

# INFORME ANUAL CIESOL

CIESOL ANNUAL REPORT



# CIESOL

Centro de Investigación en Energía Solar  
Centro Mixto UAL-PSA-CIEMAT

Solar Energy Research Center  
JOINT CENTER UAL-PSA CIEMAT

# INFORME ANUAL

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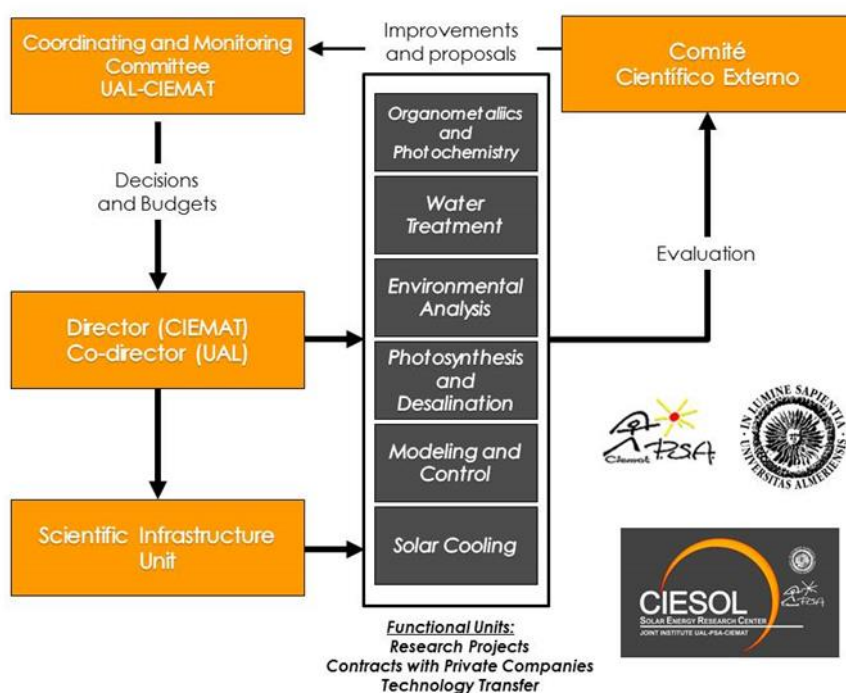
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## 0. INTRODUCTION

CIESOL brings together the experience of more than 20 years of collaboration between research groups from the University of Almería and the Plataforma Solar de Almería. This UAL-PSA relationship formally commenced in April 2005 with the signing of an agreement between the University of Almería and CIEMAT-PSA for the creation of a joint research center.

The operating structure of CIESOL is formed by a Coordination and Monitoring Committee, a highest decision making body, a Management Team and a set of 6 Operating Units uniting researchers from both institutions in different specific subject areas. It should be noted that CIESOL has an External Evaluation Committee, including four nationally and internationally renowned members, which annually assesses and supervises the scientific production of its different operating units as well as the management of the center. There is also a scientific facilities and management unit, made up of technical specialists, which is in responsible for the maintenance and operation of the center's equipment.



Functional Organisation

The Coordination and Monitoring Committee is made up of two researchers from the UAL, one of whom must be the Vice-Rector of Research, Development and Innovation of the university and two researchers from the PSA, one of whom must be the Director of the Plataforma Solar de Almería. Currently, the Coordination and Monitoring Committee comprises Antonio Posadas Chinchilla (Vice-Rector for Research) and Manuel Berenguel Soria for the UAL as well as Sixto Malato Rodríguez (Director of the Plataforma Solar de Almería) and Eduardo Zarza Moya for the PSA. The Management Team consists of a director and a deputy director, belonging to UAL and PSA (and vice versa) for three year periods. At present the director is José Antonio Sánchez Pérez from the UAL, while Sixto Malato Rodríguez from the PSA is deputy director. Regarding the External Evaluation Committee, its members are Rafael van Grieken, former director of

ANECA and current Counsellor of Education, Youth and Sport for the Community of Madrid, María Luisa Castaño, Managing Director of Innovation and Competitiveness (MINECO, Government of Spain), David Serrano, Director of IMDEA ENERGÍA from Madrid and Sebastián Dormido, Full Professor of Computer Science and Automation from the UNED (Doctor Honoris Causa from the UAL).

The six operating units are briefly described below.

#### **Organometallics and photochemistry.**

The initial scope of this Operating Unit, the synthesis of metallic catalysts for the mediation of photochemical reactions in water, has now been extended to other areas such as photo-generation of hydrogen or the transformation of small molecules by solar radiation. Its primary researchers are Antonio Manuel Romerosa Nievas (UAL) and Christoph Richter (DLR-PSA), the strategic lines of action being :

- Development of new water soluble homo- and hetero-metal-polymers with photocatalytic activity in the synthesis of high impact molecules.
- White phosphorus transformation mediated by visible-light irradiation.

#### **Water treatment.**

This Operating Unit focuses its activity on the study of solar photocatalysis for the elimination of toxic substances and the disinfection of water, as well as its combination with advanced biological methods. There is close collaboration with the "Analytical evaluation of water treatment and environmental analysis", unit, complementing and strengthening the main current lines of work. Its primary researchers are José Antonio Sánchez Pérez (UAL) and Manuel Ignacio Maldonado Rubio (PSA), the strategic lines of action being:

- Application of photo-Fenton solar to the decontamination of toxic waters and to the elimination of microcontaminants and disinfection of purified water (regeneration).
- Optimization of the operation and development of new technology for photo-Fenton. Water Economics.

#### **Analytical evaluation of water treatment and environmental analysis.**

The activity of the group is focused on the development, optimization and analytical assessment of advanced wastewater treatment processes applied to complex effluents in order to be regenerated and thus enable their possible reuse. Its primary researchers are Ana Agüera López (UAL) and Isabel Oller Alberola (PSA), the strategic lines of action being :

- Development of advanced analytical methods for characterizing complex effluents and their application to monitoring of organic micropollutants during wastewater treatment to ensure their elimination.
- Identifying transformation products generated during wastewater treatment and establishing routes of degradation.
- Study of the influence of treatments on the quality of reclaimed water and evaluating the impact of its reuse in agriculture.

#### **Photosynthesis and desalination.**

The group carries out two parallel lines of work dealing with solar energy application in desalination, using membrane systems and microalgal cultivation. This is geared particularly towards recycling by solar energy-driven synthesis of commodities such as biofertilizers or biodiesel and high-value products such as carotenoids and essential fatty acids. Seawater is the main raw material used, although the research deals with other types of sources, freshwater, brines, brackish waters or wastewaters being considered. Its primary researchers are José M. Fernández Sevilla (UAL) y Guillermo Zaragoza del Águila (PSA) and the core research lines are:

- Development of membrane-based solar desalination and effluent treatment systems.
- Application of solar energy to the treatment of hypersaline media.
- Recovery of high-value compounds from brines and hypersaline effluents.
- Design of photobioreactors for the cultivation of microalgae.
- Applications of microalgae for the purification of wastewaters and industrial effluents
- Production of valuable compounds using microalgae.

#### **Modeling and automatic control.**

The group counts among its areas of interest: intensive agriculture, solar energy, biotechnology and bioengineering, as well as modeling, mechanization and robotics in general. Collaborative activities between the group and the PSA have been carried out continuously over the past 20 years, with the noteworthy participation of UAL researchers in developing some of the SCADA (Supervisory Control And Data Acquisition) systems as part of the test facilities located in the PSA. Following the experience gained in the ARFRISOL project, the group also has a research line linked to the applications of control systems to achieve thermal, visual and air quality comfort and energy efficiency in buildings.

Its primary researchers are Manuel Berenguel Soria (UAL) and Luis José Yebra Muñoz (PSA), the strategic lines of action being :

- Modelling and control of thermosolar plants, photo-bioreactors and robotics in agriculture.
- Energy efficiency and comfort control in buildings.
- Engineering Education.
- Electric vehicles.
- Energy smart grids.
- Predictive, hierarchical and robust control.
- Supervisory systems and industrial communications.

#### **Solar resource assessment and solar cooling.**

The Solar Resource Assessment and Solar Cooling unit has extensive experience in the design/optimization of thermal systems, ground-coupled heat exchangers, and shallow geothermal systems along with the integration of solar thermal and photovoltaic energy within the construction sector. Its primary researcher is Francisco Javier Batlles Garrido (UAL) and the main research lines are:

- Modelling and control of thermosolar plants.
- Evaluation and forecast of solar resources.
- Teledetection and sky cameras.
- Design and optimization of solar thermal cooling and heating systems and trigeneration systems.
- Thermal energy storage through phase change materials

**Objectives, areas of research and scope**

As part of the CIESOL agreement UAL-CIEMAT, the following objectives are considered:

- Development of solar energy research and its environmental applications.
- Development of different lines of research in a common space, located in the UAL, sharing facilities to carry out work on joint projects.
- Support and intensify research activity connected with the UAL higher education and the CIEMAT-PSA research groups, which are part of CIESOL.
- Provide young graduates with access to the research field, as well as the training and promotion of the CIESOL staff.
- Improve relations with other national and international centers to promote a better connection in related areas.
- To promote and boost international scientific relations in the solar energy research field in order to encourage the exchange of experiences with scientists from other countries.

CIESOL focus its activities on the following fields (using UNESCO nomenclature):

- Automatic control [3311-01, 3311-02, 3311-05, 3311-15]
- Bioclimatic architecture [3305-01, 3305-14, 3305-22, 3305-90]
- Environmental chemistry [2391]
- Pollution control and physico-chemical water treatment [3308-8, 3308-06, 3308-10, 2508-11, 3302-90]
- Desalination using distillation [3328-07]
- Photochemical and organometallic synthesis [2210-22, 2303-21]
- Solar radiation measurement [2106-01, 2202-06]
- Materials technology [3312]

The scope of research activities at CIESOL enables it to:

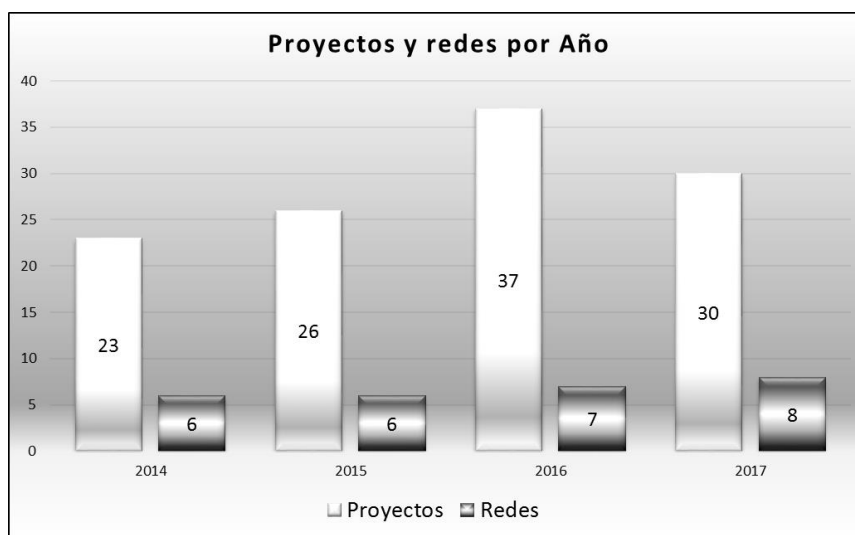
- a) Participate in calls for the European Union and the National Plan for R & D, in both research and demonstration projects.
- b) Foster collaboration with companies related to energy and the environment.
- c) Develop technological innovation patents that facilitate the industrial development of Almeria and, in turn, the Levante area as a whole (the eastern region of the Iberian Peninsula, on the Spanish Mediterranean coast).
- d) Conduct seminars and workshops dedicated to different topics related to the use of solar energy, such as: electricity generation, evaluation and prediction of solar resources, development of new materials, water treatment, photocatalysis, photochemical reactions and organometallic chemistry.
- e) Any other activities that could help to achieve the pursued goals.



## 1. EXECUTIVE SUMMARY

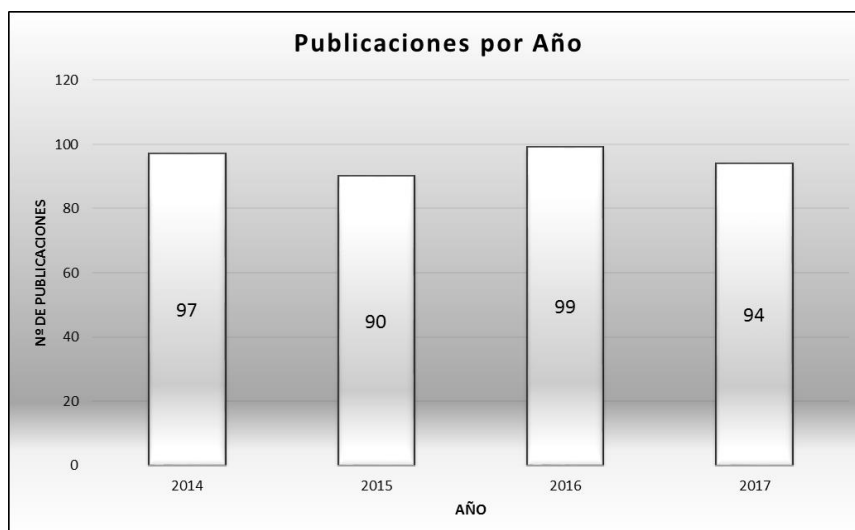
The CIESOL, together with the PSA and the UAL Escuela Superior de Ingeniería, has launched the official Master in Solar Energy of the University of Almería that began to be taught in the 2017/2018 academic year, whose academic coordinator is Professor Manuel Berenguel Soria, IP of the Modeling and Control functional unit and technical coordinator is the Research Professor Eduardo Zarza Moya, from PSA. In order to increase the external relations of the center, in February 2017 the visit was received from the President of the Social Council of the University, Magdalena Cantero, establishing communication and collaboration ties with this important university body. Likewise, CIESOL has been invited by the Association of businessmen of Almería, ASEMPAL, to collaborate in the drafting of the Integrated Territorial Investment plan whose motto is the water-energy nexus, with special dedication to solar energy. It also collaborates with the CAJAMAR bank to create a High Technology Incubator specialized in the efficient use and management of water. Regarding the management of the center, during 2016 an Internal Regime Regulation was prepared in compliance with the Research Centers Regulation of the University of Almería, approved by its Governing Council on September 28, 2016. At present, it is not yet He has received information on this from the General Secretariat.

During 2017, 74 researchers have participated in projects and contracts attached to CIESOL, 17 of them with permanent location in their laboratories and offices throughout this period. The activities of these researchers have been framed in 16 projects of the National Research Plan and 3 of the Andalusian Program of Incentives for Knowledge Agents, 6 contracts with companies and institutions and 12 European projects. In 2017, 9 new projects were requested. The figure shows the evolution of the number of projects in the last four years, since the establishment of the center in 6 functional units. An average of 29 projects in execution per year is observed.



Projects and networks by year

As for the scientific production corresponding to 2017, a total of 94 publications indexed in the Journal Citation Report have been reached. All units have participated in national (10) and international (47) scientific conferences and meetings with a total of 80 contributions. The figure shows the evolution of the number of international scientific publications in JCR in the last four years. An average of 95 articles per year is observed.



Publications by year

Also noteworthy is the financing obtained through the aforementioned projects, € 867,188 in 2017, in the order of financing obtained in previous years. All this effort would not be possible without the confluence of objectives between the UAL and CIEMAT.

It should not be overlooked that one of the most relevant results of the UAL-PSA collaboration during 2017 has been the reading of 2 doctoral theses of UAL students co-directed by UAL and PSA researchers, and that ensure the continuity and dissemination of the knowledge generated, since doctors trained in CIESOL are working in prestigious research centers in different countries around the world.

Together with the detailed information that will be made in the following chapters by the functional units and technical services, the following milestones are highlighted in this initial summary of activities throughout 2017:

#### Network participation

- Workgroup "WG5: Wastewater reuse" ( NORMAN W604002510)
- European COST Action titulada: 'NEW AND EMERGING CHALLENGES AND OPPORTUNITIES IN WASTEWATER REUSE (NEREUS)' (RED COST Action ES1403).
- RED CONSOLIDER TRAGUA (CTM2014-53485-REDC)
- European Network on Smart Inorganic Polymers (RED COST Action COST CM1302)
- Processing of brewery wastes with microalgae for producing valuable compounds (GREENBIOREFINERY) ERANET-LAC 2014
- Red Temática Nuevos materiales y reactores fotocatalíticos para la eliminación de microcontaminantes y patógenos, FOTOCAT (CTM2015-71054-REDT)
- European Robotics Research Network EURON
- Red Temática de Ingeniería de Control. Acción especial del Plan Nacional. DPI2014-51731-REDT. IP. Ramon Vilanova, 01/2015-01/2017.

- Thermal energy storage with phase change materials for solar cooling and Heating Applications: A technology viability analysis (PCMSOL) Comisión Europea (ERANET-LAC Joint call 2015-2016), MINECO (Ref. PCIN-2016-013)
- Recuperación de energía de una planta piloto de reactor batch secuencial de biofiltro granular (THERBIOR) Comisión Europea (ERA-NET Cofund WaterWorks2014 Call, Water JPI), MINECO (Ref. PCIN-2015-258)
- NETWORKING FOR EXCELLENCE IN SOLAR THERMAL ENERGY RESEARCH (NESTER) European Commission, Horizon 2020 programme
- Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis (RED-Heat-to-Power) European Commission, Horizon 2020 programme

#### **Awards received in 2016:**

- Distinction 2017 of the "El Saliente" Association, Innovation category. Antonio Giménez Fernández, 01/12/2017.
- First prize in the national contest of Control Engineering. Students: Francisco José García Mañas, Miguel Ángel Andrés Asensio. Tutores: Manuel Berenguel Soria y José Luis Guzmán Sánchez.
- Microsoft Azure Research Award. Jorge Antonio Sánchez Molina. 20/05/2017.

#### **Dissemination and research transfer:**

Within the interest in the dissemination and transfer of research, in 2017 CIESOL has actively participated in:

- Participation in the European COST Action entitled: 'NEW AND EMERGING CHALLENGES AND OPPORTUNITIES IN WASTEWATER REUSE (NEREUS).
- Contracts with companies
  - Advice on the development of a methodology for modeling soil moisture in outdoor crops. IP. Jorge Antonio Sánchez Molina, Francisco Rodríguez Díaz. 09/15/2016 - 15/01/2017. Community of Madrid / AISCOS, € 17,400.
  - Mobile Robotics application development with MRPT, 001242/2. 03/01/2017 - 31/05/2017. IP. José Luis Blanco Claraco, € 33,000.
  - Mobile Robotics application development with MRPT, 001242/1. 03/01/2017 - 31/05/2017. IP. José Luis Blanco Claraco, € 75,400.
- Agreement with the University of Brescia and participation in Sfera 2 project.
- UAL-CIEMAT Agreement
- Collaboration with the Unit of Energy Efficiency in the Building Uie3 of CIEMAT
- Collaboration in the ERASMUS + KA 107 program
- Collaboration in the STUDY ABROAD program of the University of Almería
- Collaboration with IMDEA Energy
- Plenary conference given by Francisco Javier Batlles Garrido at IWLIME, 2017. International Workshop. Lithium, Industrial, Minerals and Energy. Chochanamba (Bolivia), July 2107.
- Several meetings with the company Hedera Helix Ingeniería y Biotecnología S.L., Phase Change Technologies S.L., for the development of an energy recovery plant with phase change materials.

