium to low temperature (<250ºC).
F) Solar Furnaces (SF)	
F1.- SF-60	Composed by a 120 m^2 flat heliostat that reflects the solar beam onto a 100 m^2

Type and Name of Facility	Brief Description
	parabolic concentrator which in turn concentrates the incoming rays on the focus of the parabola. The incoming light is regulated by a louvered shutter placed between the heliostat and the concentrator. Finally, a test table movable on three axes is used to place the element to be tested in the focus. The parabolic concentrator is the main feature of this solar furnace; it is made of spherically curved facets distributed along five radii with different curvatures depending on their distance from the focus. It concentrates the incident sunlight from the heliostat, multiplying the radiant energy in the focus. The characteristics of the focus with 100% aperture and 1000 W/m^2 solar radiation are: peak flux, 300 W/cm^2, total power, 69 kW, and focal diameter, 26 cm.
F2.- SF-40 	This SF consists mainly of an 8.5 m diameter parabolic-dish (56.5 m^2 concentrator parabolic area), with a focal distance of 4.5 m coupled to a 100 m^2 reflecting surface flat heliostat, a, slats attenuator, and test table with three axis movement. The concentrator surface is made of 12 curved fiberglass petals or sectors covered with 0.8 mm adhesive mirrors on the front. The parabola thus formed is held at the back by a ring spatial structure to give it rigidity and keep it vertical. The facility reaches a peak concentration of 5,000 suns and has a power of 40 kW, its focus size is 12 cm diameter and rim angle a= 50.3°. Its optical axis is horizontal, and it is of the "on-axis" type that is parabolic concentrator, focus and heliostat are aligned on the optical axis of the parabola.
F3.- SF-5 	5 kW SF power, reach concentrations above 7,000 suns. It consists of an 8.7 m^2 concentrator mirror, placed upside-down on an 18 m high metallic tower and with the reflecting surface facing the floor; in the centre of the base of the tower there is a 25 m^2 flat heliostat, whose rotation centre is aligned with the optical axis of the concentrator. At the top of the tower, 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. SF-5 focus diameter is 2.5 cm, and is mainly devoted to heat treatment of materials at high temperature, under vacuum and controlled atmosphere conditions. The main advantage is that the focus is arranged in a horizontal plane, so that the samples may be treated on a horizontal surface.
G) Parabolic Dishes	
G1.- EURO-DISH  	Two DISTAL-II dish/Stirling units with 46 kWth total thermal power each, 8.5 m parabolic dish diameter and two-axis sun tracking system (azimuth-elevation). Previous stretched-membrane technology was replaced by a moulded composite-material system. These parabolic dishes can be used to test Stirling engines prototypes, or to perform other tests requiring a focus with 50 kWth and a max. concentration of 16,000 suns at the focus. The focal distance is 4.1 m.
G2.- AGEING TEST BED 	DISTAL-I concentrator is a 7.5 m diameter parabolic dish with 40 kW thermal power and one-axis polar solar tracking system in which the Stirling motor was replaced by different test platforms to perform accelerated temperature cycling of materials or small-scale prototypes of high concentration receivers. With fast focusing and defocusing cycles, the probes placed in the concentrator focus stand a large number of thermal cycles in a short time interval, allowing an accelerated ageing of the material. These platforms can be used testing: materials, air-cooled volumetric receivers (metal or ceramic), small-size receivers prototypes with or without heat

Type and Name of Facility	Brief Description
	transfer fluid, etc.
H) Solar Desalination facilities	
H1.- MED 	This facility is composed of the following subsystems: a) 14-stage multi-effect distillation (MED) plant, b) large-size flat plate stationary solar collector field (606 m^2), c) 40 m^3 water-based solar thermal storage system, d) double effect (LiBr-H2O) absorption heat pump and, e) fire-tube gas boiler. The MED is vertically arranged with direct seawater supply to the first effect (forward feed configuration). At a nominal 8 m^3/h feedwater flow rate, the distillate production is 3 m^3/h, and the thermal consumption of the plant is 190 kWth, with a performance ratio (number of kg of distillate produced per 2,326 kJ of thermal energy consumed) over 9. Nominal operating temperature of 70°C in the first cell with a total gradient of 40°C to the last cell. The double effect (LiBr-H2O) absorption heat pump is connected to the last effect of the MED plant. The low-pressure steam generated in this last effect (35°C, 56 mbar abs) supplies the heat pump evaporator with the thermal energy required at low temperature, cutting in half the thermal energy consumption required by the process.
H2.- CSP+D 	Facility devoted to the research of the coupling between CSP plants and Desalination (CSP+D). It is composed of two steam generators (250 kW and 500 kW) fed by thermal oil coming from a PTC field able to deliver thermal oil with temperatures up to 400°C and an auxiliary electrical power system that raises the temperature if required. The steam generators can produce steam at different pressures, which allow recreating any of the typical intermediate extractions or the exhausted steam available at a turbine of a thermal power plant. High and low-pressure steam can be used as motive and entrained vapor, respectively, in a train of four steam ejectors coupled to the PSA MED plant, simulating the behavior of a MED plant working with thermal vapor compression. The steam ejectors can work in a wide range of pressure conditions for the motive steam (40-6 bar; 4–2 bar).
H3.- MDTF 	Membrane Desalination Test Facilities formed by: a) Test-Bed for Solar Membrane Distillation Applications at Pilot-Scale, connected to two solar fields (of 20 and 40 m^2 of flat-plate collectors); b) Bench-Scale Unit for Testing Membrane Distillation applications in Air-Gap, Permeate-Gap and Direct Contact Configurations; c) Bench-Scale Unit for Flat Sheet Membrane Distillation Testing, permitting adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VMD, VAGMD); d) Bench-Scale Unit for Tests with 2-stage Forward Osmosis and Pressure-Retarded Osmosis (PRO), with three different units that can be coupled in different ways between them: (i) forward osmosis; (ii) reverse osmosis; (iii) microfiltration.
I) Water Treatment	
I1.- SOLWATER 	Water Treatment tests facilities composed by: a) 300 L PTC photo-reactor with two axes solar tracking system; b) multiple solar decontamination and disinfection pilot photo-reactors based on Compound Parabolic Collectors (CPCs, from 32-75 mm of tube diameters, 0.5-15 m^2 of irradiated surface and total volume from 10 to 300 L) equipped with heating and cooling systems for temperature control, pH and dissolved oxygen monitoring, and coupled with other treatment technologies