- 6 month stay of Francisco Javier Batlles Garrido (July to December 2017) In the SERC (Chile). He collaborated with the University of Chile and with the University of Antofagasta. Work was done on the modeling of photovoltaic plant production and characterization and encapsulation of phase change materials.
- Teaching of the PhD course "Measurement and Calculation of solar radiation". University of Antofagasta (Chile). November 2017
- Project meeting "Thermal energy storage with phase change materials for solar cooling and Heating Applications: A technology viability analysis (PCMSOL)", in Cochabamba (Bolivia), September 2017.
- Course on "Fundamentals on bioreactors, design and implementation of bioprocesses applied to microalgae biotechnology", CIBNOR, La Paz, Mexico, November 2017.
- Workshop on Innovation in Biotechnology and Hydrobiological Resources within the framework of the Diploma in Management for Technological Innovation for the sustainable use of Renewable Natural Resources at the Aturo Prat University of Chile, November 2017
- International Training School Microalgae based processes: upstream and downstream, COST ACTION EUALGAE, Almeria September 2017.
- International Summer Course Study Abroad 2017 Fundamentals of Microalgae Bioprocesses, Almeria, July 2017
- Symposium of microalgae bioprocesses in collaboration with the Oleopalma company and the ITESO University of Guadalajara, Mexico, September 2017.
- Conference by invitation Biotechnological processes based on bacteria applied to the sustainable production of vegetables. Agro-Food Technical Conference: Sustainable production of vegetables (Spanish Society of Horticultural Sciences). Almeria, Spain 2017
- Conference by invitation Sustainable production of aquafeed from microalgae: SABANA project, Challenges and opportunities for aquaculture development in Northern Chile. Antofagasta, Chile 2017
- Conference by invitation On the contribution of microalgae to wastewater treatment processes. 7th International Conference on Algal Biomass, Biofuels and Bioproducts. Miami, USA 2017
- Conference by invitation Major challenges in the production of microalgae at large scale. 8th Symposium on Microalgae and seaweed products in plant / soil systems. Mosonmagyaróvár, Hungary 2017
- Conference by invitation Sustainable algae biorefinery for agriculture and aquaculture: SABANA project. 8th Symposium on Microalgae and seaweed products in plant / soil systems. Mosonmagyaróvár, Hungary 2017

All this is explained in more detail in the section on transfer and complementary activities of each functional unit.

On the other hand, the center has had numerous stays of researchers, including two from the Technical University of Crete (Greece), three from the University of Brescia (Italy), two from the University of Rabat (Morocco), one of the University of the Republic of Uruguay (Uruguay) one of the Federal University of Santa Catalina (Brazil), one of the University of Seville, etc. All this is also detailed in each of the units.

The activities developed by each Functional Unit are detailed below.

## 2.1 ACTIVITIES OF "ORGANOMETALLICS AND PHOTOCHEMISTRY"

### 2.1.1 Functional unit description

In 2016 the unit was constituted by 10 members (three university professors, five researchers, two predoctoral contract and one postdoctoral contract) most of them pertaining to the research team FQM-317 entitled "Coordination/Organometallic Chemistry and Photochemistry" that is constituted by researchers from U. Almería, La Laguna and Cádiz and a researcher at the German Aerospace Centre - Plataforma Solar de Almería (DLR-PSA-CIEMAT). The group has research collaborations with PAI (Andalusian Research Plan) groups and CIESOL groups as well as with other Andalusian universities. The unit has not stopped growing in both projects (regional, national and international) and scientific production (> 200 articles in international journals chemical impact). The initial interest of the team, the synthesis of metal catalysts for photochemical reactions in water, has been extended to other areas such as photo-hydrogen-generation, conversion of small molecules by solar radiation and production of electricity by solar light.

### 2.1.2 Main research lines

- New water soluble homo- and hetero-metal-polymers with photocatalytic activity in the synthesis of high impact molecules and production of electricity.
- White phosphorus transformation mediated by visible-light irradiation.

### 2.1.3 Main researchers

**Antonio Manuel Romerosa Nieves** (ORCID ID = 0000-0002-6285-9262; Scopus Author ID 6603792206)

Antonio Romerosa was born in Granada (Spain) in 1964. He graduated in 1987 (University of Granada) and received his PhD (Universitat Autònoma de Barcelona) in January 1992. In the same year he undertook a postdoctoral research at the former ISSECC CNR, now ICCOM CNR, (Florence, Italy), before becoming Lecture Professor (1997) and finally Full Professor (2009) at the University of Almería (Spain). His research interests range over homogeneous catalysis and organometallic chemistry in water, phosphorus chemistry, photo-inorganic-chemistry, bioinorganic chemistry and natural stones. He has authored of more than 133 international refereed papers, 14 Spanish and international patents and made more than 230 presentations at national and international meetings. He has been responsible for more than 20 national research regional and European projects, was supervisor of 18 PhD and is supervising 2 more. He is responsible of the Junta de Andalucía research team FQM-317.

**Christoph Richter** (Scopus Author 55439554100)

PhD in Physical Chemistry from the University of Cologne in 1993. In 1994 he began to work in the Department DLR (German Aerospace Center) is at the Plataforma Solar de Almería (PSA-CIEMAT) in Spain, the largest test center for research and development in solar concentrating technologies at high temperatures. Initially working as a project manager in the area of solar chemical in development projects photochemical applications of solar energy in water treatment and fine chemical synthesis. Currently working on different aspects of the operation of solar thermal plants, including heat storage, cooling and environmental impact, and is responsible for administration and infrastructure department of DLR in Almería. Since March 2008, is the Secretary General of Solar PACES.

### 2.1.4 Summary of the functional unit's activities carried out in CIESOL during 2017

During 2017 the research team has been deeply remodeled. His manager made a stay of 7 months at the Rutherford-Appleton Laboratory in England, during which he has conducted a series of experiments that have given new meaning to the work of the group, directing it to the development of new heterometallic polymeric materials with optical properties and photochemical. The group has incorporated two predoctoral contracts and diverse students of degree and master. The main activities of the group were the student training, the publication of articles in the best journals in the area of chemistry, inorganic chemistry and materials, as well as the realization of invention patents. Recently, an AACI project has been obtained for the development of Latin American countries that, together with contracts with companies, will allow it to continue its research activity in the coming years.

### 2.1.5 New staff: pre and post-doctoral fellowships, contracts, scholarships

The changes in the staff involved in the group were: two predoctoral contracts and two master's students have been incorporated, two professors from the University of Debrecen in Hungary for two weeks, a Tunisian student for 6 months, as well as an Ecuadorian student for 2 months.

### 2.1.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

#### Papers

- Synthesis, characterization and theoretical study of the complexes  $[\text{RuCp}(\text{8MTT-}\kappa\text{S})\text{LL}']$  (8MTT = 8-methylthio-theophyllinate; L,L' = PTA, mPTA; L = mPTA, L' = PPh<sub>3</sub>; PTA = 1,3,5-triaza-7-phosphaadamantane, mPTA = N-methyl-1,3,5-triaza-7-phosphaadamantane). *Inorganica Chimica Acta*, 2017, 455, pp 557-567.
- Easy synthesis and water solubility of ruthenium complexes containing PPh<sub>3</sub>, mTPPMS, PTA and mPTA, (mTPPMS = meta-triphenylphosphine monosulfonate, PTA = 1,3,5-triaza-7-phosphaadamantane, mPTA = N-methyl-1,3,5-triaza-7-phosphaadamantane). *Inorganica Chimica Acta*, 2017, 455, pp 528-534.
- Synthesis, Characterization, Aggregation Properties, Antioxidant and Antimicrobial Activity of Novel Unmetalled and Metallophthalocyanines Bearing Coumarin Derivatives.. Hamdi, N.; Medyouni, R.; Sulaiman Al-Ayed, A.; Mansour, L.; Romerosa, A. *Journal of Heterocyclic Chemistry*, 2017, 54, 2342-2351
- An Efficient One-Pot Protocol for the Synthesis of Substituted 3,4-Dihydropyrimidin-2(1H)-ones Using Metallophthalocyanines (MPcs) as Potent Heterogeneous Catalysts: Synthesis, Characterization, Aggregation and Antimicrobial Activity. Naceur Hamdi, Rawdha Medyouni, Hallouma Bilel, Lamjed Mansour, Antonio Romerosa. *Molecules* 2017, 22(4), 605/1-605/14, doi:10.3390/molecules22040605
- Ruthenium complexes containing mPTA and thiopurines bis(8-thiotheophylline)-(CH<sub>2</sub>)<sub>n</sub> (n = 1 – 3; mPTA = N-methyl-1,3,5-triaza-7-phosphaadamantane). Lazhar Hajji, Cristobal Saraiba Bello, Franco Scalambra, Gaspar Segovia-Torrente, Antonio Romerosa, A. Canella. *J. Coord. Chem.* 2017, 70:10, 1632-1644
- Water and catalytic isomerization of linear allylic alcohols by  $[\text{RuCp}(\text{H}_2\text{O-}\kappa\text{O})(\text{PTA})_2]^+$  (PTA = 1,3,5-triaza-7-phosphaadamantane). Franco Scalambra, Manuel Serrano-Ruiz, Antonio Romerosa. *Dalton Trans.* 2017, 46, 5864 – 5871.
- Enhancement of the antiproliferative activity of  $[\text{RuCp}(\text{PPh}_3)_2(\text{dmoPTA-}\kappa\text{P})]^+$  via its coordination

to one {CoCl<sub>2</sub>} unit: synthesis, crystal structure and properties of [RuCp(PPh<sub>3</sub>)<sub>2</sub>-μ-dmoPTA-1κP:2κ<sup>2</sup>N,N'-CoCl<sub>2</sub>](OTf)·0.25H<sub>2</sub>O. Zenaida Mendoza, Pablo Lorenzo-Luis, Franco Scalambra, José M. Padrón, Antonio Romerosa. Dalton Trans. 2017, 46, 8009-8012.

## Book chapter

## Congress

- XII Congreso de Estudiantes de la Sección de Química. 11-13 de abril de 2016, La Laguna, Tenerife, España.
- 17ª Reunion científica plenaria de química inorgánica 11ª Reunión científica plenaria de química del estado sólido, 19-22 junio 2016, Torremolinos, Málaga, España.
- XXXIV GEQP Congress Organometallic Chemistry Group, 7-9 septiembre 2016, Girona, España
- 13<sup>th</sup> European Workshop on Phosphorus Chemistry. 7-9 marzo 2016, Berlín, Germany.
- 42<sup>nd</sup> International Conference on Coordination Chemistry (ICCC 2016). 3-8 julio 2016, Brest, France.
- 3<sup>rd</sup> European Conference on Smart Inorganic Polymers (3<sup>rd</sup> EUSIPs). 12-14 septiembre 2016, Porto, Portugal.
- II Congreso Internacional de Ciencia y Tecnología. Universidad Técnica de Machala, 23-25 noviembre de 2016, Machala, Ecuador
- V Congreso Nacional de i+d en Defensa y Seguridad (DESEID-2017). Toledo, 22-24 noviembre 2017.
  - Sensores de explosivos mediante polímeros heterometálicos fluorescentes en una red nanovoid. Antonio Romerosa Nieves, Franco Scalambra, Benjamin Sierra-Martín, Antonio Fernández Barbero, Pablo Antonio Lorenzo Luis, Isaac de los Rios Hierro (Oral)
- Deuteration for Neutron Scattering–DEUNET Workshop. Monday 15 May 2017 - Wednesday 17 May 2017 Oxford.
  - Catalytic Selective Deuteration by Cleavage of Vinyl-Ethers by Using [RuCp(C=C=CPh<sub>2</sub>)(mPTA)<sub>2</sub>](CF<sub>3</sub>SO<sub>3</sub>)<sub>3</sub>. Antonio Romerosa, Franco Scalambra, Pablo Lorenzo-Luis. Poster.
- Metals and Water 2017: II International Conference on Water Soluble Metal Complexes. 13<sup>th</sup> to 15<sup>th</sup> June 2017, Jaca (Huesca), Spain. (Oral).
  - Selective deuteration by cleavage of the C-O-vinyl-ether bond catalyzed [RuCp(C=C=CPh<sub>2</sub>)(mPTA)<sub>2</sub>](CF<sub>3</sub>SO<sub>3</sub>)<sub>3</sub>. Isaac de los Rios, Franco Scalambra, Pablo Lorenzo-Luis, Antonio Romerosa. (Oral).
  - Catalytic Isomerization of allylic-alcohols in water mediated by water soluble PTA-ruthenium complexes (PTA=1,3,5-triaza-7-phosphatricycle[3.3.1.1<sup>3,7</sup>]decane): some findings on the reaction. Franco Scalambra, Silvia Imberti, Nicole Holzmann, Leonardo Bernasconi, Antonio Romerosa. (Oral).

- New coordination mode of DNA-purines to water-soluble ruthenium complexes containing PTA and mPTA. Lazhar Hajji, Cristobal Saraiba, Franco Scalambra, Manuel Serrano-Ruiz, Gaspar Segovia-Torrente, Antonio Romerosa. (Oral).
- Bimetallic complex  $[\text{RuCp}(\text{PPh}_3)_2-\mu\text{-dmoPTA-1}\kappa\text{P:2}\kappa\text{2N,N}'\text{-CoCl}_2]$  and highly active antiproliferative complex. Elizabeth Zenaida Mendoza Nozeman, Pablo Lorenzo Luis, Franco Scalambra, Antonio Romerosa. (Oral).
- 31<sup>st</sup> Conference of The European Colloid and Interface Society. Madrid, Spain, 3-8 September, 2017 (ECIS2017).
  - Molecular Motion and Structure of Novel Organometallic Polymers. B. Sierra-Martín, Manuel Serrano-Ruiz, A. Maldonado-Valdivia, Franco Scalambra, Antonio Romerosa, A. Fernández-Barbero.
  - New Ruthenium Complexes as Dyes for Dye-sensitized solar Cells. A. Maldonado-Valdivia, B. Sierra-Martín, Manuel Serrano-Ruiz, Franco Scalambra, Antonio Romerosa, A. Fernández-Barbero.
- 11<sup>th</sup> Triennial Congress of the World Association of Theoretical and Computational Chemistry (WATOC2017; [www.watoc2017.com](http://www.watoc2017.com)), August 27 to September 1, 2017.
  - Combining AIMD and Neutron Scattering Data based EPSR Simulations to uncover Water Participation in Catalysis. Nicole Holzmann, Silvia Imberti, Franco Scalambra, Antonio Romerosa, Leonardo Bernasconi. PO1-155

## Patents

Aditivación de resinas epoxi mediante complejos poliméricos Homo y Heterometálicos con 1,3,5-triaza-7-fosfaadamantanofosfina y sus derivados.

P201600099 (P2016-91000000060) (26/01/2016)

ES 2 627 009 A1 (26/07/2017)

Universidad de Almería/Universidad de La Laguna

Células solares constituida por agua y complejos de rutenio con fosfinas acuosolubles: un nuevo tipo de células solares.

P201500602 (P2015-91000000557) (22/07/2015)

ES 2 597 952 A1 (24/01/2017)

Universidad de Almería



## Congress and events Organization

- Metals and Water 2017: II International Conference on Water Soluble Metal Complexes. (MW2017) ([http://www2.ual.es/mws-2017/index\\_en.html](http://www2.ual.es/mws-2017/index_en.html)). Ambito: INTERNATIONAL. Fecha: 13-15/06/2017. Jaca (Huesca, Spain)
- "Polymers in Solution and Disordered Systems: a European Training School of COST Action CM1302" . (<http://www2.ual.es/SCHOOL-2017/index.html>). Ambito: INTERNATIONAL. Fecha: 6-9/11/2017. Universidad de Almería. Almería (Spain).

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## 2.1.8 Ongoing projects in 2017

### 2.1.8.1 Water soluble fluorescent heterometallic polymers.

**Participants:**

Grupo de Inv. "Química de Coordinación, Organometálica y Fotoquímica". Universidad de Almería (FQM-317)

**Contacts:**

A. Romerosa Nievas (romerosa@ual.es)

**Funds:**

Ministerio de Economía y Competitividad. FEDER 2013 (CTQ2015-67384-R)

**Time Period:**

January 2016 - December 2018

**Current situation:**

In progress.

**Summary**

The project is targeted to the design of new heterometallic polymers with gel and fluorescent properties in water, which can be confined in a matrix that increase their respond to environment variations. The ultimate goal is to obtain sensors that are able to tune their optical response against common explosives both in dissolution and vapours.

### 2.1.8.2 Water purification using activated charcoal from rice husk.

**Participants:**

Grupo de Inv. "Química de Coordinación, Organometálica y Fotoquímica". Universidad de Almería (FQM-317)

**Contacts:**

A. Romerosa Nievas (romerosa@ual.es)

**Funds:**

H. Consejo Universitario de Ecuador N° 396/2016

**Time Period:**

October 2016 - October 2017

**Current Situation:**

In progress.

**Summary**

The project aims to avoid two serious problems of the population of the Machala region (Ecuador): the elimination of rice husk produced and the access to quality water. Water is fundamental for life and therefore having quality water is essential for the proper development of the population. This project is devoted to obtain a method that allows the rice husk to be converted into activated charcoal that will be used for water purification. The whole process should be ecological, would not produce tangential contamination and would be respectful of the productive and social means of the community where it will be developed. The

participation of one of the most important Rice Cooperatives of the region (PROASEM) guarantees adequate access to the raw material and shows the interest of the economic fabric of the area.

#### 2.1.8.3 Water purification by active carbon prepared from the rice husk.

**Participants:**

Grupo de Inv. "Química de Coordinación, Organometálica y Fotoquímica". Universidad de Almería (FQM-317)

**Contacts:**

A. Romerosa Nievas ([romerosa@ual.es](mailto:romerosa@ual.es))

**Funds:**

Agencia Andaluza de Cooperación Internacional (AACI-2016DEC020)

**Time Period:**

November 2017 - November 2018

**Current Situation:**

In progress.

#### Summary

Through the project a stable collaboration has been established between the CIESOL group and that in the U. de Machala (Ecuador). The project intends to respond to serious environmental problems in the Gold region in Ecuador: the high pollution caused by mining activity is leading to the contamination of rivers and aquifers, and the elimination of rice husk produced in that region. Water is fundamental for life and therefore having quality water is essential for the proper development of the population. The activated carbon obtained from the rice husk can purify the water selectively. The whole process would be ecological, would not produce side effect and would be respectful with the productive and social means of the community where it will be developed.

#### 2.1.9 Activities and Courses, technical capacity

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#### 2.1.10 Project's applications in 2017

"Redes de Excelencia" dentro del Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia, en el marco del Plan Estatal de Investigación Científica y Técnica y de Innovación 2013-2016.

CTQ2017-90828-REDT

CIESOL CENTRO MIXTO DE INVESTIGACIÓN EN ENERGÍA SOLAR UAL-CIEMAT

Metals and water (METALES Y AGUA)

UNIVERSIDAD DE ALMERIA-CIESOL

#### 2.1.11 Others

## 2.2 ACTIVITIES OF "ANALYTICAL EVALUATION OF WATER TREATMENT AND ENVIRONMENTAL ANALYSIS" FUNCTIONAL UNIT

### 2.2.1 Functional unit description

The staff of the Unit is made up of researchers from the Department of Chemistry and Physics at the University of Almería and the Unit of *Solar Water Treatments* from the Plataforma Solar de Almería (CIEMAT). The collaboration between the two centres dates back to 1998, the year in which the first joint work is published. Since then the group has been actively involved in national and international projects and has more than 40 joint publications. Currently, members of both centres are part of the research group "Environmental Analysis and Water Treatment (FQM-374)" of the Andalusian Research Plan (PAI).

### 2.2.2 Main research lines

The activity of the group is focused on the development, optimization and analytical assessment of advanced wastewater treatment processes applied to complex effluents in order to get their regeneration and enable their reuse. The strategic lines of action include:

- Development of advanced analytical methods for characterizing complex effluents and its application to monitoring of organic micro-contaminants during wastewater treatment to ensure its elimination.
- Identification of transformation products generated during wastewater treatments and establishment of routes of degradation.
- Study of the influence of treatments on the quality of reclaimed water and evaluating the impact of their reuse in agriculture.

### 2.2.3 Main researchers

#### **Ana Agüera López** (Scopus Author 6701415534)

Full professor at the University of Almería. Degree in Chemistry (1987). PhD in Chemistry (1995). She has more than 25 years of experience working in the development and validation of analytical method based on chromatographic technique coupled to mass spectrometry for the analysis of organic contaminants in food and environmental matrices. She has participated in 21 national and international competitive R&D Projects. She is co-author of 2 patents and 130 scientific publications in indexed international journals (h-index = 49, January 2018). She has also co-authored more than 150 conference papers, 3 books and 12 book chapters, and has participated in the organization of 7 international conferences. She has supervised 7 doctoral theses.

#### **Isabel Oller Alberola** (Scopus Author 8415190600)

Researcher at the Solar Treatment of Water Unit at the Plataforma Solar de Almería (CIEMAT), degree in Chemical Engineering (2002) and PhD in Chemical Engineering (2008). Dr. Isabel Oller scientific career is focused in the industrial and urban wastewater treatment and reuse by using advanced oxidation processes (with and without solar energy) and their combination with physic-chemical pre-treatment systems and advanced biological processes. She has developed this activity under her participation in several I+D national and European Projects (5th, 6th & 7th EU Framework programs). Her scientific production it is worthy to mention she is author of 1 National Editorial book and co-author of 10 International Editorial books chapters. Furthermore, she is co-author of 87 publications in indexed scientific international journals and 80 contributions to different International Congresses and Symposiums (until January 2018). She has also

participated as teacher in some national and international courses and masters related with Advanced Treatment of Wastewater. H-index (January 2018): 33.

#### 2.2.4 Summary of the functional unit's activities carried out in CIESOL during 2017

During this year, the activities derived from the ongoing projects have continued. Within the framework of project P12-RNM-1739, the toxicological characterization of raw cork boiling wastewater has been completed after physical-chemical pre-treatment, and after partial oxidation through the photo-Fenton solar process, with the development of techniques and protocols for the determination of chronic toxicity, including respirometry (active sludge from WWTP), *Vibrio fischeri*, *Daphnia magna*, Protozoan ciliate *Tetrahynema termopila* and *Artemia franciscana*. The results confirmed the generation of chronic toxicity by this type of wastewater with respect to different microbiological species. This confirms the need to oxidize this type of wastewater to very advanced stages of mineralization in order to be able to introduce them in a final refining system through membranes and achieve a sufficient quality improvement to be reused in the boiling process itself. Likewise, the treatment of landfill leachates was addressed, establishing as an optimal treatment line its pre-treatment by coagulation with FeCl<sub>3</sub> and its subsequent filtration by a sand filter, followed by a partial oxidation by solar photo-Fenton (and subsequent filtration). This treatment line was coupled to a biological reactor with the objective of operating continuously trying to maximize the treatment capacity of the system. The feed flow was optimized, although it was found that throughout the continuous operation of the biological reactor, a final accumulation of nitrogen in the form of ammonium did not comply with the discharge rates. As an option to eliminate the ammonium from the effluent already treated, we will try to take advantage of this high content of ammonium as a high added value residue for the fertilization of fields in crop irrigation. It is therefore proposed to continue this work with the study of ammonium recovery in membrane distillation systems that use temperature difference as a driving force for the separation, through the membrane, of, in this case, ammonium. So that a permeate stream could be obtained with a quality sufficient for its reuse in crop irrigation and enriched with ammonium.

In the SOLFENDIS project, we have collaborated in the tasks already described by the Water Regeneration group. In parallel, a multi-residue method has been developed for the monitoring of selected antibiotics in deputed and treated wastewater, in order to evaluate their elimination in the treatment and establish a correlation between the compounds and concentrations found and the population of antibiotic-resistant bacteria. In the latter aspect, the presence of bacteria resistant to cefotaxime was monitored in the effluents of the El Bobar WWTP, obtaining positive results in all the samples analyzed.

Within the framework of the REAQUA project, efforts have been made to improve quantitative methods for the analysis of microcontaminants in wastewater, in order to solve the problems derived from the absence of "blanks", which do not contain the analytes in question, for the preparation of calibration curves. Different matrices have been tested to replace the real wastewater and a statistical study has been carried out to select the one that presents a greater similarity and less matrix effect. The results of this work will simplify and minimize errors in the quantification stage.

In the line of research about the impact of the reuse of reclaimed water in irrigation practices, the multiresidue method of analysis of microcontaminants in different plant matrices has been published (already available on the web), which includes its application to crops under controlled conditions. The work that includes the validation of a method for the analysis of said pollutants in agricultural soils, and its application to soils irrigated for long periods with regenerated waters, is also being finalized. It is intended in

this case to provide information about the behavior and persistence of microcontaminants, not investigated so far, in the soil and its potential availability for translocation to crops.

### 2.2.5 New staff: pre and post-doctoral fellowships, contracts, scholarships

In 2017 Dr. Patricia Plaza Bolaños joined the unit, with a HIPATIA 2016 postdoctoral contract. Ms. Elisa García Gómez has also joined, with an internship contract through the National Juvenile Guarantee System.

### 2.2.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

#### Papers

- Ponce-Robles, L., Rivas, G., Esteban, B., Oller, I., Malato, S., Agüera, A. Determination of pesticides in sewage sludge from an agro-food industry using QuEChERS extraction followed by analysis with liquid chromatography-tandem mass spectrometry (2017) *Analytical and Bioanalytical Chemistry*, 409 (26), pp. 6181-6193.
- Rivas Ibáñez, G., Bittner, M., Toušová, Z., Campos-Mañas, M.C., Agüera, A., Casas López, J.L., Sánchez Pérez, J.A., Hilscherová, K. Does micropollutant removal by solar photo-Fenton reduce ecotoxicity in municipal wastewater? A comprehensive study at pilot scale open reactors (2017) *Journal of Chemical Technology and Biotechnology*, 92 (8), pp. 2114-2122.
- Campos-Mañas, M.C., Plaza-Bolaños, P., Sánchez-Pérez, J.A., Malato, S., Agüera, A. Fast determination of pesticides and other contaminants of emerging concern in treated wastewater using direct injection coupled to highly sensitive ultra-high performance liquid chromatography-tandem mass spectrometry (2017) *Journal of Chromatography A*, 1507, pp. 84-94.
- Michael, C., Bayona, J.M., Lambropoulou, D., Agüera, A., Fatta-Kassinos, D. Two important limitations relating to the spiking of environmental samples with contaminants of emerging concern: How close to the real analyte concentrations are the reported recovered values? (2017) *Environmental Science and Pollution Research*, 24 (17), pp. 15202-15205.
- Arzate, S., García Sánchez, J.L., Soriano-Molina, P., Casas López, J.L., Campos-Mañas, M.C., Agüera, A., Sánchez Pérez, J.A. Effect of residence time on micropollutant removal in WWTP secondary effluents by continuous solar photo-Fenton process in raceway pond reactors (2017) *Chemical Engineering Journal*, 316, pp. 1114-1121.
- Ponce-Robles, L., Miralles-Cuevas, S., Oller, I., Agüera, A., Trinidad-Lozano, M.J., Yuste, F.J., Malato, S. Cork boiling wastewater treatment and reuse through combination of advanced oxidation technologies (2017) *Environmental Science and Pollution Research*, 24 (7), pp. 6317-6328.
- Miralles-Cuevas, S., Oller, I., Agüera, A., Llorca, M., Sánchez Pérez, J.A., Malato, S. Combination of nanofiltration and ozonation for the remediation of real municipal wastewater effluents: Acute and chronic toxicity assessment (2017) *Journal of Hazardous Materials*, 323, pp. 442-451.
- Prieto-Rodríguez, L., Oller, I., Agüera, A., Malato, S. Elimination of organic micro-contaminants in municipal wastewater by a combined immobilized biomass reactor and solar photo-Fenton tertiary treatment (2017) *Journal of Advanced Oxidation Technologies*, 20 (1), .

- Miralles-Cuevas, S., Oller, I., Agüera, A., Sánchez Pérez, J.A., Malato, S. Strategies for reducing cost by using solar photo-Fenton treatment combined with nanofiltration to remove microcontaminants in real municipal effluents: Toxicity and economic assessment (2017) *Chemical Engineering Journal*, 318, pp. 161-170.
- Freitas, A.M., Rivas, G., Campos-Mañas, M.C., Casas López, J.L., Agüera, A., Sánchez Pérez, J.A. Ecotoxicity evaluation of a WWTP effluent treated by solar photo-Fenton at neutral pH in a raceway pond reactor (2017) *Environmental Science and Pollution Research*, 24 (2), pp. 1093-1104.
- Martín-De-Lucía, I., Campos-Mañas, M.C., Agüera, A., Rodea-Palomares, I., Pulido-Reyes, G., Leganés, F., Fernández-Piñas, F., Rosal, R. Reverse Trojan-horse effect decreased wastewater toxicity in the presence of inorganic nanoparticles (2017) *Environmental Science: Nano*, 4 (6), pp. 1273-1282.
- Christou, A., Agüera, A., Bayona, J.M., Cytryn, E., Fotopoulou, V., Lambropoulou, D., Manaiá, C.M., Michael, C., Revitt, M., Schröder, P., Fatta-Kassinos, D. The potential implications of reclaimed wastewater reuse for irrigation on the agricultural environment: The knowns and unknowns of the fate of antibiotics and antibiotic resistant bacteria and resistance genes – A review (2017) *Water Research*, 123, pp. 448-467.

#### **Book chapter**

- Analytical Strategies Used in HRMS (2017) En: *Applications in High Resolution Mass Spectrometry: Food Safety and Pesticide Residue Analysis*, Elsevier Inc. pp. 59-82. ISBN: 978-0-12-809464-8

#### **Congress**

- 18<sup>th</sup> European Meeting on Environmental Chemistry: EMEC 18. Oporto, Portugal, 26-29 Noviembre, 2017
  - Suspect-screening Strategy Applied to the Identification of Transformation Products of Carbamazepine in Lettuce And Soil Commodities. Comunicación Oral. A.B. Martínez-Piernas, S. Nahim-Granados, M.I. Polo-López, S. Malato, S. Murgolo, G. Mascolo, P. Fernández-Ibáñez, A. Agüera.
  - Disinfection of Secondary Effluent from WWTP by Solar Photo-Fenton Process at Neutral pH in Raceway. Poster. A. Agüera, B. Esteban García, G. Rivas Ibañez, A. Lorenzo, J.A. Sánchez Pérez.
  - Multiresidue Determination of Antibiotics in Wastewater Effluents using Liquid Chromatography-Triple Quadrupole Mass Spectrometry. Poster. A. Lorenzo, B. Esteban García, J.A. Sánchez-Pérez, A. Agüera.
- 3<sup>rd</sup> Iberoamerican Conference on Advanced Oxidation Technologies (III CIPOA) and 2<sup>nd</sup> Colombian Conference on Advanced Oxidation Processes (II CCPAOX) Medellín (Guatapé), Colombia. 14-17 Noviembre, 2017
  - Development and validation of LC-MS/MS method for microcontaminant evaluation in real wastewater effluent during solar photo-Fenton treatment. Poster. J.A. Sánchez-Pérez, M.C. Campos-Mañas, A. Lorenzo, G. Rivas Ibañez, A. Agüera.
- 5<sup>th</sup> European Conference on Environmental Applications of Advanced Oxidation Processes (EAAOP5). Praga, 25-29 Junio, 2017.

- Landfill leachate treatment and reuse for nutrient recovery by combination of advanced technologies. Poster. A. Ruíz-Delgado, L. Ponce Robles, I. Salmerón, I. Oller, M.I. Polo-López, S. Malato, A. Agüera.
- Advanced analytical techniques applied to cork boiling wastewater treatment and reuse by using advanced oxidation processes. Oral. L. Ponce-Robles, A. Agüera, L. Pérez-Estrada, S. Malato, I. Ollera.
- 13<sup>th</sup> SOLLAB Doctoral Colloquium on Solar Concentrating Technologies. Berlin, Junio 15 – 17, 2017.
  - Treatment Strategy for Landfill Leachate Solar Remediation and Reuse. A. Ruíz-Delgado, L. Ponce Robles, I. Salmerón, I. Oller, M.I. Polo-López, S. Malato, A. Agüera.
- CorkScience – Cork in Science and Applications. 7-8 September 2017, Universidade de Aveiro, Portugal.
  - Cork boiling wastewater treatment and reuse by combination of advanced physicochemical technologies. L. Ponce-Robles, A. Agüera, L. Pérez-Estrada, I. Oller, M.J. Trinidad-Lozano; F.J. Yuste, S. Malato

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## 2.2.8 Ongoing projects in 2017

### 2.2.8.1 Characterization and treatment of wastewater from various sources (landfill leachate and effluent of the cork industry)

**Participants:**

Functional Unit of "Environmental Analysis"

**Contacts:**

A. Agüera (aaguera@ual.es)  
I. Oller (Isabel.oller@psa.es )

**Funds:**

Junta de Andalucía. Proyecto de Excelencia. Convocatoria 2012. (P12-RNM-1739)

**Time Period:**

January 2014 - January 2019. Extended

**Current Situation:**

In progress

**Summary:**

The project aims to address the treatment of complex wastewaters integrating different advanced oxidation processes (AOPs) (photo-Fenton and solar  $O_3/H_2O_2$ ) with biotreatment (Bio). The strategies of treatment will include combinations of both PAO/Bio and Bio/PAO, depending on biodegradability characteristics of the water to be treated. Two types of wastewater, landfill leachate and effluents from the cork industry, will be used. Due to the complexity of these waters, advanced analytical techniques (LC-MS, GC-MS), global parameters (TOC, COD, biodegradability, etc.) and batteries of bioassays will be applied in the initial characterization of the waters and during the monitoring of the evolution of treatments.

**Objectives:**

1. Characterization of wastewaters from different origin by wide spectrum analytical protocols including extraction procedures and combined analytical techniques.
2. Establishment of a comprehensive methodology for determining the biocompatibility and detoxification of wastewater treated by advanced processes, by comparing different methods for measuring toxicity and biodegradability.
3. Selecting the best choice among different advanced oxidation treatments (photo-Fenton,  $O_3/OH-O_3/H_2O_2$ ) and its combination with biological treatment.

### 2.2.8.2 Cost reduction of solar photo-Fenton process using extensive open reactors for water regeneration (REQUA)

**Participants:**

Functional Units: "Water Treatments" and "Environmental Analysis"

**Contacts:**

J. A. Sánchez (jsanchez@ual.es)

A. Agüera (aaguera@ual.es)

**Funds:**

Ministerio de Economía y Competitividad. (CTQ2013-46398-R)

**Time Period:**January 2014 – December 2016. Extended to December 2017.**Current Situation:**

In progress

**Summary:**

The removal of low concentrations of pollutants by photo-Fenton presents new challenges, scientifically and technically. It must be delved into reactions mechanisms and detection of generated transformation products, as kinetic behavior is different with respect to that observed with high concentration of pollutants, where chemical oxygen demand and dissolved organic carbon are monitored.

Furthermore, the irradiation needs are fewer, reaching a point of kinetic saturation at high irradiances (light excess), so light distribution inside the reactor is especially important. Thus, we lay out a study of new treatment plants where the photoreactor surface and treated water volume per surface area are taken into account. This concept was barely studied in the development of the first experimental plants, as the ability to concentrate solar energy was prioritized.

In addition to the technical development, an economic assessment has become essential to turn the photo-Fenton process into a commercial treatment. In this project, we propose the use of open reactors, "raceway"

type, due to their low cost (amortization and operation) and the fact that they allow changing the optical path (volume depth) as a function of incident solar radiation. We expect to minimize total costs, maximizing reclaimed water volume per surface area. To this effect special attention will be given to the operating variables, reactant dosage and operating mode, batch and continuous (during the day).

Analytical assessment is especially important to monitor micro-contaminants and detect their transformation products during the treatment. This will permit to evaluate the reactor efficiency and the optimization of the operating parameters. For this purpose, highly sensitive and selective analytical techniques, based on mass spectrometry, will be used. It will also be proposed the development of simpler and faster detection strategies, which use pollution tracers.

**Objectives:**

- Show the technical and economic feasibility of "raceway" reactors for decontamination, disinfection and wastewater reclamation at pilot plant scale.
- Obtain the best operating conditions for the proposed system
- Improve and validate new analytical methods based on mass spectrometry which allow an adequate evaluation of the treated water
- Ensure effective removal of micro-contaminants and their transformation products during treatment, to obtain effluent suitable for reuse in different applications.

**2.2.8.3 Disinfection of WWTP secondary effluents by solar photo-Fenton process in raceway pond reactors. Effect on antibiotic resistance transfer. (SOLFENDIS).****Participants:**

Functional Units: "Water Treatments" and "Environmental Analysis"

**Contacts:**

J. A. Sánchez (jsanchez@ual.es)  
A. Agüera (aaguera@ual.es)

**Funds:**

Ministerio de Economía y Competitividad. (CTQ2013-46398-R)

**Time Period:**

December 2016 – December 2019.