Type and Name of Facility	Brief Description
	(electro-oxidation, ozonation, etc.); c) 2 m^2 solar disinfection reactor with different reflector shape (CPC and U mirror type) equipped with a solar water heating panel; d) Ultraviolet pilot plant equipped with a reagents dosing system; e) micro- and nano-membranes pilot plants, including pH automatic control; f) wet air oxidation pilot plant prepared to operate under 200 bar and a maximum temperature of 300°C; g) electro-oxidation pilot plant (four electrochemical cells); h) two ozonation pilot plants; i) Biological pilot plant reactors with a double depuration system (fluidized biomass systems and sequencing batch reactors); j) 30 m^2 Culture crop chamber used for wastewater reclamation testing (4 individual areas with cooling and heating system).
I2.- HYWATOX 	Photocatalytic hydrogen production pilot plant composed by a stainless steel tank (22 L), fitted with gas and liquid inlet and outlet (mass flow controllers) and a sampling port connected to GC/TCD coupled to a solar CPC reactor (20 L and 2 m^2 of illuminated surface).
J) Solar Radiation Characterization	
J1.- METAS 	The METAS station instruments provides information on solar radiation and more general atmospheric variables that can be used for spectral models validation as well as all other PSA research activities. Some key specific available data: a) measurement of the terrestrial radiation balance; b) incoming and outgoing shortwave and long-wave radiation is measured at 30 m; c) solar radiation component characterization: (global, direct and diffuse); d) UV and PAR spectral bands; e) spectroradiometer (200 to 2500 nm); f) vertical wind profile: wind speed and direction at 2, 10 and 30 m; g) vertical temperature and humidity profile at 2 and 10 m; g) miscellaneous weather information: rain gauge, barometer and psychrometer. Since 2005 METAS follows Baseline Surface Radiation Network quality requirements.
K) Energy Efficiency	
K1.- LECE 	The Building Component Energy Test Laboratory (LECE) is devoted to the research of energy analysis of buildings, integrating passive and active solar thermal systems to reduce the heating and cooling demand. It is composed by: a) five test cells, each of them made up of a high-thermal-insulation test room and an auxiliary room to the experimental characterisation of building envelopes; b) PASLINK test cell incorporating a Pseudo-Adiabatic Shell concept; c) CETeB test cell for roof testing; d) Solar Chimney; e) Single-zone building for in-depth energy evaluation methodologies for experimental buildings.
K2.- ARFRISOL Building 	Fully instrumented and continuously monitored Energy Research Demonstrator Office Building Prototype of around 1000 m^2 built area. It is designed to minimize heating and air-conditioning energy consumption whilst maintaining optimal comfort levels by including passive and active (mainly solar) energy saving strategies based on architectural and construction design.
M) Materials	
M1.- OPAC	Optical Characterization and Durability Testing of Solar Reflectors facility. This facility is the largest one worldwide devoted to the complete study of the materials used as reflectors in concentrating solar thermal systems, allowing the

Type and Name of Facility	Brief Description
	determination of characteristic optical parameters, their possible deterioration along the time, as well as different O&M aspects. It is composed by several unique outdoor facilities to assess the possible degradation mechanisms affecting this optical component (including a high number of test benches that simulate different operating conditions) and three full equipped laboratories to reproduce such degradation mechanisms under accelerated aging conditions in weathering chambers.

The following table briefly indicate and describe the complementary laboratories to complete the studies carried out in the PSA facilities.

Table 4. PSA Laboratories (see also Figure 2 with indication of physical location)

Laboratory	Brief Description
L1.- GeoLab	Geometrical characterization of solar concentrators mainly based on photogrammetry assessment (three-dimensional modelling of any object from photographs that capture it from different angles), used technique to quantify the optical quality of Parabolic-trough collector elements (facets or modules), Heliostats, Fresnel lenses and reflectors, Parabolic dishes, etc. Photogrammetry modelling precision is 1:50,000 (order of 0.1 mm for parabolic-trough collector facets and 0.6-0.7 mm for 12-m-long parabolic-trough modules).
L2.- RadLab	Radiometry laboratory perform high quality measurement of radiometric magnitudes associated with high solar concentration, such as solar irradiance (flux) and surface temperature of irradiated materials (detection by IR).
L3.- SRTLab	Testing and characterization of receiver tubes for line focussing collectors. Composed of two test benches (HEATREC and RESOL). Thermal losses evaluation (between 100ºC and 400ºC) in linear-focusing receivers up to 4.5 m length and 125 mm O.D. can be performed in HEATREC, while RESOL is a test bench for the evaluation of thermal emission, thermal absorption and transmissivity.
L4.- MaterLab	Lab. for the assessment of the durability and characterization of materials under concentrated solar radiation. It is formed by 4 different rooms (Metallography, Microscopy, Thermogravimetry and Thermal Cycling rooms) devoted to the metallographic and thermogravimetric analysis and characterization of test pieces treated with concentrated solar radiation and eventually thermal cycling for accelerated ageing.
L5.- WATLAB	The Water Technologies laboratory includes all necessary equipment for evaluation of chemical, toxicological, and microbiological quality of water and wastewater. It is composed by 4 different labs: Chromatography (2 UPLC/DAD, 2 ionic chromatographs, 2 TOC analysers with Nitrogen modules, PCR), Microbiology (biosecurity II), Microscopy (optical, SEM -scanning electron microscopy- and X-ray analyser –EDX-), and General lab (biological, acute and chronic toxicity and phytotoxicity tests, as well as two solar simulators).
L6.- TESLab	Laboratory for studying the feasibility of materials, and not only molten salts, as storage media. It is, mainly, composed of several furnaces with different capabilities in terms of temperature range and atmospheres.
L7.- DesaLab	Laboratory for supporting the activities done in desalination, including basic water analysis, two membrane distillation facilities for analysing the process in all configurations at small scale (with 250 cm^2 and 375 cm^2 effective membrane areas, respectively), and a test-bed with two small modules of forward osmosis (effective membrane area 100 cm^2 each) that can be operated in

Laboratory	Brief Description
	pressure retarded osmosis mode.
L8.- OCTLAB	Advanced Optical Coating Laboratory. Laboratory located in CIEMAT-Madrid.
L9.- POMELAB	Porous Media Laboratory for solar concentrating systems. Laboratory located in CIEMAT-Madrid.
L10.- ATYCOS	Laboratory located in CIEMAT-Madrid.