**Current Situation:**

In progress

**Summary:**

Disinfection of secondary effluents using solar photo-Fenton has been reported; mainly at lab scale and only a few papers deal with pilot plant scale in tubular reactors equipped with Compound Parabolic collectors (CPC). Despite the interest in that water reclamation for irrigation in Spain, no experiences at large scale and cost evaluation are known, mainly due to the recent nature of these investigations. For any of the different uses for which the reuse of treated wastewater is allowed (RD 1620/2007), it is necessary to reduce the content of pathogenic microorganisms in reclaimed water. In this regard, the applicant team has investigated the use of raceway pond reactors for the removal of organic micropollutants with promising results that have aroused the interest of the scientific community. However, to the best of our knowledge, this kind of reactor has never been used for water disinfection. Another aspect that has not been evaluated is its ability to reduce the risk of spreading antibiotic resistance (AR). The antibiotic resistance is today one of the most pressing problems worldwide for public health. Spain is recognized as a country with a high prevalence of resistance, especially in species that cause infections mainly: Pneumococcus, meningococcus, Haemophilus influenzae, Campylobacter, Salmonella sp or E. coli. Spain is also one of the countries with the highest consumption of antibiotics per capita. There is evidence that conventional

disinfection processes of wastewater are not effective in controlling the spread of AR. In this context, the generation of disinfection by-products has also been investigated and the need for sophisticated analytical monitoring using advanced techniques has been reported. Finally, the economic assessment and cost minimization are key to bringing this technology to the commercial scale, ultimate goal of the proposed research.

The hypothesis of this project is that raceway pond reactors can be used to disinfect water by the solar photo-Fenton process without generating toxic by-products, improving control of the spread of antibiotic resistance and reducing costs substantially.

**Objectives:**

- The study of the operating variables of raceway pond reactors for water disinfection, dosing of reagents and liquid depth, at pilot plant scale
- The analytical monitoring of micropollutants and their transformation products, improving and validating new analytical methods.
- Evaluating the effect of treatments on the transfer of AR, through the inactivation of ARB and ARG.
- The economic optimization of the proposed process at pilot plant scale to facilitate decision-making for implementation on a larger scale and pre-commercialization of the developed technology.

**2.2.8.4 SFERA II: Photo-Fenton assisted photocatalytic degradation of beta-lactam antibiotics under solar irradiation in aqueous solutions**

**Participants:**

Functional Units: "Water Treatments" and "Environmental Analysis"

**Contacts:**

A. Agüera ([aaguera@ual.es](mailto:aaguera@ual.es))

J. A. Sánchez ([jsanchez@ual.es](mailto:jsanchez@ual.es))

**Funds:**

SFERA II Programme (Solar Facilities for the European Research Area)

**Time Period:**

May 2017 – June 2016

**Current Situation:**

Finalized

**Summary:**

The SFERA-II project (<http://sfera2.sollab.eu>), in which CIESOL is third party of CIEMAT-PSA, finances research stays of European groups in our facilities. During 2014, the functional units of "Analytical evaluation of water treatment and environmental analysis" and "Advanced Technologies for water regeneration" have welcomed the group of Prof. Nikos Xekoukoulotakis, Department of Environmental Engineering, Technical University of Crete (Greece). The approved project was related to the study of the photochemical degradation under solar radiation of two  $\beta$ -lactam antibiotics, meropenem of the subgroup of carbapenems and cefotaxime of the subgroup of cephalosporins, in aqueous solutions, in ultrapure water (UPW) and wastewater (WW).

**Objectives:**

- Develop analytical protocols for the determination of the two antibiotics in the matrices tested.
- Study the photolytic and photocatalytic degradation by photo-Fenton.
- Identification of the main degradation products generated in both processes.

### 2.2.9 Activities and Courses, technical capacity

Participation in the **European COST Action entitled 'NEW AND EMERGING CHALLENGES AND OPPORTUNITIES IN WASTEWATER REUSE (NEREUS)'** (<http://www.nereus-cost.eu/>). The action's main objective is to develop a multidisciplinary network to determine which of the current challenges related to wastewater reuse are the most concern to public health and environmental protection, and how they can be overcome. The group is actively involved in the action through working groups on "Uptake and translocation of organic microcontaminants and ARB&ARG in crops" (WG2) and "Technologies efficient/economically viable to meet the current wastewater reuse challenges" (WG4). During the past September 2017, it took place the **"5th Management Committee and Working Groups Meeting"** in Vienna. The Unit has participated, together with the unit of "Water Treatments" in a study of detection of antibiotics resistant bacteria at European level, in order to acquire general knowledge about the dispersion of ARB through the effluents of WWTPs.

### 2.2.10 Project's applications in 2017

- LIFE Environment and Resource Efficiency Program. Title of the Project: Pollutant Photo-NF remediation of Agro-Water. Led by the Benaki Phytopathological Institute (Kifissia, Greece). Participants: CIESOL (Spain); National Center for Scientific Research "Demokritos" (Agia Paraskevi, Greece), Agricultural Cooperative of Zagora Pilion (Zagora-Pilion, Greece).

### 2.2.11 Others

#### Students in curricular internships:

- Francisco Jesus Cara Rodriguez. Degree in Chemistry
- Germán Muñoz Bruque. Degree in Chemistry

#### Final degree projects:

- Francisco Jesus Cara Rodriguez: Determination of pesticides in wastewater by solid phase extraction and liquid chromatography coupled to mass spectrometry.

#### Stays in CIESOL of researchers from other research centers:

- Virginia Papadosifou. Technical University of Crete, Greece (28/05 / 2017-24 / 06/2017).

#### Doctoral thesis in course

- Marina Celia Campos Mañas (supervisors Ana Agüera and Jose Antonio Sánchez).
- Ana Belén Martínez Legs (supervisors Ana Agüera and Pilar Fernández).
- Ana Ruiz Delgado (supervisors Isabel Oller and Ana Agüera).
- Laura Ponce Robles (supervisors Sixto Malato and Isabel Oller).
- Ana Isabel Lorenzo Flores (supervisors Ana Agüera and Jose Antonio Sánchez)

## 2.3 ACTIVITIES OF "WATER TREATMENT" FUNCTIONAL UNIT

### 2.3.1 Functional unit description

The Functional Unit has been formed during 2017 by 11 researchers, with a cathedra professor, an OPI principal researcher, a researcher hired from OPI, three university professors, two doctors hired in charge of projects and three predoctoral researchers, as detailed in section 2.3.7. The group works on the decontamination of water contaminated with persistent toxics, removal of microcontaminants and disinfection of treated wastewater for reuse. It has basic analytical equipment located in laboratories 1 and 2 of the center, as well as pilot plants for biological and photochemical water treatments, in the test yard.

### 2.3.2 Main research lines

Study of solar photocatalysis for the removal of toxic substances and water disinfection and its combination with advanced biological methods. The strategic lines of action are:

- Use of solar photo-Fenton for decontamination of toxic water
- Use of solar photo-Fenton for micropollutant removal from treated wastewater
- Use of solar photo-Fenton for wastewater disinfection
- Combination of solar photo-Fenton and membrane bioreactor (pre-and post-treatment)
- Optimization of the operation and development of new technology for photo-Fenton
- Water treatment economics

### 2.3.3 Main researchers

**José Antonio Sánchez Pérez** (Scopus Author ID 7006076735)

Full Professor. Department of Engineering. Degree in Chemical Engineering by Univ. of Granada (1988); PhD by the Univ. of Granada (1992). He has been involved in 17 research projects (European and Spanish projects) and has led 9 of them. 12 Research contracts with private companies most of them related with the development of Solar Technologies applied to wastewater treatment. He has directed 14 PhD theses in different fields such as biotechnology of microalgae, filamentous fungi fermentation and water treatment, co-authored more than 130 peer-reviewed international papers.

**Manuel Ignacio Maldonado Rubio** (Scopus Author ID 7102035826)

Degree in Chemistry by Univ. of Granada (1994); PhD by the Univ. of Almería (2001). Master in Environmental Sciences by the Instituto de Investigaciones Ecológicas (Málaga, 1999). He is a researcher, since 2002, in the Area of Environmental Applications of Solar Energy in the Almería Solar Platform (CIEMAT). His scientific work has been fundamentally focused on R&D projects related to water decontamination through advanced oxidation processes. He has participated as a researcher in 9 National Projects, 15 International Projects (IV, V, VI and H2020 European Union Framework Programs) and 5 R&D Contracts with private companies related to the development of Solar Technologies for the treatment of industrial wastewater and desalination. Author of 6 books in national editorial and co-author of 20 books and book chapters in international editorial, co-author of more than 106 publications in international scientific journals with impact index (factor H = 42), more than 140 contributions to international congresses and symposiums and various contributions to national congresses. Designated by the statistical website <http://indice-h.webcindario.com/> as "researcher of excellence" of the national ranking.

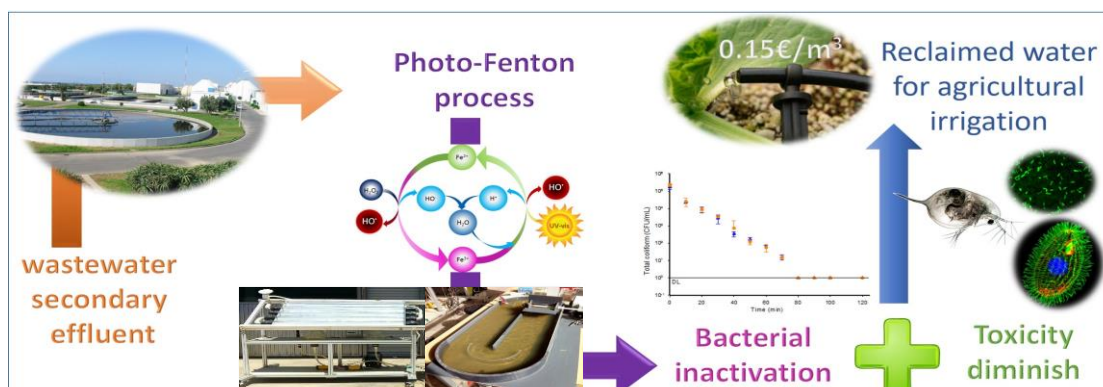
### 2.3.4 Summary of the functional unit's activities carried out in CIESOL during 2017

This year 2017 has meant the consolidation of the use of open "raceway" reactors as a new technological option for the application of the solar photo-Fenton process to water treatment. As more significant milestones of the progress achieved, highlight: i) the pioneering work on the continuous flow operation of the photo-Fenton solar process at acidic pH; ii) the kinetic study of the elimination of microcontaminants at neutral pH, through the use of the  $\text{Fe}^{3+}$ /EDDS complex, taking into account the effect of the photon absorption rate; and iii) the first application of the raceway reactors to the disinfection of secondary waters. Regarding point i) so far, for the elimination of microcontaminants little attention has been paid to the treatment time itself and the photo-Fenton process has been applied in batch mode even though the filling and emptying stages are much longer than the reaction time. For the first time, our group has continuously operated the solar photo-Fenton process in raceway reactors to eliminate microcontaminants in secondary effluents of WWTP. It has worked at two depths of liquid, 5 and 15 cm and three times of hydraulic residence (HRT), 80, 40 and 20 min. The reagent concentrations were  $5.5 \text{ mg L}^{-1} \text{ Fe}^{2+}$  and  $30 \text{ mg L}^{-1} \text{ H}_2\text{O}_2$ , resulting in a treated wastewater volume of  $450 \text{ L m}^{-2} \text{ day}^{-1}$  for a depth of 5 cm and a HRT of 40 min during 6 hours in a day in winter, with 84% removal of microcontaminants and 66% conversion of hydrogen peroxide.

In order to execute the photo-Fenton process as a tertiary wastewater treatment at neutral pH, the use of chelating agents, such as EDDS (ii), has been proposed. For the design and optimization of photocatalytic reactors, the concept of volumetric photon absorption speed (VRPA) is very useful, since it combines the effects of light absorption and reactor geometry. We have studied the effect of VRPA on the kinetics of microcontaminant removal by solar photo-Fenton at neutral pH using the  $\text{Fe}^{3+}$ /EDDS complex. The results obtained show, for the first time, that the reaction kinetics of the photo-Fenton process at neutral pH operated with  $\text{Fe}^{3+}$ /EDDS, depends linearly on the initial VRPA, reaching photosaturation in  $\text{VRPA} \approx 1550 \mu\text{E m}^{-3} \text{ s}^{-1}$ , a higher value than that obtained at acidic pH with free  $\text{Fe}^{3+}$ , due to the greater absorptivity of complexed  $\text{Fe}^{3+}$ . However, because the radiation absorption changes over time due to the photolysis of the  $\text{Fe}^{3+}$ /EDDS complex, the change of the VRPA with the reaction time must be taken into account for kinetic modeling. These results allow new developments for large-scale application given the relevance of quantifying the radiation absorption in the process performance, as a function of the optical path length. Despite the instability of the complex with light, high treatment capacities can be achieved with low concentrations of  $\text{Fe}^{3+}$ /EDDS and reaction times in the range of tens of minutes. This is consistent with the application for the elimination of microcontaminants in secondary effluents. Therefore, EDDS is an alternative to acidic pH (and subsequent neutralization) in the treatment with photo-Fenton of microcontaminants, mainly for applications related to water reuse, for example in irrigation.

Regarding the disinfection of treated wastewater (iii), the application of raceway reactors has been studied for the first time. A comparison was made with a tubular reactor equipped with a composite parabolic manifold (CPC) and the disinfection times were the same for a CPC with a tube diameter of 5 cm and a raceway operated at 5 cm depth of liquid. The results demonstrated the viability and efficiency of the use of these open reactors for the inactivation of bacteria (total coliforms, *E. coli* and *Enterococcus*) by solar photo-Fenton at neutral pH with  $20 \text{ mg L}^{-1} \text{ Fe}$  and  $50 \text{ mg L}^{-1} \text{ H}_2\text{O}_2$ . In addition, the estimated cost of this treatment was  $\text{€} 0.15 \text{ m}^{-3}$ . This cost is very competitive because there is the range of agricultural irrigation prices in Spain ( $\approx \text{€} 0.6 \text{ m}^{-3}$ ). Therefore, the use of low-cost raceway reactors would significantly help spread the solar photo-

Fenton process as a tertiary treatment. In addition, as the treatment does not increase the toxicity of effluents, the risks to health and the environment associated with their reuse would be reduced



**Figure.** Comparison of a 5 cm diameter tubular reactor with CPC collector and a raceway reactor for the disinfection of secondary waters using the solar photo-Fenton process at neutral pH.

### 2.3.5 New staff: pre and post-doctoral fellowships, contracts, scholarships

During 2017 there have been no new additions to the group.

### 2.3.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

#### Papers

- S. Miralles, I. Oller, A. Agüera, M. Llorca, J. A. Sánchez Pérez, S. Malato. Combination of nanofiltration and ozonation for the remediation of real municipal wastewater effluents: Acute and chronic toxicity assessment. *Journal of Hazardous Materials* Feb 5, 323 (Pt A): 442-451 (2017)
- M. J. Abeledo-Lameiro, A. Reboredo-Fernández, M. I. Polo-López, P. Fernández-Ibáñez, E. Ares-Mazás, H. Gómez-Couso. Photocatalytic inactivation of the waterborne protozoan parasite *Cryptosporidium parvum* using TiO<sub>2</sub>/H<sub>2</sub>O<sub>2</sub> under simulated and natural solar conditions. *Catalysis Today*. 2017, volume 280, Part 1, pp. 132-138.
- A. Y. Booshehri, M.I. Polo-Lopez, M. Castro-Alfárez, P. He, R. Xu, W. Rong, S. Malato, P. Fernández-Ibáñez. Assessment of solar photocatalysis using Ag/BiVO<sub>4</sub> at pilot solar Compound Parabolic Collector for inactivation of pathogens in wellwater and secondary effluents. *Catalysis Today*. 2017 volume 281, Part 1, pp. 124-134.
- M. I. Polo-López, M. Castro-Alfárez, S. Nahim-Granados, S. Malato, P. Fernández-Ibáñez. *Legionella jordanis* inactivation in water by solar driven processes: EMA-qPCR versus culture-based analyses for new mechanistic insights. *Catalysis Today*. 2017, volumen 287, pp. 15-21.
- M. Castro-Alfárez, M. I. Polo-López, J. Marugán, P. Fernández-Ibáñez. Mechanistic model of the *Escherichia coli* inactivation by solar disinfection based on the photo-generation of internal ROS and the photo-inactivation of enzymes: CAT and SOD. *Chemical Engineering Journal*. 2017, volumen 318, pp. 214-223.
- M. Castro-Alfárez, M. I. Polo-López, J. Marugán, P. Fernández-Ibáñez. Mechanistic modeling of UV and mild-heat synergistic effect on solar water disinfection. *Chemical Engineering Journal*. 2017, volumen 316, pp. 111-120.
- A.M. Freitas, G. Rivas, M.C. Campos-Mañas, J. L. Casas López, A. Agüera, J. A. Sánchez Pérez. Ecotoxicity evaluation of a real WWTP effluent treated by solar photo-Fenton at neutral pH in a raceway pond reactor. *Environmental Science and Pollution Research* 24(2): 1093-1104 (2017)
- S. Miralles, I. Oller, A. Agüera, M. Llorca, J. A. Sánchez Pérez, S. Malato. Combination of nanofiltration and ozonation for the remediation of real municipal wastewater effluents: Acute and chronic toxicity assessment. *Journal of Hazardous Materials* 323: 442-451 (2017)
- S. Miralles, I. Oller, A. Agüera, J. A. Sánchez Pérez, S. Malato. Strategies for reducing cost by using solar photo-Fenton treatment combined with nanofiltration to remove microcontaminants in real municipal effluents: toxicity and economic assessment. *Chemical Engineering Journal* 318: 161-170 (2017)