Figure 2 show the location of previous facilities and labs within the 103 hectares' of PSA surface:

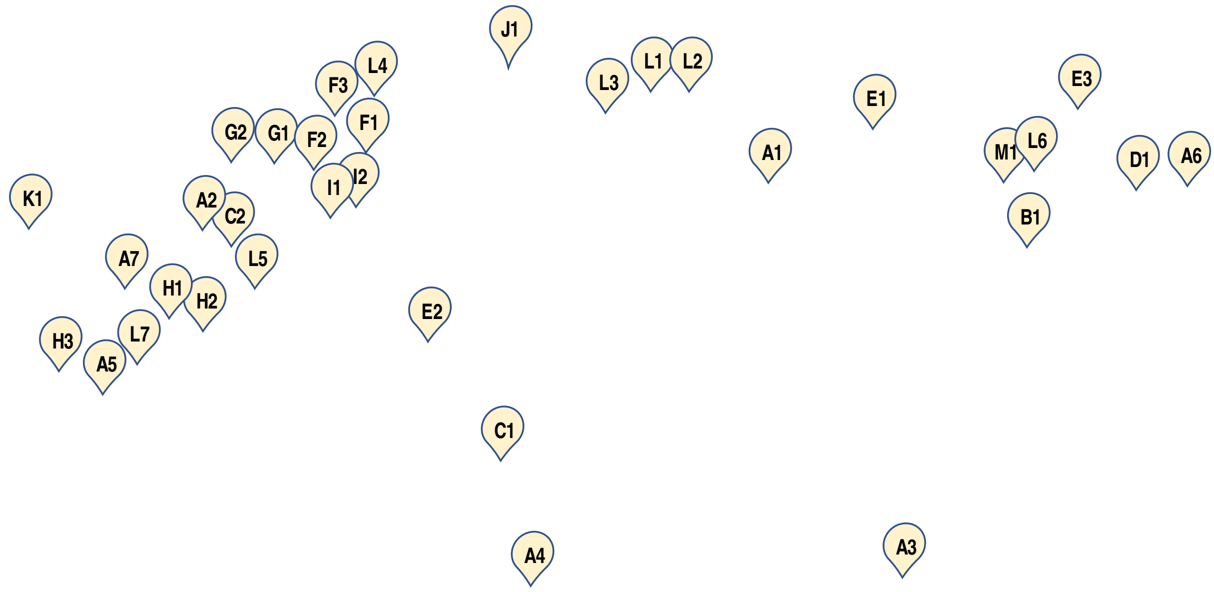


Fig. 2 PSA aerial photography and location of test facilities and labs described in Tables 3 and 4

2.3. COLLABORATION, ALLIANCES AND EXTERNAL PROJECTION

- **<u>Linear Focusing concentrating technologies</u>**
  This Unit has a strong international collaboration with other European R+D centres and foreign industries in projects related to concentrating solar thermal technologies and their applications. At present researchers of this Unit are participating in the European projects SFERA-III, SOLWARIS, SING, POSYTYF and Si-Co. The head of this Unit is the Spanish representative at the SolarPACES Executive Committee, while another member of this Unit is the Leader of the Sub-programme of Linear Focussing Technologies of the Joint Programme CSP of EERA (https://www.eera-set.eu/). This Unit is also undertaking the Secretariat of the international standardization committee IEC/TC117. At international level is also significant the involvement in Task III of SolarPACES, participating in several working groups, especially in those related to silicone-based oils and flexible connections for linear focussing collectors. There exists also a long-lasting collaboration with foreign universities (e.g. Universidad Católica de Chile and Universdad de Antofagasta (Chile), Universidad del Norte (Colombia), Universities of Sao Paulo and Federal de Pernambuco (Brasil), Universidad de La Plata (Brasil), Universidades Nacional Autónoma de México y Autónoma del Estado de México (México), Universidad de Crandfiel (UK) and several German universities, among others). At international level, it is also important the good collaboration with ESTELA (European Solar Thermal Electricity Association), because the Head of this Unit is member of its Scientific Committee. At national level, the research project SOLTERMIN is coordinated by this Unit, having a strong collaboration with other PSA R+D Units within the framework of this project. It is worth mentioning that the Head of this Unit is coordinating at present the Spanish Strategic Network SOLTERCO (Solar Thermal Concentrating

technologies, 2020-21) where a group of eight Spanish R+D, universities and technology centres (CIEMAT, CENER, IMDEA, CIC-ENERGIGUNE, TEKNIKER, Universities of Seville and Carlos III of Madrid, Polytechnic University of Barcelona) are collaborating to promote the use of concentrating solar thermal technologies. There is also an excellent collaboration with PROTERMOSOLAR (Spanish association of the concentrating solar thermal power industries) and relevant Spanish industries of this sector (ACS, ACCIONA, COBRA, SENER, IDOM, among others. In summary, this PSA Unit is very well positioned at national and international level.

- **Point Focus Solar Thermal Technologies**

  This research unit collaborates with all the partners, Spanish and international ones, that are playing an important role in point focus solar thermal technologies. Concerning the educational sector, two main collaborations are highlighted, CIESOL with the active participation in the *Solar Energy Master* of Universidad de Almería, and Dalarna University (Sweden) under an educational agreement in the *Renewable Energy Erasmus Mundy Master*. Moreover, other educational collaborations include Universidad Nacional de La Plata (Argentina), Universidad Nacional Autónoma (Mexico), and many others in South American, and national Universities. Besides the natural alliance with DLR, with whom we have a very tight collaboration in many R&D projects, our alliances to develop power tower technology are with the main European companies and research centres such as ENEA, CENER, IMDEA, Fraunhófer-IKTS, Oxford University, LiqTech, Engicer, Tewer, Cobra, Acciona, Magtel, Tekniker, TSK-Flagsol, Bluebox Energy, Haver and Boecker, etc. Additionally, the unit actively participates in different working groups in SolarPaces and IEA-Solar heating and cooling. At the same time, the unit is involved in the development of national and international standardization of high concentration solar technology sector through UNE (Spanish standardization body) and IEC (International standardization body).

- **Thermal Energy Storage for concentrating solar thermal technologies**

  CIEMAT's researchers actively participate as experts and coordinators in several INTERNATIONAL SCIENTIFIC NETWORKS on Thermal Storage like those currently alive as:
  - Task III of the SolarPACES TCP of the International Energy Agency (IEA), where CIEMAT coordinates the whole Thermal Storage Activity, which counts with the participation of 13 R&D and educational centres and 4 companies worldwide. Two out of the four activities this SolarPACES working group are led by members of the Thermal Energy Storage Unit of CIEMAT PSA: *Characterization of specific equipment for commercial TES (using sensible and molten salts)* and *Survey of R&D&I Activities on Thermal Storage Systems* (http://www.solarpaces.org/csp-research-tasks/task-annexes-iea/task-iii-solar-technology-and-advanced-applications/thermal-energy-storage-working-group/).
  - EERA Joint Programme on Energy Storage, in the work package of Thermal Storage.
  - SHC Task 58 / ECES Annex 33 ("Material and Component Development for Thermal Energy Storage", 2017-2019) of the IEA. A following new task is pending of approval.
  - CIEMAT's researchers take part as well in **NATIONAL AND INTERNATIONAL standardization COMMITTEES** related to thermal storage for STE plants like AEN/CTN 206GT3 of AENOR, IEC/TC117/TS 6286221 and ASME PCT52.