- J. A. Sánchez Pérez, P. Soriano Molina, G. Rivas Ibáñez, J. L. García Sánchez, J. L. Casas López, J. M. Fernández Sevilla. Effect of temperature and photon absorption on the kinetics of micropollutant removal by solar photo-Fenton in raceway pond reactors. *Chemical Engineering Journal*. 310: 464-472 (2017)
- I. De la Obra, B. Esteban García, J. L. García Sánchez, J. L. Casas López, J. A. Sánchez Pérez. Low cost UVA-LED as a radiation source for the photo-Fenton process: A new approach for micropollutant removal from urban wastewater. *Photochemical & Photobiological Sciences* 16(1): 72-78 (2017).
- I. De la Obra, L. Ponce-Robles, S. Miralles-Cuevas, I. Oller, S. Malato, J. A. Sánchez Pérez. Microcontaminant removal in secondary effluents by solar photo-Fenton at circumneutral pH in raceway pond reactors. *Catalysis Today* 287:10-14 (2017)
- S. Arzate, J. L. García Sánchez, P. Soriano Molina, J. L. Casas López, M.C. Campos-Mañas, A. Agüera, J. A. Sánchez Pérez. Effect of residence time on micropollutant removal in WWTP secondary effluents by continuous solar photo-Fenton process in raceway pond reactors. *Chemical Engineering Journal*. 316: 1114-1121 (2017) DOI: 10.1016/j.cej.2017.01.089 (2017)
- G. Rivas Ibáñez, M. Bittner, Z. Toušová, M.C. Campos-Mañas, A. Agüera, J. L. Casas López, J. A. Sánchez Pérez, K. Hilscherová. Does micropollutant removal by solar photo-Fenton reduce ecotoxicity in municipal wastewater? A comprehensive study at pilot scale open reactors. *Journal of Chemical Technology & Biotechnology*. DOI: 10.1002/jctb.5212 (2017)
- M.C. Campos-Mañas, P. Plaza-Bolaños, J. A. Sánchez Pérez, S. Malato, A. Agüera. Fast determination of pesticides and other contaminants of emerging concern in treated wastewater using direct injection coupled to highly sensitive ultra-high performance liquid chromatography-tandem mass spectrometry. *Journal of Chromatography A*. 1507: 84-94 (2017)
- A. Cabrera Reina, S. Miralles, J. L. Casas López, J. A. Sánchez Pérez. Pyrimethanil degradation by photo-Fenton process: influence of iron and irradiance level on treatment cost. *Science of the Total Environment* 605-606: 230-237 (2017)
- P. Soriano Molina, J. L. García Sánchez, S. Malato, L. A. Pérez-Estrada, J. A. Sánchez Pérez. Effect of Volumetric Rate of Photon Absorption on the kinetics of micropollutant removal by solar photo-Fenton with Fe<sup>3+</sup>-EDDS at neutral pH. *Chemical Engineering Journal* 331C: 84-92 (2018)
- A. Cabrera Reina, A. B. Matínez-Piernas, Y. Bertakis, C. Brebou, N. P. Xekoukoulotakis, A. Agüera, J. A. Sánchez Pérez. Photochemical degradation of the carbapenem antibiotics imipenem and meropenem in aqueous solutions under solar radiation. *Water Research* 128: 61-70 (2018)
- B. Esteban García, G. Rivas, S. Arzate, J. A. Sánchez Pérez. Wild bacteria inactivation in WWTP secondary effluents by solar photo-Fenton at neutral pH in raceway pond reactors. *Catalysis Today* Accepted 24-10-2017
- S. Nahim-Granados, J. A. Sánchez Pérez, M. I. Polo-López. Effective solar processes in fresh-cut wastewater disinfection: inactivation of pathogenic *E. coli* O157:H7 and *Salmonella enteritidis*. *Catalysis Today* Accepted 29-10-2017
- J.A. Garrido-Cardenas, M. I. Polo-López, I. Oller-Alberola. Advanced microbial analysis for wastewater quality monitoring: metagenomics trend. *Appl Microbiol Biotechnol*. DOI 10.1007/s00253-017-8490-3 Accepted 19-08-2017
- R. Poblete, I. Oller, M. I. Maldonado, Y. Luna, E. Cortes. Cost estimation of COD and color removal from landfill leachate using combined coffee-waste based activated carbon with advanced oxidation processes. *Journal of Environmental Chemical Engineering* 5 (2017) 114–121
- Rivas Ibáñez, G., Molina Ruíz, J.M., Román Sánchez, M.I., Casas López, J.L.. A corporate water footprint case study: The production of Gazpacho, a chilled vegetable soup. *Water Resources and Industry* 17 (2017), 34-42.

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### 2.3.8 Ongoing projects in 2017

#### 2.3.8.1 Design of new photo-Fenton solar reactors applied to water regeneration. Economy, scaling and process control (SULAYR)

**Participants:**

- Grupo de Inv. "Ingeniería de Bioprocesos y Tecnologías del Agua". Universidad de Almería (BIO-263)
- Unidad de "Tratamientos Solares de Agua". PSA-CIEMAT

**Contacts:**

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**Funds:**

Junta de Andalucía. Proyecto de Excelencia 2012. (P12-RNM-1437)

**Time Period:**

January 2014 - January 2019

**Current Situation:**

In progress

**Summary:**

Many aspects about the photo-Fenton process have been studied in order to know the factors that affect it and thus improve its efficiency. An important factor is the type of photoreactor where the process takes place. These photoreactors were developed on an experimental scale in parallel with the other applications of solar energy and in the first years of the 21st century the use of plants based on compound parabolic collectors (CPC) was accepted. Having reached a fairly broad knowledge of the process, the study of new treatment plants that take into account the space (area) that the photoreactors occupy and the volume of water that can be treated in this area is considered. This concept was little studied in the development of the first plants, it was prioritized in the capacity of solar collection.

**Objectives:**

- Design new solar photoreactors (collector configuration, tube diameter, tube layout) to modify both the incident solar radiation and the volume of water treated per unit area.
- Design new control and automation processes for solar photo-Fenton reactor applying various reagent addition strategies optimizing its consumption.
- Study the scaling of the water regeneration process considering the reactor design variables and the quality objectives of the treated water.
- Carry out a detailed economic study of the implementation of the photoreactors developed for wastewater tertiary treatment.

#### 2.3.8.2 Cost reduction of solar photo-Fenton process using extensive open reactors for water reclamation (REQUA)

**Participants:**

- Unidad funcional "Tecnologías avanzadas para la regeneración de aguas"
- Unidad funcional "Evaluación analítica de tratamientos de aguas y análisis ambiental"

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**Source of funding:**

Ministerio de Economía y Competitividad. (CTQ2013-46398-R)

**Duration:**

January 2014 – December 2017

**Status:**

In progress

**Abstract:**

The removal of low concentrations of pollutants by photo-Fenton presents new challenges, scientifically and technically. It must be delved into reactions mechanisms and detection of generated transformation products, as kinetic behavior is different with respect to that observed with high concentration of pollutants, where basically chemical oxygen demand and dissolved organic carbon are monitored.

Furthermore, the irradiation needs are fewer, reaching a point of kinetic saturation at high irradiances (light excess), so light distribution inside the reactor is especially important. Thus, we lay out a study of new treatment plants where the photoreactor surface and treated water volume per surface area are taken into account. This concept was barely studied in the development of the first experimental plants, as the ability to concentrate solar energy was prioritized.

In addition to the technical development, an economic assessment has become essential to turn the photo-Fenton process into a commercial treatment. In this project, we propose the use of open reactors, "raceway" type, due to their low cost (amortization and operation) and the fact that they allow changing the optical path (volume depth) as a function of incident solar radiation. We expect to minimize total costs, maximizing reclaimed water volume per surface area. To this effect special attention will be given to the operating variables, reactant dosage and operating mode, batch and continuous (during the day).

Analytical analysis is especially important to monitor micropollutants and detect their transformation products during the treatment. This will permit to evaluate the reactor efficiency and the optimization of the operating parameters. For this purpose, highly sensitive and selective analytical techniques, based on mass spectrometry, will be used. It will also be proposed the development of simpler and faster detection strategies which use pollution tracers.

**Objectives:**

- Show the technical and economical feasibility of "raceway" reactors for decontamination, disinfection and wastewater reclamation at pilot plant scale.
- Obtain the best operating conditions for the proposed system
- Improve and validate new analytical methods based on mass spectrometry which allow an adequate evaluation of the treated water
- Ensure effective removal of micropollutants and their transformation products during treatment, to obtain effluent suitable for reuse in different applications.

**2.3.8.3 Treatment in raceway pond reactors of water contaminated with emerging organic compounds by the photo-Fenton process using metallurgical slags and titanium-supported iron oxide nanoparticles as catalysts****Participants:**

Grupo de Inv. "Ingeniería de Bioprocesos y Tecnologías del Agua". Universidad de Almería (BIO-263)

**Contacts:**

J. A. Sánchez (jsanchez@ual.es)

**Source of funding:**

*Fondo de Colaboración Internacional del Instituto de Ingeniería de la UNAM, México*

**Duration:**

January 2016 – December 2017

**Status:**

In progress

**Abstract:**

The economic problem that is proposed to solve is the reduction of the cost of water treatment by the photo-Fenton process, because when it is carried out in homogeneous phase the catalyst is lost. In order to alleviate this problem, catalysts have been developed using (economic) iron-based industrial wastes and byproducts, which have the limitation of acceptable performance but can be improved by more efficient agitation to reduce mass transfer problems, but which at the same time is economical. The use of raceway pond reactors for the photo-Fenton process also allows a better use of solar energy, which is a source of irradiation at no cost, to activate catalysts and which can significantly increase the efficiency of water treatment. Slags have the great advantage that they are also good adsorbents of toxic metals such as arsenic. All these improvements of the proposed system for the photo-Fenton reaction make it possible, as a whole, to be applied as a tertiary treatment to the effluent from a WWTP for the reuse of those waters in agricultural irrigation.

**Objectives:**

It is proposed to use raceway pond reactors to reduce costs and make more efficient the use of metallurgical slags (iron, copper and titanium oxides) as alternative catalysts, to degrade organic compounds and disinfect water contaminated with pathogens in a photo-Fenton system that operates at pH neutral.

**2.3.8.4 New photocatalytic materials and reactors for removal of micropollutants and pathogens, FOTOCAT, (CTM2015-71054-REDT)**

**Participants:**

Grupo de Inv. "Ingeniería de Bioprocesos y Tecnologías del Agua". Universidad de Almería (BIO-263)

**Contacts:**

J. A. Sánchez (jsanchez@ual.es)

**Source of funding:**

Ministry for Economy and Competitiveness

**Duration:**

January 2016 – December 2017

**Status:**

In progress

**Abstract:**

To achieve a sustainable use of water resources, it is necessary to increase the volume of reclaimed water. To obtain an effluent of suitable quality for the different uses permitted for reclaimed water it is necessary to reduce the content of pathogens and persistent organic pollutants. This could be achieved through the proper development of photocatalytic processes. The aim of the FOTOCAT network is to achieve a significant progress in the development of materials and photocatalytic reaction systems for the treatment and reuse of wastewater. The research groups that comprise the FOTOCAT network (Rovira i Virgili University, U. Extremadura, U. Ramon Llull, U. Rey Juan Carlos, U. Polit cnica de Valencia., U. Almer a, PSA-CIEMAT and ICRA) have altogether a wide experience in the synthesis of new catalytic materials, photocatalytic reactor design and implementation of these processes for the treatment and reuse of wastewater, allowing them to face the challenges identified for their industrial application.

Scientific advances arising from the activities of the FOTOCAT network will contribute to R+D+I plans, both European (H2020-Social Challenge 5, Water JPI), state (Spanish Strategy for Science, Technology and Innovation-Research facing Society Challenges) and regional (particularly RIS3 strategies).

**Objectives:**

- To contribute to the training of new researchers in the application of photocatalytic processes for water treatment.
- To promote the implementation of photocatalysis for water treatment on an industrial scale and increasing the impact and international projection of the Spanish groups in this field, both at European and Iberoamerican level.

### 2.3.8.5 Disinfection of secondary effluents from WWTP by the solar photo-fenton process in raceway type reactors. Effect on the transfer of resistance to antibiotics (SOLFENDIS)

**Participants:**

- Unidad funcional "Tecnolog as avanzadas para la regeneraci n de aguas"
- Unidad funcional "Evaluaci n anal tica de tratamientos de aguas y an lisis ambiental"

**Contacts:**

- J. A. S nchez (jsanchez@ual.es)
- Ag era (aaguera@ual.es)

**Funds:**

Ministerio de Econom a y Competitividad. (CTQ2016-78255-R)

**Time Period:**

January 2017 - December 2019

**Current Situation:**

In progress

**Summary:**

Although the interest that the regeneration of irrigation water has in Spain, no large-scale experiences or cost evaluation of the solar photo-Fenton process are known, mainly due to the recent nature of these investigations. For any use for which the reuse of treated wastewater is allowed (RD 1620/2007), it is necessary to reduce the content of pathogenic microorganisms in the regenerated water. In this regard, raceway reactors have never been used for water disinfection. Another aspect that has not been evaluated is its ability to reduce the risk of diffusion of antibiotic resistance (RA). Antibiotic resistance is today one of the most pressing public health problems worldwide. Spain is recognized as a country with a high prevalence of resistance, especially in species that cause infections: Pneumococcus, Meningococcus, Haemophilus

influenzae, Campylobacter sp, Salmonella sp or E. coli, being also one of the countries with the highest consumption of antibiotics by habitant. There is evidence that standard wastewater disinfection processes are not specific in the control of AR diffusion. In this context, research has also been conducted on the generation of derivative products in disinfection processes and the need for analytical control through advanced sophisticated techniques, as well as the monitoring of the ecotoxicity of treated waters. Finally, economic evaluation and cost minimization are decisive to bring this technology to the commercial field.

**Objectives:**

- Study the operation variables of the raceway reactors for water disinfection, reagent dosing and liquid depth, at pilot scale.
- Analyze microcontaminants, their transformation products and products derived from disinfection, improving and validating new methods.
- Evaluate the effect of treatments on the potential of AR transfer, through the inactivation of ARBs and the evaluation of resistant gene variation (ARG).
- Optimize the pilot scale process from an economic point of view in order to facilitate decision-making for its larger-scale implementation and pre-commercialization.

**2.3.8.6 Toward a smart & integral treatment of natural radioactivity in water provision services (LIFE ALCHEMIA) (LIFE16 ENV/ES/000437)**

**Participants:**

- CIESOL. Unidad funcional "Tecnologías avanzadas para la regeneración de aguas"
- Fundación CARTIF (Coordinadores)
- Diputación de Almería
- Tallinn University of Technology
- University of Tartu
- Viimsi Vesi Ltd (Estonia)

**Contacts:** J. L. Casas López (jlcasas@ual.es)

**Funds:** Unión Europea. Programa LIFE (LIFE16 ENV/ES/000437)

**Time Period:** October 2017 - December 2020

**Current Situation:** In progress

**Summary:**

The Life Alchemia project tackle one of the current challenges in the treatment of water for human consumption, such as the presence of natural radioactivity. There is a notable lack of knowledge on the part of those involved in water management and despite current legislation (Directive 2013/51 / Euratom), radioactivity is not a parameter that is being systematically monitored at European level. In this regard, it should be noted that this project has the support of 43 of these actors, including the highest national authorities of the 2 member countries of the consortium: the Estonian Ministry of Environment and the Spanish Nuclear Safety Council. It is an environmental problem that cannot be solved at the source, since it is generated by the dilution in groundwater of minerals rich in radioactive isotopes, mainly uranium (U), radium (RA) and thorium (TH). Therefore, new systems capable of providing a sustainable elimination of radioactivity from the point of view of profitability and sustainability are needed. Reverse osmosis (RO) is the most used treatment for this application; However, the carbon footprint of this process is very high and generates large

volumes of water rejection with radioactivity that needs additional treatment. The LIFE Alchemia project offers a breakthrough to this problem from two angles. First, with the use of filter bed based treatment systems that will reduce the cost of water treatment up to five times. Second, considering the entire life cycle of radioactivity, including the management of generated waste.

**Objectives:**

- Demonstrate the technical and economic feasibility of filter beds that will be optimized to eliminate water radioactivity and minimize the generation of natural radioactive materials (NORM). Four pilot plants will be operated, three in Spain and one in Estonia, with different strategies to prevent the generation of NORM waste.
- Replicate Life Alchemia solutions in facilities in five other European countries (Italy, Poland and Finland, among others).
- Promote the transfer to other facilities and members of the EU.
- Encourage the active participation of interested parties in the implementation of Directive 2013/51 / Euratom to minimize the environmental impact of radionuclide treatment on water supply services.

During the execution of the project, the specific stakeholders of the target sectors (water suppliers, manufacturers, policy makers) will ensure compliance with the aforementioned objectives.

**2.3.9 Activities and Courses, technical capacity**

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**2.3.10 Project's applications in 2017**

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**2.3.11 Others**

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## 2.4 ACTIVITIES OF “MODELING AND AUTOMATIC CONTROL” FUNCTIONAL UNIT

### 2.4.1 Functional unit description

This functional unit is composed by researchers of the group “Automatic Control, Robotics and Mechatronics (TEP197, arm.ual.es) of the University of Almería (UAL) and the Automatic Control Unit of the Plataforma Solar de Almería (PSA). The group has among its areas of interest: intensive agriculture, solar energy, biotechnology and bioengineering, in addition to control education, mechanization and robotics in general. Collaborative activities between the group and the PSA have been developing continuously over the past 20 years, with remarkable participation of UAL researchers in developing some of the SCADA (Supervisory Control And Data Acquisition) system involved in test facilities located in the PSA. Following the experience gained in the ARFRISOL project, the group also has a research line linked to applications of control systems to achieve thermal, visual and air quality comfort and energy efficiency in buildings.

### 2.4.2 Main research lines

The main research lines of the group are:

- *Modeling and control of thermosolar plants.*
- *Modeling, control and robotics in agriculture.*
- *Energy efficiency and comfort control in buildings.*
- *Engineering Education.*
- *Modeling and control of photobioreactors.*
- *Electric vehicles.*
- *Energy smart grids*
- *Predictive, hierarchical and robust control.*
- *Supervisory systems and industrial communications.*

### 2.4.3 Main researchers

**Manuel Berenguel Soria** (Scopus Author 6701834872)

*He received the industrial engineering and Ph.D. (extraordinary doctorate award) degrees from the University of Seville, Seville, Spain. He is Full Professor of automatic control and systems engineering with the University of Almería, Almería, Spain. His research interests include control education and in predictive and hierarchical control, with applications to solar energy systems, agriculture, and biotechnology. He has been Vice-Rector of ICT at University of Almería (2007-2012) and is the head of the research group “Automatic Control, Robotics and Mechatronics” (<http://arm.ual.es>) from 2000. He has participated in more than 60 R&D projects and 30 contracts with companies. He is co-author of the books Advanced Control of Solar Plants (Springer, 1997), Control of Solar Energy Systems (Springer, 2012), Control Automático con Herramientas Interactivas (Pearson Education, 2012), Comfort Control in Buildings (Springer, 2014) and Modeling and Control of Greenhouse Crop Growth (Springer, 2014). He has been director and co-director of 15 PhD Thesis in these lines. He is co-author of more than 120 international journal papers, more than 150 papers in international conferences and 4 patents. H-index: 38 (Google Scholar), 30 (Scopus), 24 (Web of Science). He has participated in the International Program Committee of 8 international conferences (in one as IPC Chair) and 3 national conferences, where he has been chairman in many occasions. He is reviewer of more than 15 renowned international journals (more than 100 reviews) and from 2013 is adjoin-director of the journal*

Revista Iberoamericana de Automática e Informática Industrial (indexed in SCI). He has been member of the board of Governors of the Comité Español de Automática (main Spanish Association in Automatic Control) from 2003 to 2008 and 2012-2016, senior member of IEEE Control System Society from 2000 and member of the IFAC Technical Committees TC 8.01 Control in Agriculture, TC 6.3. Power and Energy Systems and TC 8.4 Biosystems and bioprocesses and member of the Coordination and management committee of the Mixed R&D Center CIESOL between the University of Almería and CIEMAT- Spanish Research Center in Energy, Environment and Technology (from 2005) and member of Scientific Committee of IMDEA Energy from 2015. He was the organizer of the XXVII Jornadas de Automática (the annual meeting of the Spanish Automatic Control Committee) in 2006.

**Luis José Yebra Muñoz** (Scopus Author 15926309900)

He belongs to the MINECO Research Scientists body. He began his research activity in CIEMAT, in the Plataforma Solar de Almería center (PSA-CIEMAT) in 1999, developing a thesis on modeling and control of solar thermal plants, with specialization in object-oriented modeling activities of thermosolar plants with two-phase flow parabolic troughs. He has participated in research activities summarized in 35 research projects with public funding, 2 contracts with companies, creation of a spin-off, codirection of 4 PhD Theses, 26 journal publications in JCR, 72 contributions to conferences and 4 books. During some periods he has combined the research activity with the coordination of groups of technical services in PSA, as the Computing Service or the Industrial Informatics group, leading the Automatic Control group of PSA-CIEMAT from 2011 composed by 4 researchers. This activity was also combined with educational ones at the University of Almería within the Systems Engineering and Automatic Control area. He is also editor and reviewer of scientific journals in this area, like Mathematical and Computer Modelling of Dynamical Systems or Solar Energy. He is also associate Editor of Mathematical Problems in Engineering.

**2.4.4 Summary of the Modeling and Automatic Control functional unit's activities carried out during 2017**

- Control and energy management strategies in production environments with support of renewable energy.
- Modeling and control of fotobioreactors and fotoreactors. Control and optimization for the biomass production from microalgae as renewable energy source.
- Modeling and control of solar desalination plants.
- Set up and technical and energetic evaluation of a novel hybrid loop for thermal generation (solar and biomass) for climate control of semi-closed greenhouses.
- Development of fertigation models and controllers, humidity control in greenhouses and coupling to a solar desalination plant.
- Control of greenhouse crop growth optimizing sustainability, energy and economic criteria.
- Multi-objective optimization of air conditioning and lighting systems for comfort achievement in sustainable buildings.
- Simulation and control of thermosolar plants with parabolic troughs in industrial and refrigeration applications.
- Preparation and coordination of activities for future projects in TCP-100 PSA field.

- Kinematic and dynamic modeling and control of electrical vehicles focusing on energy efficiency using solar energy.
- Control of unmanned aerial vehicles (UAV).
- Development of interactive tools and virtual and remote laboratories for automatic control.
- Robot design and control.



#### 2.4.5 New staff: pre and post-doctoral fellowships, contracts, scholarships

- Francisco José Mañas Álvarez. Contract the Ministry of Economy and Competitiveness - project ENERPRO DPI2014-56364-C2-1-R (supervisors: José Luis Torres Moreno, José Luis Blanco Claraco, Francisco Rodríguez Díaz).
- Guillermo José Felices Rodríguez. Contract of the Youth Guarantee Fund (CIESOL).
- Blas Salvador Criado. Contract of the Youth Guarantee Fund (GRUPO TEP-197).
- Miguel Ramón Urrutia Contract of the Youth Guarantee Fund (CIESOL).
- Yaser Alamin. Granted by EU Project Phoenix-Marhaba (supervisors: José Domingo Álvarez Hervás, Antonio Ruano)
- Alice Branco. Collaborator. Universidad Federal de Santa Catarina, Brasil.
- Jerónimo Ramos Teodoro. FPI contract of the Ministry of Economy and Competitiveness - project ENERPRO DPI2014-56364-C2-1-R (supervisors: Francisco Rodríguez Díaz, Manuel Berenguel).
- Juan Diego Gil Vergel. Contract the Ministry of Economy and Competitiveness - project ENERPRO DPI2014-56364-C2-1-R (supervisors: Manuel Berenguel Soria, Lidia Roca Sobrino).

- Marta Barceló Villalobos. Contratado FPI del Ministerio de Economía y Competitividad adscrito al proyecto PROBIOREN DPI2014-55932-C2-1-R (supervisores: José Luis Guzmán Sánchez, Francisco Gabriel Acién).
- Ángeles Hoyo Sánchez. Contratado laboral adscrito al proyecto PROBIOREN DPI2014-55932-C2-1-R (supervisores: José Luis Guzmán Sánchez, José Carlos Moreno Úbeda).
- Wang Hui. Researcher from NERCITA (China). PhD student of ARM group (supervisors: Jorge Antonio Sánchez Molina, Fernando Bienvenido Bárcena).

#### 2.4.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

##### Papers

- Y. Alamin, M. Castilla, J.D. Álvarez, A. Ruano. An economic Model-based Predictive Control to manage the users' thermal comfort in a building. *Energies*, 10(3), 321. DOI: 10.3390/en10030321. Impact factor (2016 JCR Science Edition): 2.262, 45/92 Q2 (Energy & Fuels).
- J. Bonilla, M. Rodríguez, A. de la Calle, L. Roca, L. Valenzuela. Study on Shell-and-Tube Heat Exchanger Models with Different Degree of Complexity for Process Simulation and Control Design. *Applied Thermal Engineering*, 124, 1425-1440, 2017. DOI: 10.1016/j.applthermaleng.2017.06.129. Impact factor (2016 JCR Science Edition): 3.356, 8/58 Q1 (Thermodynamics), 29/92 Q2 (Energy & Fuels), 12/130 Q1 (Engineering, Mechanical), 10/133 Q1 (Mechanics).
- J. Bonilla, M. Rodríguez, L. Roca, A. de la Calle, L. Valenzuela. Design and experimental validation of a computational effective dynamic thermal energy storage tank model. *Energy*, in Press, 2017. DOI: 10.1016/j.energy.2017.11.017. Impact factor (2016 JCR Science Edition): 4.520, 3/58 Q1 (Thermodynamics), 17/92 Q1 (Energy & Fuels).
- J. Bonilla, L. Roca, A. de la Calle, S. Dormido. Modelo dinámico de un recuperador de gases-sales fundidas para una planta termosolar híbrida de energías renovables. *Revista Iberoamericana de Automática e Informática Industrial*, 14(1), 70-81, 2017. DOI: 10.1016/j.riai.2016.11.003. Índice de Impacto: 0.500, Q4 (Automation & Control Systems).
- J.J. Cañadas, J.A. Sánchez, F. Rodríguez, I. del Águila. Improving automatic climate control with decision support techniques to minimize disease effects in greenhouse tomatoes. *Information Processing in Agriculture*, 4(1), 60-63, 2017.
- J.A. Carballo, J. Bonilla, L. Roca, A. de la Calle, M. Berenguel. Optimal operating conditions analysis of a multi-effect distillation plant. *Desalination and Water Treatment*, 2017. DOI: 10.5004/dwt.2017.0703. Impact factor (2016 JCR Science Edition): 1.631, 66/135 Q2 (Engineering, Chemical), 43/88 Q2 (Water Resources).
- N.C. Cruz, J.L. Redondo, M. Berenguel, J.D. Álvarez, P.M. Ortigosa. Review of software for optical analyzing and optimizing heliostat fields. *Renewable and Sustainable Energy Reviews*, 72, 1001-1018, 2017. DOI: 10.1016/j.rser.2017.01.032. Impact factor (2016 JCR Science Edition): 8.050, 2/31 Q1 (Green & Sustainable Science & Technology; 5/92 Q1 (Energy & Fuels).

- N.C. Cruz, J.L. Redondo, J.D. Álvarez, M. Berenguel, P.M. Ortigosa. A parallel Teaching-Learning-Based optimization procedure for automatic heliostat aiming. *Journal of Supercomputing*, 73(1), 591-606, 2017, published online: 10 November 2016, DOI 10.1007/s11227-016-1914-5. Impact factor (2016 JCR Science Edition): 1.929, 35/52 Q3 (Computer Science, Hardware & Architecture), 52/104 Q2 (Computer Science, Theory & Methods), 162/260 Q3 (Engineering, Electrical & Electronic).
- N.C. Cruz, J.D. Álvarez, J.L. Redondo, J. Fernández-Reche, M. Berenguel, R. Monterreal, P.M. Ortigosa. A new methodology for building-up a robust model for heliostat field flux characterization. *Energies* (Basel), 10(5), 730-474, 2017. Impact factor (2016 JCR Science Edition): 2.262, 45/92 Q2 (Energy & Fuels).
- N.C. Cruz, J.L. Redondo, M. Berenguel, J.D. Álvarez, A. Becerra-Terón, P.M. Ortigosa. High performance computing for the heliostat field layout evaluation. *Journal of Supercomputing*, 73, 259-276, 2017. Published online: 16 March 2016, DOI 10.1007/s11227-016-1698-7. Impact factor (2016 JCR Science Edition): 1.929, 35/52 Q3 (Computer Science, Hardware & Architecture), 52/104 Q2 (Computer Science, Theory & Methods), 162/260 Q3 (Engineering, Electrical & Electronic).
- J.D. Gil, L. Roca, A. Ruiz-Aguirre, G. Zaragoza, M. Berenguel. Optimal operation of a solar membrane distillation pilot plant via nonlinear model predictive control. *Computers & Chemical Engineering*, 109, 151-165, 2018. DOI: 10.1016/j.compchemeng.2017.11.012.
- C. Hernández, F. Rodríguez, J.C. Moreno, P. R. Da-Costa, J.E. Normey-Rico. The use of Model Predictive Control (MPC) in the optimal distribution of electrical energy in a microgrid located in southeastern of Spain: A case study simulation. *Renewable Energy & Power Quality Journal*, 1(15), 221-226, 2017. DOI: 10.24084/repqj15.278.
- C. Hernández, F. Rodríguez, J.C. Moreno, P.R. Da Costa, J.E. Normey-Rico, J.L. Guzmán. The comparison study of short-term prediction methods to enhance the model predictive controller applied to microgrid energy management. *Energies*, 10(7), 884-908, 2017. Impact factor (2016 JCR Science Edition): 2.262, 45/92 Q2 (Energy & Fuels).
- A. Pawlowski, J.L. Guzmán, M. Berenguel, J.E. Normey-Rico, S. Dormido. Event-based GPC for multivariable processes: A practical approach with sensor deadband. *IEEE Transactions on Control Systems Technology*, 25(5), 1621-1633, 2017. DOI: 10.1109/TCST.2016.2620061. Impact factor (2016 JCR Science Edition): 3.882, 9/60 Q1 (Automation & Control Systems), 42/305 Q1 (Engineering, Electrical & Electronic).
- A. Pawlowski; J.A. Sánchez, J. L. Guzmán, F. Rodríguez, S. Dormido. Evaluation of Event-Based Irrigation System Control Scheme for Tomato Crops in Greenhouses. *Agricultural Water Management*, 183, 16-25, 2017. DOI: 10.1016/J.AGWAT.2016.08.008. Impact factor (2016 JCR Science Edition): 2.848, 13/83 Q1 (Agronomy), 14/88 Q1 (Water Resources).
- A. Pawlowski, F. Rodríguez, J. Sánchez-Hernosilla, S. Dormido. Adaptive Weighing System With Fast Nonstationary Filtering and Centrifugal Force Compensation. *IEEE Transactions On Instrumentation And Measurement*, 66 (2) , 3210-3217 2017. DOI: 10.1109/TIM.2017.2737838. Impact factor (2016 JCR Science Edition): 2,456, 14/58 Q1 (Instruments and Instrumentation)

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- A. Pérez-Castro, J.A. Sánchez, M. Castilla, J. Sánchez, J.C. Moreno, J.J. Magán. cFertigUAL: A fertigation management app for greenhouse vegetable crops. *Agricultural Water Management*, 183, 186-193, 2017. DOI: 10.1016/J.AGWAT.2016.09.013. Impact factor (2016 JCR Science Edition): 2.848, 13/83 Q1 (Agronomy), 14/88 Q1 (Water Resources).
  - A. Pérez-Castro, J. Sánchez, M. Castilla. PhotoBioLib. A Modelica library for modeling and simulation of large-scale photobioreactors. *Computers & Chemical Engineering*, 98, 12-20, 2017. DOI: 10.1016/j.compchemeng.2016.12.002.
  - A. Pérez-Castro, J. Sánchez, M. Castilla. Development of an open experimentation tool based on JavaScript for the control of a four-tank plant. *Computer Applications in Engineering Education*, 1-11, 2017. DOI: 10.1002/cae.21879. Impact factor (2016 JCR Science Edition): 0.694, 98/105 Q4 (Computer Science, Interdisciplinary applications), 31/41 Q4 (Education, Scientific Disciplines), 63/85 Q3 (Engineering, Multidisciplinary).
  - G. Reina, M. Paiano, J.L. Blanco-Claraco. Vehicle parameter estimation using a model-based estimator. *Mechanical Systems and Signal Processing*, 87-B, 227-241 2017. DOI: 10.1016/j.ymsp.2016.06.038. JCR Q1 (13/132 Mechanical Engineering).
  - A. Ruiz, M. Beschi, A. Visioli, S. Dormido, J. Jiménez. An unified event-based control approach for FOPTD and IPTD processes based on the Filtered Smith Predictor. *Journal of the Franklin Institute*, 354(2), 1239-1264, 2017. DOI: 10.1016/j.jfranklin.2016.11.017. Índice de Impacto: 1.356, Q1 (Automation & Control Systems).
  - J. Sánchez, J.L. Guzmán, F. Rodríguez, S. Dormido. Evaluation of event-based control scheme for greenhouse irrigation system. *Agricultural Water Management*, 183,16-25, 2017. DOI: 10.1016/J.AGWAT.2016.08.008. Impact factor (2016 JCR Science Edition): 2.848, 13/83 Q1 (Agronomy), 14/88 Q1 (Water Resources).
  - J.A. Sánchez-Molina, M. Li; F. Rodriguez; J.L. Guzman; H. Wang; Yang, Xinting. Development and test verification of air temperature model for Chinese solar and Spanish Almeria-type greenhouses. *International Journal of Agricultural and Biological Engineering*, 10 (4), 66-76 DOI: 10.25165/j.ijabe.20171004.2398 Impact factor (2016 JCR Science Edition): 0.515, 9/14 Q3 (Agricultural Engineering)
  - E. Sanjurjo, M.A. Naya, J.L. Blanco-Claraco, J.L. Torres-Moreno, A. Giménez-Fernández. Accuracy and efficiency comparison of various nonlinear Kalman filters applied to multibody models. *Nonlinear Dynamics*, 88(3), 1935-1951, 2017. DOI: 10.1007/s11071-017-3354-z. Índice de impacto: 3.464.JCR Q1 (8/135 Mechanics).
  - H. Wang, J.A. Sánchez-Molina, M. Li, M. Berenguel, X.T. Yang, J.F. Bienvenido. Leaf area index estimation for a greenhouse transpiration model using external climate conditions based on genetic algorithms, back-propagation neural networks and nonlinear autorregressive exogenous models. *Agricultural Water Management*, 183, 107-115, 2017. DOI: 10.1016/J.AGWAT.2016.11.012. Impact factor (2016 JCR Science Edition): 2.848, 13/83 Q1 (Agronomy), 14/88 Q1 (Water Resources).

### Book chapters

- Book: Geothermal, Wind and Solar Energy Applications in Agriculture and Aquaculture. Capítulo: Renewable energy technologies for greenhouses in semi-arid climates. Cabrera, F.J., Sánchez-Molina, J.A., Zaragoza, G., Pérez-García, M. y Rodríguez-Díaz, F. CRC Press/Balkema, Taylor & Francis Group 2017. ISBN 9781138029705.
- Book: Prospects and Challenges in Algal Biotechnology. Chapter 1: Event-based control systems for microalgae culture in industrial reactors. A. Pawlowski, J.L. Guzmán, M. Berenguel, F.G. Acién, S. Dormido. Springer 2017, pp.1-48. ISBN: 978-981-10-1949.
- Book: Prospects and Challenges in Algal Biotechnology. Chapter 2: Dynamic modelling of microalgal production in photobioreactors. I. Fernández, J.L. Guzmán, M. Berenguel, F.G. Acién. Springer. 2017, pp.48-87. ISBN: 978-981-10-1949.
- Book: Advances on Mechanics, Design Engineering and Manufacturing. Lecture Notes in Mechanical Engineering. Capítulo: 3 coastal monitoring from very dense UAV-Based photogrammetric point clouds. F. Aguilar, I. Fernández-Luque, J.A. Casanova, F.J. Ramos, M. Aguilar, J.L. Blanco-Claraco, J.C. Moreno. Springer International Publishing. 2017. ISBN: 978-3-319-45780-2.
- Book: Robotics – Legal, Ethical and Socioeconomic Impacts. Capítulo: Robots Liability: A Use Case and a Potential Solution. A Zornoza, J. C. Moreno, J. L. Guzmán, F. Rodríguez, J. Sánchez-Hermosilla. InTechOpen. 2017. ISBN: 978-953-51-3636-1.

### Congress

- Jornadas SARTECO 2017, Málaga, España
  - Calvo-Cruz, Nicolás; Salhi, Said; López-Redondo, Juana; Álvarez, José Domingo; Berenguel, Manuel; Martínez-Ortigosa, Pilar. Diseño de un método genético paralelo para la optimización continua del campo de helióstatos
- 20<sup>th</sup> IFAC World Congress, Toulouse, France (5 aportaciones)
  - Rodríguez-Contreras, Carlos; Guinaldo, M.; Aranda, E.; Guzmán, José Luis; Dormido-Bencomo, Sebastián. An Object-Oriented Library for Process Control Simulations in MATLAB.
  - Pawlowski, Andrzej; Guzmán, José Luis; Sánchez-Hermosilla, J.; Rodríguez-Contreras, Carlos; Dormido-Bencomo, Sebastián. A low-cost embedded controller design for selective spraying vehicle.
  - Pawlowski, Andrzej; Rodríguez-Contreras, Carlos; Berenguel, Manuel; Dormido-Bencomo, Sebastián. Predictive feedforward compensator for dead-time processes
- 17<sup>th</sup> International Conference on Computational and Mathematical Methods in Science and Engineering. Rota, Cádiz, España
  - Calvo-Cruz, Nicolás; Salhi, Said; López-Redondo, Juana; Álvarez, José Domingo; Berenguel, Manuel; Martínez-Ortigosa, Pilar. A parallel genetic algorithm for continuous and pattern-

free heliostat field optimization.