- **Materials for solar concentrating technologies**

  CIEMAT collaborates with all the national and international partners that are playing a significant role in materials for CST technologies. Our strong **alliance** with DLR is complemented with a fruitful **collaboration** with other R&D institutions (Fraunhofer ISE, ENEA, CENIM, CSIC, NREL, CEA, CENER, CNRS, Cranfield University, Tekniker, Universidad de Sevilla, Universidad de Zaragoza, etc.) and companies (BrightSource, Sener, Acciona, Abengoa, TSK, Huiyin, Archimede, Rioglass, AGC, Alanod, TG-Yueda, Sunnpo, Sundhy, etc.). In the **education sector**, we participate in the "Solar Energy Engineering Master" of Dalarna University (Sweden), "Solar Energy Master" of Universidad de

Almería (Spain), and "Energy and Fuels for the Future" of Universidad Autónoma de Madrid (Spain). In addition, we actively participate as experts and coordinators in several **international scientific newtworks**, such as SolarPACES/IEA Task III, "Solar Technology and Advanced Applications" (coordination of the working group about "Reflectance Measurements", integrated by 11 R&D centers and companies, and participation in the working group about "Accelerated Aging of Solar Reflectors"), and EERA Concentrated Solar Power Joint Programme (participation in the sub-programme SP4, "Materials for Solar Thermal Energy Components and Receivers"). Regarding **national and international standardization committees**, we are involved in the Spanish stardardization committee UNE CTN 206SC117, the International standardization committee IEC TC117 (coordination of the proposal for the new standard "Laboratory Reflectance Measurement of Concentrating Solar Thermal Reflectors") and the CEN-CENELEC Workshop Agreement "High temperature accelerated ageing of ceramic specimens and small solar receivers under concentrated solar radiation" (participation as chairman under the frame of the NEXTOWER project, which resulted as winner in the "Project" category of the second edition of the Standard + Innovation Awards).

- <u>**Thermochemical processes for hydrogen and raw materials production**</u>
  At European level, CIEMAT coordinates the 'Joint Programme on Concentrating Solar Power (CSP) Technologies' of the European Energy Research Alliance (EERA) (www.eera-set.eu). The Solar Fuel Unit also participates in the EERA Subprogramme 5, Solar Thermochemical Production of Fuels. Since 2007 CIEMAT has been part of a European initiative called the European Joint Technology Initiative (JTI), which will invest approximately 650 million euros over the multi-annual Work-Plan 2014-2020 in research, technological development and demonstration projects on fuel cells and hydrogen. At international level, CIEMAT participates in the international network SolarPACES (www.solarpaces.org), set up under the umbrella of the International Energy Agency (IEA). Task II addresses the demonstration, scale-up, and market penetration of solar-driven thermochemical processes for the production of fuels (e.g. hydrogen, syngas, methanol, kerosene, diesel) and materials (e.g. metals – Zn, Al, Fe). The task II accounts with the participation of 14 R&D and educational centres worldwide. Finally, CIEMAT is also part of the Spanish Hydrogen and Fuel Cell Technology Platform (PTE-HPC), an initiative promoted by the Spanish Hydrogen Association and supported by the Ministry of Science and Innovation. The main objective of the Spanish Hydrogen and Fuel Cell Technology Platform (PTE-HPC) is to facilitate and accelerate the development and use in Spain of systems based on fuel cells and hydrogen, in their different technologies, for application in the transport, stationary and portable sectors. It takes into account the entire R&D&I chain.

- <u>**Solar process heat applications**</u>
  - Participation in the SubTask B (Modularization) of the IEA SHC Task 64 (Solar Process Heat).
  - Coordination of the Working Group "Renewable Energy Desalination" of the Water Europe platform.
  - The unit collaborates with a large number of international partners in EU projects consortia…

- <u>**Solar treatment of water**</u>
  Solar Treatment of Water Research Unit (STW) activities are focused in the field of solar radiation applications for water treatment (decontamination and disinfection) and it is nowadays working on different Investigation and Development Programs in collaboration with different national and international organisms and universities. Over the past years STW group have built strong relationships with Universities and Research Centres, making also strong links with industry related to water treatment and management & reuse, nanomaterials, sensors, and energy. Collaborations in the academic sector include UNESCO-IHE (Institute for Water Education), Delf (Netherlands), NTU-Nanyang Technical University of Singapore, University of Ulster (UK), Royal College of Surgeons in Ireland (Dublin & Bahrain), University of Santiago (Spain), Comisión Nacional de Energía Atómica

(Argentina), EAWAG and ÉPFL (Switzerland), CNRS (France), University of Salerno (Italy), Cranfield Water Research Institute (UK), Uni. of Athens (Greece), CSIC (Spain), University of Porto (Portugal), University of Cincinatti (US), University of Barcelona (Spain), Universidad Complutense and Politecnica de Madrid and University Rey Juan Carlos (Spain), University of Cyprus (Greece), Universidad Nacional de San Martin (Argentina), Universidad de las Américas de Puebla (Mexico), Universidad de Antioquia (Colombia), Universidad de la Amazonia (Colombia), Universidad de Cartagena (Colombia), Universidad de Tarapacá (Chile), Universidad de Concepción (Chile), Loughborough University (UK), Aristotle University of Thessaloniki, ICRA (Spain), Universidad de Cantabria (Spain), Universidad de Sevilla (Spain), Centre of Research and Technology, HELLAS (Thessaloniki, Greece), University of Lebanon (Lebanon), CERTE (Tunisia), University of Torino (Italy), University of Aalborg (Denmark), Ecole Polytechnique (France), Birla Institute of Technology and Science Society (India), Buckinghamshire New University (UK), Council of Scientific and Industrial Research (India), Institute of Technology Sligo (Ireland), University of Salento (Italy), National Univeristy of Ireland Maynooth (Ireland), IMDEA water and IMDEA energy (Instituto Madrileño de Estudios Avanzados), Universidad Politécnica de Valencia (Spain). Industrial collaborations include: Helioz GmbH (Austria), Ecosystem, Environmental Services (Spain), Aqualia (Spain), Water Service in Spain (Spain), Acuamed (Spain), Hidrocen (Spain), Albaida Recursos Naturales y Medioambiente, S.A. (Spain), Nilo Medioambiente S.L.U. (Spain), BEFESA Gestión de Residuos Industriales (Spain), APRIA Systems S.L. (Spain), IQD Invesquia (Spain), Zonosistem S.L (Spain), DeNora (Italy), Gestión Medioambiental (Spain), ESAMUR Murcia (Spain), DeNora (Italy), Integrated Resources Management (IRM) Company Limited, AEE-INTEC (Austria), Liqtech International A/S, SolarDew S.L, Società Metropolitana Acque Torino S.p.A (Italy), NIVA (Denmark), Innova SRL (Italy), Affordable Water Solutions (India), AQUASOIL SRL (Italy), Kwality Photonics Private TTD (India) and Lasing S.A. (Spain), ARENYS inox S.L. (Spain), LEITAT (Spain), IFE (Norway).

2.4. KEY PERFORMANCE INDICATORS (2016-2020)

2.4.1. Projects and financial sources

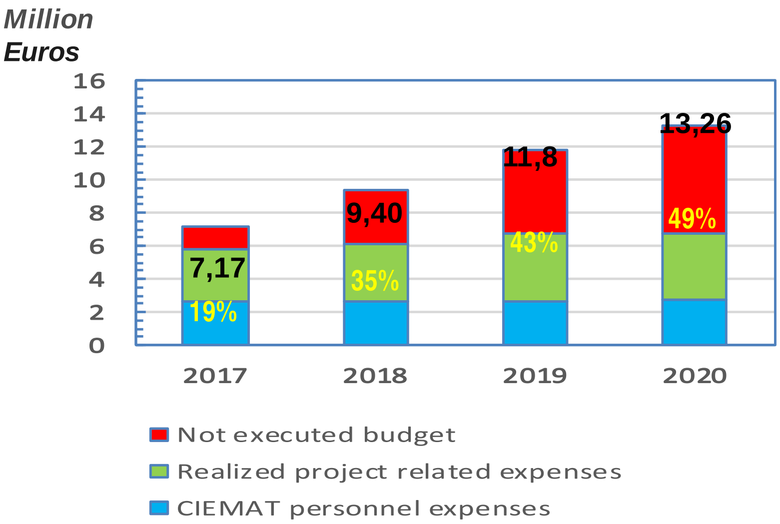
Table 4 show the formally defined Key Performance Indicators (KPIs) related to projects and financial resources, previously submitted to the Spanish Ministry of Science and Innovation (PSA-ICTS periodic evaluation), where the original numbering of the KPIs are maintained.

Table 4. Defined Key Performance Indicators related with projects and financial resources (2016-2020)

#	KPI	Done 2017-2020	Value 2016-2020
1	Number of approved International R&D Projects	21	
2	Number of approved National R&D Projects	9	
3	Total number of R&D proposals submitted for competitive funds	142	
4	Income from public competitive R&D funds (million Euros)	9.2 [1]	
5	Number of weeks of access of total users (internal and external) to the PSA facilities	920	
9	Income from non-competitive R&D funds (million Euros)	2.8	
11	Income from industrial property rights (thousand Euros)	260	

[1] Additionally, 12 M€ were achieved (competitive process) during the reported period from the Ministry fund to support ICTS infrastructures

However, the main problem affecting all activities of PSA during the period 2017-2020 was related to budget execution, consequence of the administrative limitations clearly inadequate to the specific research activity to be carried out (such as the imposed yearly budget, fully incompatible with the nature and normal development of multi-year research projects). It should be noticed that these administrative regulations, in the case of the PSA, could be partially overcome during the previous period 2013-2016 thanks to the existence of a special account, cancelled just in 2016. In addition, the non-existence of national Spanish budget (during the years 2018, 2019 and 2020) added significant supplementary difficulties as, in many cases, the initially allocated budget simply was later non available. The consequence is clearly stated within the Fig. 1, which shows the percentage of non-executed budget within the period 2017-2020 (19% in 2017, 35% in 2018, 43% in 2019 and 49% in 2020, considering the total initial budget, CIEMAT personnel expenses included). It is clear that with these levels of non-execution of projects allocated budget, the objectives are very difficult to be achieved.



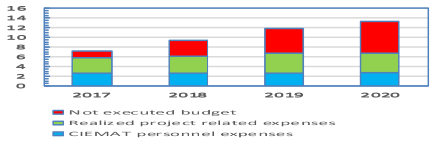


Fig. 3. Breakdown of yearly PSA budget during the period 2017-2021

2.4.2. Scientific and technological production

Table 5 show the formally defined Key Performance Indicators (KPIs) related to the scientific and technological production, previously submitted to the Spanish Ministry of Science and Innovation (PSA-ICTS periodic evaluation), where the original numbering of the KPIs are maintained.

Table 5. Defined Key Performance Indicators related with PSA scientific and technological production (period 2016-2020)

#	KPI	Done 2017-2020	Value 2016-2020
6	Number of scientific publications in peer review JRC journals	261	
7	Number of invited oral presentations in keynotes, plenary lectures and conferences	174	
8	Number of PSA participations in conferences, seminars, scientific meetings, etc.	217	
10	Number of industrial property rights (patents, inventions and protected know-how)	6	
14	Number of participations in editions of special issues in peer review JRC journals	12	
15	Number of associated editor or member of editorial committees in JRC journals	10	

2.4.3. Training and capacity building

Table 6. Defined Key Performance Indicators related with PSA scientific and technological production (period 2016-2020)

#	KPI	Done 2017-2020	Value 2016-2020
12	Number of PhD thesis supervised by PSA researchers	19	
13	Number of Post-Doc positions/contracts at PSA	2	
16	Number of students at Master UAL	38 [1]	38 [1]
17	External training activities (courses) promoted or with PSA collaboration	103	

[1] Value from 2017, initial edition of the master on Solar Energy of the University of Almeria (UAL)

The PSA is the largest concentrating solar technology research, development and test centre in Europe. PSA main objective is to maintain this elite position in the scientific scope. A permanent staff of researchers, support staff, financial resources and infrastructure are required to achieve this overall objective by pursuing the following partial objectives.