- 4<sup>th</sup> Experiment@International Conference 2017. Algarve, Portugal
- 3<sup>rd</sup> International Conference on Control, Communication, and Signal Processing. Funchal, Madeira, Portugal
- 12<sup>th</sup> International Modelica conference. Praga, Republica Checa
  - Bonilla-Cruz, Javier; Carballo, José Antonio; Roca-Sobrino, Lidia; Berenguel, Manuel. Development of an open source multi-platform software tool for parameter estimation studies in FMI models
- SOLLAB Doctoral colloquium on solar concentrating technologies. Berlin, Alemania.
  - Carballo, José Antonio; Bonilla-Cruz, Javier; Berenguel, Manuel. Modeling, optimization and control for efficient management of resources in solar processes.
- EuroMed 2017 Desalination for Clean Water and Energy: Cooperation around the World. Israel
  - Carballo, José Antonio; Bonilla-Cruz, Javier; Roca-Sobrino, Lidia; De La Calle-Alonso, Alberto; Berenguel, Manuel; Palenzuela-Ardila, Patricia .Optimal operating conditions analysis for a Double-Effect Absorption Heat Pump coupled to a Multi Effect Distillation Plant.
- 2017 Meeting of EUVRIN Working Group Fertilisation and Irrigation, Almería, Spain.
  - Bonachela-Castaño, Santiago; Fernández-Fernández, M<sup>a</sup> Dolores; Granados-García, Maria Rosa; Cabrera-Corral, Francisco Javier. Automated irrigation of soil-grown greenhouse tomato crops in a Mediterranean area.
- 14<sup>th</sup> International Conference on Remote Engineering and Virtual Instrumentation, New York, EEUU.
- XXXVIII Jornadas de Automática, Gijón, España.
  - JD Gil, L Roca, M Berenguel Soria, A Ruiz-Aguirre, G Zaragoza del Águila. Control predictivo para la operación eficiente de una planta formada por un sistema de desalación solar y un invernadero.
- 25<sup>th</sup> Mediterranean Conference on Control and Automation, La Valletta, Malta.
  - JD Gil, L Roca, A Ruiz-Aguirre, G Zaragoza, JL Guzmán, M Berenguel. Using a Nonlinear Model Predictive Control strategy for the efficient operation of a solar-powered membrane distillation system
- IX Congreso Ibérico de Agroingeniería, Braganza, Portugal.
- XV Simposio de Ingeniería de Control, Salamanca, España.
- International Conference on Renewable Energies and Power Quality (ICREPQ'17), Málaga, España.
- Datasharing 2017 de IOF2020, Bratislava, Slovak Republic.



### Organization of Congresses

- Torneo Clasificatorio de la FIRST Lego League 2017. 18/02/2017.
- II Jornadas de Automática, Robótica y Mecatrónica. 28/04/2017.
- Desafío Club de Robótica de la UAL 2016-2017. 23/05/2017.

### PhD Thesis

- Medina-Hernández, J. Avances en la interacción física segura humano-robot y el desarrollo de sistemas elásticos articulares. Directores: Jardón-huete, Alberto; Balaguer-bernaldo De Quirós, Carlos; Gimenez-Fernandez, Antonio. Universidad Carlos III de Madrid. Escuela Politécnica Superior. 30/11/2017.
- Hernández, C. Estrategias de control y supervisión para la gestión integrada de instalaciones en entornos energéticamente eficientes. Directores: Francisco Rodríguez, José Carlos Moreno. Universidad de Almería. Escuela Superior e Ingeniería. 19/10/2017.

### 2.4.7 Staff members

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## 2.4.8 Ongoing projects in 2017

### 2.4.8.1 ENERPRO – Control and energy management strategies in production environments with support of renewable energy

**Participants:**

Research group "Automatic Control, Robotics & Mechatronics". University of Almería (TEP 197)  
PSA-CIEMAT

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**Source of funding:**

Ministerio de Economía y Competitividad. Plan Nacional 2014 (DPI2014-56364-C2-1-R)

**Duration:**

January 2015 – December 2018

**Status:**

Under development

**Abstract:**

This project deals with the analysis, design and application of modeling, control and optimization techniques (in the framework of hierarchical and model-based predictive control, MPC) to achieve an efficient energy (electricity and process heat/water), water and CO<sub>2</sub> management in production environments with support of renewable energy and storage systems. Through optimal management of these resources and by adapting generation to demand, it should be demonstrated how automatic control allows to achieve cost savings and reduce the environmental impact on the operation of complex processes.

Around this theme, concepts like micro-grids (MG), related to the efficient use of electricity, renewable heat and cooling (RHC), in the area of primary energy supply from renewable sources and water efficiency (WE), around adequate use of water have arisen. The paradigm treated in this project goes beyond, since it treats comprehensive and coordinated management of those heterogeneous resources focusing on efficiency and economics. The problem is composed by different control and decision levels about the final use of the available energy based on different objectives (minimizing the use of conventional fossil energy sources, economic, environmental and quality aspects, etc.) This gives rise to a hierarchical control problem that requires coordination and cooperation between systems and that will be addressed using hierarchical and hybrid predictive control techniques, both in centralized and distributed versions. It will be also necessary to develop models, estimators and predictors of the energy generation and demand stages.

A key element of the project is that a real production system will be use as test-bed plant (including a bioclimatic building, a greenhouse, an electric vehicle and a solar desalination plant), on which the developed modeling and control techniques will be validated.

**Objectives:**

The three basic objectives of the coordinated project are:

1. Development of methodologies for obtaining models of processes that contain renewable energy sources to produce/consume process heat, electricity, water and CO<sub>2</sub>. Development of estimators and predictors of generation and demand stages.

2. Development of hierarchical, hybrid and, in general, MPC control and management strategies to optimize production from the economic, security and energy and water use points of view in heterogeneous systems, using a coordinated and comprehensive approach.
3. Implementation and validation of the strategies in the production environment selected as test-bed plant. This will facilitate the development of the different tasks of the project over realistic conditions. Possible extensions to more complex environments like campus or industrial clusters will be demonstrated.

The fulfilment of the preceding goals represents a significant contribution with real impact in this class of processes as evidenced by the interest shown by firms like Fundación Cajamar, Unica Group SCA, Wagner Solar, Solar Jiennense, naming only a few. The proposal is also a natural continuation follow-up of previous work carried out the research groups integrating the project. The team has a remarkable experience in control systems backed by many papers published in some of the most cited scientific journals and relationships with international research teams.

#### **2.4.8.2 PROBIOREN Control and optimization for the biomass production from microalgae as renewable energy source**

**Participants:**

Research group "Automatic Control, Robotics & Mechatronics". University of Almería (TEP 197)  
Department of Informatics and Automatic Control – UNED -Madrid

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**Source of funding:**

Ministerio de Economía y Competitividad. Plan Nacional 2010. (DPI2014-55932-C2-1-R)

**Duration:**

January 2015 – December 2017

**Status:**

Under development

**Abstract:**

The project deals with the application of modelling and control approaches for the optimal biomass/biofuel production in raceway photobiorreactors to be competitive in the energy sector market. The main goal consists in reaching a near optimal environment for microalgae to grow, multiply, and produce biomass, together with an assessment of the balance between the requested energy to maintain an optimal microalgae growth, the injected CO<sub>2</sub>, and the recovered costs through biomass-biofuel. According to the nonlinear dynamics, and the complex and hierarchical nature of these processes, different control approaches will be evaluated to reach the proposed objectives. Event-based, reset, and fractional control approaches together with hierarchical model predictive control algorithms will be used to achieve an efficient microalgae biomass production in raceway photobiorreactors. Moreover, nonlinear models, estimators and predictors of the main photobiorreactor variables will be developed.

**Objectives**

The main objectives of the coordinated project are:

1. Development of a modelling framework to obtain nonlinear dynamical models for microalgal biomass production based on raceway photobiorreactors to be used for renewable energy purposes. The resulting models will be used for reactor design and control design purposes.

2. Development of low-level and high-level control strategies (mainly event-based, reset fractional, and model predictive control algorithms) for the optimal biomass production in raceway photobiorreactors looking for reducing costs and being competitive in the energy sector market, and contributing at the same time in the mitigation of the environment pollution.
3. Implementation and validation of the developed modelling and control strategies in different experimental plants with clear industrial relevance. Concretely, two industrial raceway photobiorreactors will be mainly considered for this purpose.

This proposal constitutes the continuation of a new research line on biomass production from microalgae in photobiorreactors, that was opened for the applicant control engineering groups in a previous research project focused on tubular photobiorreactors. The applicant groups have had a strong collaboration during the last years through research projects and joint publications. The team has a remarkable experience in control systems backed by many papers published in some of the most cited scientific journals. On the other hand, the multidisciplinary of the group is complemented with researchers with strong background in microalgal biomass production by photobiorreactors. Moreover, the international collaboration is fostered in the project because three relevant researchers from two European universities (Swedish and Italian) and one researcher from Arizona State University (USA) belonging to the control engineering field take part in the proposal. On the other hand, the project topic belongs to the strategic research lines of the European Union and the National Research Plan, within the challenge on Secure, Efficient and Clean Energy and thus being a hot research topic. Hence, the fulfilment of the proposed objectives would be a significant contribution in this emerging renewable energy field and it would have a real impact in the energy market competitiveness of this type of processes. Consequently this proposal has risen the interest of different companies and research centers such as Acciona, AlgaEnergy or CIESOL.

#### 2.4.8.3 Internet of Food and Farm IoF2020

##### **Participants:**

Grupo de Inv. "Automática, Robótica y Mecatrónica". Universidad de Almería (TEP 197)  
72 partners internacionales

##### **Contacts:**

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Jorge Sánchez ([jorgesanchez@ual.es](mailto:jorgesanchez@ual.es)).  
C. Giagnocavo (cgiagnocavo@ual.es)

##### **Source of funding:**

H2020 Call for proposals: H2020-IOT-2016-2017 (H2020-IOT-2016). Proposal: 731884 — IoF2020. IoT-01-2016 — Large Scale Pilots. Innovation action.

##### **Duration:**

January 2017 – December 2020

##### **Status:**

Under development

##### **Abstract:**

The European Project Internet of Food & Farm 2020 (IoF2020, Internet of Food and Farming) aims to investigate and promote the large-scale implementation of the Internet of Things (IoT, Internet of Things) in the agricultural and food sector European. With a budget of 30 million euros, co-financed by the European Union, the project has the potential to introduce a paradigm shift in this area, drastically improving productivity and sustainability. The added value of networks and smart websites of interconnected objects,

sensitive to the context and that can be identified, equipped with sensors and remotely controlled in the agri-food sector, will be demonstrated. The project has begun on January 1, 2017 and will last for four years.

IoF2020: 5 trials, 19 case studies: IoT has the potential to be a true transforming element of agriculture. Recent initiatives have demonstrated the sector's interest in taking advantage of the opportunities offered by Information and Communication Technologies (ICT), networks and data-oriented technologies. However, the current available applications remain fragmentary and are used mainly by a small group of innovative users.

The IoF2020 project will offer solutions and facilitate the large-scale adoption of IoT, addressing the organizational and technological challenges facing the European agricultural and food sector. IoT can be used for example to optimize the quality of meat in the European Union (EU) while minimizing the possibilities of fraud through an increase in transparency and traceability. Another example: in global figures, the EU wine industry has the highest proportion of EU agricultural income. To stay competitive internationally, both conventional and organic viticulture, the technologies associated with the IoT can be used to obtain a higher quality environmental sustainability, together with the reduction of production costs. The project, which focuses on 19 case studies spread across Europe, offers solutions to 5 agri-food areas: herbaceous agricultural crops, dairy products, meat, vegetables and fruits and takes into account their own needs and obstacles.

IoF2020 involves all the actors in the food chain: from farmers, cooperatives, suppliers of equipment and logistics, food processing companies, to consumer organizations and including ICT developers.

The project will develop innovative IoT solutions encouraging co-creation in iterative improvement cycles focused on user acceptability and business models to improve technology and market acceptance. End users are the core of the IoF2020 model and will participate in the evaluation and improvement of the technologies at stake, ensuring that they meet the requirements and expectations of the sector.

#### **2.4.9 Activities and Courses, technical capacity**

##### **Contracts with private companies**

- Asesoramiento al desarrollo de una metodología de modelado de la humedad de suelo en cultivos de exteriores. IP. Jorge Antonio Sánchez Molina, Francisco Rodríguez Díaz. 15/09/2016-15/01/2017. Comunidad de Madrid/AISCOM, 17.400 €.
- Mobile Robotics application development with MRPT, 001242/2. 01/03/2017-31/05/2017. IP. José Luis Blanco Claraco, 33.000 €.
- Mobile Robotics application development with MRPT, 001242/1. 01/03/2017-31/05/2017. IP. José Luis Blanco Claraco, 75.400 €.

**Agreement with University of Brescia and participation in Sfera 2 project**

The agreement includes joint supervision of theses, Erasmus Exchange, double degree students in Mechatronics for industrial automation, ... Result of the agreement has been the co-direction of the PhD thesis of Manuel Beschi (A. Visioli and M. Berenguel) in co-tutela, some research stays in the framework of Sfera 2 project (Domenico Gorni y Antonio Visioli) and joint publications in the framework of Building models and another stay (Luca Merigo) dedicated to the development of event-based control algorithms.

**UAL-CIEMAT Agreement**Participants:

- Research group "Automatic Control, Robotics & Mechatronics". University of Almería (TEP 197)
- Automatic control group of PSA

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Objectives:

The overall objective is to contribute to the development and application of activities related to research in modeling and control of thermosolar plants, using the PSA installations. The specific objectives are:

- Study of processes and subsystems involved in hybrid solar plants at PSA.
- Development of dynamic models of hybrid solar plants and validation.
- Development of control strategies for hybrid solar plants.

**Collaboration with the Energy Efficiency unit UiE3 of CIEMAT**Participants:

- Research group "Automatic Control, Robotics & Mechatronics". University of Almería (TEP 197)
- Energy Efficiency in Buildings Unit UiE3 (CIEMAT)

Contacts:

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- María José Jiménez (mjose.jimenez@psa.es)

Objectives:

- Collaboration in organizing training activities.
- Support of PhD thesis.
- Collaboration in the application to national and/or UE Research Calls.

**Collaboration in ERASMUS+ KA 107 Programme**Participants:

- Modeling and Automatic Control Unit
- International Relationship Office of UAL

Contacts:

- Manuel Pérez García (mperez@ual.es)
- María del Mar Sánchez (sri@ual.es)



Objectives:

The Erasmus + KA 107 program is a student and teacher exchange program aimed at collaborating with partner countries. In it, stays of professors and students of master's and doctorate that include research activities are admitted. Throughout the year 2017, collaborations have been carried out within the framework of this program with the International University of Rabat and the University of the Republic of Uruguay.

**Collaboration with the STUDY ABROAD Programme**

Participants:

- Modeling and Automatic Control Unit
- International Relationship Office of UAL

Contacts:

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- María del Mar Sánchez ([sri@ual.es](mailto:sri@ual.es))

Objectives:

The summer program STUDY ABROAD of the UAL offers a complete package that includes tuition and accommodation and a set of cultural services to international students who offer specialized courses of 80 hours to be taught in the month of July organized by departments and research centers of the University of Almería. The Modeling and Automatic Control Unit has coordinated the course called "Energy Transfer Processes in Solar Thermal Installations. Modeling and applications to design".

**Collaboration with IMDEA Energy**

Participants:

- Modeling and Automatic Control Unit

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Objectives

Collaboration in the Sun2Liquid european project from IMDEA Energía, in modelling and control of a heliostat field aimed at solar fuel production in a chemical reactor. The modelling works are focused mainly in the mechanical modelling of a heliostat different from those usually operated at PSA. This heliostat type need a detailed model for its operation and its experimental calibration to accomplish the strict requested aiming point operation specifications. Activities not performed so far in the thermo-fluid modelling domain are being afforded in this one, as the real time model based control of heliostats in the operation of the facility.

**2.4.10. Project's applications in 2017**

- CHROMAE: Control y gestión óptima de recursos heterogéneos en distritos productivos agroindustriales integrando energías renovables. Control and optimal management of heterogeneous resources in productive agro-industrial districts integrating renewable energies [F. Rodríguez, Plan Nacional DPI]
- CALRESI: Modelado y Control del proceso combinado de producción de microALgas y tratamiento de aguas RESIduales con reactores industriales. Modeling and Control of the combined process of

microalgae production and wastewater treatment with industrial reactors [J.L. Guzmán, Plan Nacional DPI]

- AL-FLU-RAD-IN: Algoritmos para generación de patrones genéricos de flujo de radiación concentrada en aplicaciones industriales. Algorithms for generating generic patterns of concentrated radiation flow in industrial applications [J.D. Álvarez, Explora Ciencia/Tecnología 2017]
- Sistema abierto y escalable de supervisión, gestión eficiente de la energía y control de confort del edificio singular y estratégico CIESOL [Infraestructura FEDER CIESOL]
- Solicitud de Acción COST. In-Situ BEPA-MAS – OC-2016-2-21388. Building Energy Performance Assessment based on in-situ Measurement, Analysis and Simulation. Participantes: CIEMAT (coord.), CIESOL-UAL (ES), Universidad de Innsbruck (AT), Universidad de Leuven (BE), INIVE EEIG (BE), Belgian Building Research Institute (BE), ES-SO vzw European Solar-Shading Organization (BE), Universidad de Praga (CR), Universidad Técnica de Dinamarca (DK), Centro científico-técnico de Bâtiment (FR), Universidad de Mont-Blanc (FR), Cerema, (FR), Universidad de Bolonia (IT), Grupo Permasteelisa (IT), Universidad de Tecnología de Kaunas (LT), Saxion Hogeschool (NL), Universidad de tecnología de Wroclaw (PL), Universidad de Porto (PT), Universidad del País Vasco (ES), ACCIONA (ES), greenTEG AC (SW), Instituto de Ingeniería Termo-física de NASU (Ukraine), Universidad de Strathclyde (UK), University College London (UK), Universidad Leeds Beckett (UK), Universidad de Salford (UK). No concedido.