2.4.4. International dimension

In addition to the broad collaboration network described in the previous section 2.3, it is considered that one of the best indicators of the international dimension of the PSA during the period 2016-2020 is given by the number of joint publications

Table 7. List of international organizations with five or more scientific publications with joint authorship with PSA researchers, during the period 2016-2020 (Scopus, March 2021)

International Scientific and Technological Organization	Number of joint publications
1) Deutsches Zentrum fur Luft- Und Raumfahrt / DLR (Germany)	63
2) Ulster University (UK)	25
3) Panepistimion Patron / Univ. of Patras (Greece)	18
4) Universidad de Antofagasta	17
5) Mines ParisTech (France)	17
6) Universidad de Tarapacá de Arica (Chile)	17
7) Università degli Studi di Palermo (Italy)	16
8) CSP Services GmbH (Germany)	15
9) Cranfield University (UK)	11
10) Fraunhofer Institute for Solar Energy Systems ISE (Germany)	11
11) Qatar Environment and Energy Research Institute (Qatar)	11
12) Laboratório Nacional de Energia e Geologia (Portugal)	10
13) Université PSL (France)	10
14) TSK Flagsol Engineering GmbH (Germany)	9
15) Pontificia Universidad Católica de Chile (Chile)	9
16) Universidade do Porto (Portugal)	8
17) Institut de Recherche en Energie Solaire et Energies Nouvelles (France)	8

18) ENEA Centro Ricerche Casaccia (Italy)	7
19) Instituto Superior Técnico (Portugal)	6
20) Università di Salerno (Itay)	6
21) Universidad de Chile (Chile)	6
22) Consiglio Nazionale delle Ricerche (Italy)	6
23) Universitatea Transilvania din Brasov (Romania)	6
24) University of Technology Sydney (Australia)	6
25) National Renewable Energy Laboratory / NREL (USA)	6
26) Técnico Institute for Mechanical Engineering (Portugal)	6
27) Hamad Bin Khalifa University (Qatar)	6
28) Universidade de Lisboa (Portugal)	6
29) Qatar Foundation (Qatar)	6
30) Inst. of Materials and Machine Mechanics Slovak Academy of Sciences	5
(Slovakia)	5
31) Slovak University of Technology in Bratislava (Slovakia)	5
32) Universidad Técnica Federico Santa María (Chile)	5
33) CNRS Centre National de la Recherche Scientifique (France)	5
34) Slovak Academy of Sciences (Slovakia)	5
35) University of Oregon (USA)	5
36) Universidade Federal de Santa Catarina (Brazil)	5
37) University of Évora (Portugal)	5
38) University of Cyprus (Cyprus)	5
39) Laboratoire Procédés, Matériaux et Energie Solaire (France)	

Table 8. Defined Key Performance Indicators related with PSA international dimension (2016-2020)

#	KPI	Value 2016-2020
18	Number of international organizations with 5 or more scientific publications with joint authorship with PSA staff, during the reporting period	39
19	Number of international organizations with at least one scientific publications with joint authorship with PSA staff, during the reporting period	158
20	Number of participations of PSA staff in international committees	

3. SWOT ANALYSIS

- Strengths

- Excellent international and national recognition on research on Solar Thermal Energy technologies and applications.

- Highly multidisciplinary and trained teams with great experience, prestige and international visibility. Most of PSA staff has been working in the centre for more than 10 years and some of the researchers are known worldwide and have been recognized for their work.
- Great variety of available experimental pilot plant facilities, unique in the world and of pre-industrial scale enabling technological developments very close to commercial application. To this end, the centre covers all possible solar concentrating technologies from ambient temperature to 2500°C as well as advanced water treatments including decontamination, disinfection and desalination.
- Very large network of national and international organizations (public and private entities) with historical collaboration activities, which is of significantly relevance to identify and promote launching new projects and activities.
- Excellent collaboration with the industry.
- A high success rate in achieving R&D projects, which imply high external financing (reaching up to 60% of total centre expenditures).
- Excellent compatibility of scientific production and external financing.
- Experience and capabilities for training.

- Weaknesses

- The PSA has a large number of highly sophisticated infrastructures that require constant monitoring and maintenance, which hampers the economic viability of the Centre.
- Very important shortage of research staff in relation to both the number and size of its research facilities and the activity carried out at such facilities.
- Previous point is aggravated by the fact of high number of retirements (of highly experienced staff) not possible to be replaced in the last years.
- In addition, a very high ratio of temporary staff (higher than 40%), due to the difficulties of personnel consolidation through permanent positions. This creates uncertainty on affected personnel (deciding some of them leave the centre after some time), as well as an important pressure on administrative and technical staff as continuously contracts should be renewed, following strict procedures and with the proper financing previously acquired.
- Administrative and budget execution difficulties as consequence of government regulations clearly inadequate to the specific research activity to be carried out (in special, the imposed yearly budget is not compatible with the nature and normal development of multi-year research projects).

- Opportunities

- PSA objectives are in line with the targets set by the European Commission in its climate and energy targets plans for the year 2030. Therefore, there are promising prospect of Spanish and European research programs and funding calls focused on renewable energy and environmental water initiatives.
- Excellent national and European context for the development of CSP/STE technologies due to the expected strong support to Clean Energy Transition initiatives.
- Excellent position of CSP/STE related technologies, at both national and international level, as a key element in the current energy transition process to renewables worldwide, thanks to the dispatchability provided by large capacity the thermal energy storage systems.
- Increasing interest of the industry in new innovative developments, especially due to the expected relaunching of the Spanish CSP/STE commercial deployment program. This is a major source of activity for R&D in a Centre as specialized as the PSA is.
- Spanish leadership of the CSP Implementation Plan of the SET-PLAN and associated initiatives.
- The National R+D+i Plan aims to consolidate large scientific singular facilities, PSA being one of them.

- Threats

- Existence of competitors with more flexibility and attractiveness to lead and participate in international projects due to administrative and budget execution difficulties PSA (and CIEMAT) has faced during the last years (especially since 2016), as a direct result of restrictive imposed administrative rules (which are different from those in the main R&D Spanish sector, formed by the Universities and CSIC).
- Overload in technical, operational and administrative tasks due to the numerous infrastructure and laboratories PSA has and the indicated shortage of staff.
- The lack of sufficient technical staff associated to the proper maintenance of PSA large installations and facilities is creating difficulties into the daily operation and management of such facilities.
- Loss of trained and highly valuable human resources due to the lack of professional development and incentives for achieving objectives, fact worsened by significant recruitment difficulties.
- Decrease in competitive public funding.

4. ACTION PLAN (2021-2025)

4.1. SCIENTIFIC AND TECHNICAL ACTIVITIES

Breve descripción del programa de trabajo a desarrollar, indicando entre otros el tipo de proyectos y ámbitos de actuación. (≤ 2 pages)

4.2. OBJECTIVES

4.2.1. Technical and Scientific objectives

(1 - 5 pages)

- **Linear Focusing concentrating technologies**

- **Point Focusing concentrating technologies**

- **Thermal Energy Storage for concentrating solar thermal technologies**

- **Materials for solar concentrating technologies**

- **Thermochemical processes for hydrogen and raw materials production**

- **Solar process heat applications**

- **Solar treatment of water**

4.2.2. Target Key Performance Indicators for the period

The targets formally and officially defined within the Strategic Plan of PSA as ICTS for the period 2021-2025 are provided within the following table.

Table XX. Tracking indicators target objective for the period 2021-2025

#	KPI	Per year	Target
1	Number of approved International R&D Projects	10[1]	30[2]
2	Number of approved National R&D Projects	6[1]	18[2]
3	Total number of R&D proposals submitted for competitive funds	25	125
4	Income from public competitive R&D funds (million Euros)	2.5	12.5
5	Number of weeks of access of total users (internal and external) to the PSA facilities	300	1500
6	Number of scientific publications in peer review JRC journals	75	375
7	Number of invited oral presentations in keynotes, plenary lectures and conferences	50	250
8	Number of PSA participations in conferences, seminars, scientific meetings, etc.	60	300
9	Income from non-competitive R&D funds (million Euros)	0.6[3]	3.0[3]
10	Number of industrial property rights (patents, inventions and protected know-how)	2	10
11	Income from industrial property rights (thousand Euros)	75	375
12	Number of PhD thesis supervised by PSA researchers	12[4]	25[4]
13	Number of Post-Doc positions/contracts at PSA	1	5
14	Number of participations in editions of special issues in peer review JRC journals	3	15
15	Number of associated editor or member of editorial committees in JRC journals	---	5
16	Percentage of women at PSA activities contracted by CIEMAT	---	42%

1. Usually 3-4 years' projects.
2. Total quantity of different projects.
3. Including agreements with other institutions.
4. PhD running per year and total PhD supervised by PSA researchers defended 2021-2024.

4.2.3. Training and Capacity Building Plan

(1 page)

4.2.4. International Collaboration Plan

(1 page)

4.2.5. Knowledge Transfer Plan

(1 page)

4.2.6. Planned Dissemination Activities

(1 page)

4.2.7. Strategic Opportunities and Social Impact

(1 page)

4.2.8. Alliances and Collaboration Network

(1 page)

4.3. NEEDED RESOURCES

(1 page)

- *Indicar los recursos necesarios del CIEMAT: personal, instalaciones, equipos…*
- *Cómo se consiguen: financiación externa, reagrupamiento de recursos del CIEMAT, recursos no existentes que requieran inversión directa del CIEMAT…*

Resources

Table 8. Expected resources to be applied to implement the ICTS Strategic Plan (period 2021-2024)

Resource	Description	Forecast Investment	Justification
Income from CIEMAT (PGE)	Funds available in State General Estimates for PSA	10 M€	Average income 2017-2020, 2.5 M€/y
R&D Projects	National, European and Private R&D funds. PSA R&D Units support their R&D by competitive funds.	10 M€	Average income 2017-2020, 2.5 M€/y
Cooperation Agreement between CIEMAT and DLR in the Field of Solar Energy Research	DLR maintains a permanent delegation at the PSA. The capacity and staffing of this delegation is negotiated annually with CIEMAT on the basis of the DLR workload and task schedules associated with the fulfilment of its obligations in the execution of PSA-related projects.	2 M€	Average income 2017-2020, 0.5 M€/y
Specific funds to Singular Scientific and Technological Infrastructures (ICTS)	Expansion, Improvement, Renovation and Remodelling of the Plataforma Solar de Almería (PSA), Second Phase (SolarNOVA-II) extension	9 M€[1]	Described within additional Investment Plan described in the Annex
Research and Technical Staff	Seniors Researchers and technicians, permanent staff of PSA	30 persons[2]	Permanent staff
	Non-permanent researchers, PhD students, technicians and other personal of PSA sponsored by PGE, R&D projects and other resources	95 persons	Average of last 5 years.

[1] Available resources
[2] It is expected to increase up to around 50 permanent positions during the period 2021-2024

4.4. ACTIONS NEEDED

Para garantizar que el CIEMAT puede desarrollar el plan propuesto por el área C-T. (Muchas de ellas serán respuesta al análisis DAFO: recursos necesarios, nueva contratación, inversiones, reorganización…) (1 page)

Description of objectives

The general objectives inspiring the research and technology activities in the PSA for 2021-2024:

- Maintaining acknowledged leadership and international excellence in related research technologies and applications.
- To increase the scientific quality and international relevance of PSA.
- To promote the development of technological innovations aimed at reducing costs that contribute to increase the efficiency of concentrated solar and water treatment technologies, also favouring its market penetration.
- To strength the cooperation between the business sector and scientific institutions in the field of research, development and demonstration of technologies related to the concentration of solar radiation and water treatment.
- To address the training and formation of specialised researchers, engineers and technicians in concentrated solar and water treatment technologies, to provide high skilled workers with especial focus on the Spanish labour market.
- To increase the cooperation with foreign organizations, with special focus on European, Mediterranean and Latin American areas, expanding the PSA collaboration network.

These general objectives are included in the specific objectives listed below.

Table 5. PSA Specific Objectives for the period 2021-2024; associated strategies are listed in Table 6; related Key Performance Indicators (KPIs) are indicated in Table 9

Specific PSA Objectives	Actions and tools to be performed or used	Associated	
		Strategies	KPIs
A) Increasing number of projects & funding from competitive public calls	- Continuous submission of project proposals - Participation in strategic forums, platforms and clusters to increase PSA network	1, 3, 4, 5, 6, 15	1, 2, 3
B) To increase the number of contracts and services to industrial companies	- Dissemination of finished and on-going projects and achievements at industrial workshops - Identify and promote potential interest of related companies (direct bilateral meetings)	1, 4, 5, 10, 11, 12	9
C) To increase the number of scholarship holders working at PSA	- Active policy to attract top PhD students, seeking grant funding opportunities and assist students in the application process - International Master in Solar Energy at the Almeria Univ.	13, 16	12
D) To increase the number of post-doc holders at PSA	- Active seek of post-doc grant funding opportunities - Active seek of high-quality recent PhDs to offer applications to suitable calls	16	13
E) To increase the number of users of PSA installations	- Expansion of R&D capacities and services in all PSA research areas as well as the high-quality ones - New or improved measurement techniques associated to the facilities and laboratories	3, 4, 5, 6, 7, 8, 10	4, 5
F) To increase the number and quality of scientific publications	- Active pressure to publish all available project results - Promote the role of Editors in Journals - Increase the number of PhD thesis	2, 9, 13, 16	6, 14, 15
G) To increase the number of patents and associated income	- Active internal policy to promote patent applications - Active dissemination of patents & key project results	10, 11, 12	10, 11
H) To increase the number of PSA staff with permanent positions	- Continuous insistence to our Ministry about the necessity to reduce the percentage of temporary scientific staff (currently exceeding the 50%,	----	N/A[1]

Specific PSA Objectives	Actions and tools to be performed or used	Associated Strategies	Associated KPIs
	excluding PhD and post-doc personnel)		
I) To increase visibility and the knowledge of PSA activities by the general society	- Open and wide dissemination of main successful project results and achievements	14, 15	7, 8
J) Normalize equal participation of woman on all PSA activities	- Encourage women applications to all open positions announced related to PSA (advertisement campaigns)	17	16
K) Safety, quality and environmental	- PSA internal Quality Plan - PSA internal plan for Health and Safety Risks Issues	18	N/A[2]

1. No KPI associated as this topic, besides being considered a critical issue to the PSA, does not depend on any internal action or performance. Nevertheless, it is included here to continuously remind the necessity to normalize the current staff situation.
2. No KPI defined and associated to this topic.

Strategies for achieving the objectives

The following tables describe the 19 strategies that will be implemented to the achievement of previously indicated objectives. Within each Research Unit of the PSA (indicated and described within section 2.3) the responsible of achieving these goals are the Head of Unit with the obvious strong assistance and close collaboration of all staff of such Unit (including scholarship holders).

Table 6. Strategies for achieving the objectives and associated KPIs (see also Table 9)

Objective	ICTS related topic	Defined strategy	KPI
A	a) General	1. Remain leaders in related research and development activities	3, 4
		2. Increase the scientific production 'per capita'	All
E	b) Operability	3. Improve the operatively and availability of ICTS infrastructures	5
E	c) Capacity	4. Increasing the current list of available PSA services	9
		5. Creating new infrastructures and properly maintain the existing ones	N/A
E	e) Access	6. Increasing participation in national and international projects	1, 2
		7. Increasing the external access to PSA facilities	5
		8. Increasing the number of facilities available to external access	5
F	j) Scientific production	9. Increasing publications in high quality peer review journals	6
B, G	k) Knowledge transfer	10. Increasing and facilitating the support to external stakeholders	9
		11. Increasing the number of patent applications	10
		12. Increasing the number of contracts with companies	9
C	p) Training	13. Increasing the number of doctoral thesis and their types	12
I	q) General public	14. Improving the performance and activities of the visitor centre	N/A
A, B, E	r) International coop.	15. Increasing the cooperation with defined world focus areas	1
D, H	s) Human resources	16. Increasing the number of post-doc researchers and PhD students	12

Objective	ICTS related topic	Defined strategy	KPI
J	t) Gender equality	17. Increasing the number of women participating in ICTS activities	16
K	u) Quality & safety	18. Improving the safety and quality protocols	N/A

4.5. SUSTAINABILITY

Previsión a corto y medio plazo sobre la línea de actividad considerando los puntos anteriores (1 page)

4.6. OTHER

En este apartado puede indicar otros aspectos que considere relevantes. (1 page)

Development of strategies

The planned actions to facilitate the adequate development of previously indicated 18 strategies to the proper achievement of defined objectives are summarized within the Table 7.

Table 7. Development of strategies for achieving the objectives

Defined strategy	Associated planned & supporting actions during the period 2021-2025
1. Remain leaders in related research and development activities	Continuous improvement in research and infrastructure
	Encourage PSA staff and Research Units, through internal protocols, to maintain scientific excellence, always also trying to improve it
3. Increase the scientific production 'per capita'	Continuous training of members and researchers of the centre
	Freeing researchers of doing maintenance and operations works
	Active participation and contribution to related conferences, symposia, workshops …
6. Improve the operatively and availability of ICTS infrastructures	Development and preparation of an 'Infrastructure Improvement Plan'
	Operate facilities to its optimum level with continuous supervision to early identify needed or convenient actions which could improve previous Plan
8. Increasing the current list of PSA services	Full definition of available services to the industrial and external R&D organizations
	Determination of cost of all previous identified services
10. New infrastructures / Maintenance of existing ones	Active and continuous interaction with industrial stakeholders to identify new necessities and associated new or improved infrastructures
	Continuous update of the Maintenance Plan of general and individual infrastructures
12. Increasing participation in national and international projects	To promote the increment of proposals submitted to either national or EC calls
	To promote the increase of networking activities to facilitate the participation in successful consortiums
	Contacting potential partners showing PSA capacities
15. Increasing of external access to PSA facilities	Facilities better adapted to specific ISO standards
	Whenever possible, encourage the reporting, by all researchers, about the Access possibilities in workshops and conferences

Defined strategy	Associated planned & supporting actions during the period 2021-2025
	Full definition of available services to the industrial and external R&D organizations
	Determination of cost of all identified services, making it available on ICTS website
19. Increasing the number of facilities available to external access	Try to reduce to the minimum the number of facilities not offered to external access
	Increasing the availability of specific services with higher external demand
	Optimize the coordination of the maintenance program of different facilities to minimize the number of them unavailable for research activities
22. Increasing publications in high quality peer review journals	Encouraging researchers to publish their results in top journals by periodically distribute the updated list of Q1 scientific publications
	Request, when possible, a publication from any access realized to PSA facilities
24. Increasing the support to external stakeholders	Openly negotiate the specific needs (financial/technical) trying to find a solution
	Try to fit the needs of external users through additional external funds (calls)
26. Increasing the number of patent applications	Periodic workshops realization to explain and promote the patent application process
	To provide external assistance to PSA researchers in the whole application process
28. Increasing the number of contracts with companies	Increasing the availability of specific services with higher external demand
	Openly negotiate company needs (financial/technical) trying to always find a solution
	Increasing the current list of existing PSA services
	Increasing agreements with companies
32. Increasing the number of doctoral thesis and their types	To actively advocate to the increase of CIEMAT PhD funding program
	Active policy to promote presentations and seminars in Universities
	To always trying to include budget for PhD grants within project proposals
	Announce at PSA website suitable calls to PhD recruitment, encouraging applications
	Establishment of agreement with the University of Almeria to joint PhD co-direction
37. Improving the performance and dissemination activities of the visitor centre	Schedule and launch specific programs and dissemination campaigns to attract more external visitors to the ICTS centre
	Prepare and announce specific activities at defined facilities with occasion of well-known periodic events: the night of researchers, the day of the women is Science, …
39. Increasing the cooperation with defined non-EU regions	Internally promoting the increase of the cooperation with North Africa and Middle East organizations due to the strong synergy and interest on PSA-ICTS activities
	Increasing cooperation with Latin and Central America organizations
41. Increasing the number of post-doc researchers and PhD students	Announce at PSA website suitable calls to PhD recruitment, encouraging applications
	Announce at PSA website suitable calls for post-doc positions, encouraging applications of students with good academic record
43. Increasing the number of women in ICTS activities	Keeping the actual line of equality, always analysing improving possibilities
	Whenever possible, try to increase the number of women researchers and technicians at PSA

Defined strategy	Associated planned & supporting actions during the period 2021-2025
45. Improving the safety and quality protocols	Definition and development of a PSA Quality Plan, to the assessment of quality and efficiency of all PSA activities
	Yearly updating the internal PSA plan for health and safety risks issues
	Modernization and expansion of the communications network
	Greater energy efficiency and comfort by Infrastructure and buildings remodelling