#### 2.4.11 Otros

##### Committees:

- Coordination of the Specialized Medium Temperature Group of the National Technological Platform SOLARCONCENTRA
- The Control Engineering Thematic Network. Special action of the National Plan. DPI2014-51731-REDT. IP. Ramon Vilanova, 01/2015-01/2017.
- Spanish Technological Robotics Platform HISPARO (http://www.hisparob.es)
- Spanish Automatic Control Committee (www.ceautomatica.es)

##### Collaborators of the group in CIESOL:

- Francisco Javier Cabrera Corral (CAPDR-Junta de Andalucía)
- Sebastián Dormido Bencomo (UNED)
- Carlos Rodríguez Contreras (UNED)
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- Nicolás Calvo Cruz (UAL)
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- José María Cámara (UMH).
- Ramón Costa Castelló (UPC)

- Carlos Bordóns (US)
- Eduardo F. Camacho (US)
- Manuel G. Ortega (US)
- Manuel R. Arahál (US)

#### **Students Practices:**

- Almagro, A. Design of a system of location in interior of buildings based on wireless signals. Degree in Industrial Electronic Engineering.
- García Mañas, F. Design of a bidirectional recharging point for electric vehicles. Degree in Industrial Electronic Engineering.
- Gómez, M.A. Analysis of the lighting control system and blinds of CIESOL. Degree in Industrial Electronic Engineering.
- Heredia, G. Automation design for the control of a Fresnel linear solar concentrator. Degree in Electrical Engineering.
- López González de Quevedo, J.M. Modeling water consumption in an energy efficient building. Application to Ciesol. Degree in Industrial Electronic Engineering.
- Lorenzo, E. Modeling of an absorption machine. Degree in Industrial Chemical Engineering.
- Mañas Álvarez, F. Redesign of the layout and wiring of the hardware elements of the control architecture of an autonomous electric vehicle. Degree in Industrial Electronic Engineering.
- Martell, M. Multi-objective control of comfort, air quality and lighting in the CIESOL building, with criteria of energy efficiency. Degree in Industrial Electronic Engineering.
- Ordóñez, J. Development of an artificial vision system to estimate the reflection in rooms. Degree in Industrial Electronic Engineering.
- Sainz-Cantero, J. A. Design of an automated emergency exit management system. Degree in Industrial Electronic Engineering.
- Sánchez Montila, F. Development of an HMI interface for the management of lighting comfort in the meeting room of the CIESOL building. Degree in Industrial Electronic Engineering.
- Sánchez Pelegrina, A. Modeling and control of the nanofiltration plant. Degree in Chemical Industrial Engineering.

#### **Grade and Master Theses**

- Aguado Puertas, Manuel; Desarrollo de plantas virtuales para el control de procesos con Matlab y Easy Java Simulations (07/2017)
- Álvarez García, Marcos; study of the use of residues generated in the raising of tilapia for the production of ornamental crops and the generation of bioenergy (09/2017)
- Bogas Herrera, José Antonio, Development of a flexible manufacturing cell based on the machining center Concept Mill 155 (09/2017)
- Bretones Castillo, Laura. Development of End of Degree Work: Control of temperature in the greenhouse through natural ventilation: Compensation of disturbances through Feedforward control.

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- Cabrera Arcas, Javier. Unification of Two Polishing Lines in a Superline for the Silestone Quartz Agglomerate Industry. (TFG Grado Ingeniería Mecánica, 20/09/2017)
  - Camero Castañeda, Catalina; Design of an installation for the testing of concentration solar collectors with pressurized water (12/2017)
  - Cantón Ortega, José Carlos; Analysis of the flexibility of a pipe system in a thermal oil circuit at 400°C in a solar concentrating installation (09/2017)
  - García Hernández, Rocío. Development of a built-in system to control the pressure in a CO2 storage plant for use in greenhouses. 22/09/2017.
  - García Mañas, Francisco. Development of state estimators for photobioreactors. TFG Industrial Electronics Engineering (05/09/2017).
  - García Martínez, Daniel; Calculation and mechanical design of a solar tracker for photovoltaic self-consumption in a single-family house in Almería (12/2017)
  - Giacomelli, Marco. Advanced control techniques for industrial overhead cranes. TFG Ingeniería Electrónica Industrial (18/12/2017). Double title UAL-UNIBS.
  - López González de Quevedo, José Miguel; Dynamic simulation of a solar-biomass hybrid heat generation system for the climate control of greenhouses in the province of Almería (09/2017)
  - Lozano López, María del Mar. Development of Final Master Project: Implementation of the simulation engine of a tool to help decision making (DSS) on the management of climate, production and economic cost applied to a polygon of greenhouses.
  - Mañas Alvarez, Francisco Jose. Characterization And Control Of Drive-By-Wire System In Electric Vehicle. (TFG Degree in Industrial Electronics Engineering, 15/09/2017)
  - Martell Gálvez, María. Multi-objective optimization of comfort and energy efficiency in sustainable building. Application to the CIESOL Mixed Center. TFG Industrial Electronics Engineering (05/09/2017).
  - Martín Barrionuevo, José Miguel; Temperature control of a greenhouse using Arduino (07/2017)
  - Martín Fernández, José Antonio; Solar cooling in horticultural plants: analysis of applications in the province of Almería (02/2017)
  - Martínez Terual, Jesús; Design of electrical diagrams for a tire testing machine (09/2017)
  - Martos Guzman, Fernando. Design Of An Inertia Steering Wheel For A Test Bench Of An Electric Motor. (TFG Mechanical Engineering Degree, 19/09/2017)
  - Merchán Soriano, Alejandra. Virtual laboratory of solar collectors. TFG Industrial Electronics Engineering (20/12/2017).
  - Mustapha, Anis. Development of control algorithms for robox RP-1 industrial controllers. TFG Ingeniería Electrónica Industrial (18/12/2017). Double title UAL-UNIBS.
  - Pérez Candela, Alberto. Study of the Management of an Electric Vehicle Using CAD-CAE Tools. (TFG Mechanical Engineering Degree, 17/07/2017)
  - Ramos Teodoro, Jerónimo. Master's Thesis Energy management of a heterogeneous production system under the energy hub paradigm. Master's Degree in Industrial Engineering. Universidad Carlos III de Madrid. (14/07/2017)
  - Rivera Hernández, Leonardo. Development of Final Master Project (Master in Innovation and Greenhouse Technology): Analysis of technical and economic viability of the use of robots in greenhouses. Proposal for the Almería model.

- Rodriguez Perez, Carlos Raul. Technical Work Design And Manufacture Of Engraving And Laser Cutting Machine Cnc. (TFG Mechanical Engineering Degree, 22/09/2017)
- Rodríguez Sánchez, Javier; Robotization of the horticultural seedling grafting process (09/2017)
- Rojas Sebastian, Jose Antonio. Management of an Industrial Maintenance System for Facilities and Machinery in the Port Area. (TFG Mechanical Engineering Degree, 13/02/2017)
- Rubio Salvador, Pedro; mechatronic system for the automatic management of a self-supply garden based on the Farmbot proposal 09/2017)
- Ruiz Recio, Juan José; Development of a vision platform based on reconfigurable HALCON for different production lines (09/2017)
- Velasco Vela, Noelia. Design of a Test Bench for the Analysis of Vibrations in Machine Components. (TFG Mechanical Engineering Degree, 17/07/2017)

**International collaborations:**

- Antonio Visioli y Domenico Gorni (University of Brescia, Italy).
- Tore Hägglund (Lund University, Sweden).
- Antonio Ruano y Hamid Khosravani (Universidade del Algarve, Portugal).
- Julio Normey, Daniel Pagano, Gustavo Andrade (Universidade Federal de Santa Catarina, Brasil).
- Ricardo Silva (ITE-Cons, Universidade de Coimbra).

**Stays abroad:**

- María del Mar Castilla Nieto. University of Brescia, (Italy), 29/06/2017-10/09/2017.

**Stays in CIESOL of researchers coming from abroad:**

- Alice Branco, Universidade Federal de Santa Catarina, Brasil (15/09/2017-30/01/2018).
- Luca Merigo, Universidad de Brescia, Italia (01/09/2017-31/10/2017).
- Antonio Javier Gallego Len. Universidad de Sevilla, España (01/04/2017-01/10/2017).
- Mohsine Bouya, Universidad Internacional de Rabat. Morocco (21/11/2016-23/11/2016).
- Mokhtar Ghazouani. Universidad Internacional de Rabat, Morocco (16/01/2017-16/04/2017)
- Juan Pablo García. Universidad de la Republica (UDELAR, Uruguay) (22/05/2017-26/05/2017).

**Organization of Conferences:**

- Organization of a Minisymposium in Modelling and Simulation in Solar Thermal Power Plants at the 9th Vienna International Conference on Mathematical Modelling (MATHMOD 2018) to be held in February 2018.

**PhD Theses in progress by other personnel:**

- Francisco José Gómez Navarro (supervisors Luis José Yebra y Antonio Giménez).
- Ana Paola Montoya (supervisors José Luis Guzmán y Francisco Rodríguez Díaz).
- Margarita Rodríguez García (supervisors Manuel Pérez García y Eduardo Zarza Moya)
- José María Márquez Payés (supervisor Manuel Pérez García)

- Francisco Manuel Márquez García (supervisors Pedro José Zufiria Zatarain y Luis José Yebra)
- Jerónimo Ramos Teodoro (supervisors Manuel Berenguel y Francisco Rodríguez)
- Juan Diego Gil Vergel (supervisors Manuel Berenguel y Lidia Roca)
- Ángeles Hoyo Sánchez (supervisores José Luis Guzmán Sánchez y José Carlos Moreno Úbeda)

**Awards**

- Distinction of the El Saliente Association 2017, Innovation category. Antonio Giménez Fernández, 01/12/2017.
- First prize in the national contest of Control Engineering. Students: Francisco José García Mañas, Miguel Ángel Andrés Asensio. Tutors: Manuel Berenguel Soria y José Luis Guzmán Sánchez.
- Microsoft Azure Research Award. Jorge Antonio Sánchez Molina. 20/05/2017.

**Assistance to technology transfer meetings**

- FIWARE Tech Summit, Málaga, December 2017.
- Researchers Night, Almería, September 2017.
- Science Week, Almería, November 2017.
- European Robotics Week, Almería, November 2017.

**Other scientific activities**

- M. Berenguel. Scientific Committee of MED 2017.
- A. Giménez Fernández. Co-chair of Jornadas Nacionales de Robótica 2017, <http://jnr2017.ai2.upv.es/es/inicio/>
- M. Pérez. ISES Member. International Solar Energy Society.
- M. Pérez. RSEF Member. Real Sociedad Española de Física.
- M. Pérez. Board Member AEDES. Asociación Española de Energía Solar.
- J.L. Blanco-Claraco. Scientific Committee of ECMR 2017, IROS 2017.
- M. Castilla. Member of International Programm Committee del The 9<sup>th</sup> International Renewable Energy Congress (<http://irec-conference.com/committees.html>).

## 2.5 ACTIVITIES OF “SOLAR RESOURCE ASSESSMENT AND SOLAR COOLING” FUNCTIONAL UNIT

### 2.5.1 Functional unit description

Solar Resource Assessment and Solar Cooling unit is composed of the members of the groups “Solar Energy Resources Assessment and Climatology (TEP165)” and “Interdisciplinary Group of Complex Fluids (FQM230)”. TEP 165 is a stable group since its creation in 1997 within the Andalusian Research Plan of Junta de Andalucía, being responsible since its founding Francisco Javier Batlles Garrido. The group has been considered on numerous occasions as an Excellence Group within the Andalusian Research Plan. It is composed of Ph.D. teachers from Applied Physics area and Computer Languages and Systems area, and three research fellows also Ph.D. FQM230 group was created in 1995, and its research lines are focused on the study of complex fluids. It is currently composed of seven Ph.D., all of them from the Applied Physics area, and it is directed by Manuel Servando Romero Cano.

### 2.5.2 Main research lines

The main research lines of the unit are the following:

- Evaluation and forecast of solar resource
- Tele detection
- Sky cameras
- Optimization of sky cameras
- Design and optimization of solar thermal cooling and heating systems
- Design and optimization of air-conditioning system coupled with shallow geothermal systems and ground-coupled heat exchanger
- Design and optimization of trigeneration systems
- Integration of the solar thermal and photovoltaic energy in the construction, warehouses or greenhouses
- Thermal energy storage through phase change materials (PCM)

### 2.5.3 Main researchers

**Francisco Javier Batlles Garrido** (Scopus Author 6602731047)

He received his physics degree and the Ph.D. from the University of Granada, Spain, in 1986 and 1995, respectively. He is a professor in the Department of Chemistry and Physics at the University of Almería, Almería, Spain. Since the beginning, he is the head of the research group “Solar Resource Assessment and Climatology” at the University of Almería. Member of the Scientific and Technological Evaluation Commission of Andalusia, within Andalusian Research Plan, from 2002 to 2005. International Evaluator of the National Accreditation Commission of Chile. His research interests include evaluation and forecast of the solar resource, design and optimization of the solar thermal cooling and heating systems. Professor Francisco Javier Batlles Garrido has been the Main Researcher in 7 projects of the Research National Plan, and 1 of the European Community. He has been the Main Researcher of 10 research projects funded by the Ministry of Science and Innovation and contracts with different companies such as GEMASOLAR 2006, S.L., Torresol Energy O & M, S.A, Solar Millennium, German Aerospace Centre. He has authored and co-authored over 60

articles in international journals, about 150 conference papers, both national and international, as well as a National Book. He has directed 8 doctoral theses.

#### 2.5.4 Summary of the functional unit's activities carried out in CIESOL during 2017

During 2017 the Solar Resource Assessment and Solar Cooling group's activities were related with the ongoing project, titled "Multipurpose pilot module for assessment, optimization and improvement of agri-food cold storage systems based on renewable energies, UNAM13-1E-2532". The Pilot Module consisting of three complementary main modules was built, along with the supervision and control room, where a data acquisition system was installed to monitor and control all variables. An energetic and exergetic analysis of the three different systems has been carried out: absorption system, PCM system and conventional system.

We have been working on characterization of PCMs. The Solar Resource Assessment and Solar Cooling group has been actively collaborating with Professor Svetlana Ushak University of Antofagasta (Chile), Professor Antonio Manuel Puertas Lopez, member of the Chemistry and Applied Physics Department (University of Almería) as well with Phase Change Technologies S.L. (Spanish company) in research tasks related with development of a new methodology for the thermal characterization of new highly energy performing materials used in the manufacture of PCMs. In this regard, Professor Francisco Javier Batlles Garrido made a research stay in Chile at the Solar Energy Research Centre (SERC). In this stay, he collaborated with the University of Antofagasta and the University of Chile in the design of Phase Change Materials.

Within the evaluation and forecast of solar resource research line the Solar Resource Assessment and Solar Cooling group has been actively collaborating with the University of Antofagasta and the University of Chile. In the aforementioned research stay, Professor Francisco Javier Batlles Garrido collaborated on the production modelling of photovoltaic plants. Currently, a doctoral thesis is being co-directed between the University of Almería and the University of Antofagasta. Also, a study about the characterization and influence of dust in the production of photovoltaic panels has been carried out.

#### 2.5.5 New staff: pre and post-doctoral fellowships, contracts, scholarships

- Predoctoral contract of Francisco Portillo, charged to a European Project.
- Predoctoral contract of Irene Pascual, charged to the Youth Employment Plan of Junta de Andalucía.

#### 2.5.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

##### Articles

- A.M. Puertas, M. S. Romero-Cano, F.J. De Las Nieves, S. Rosiek, F.J. Batlles. Simulations of melting of encapsulated  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  for thermal energy storage technologies. 2017, *Energies*, 10:568.
- J. Alonso-Montesinos, J. Barbero, J. Polo, G. López, J. Ballestrín, F.J. Batlles. Impact of a Saharan dust intrusion over southern Spain on DNI estimation with sky cameras, *Atmospheric Environment*. 2017, 170, pp.279-289.
- J. Polo, J. Ballestrín, J. Alonso-Montesinos, G. López-Rodríguez, J. Barbero, E. Carra, J. Fernández-Reche, J.L. Bosch, F.J. Batlles. Analysis of solar tower plant performance influenced by atmospheric



attenuation at different temporal resolutions related to aerosol optical depth, Solar Energy. 2017, 157, pp.803-810.

- A. Marzo, M. Trigo-González, J. Alonso-Montesinos, M. Martínez-Durbán, G. López, P. Ferrada, E. Fuentealba, M. Cortés, F.J. Batlles. Daily global solar radiation estimation in desert areas using daily extreme temperatures and extraterrestrial radiation, Renewable Energy. 2017, 113, pp.303-311.

### Congresses

- ENERSOL 2017, 5-6 octubre 2017, Antofagasta (Chile)J
  - Alonso-Montesino. Short-term solar radiation forecasting using sky cameras. .
  - F. J. Batlles. Evaluación de recursos solares en zonas de topografía compleja y la aplicación a la generación de mapas radiación solar.
- SolarPACES 2017, 26-29 septiembre 2017, Santiago de Chile (Chile).
  - J. Alonso-Montesinos et al. A First Approach of the Direct Normal Irradiance Forecasting in the Receiver of a Central Tower Combining Remote Sensing Techniques and Solar Power Plant Models.
  - J. Ballestrín, F.J. Barbero et al. Novel Measurement System for Solar Extinction.
  - F. J. Barbero et al.. Evolution of the Aerosol Extinction Coefficient at 100 m Above Ground During an Episode of Saharan Dust Intrusion as Derived from Data Registered by a Ceilometer in Almería (SE Spain).
  - F.J. Batlles, Gabriel López et al. Estimation of Visibility from Spectral Irradiance Using Artificial Neural Networks
  - Jesús Polo, J.Alonso-Montesinos et al.. Modelling Atmospheric Attenuation at Different AOD Time-scales in Yield Performance of Solar Tower Plants.
  - A. Marzo. Reference Solar Spectra for Chile's Sunbelt: Comparison with Current International Reference Spectra.
- Congreso Internacional de Cambio climático, 10-12 mayo 2017, Huelva (España)
  - G. López, M. Martínez-Durbán et al.. Towards clean electricity: the PRESOL Project.

### 2.5.7 Staff members

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## 2.5.8 Ongoing projects in 2017

### 2.5.8.1 Thermal energy recovery from a novel sequencing batch biofilter granular reactor (THERBIOR)

**Participants:**

University of Almería (Spain), Water Research Institute IRSA-CNR (Italy), Hedera Helix (Spanish company) and Lca-Consultants (Danish company).

**Project Leader:**

Francisco Javier Batlles Garrido.

**Contact:**

F.J. Batlles ([fbatlles@ual.es](mailto:fbatlles@ual.es)).

**Amount:**

1.912.000 €

**Funds:**

European Commission (ERA-NET Cofund WaterWorks2014 Call, Water JPI), MINECO (Ref. PCIN-2015-258)

**Time Period:**

April 2016 – April 2018

**Current Status:**

In progress

**Web Page:**

[www2.ual.es/therbior](http://www2.ual.es/therbior)

### **Summary:**

THERBIOR focuses on the development, implementation and diffusion of technologies to improve energy efficiency in wastewater treatment plants (WWTPs) using a fully off-grid solar-assisted heat pump (HP) hybrid system, applicable Europe-wide but centred on the Mediterranean region. THERBIOR project aims to provide solution for the touristic sector, which is characterised by intense seasonal water demand and wastewater discharge. The integration of physical infrastructure such as a highly efficient tubular heat exchanger coupled to a fully off-grid reversible water-source HP with a pioneering, novel Sequencing Batch Biofilter Granular Reactor (SBBGR) already installed in the Water Research Institute (CNR-IRSA, Italy), which creates new value through reuse and repurposing. This technology may help to produce benefits for local populations in the form of wastewater management, giving people access to clean water, and thus contributing to societal well-being through better human health as a result of better water quality. Projections for future climate change point to increasing resource depletion and water scarcity, which will have a serious socio-economic and environmental impact. Current global changes (such as climate change and urban sprawl) demand innovative practices to minimise the risks associated with water distribution and storage facilities in urban areas. Consequently, efforts are needed to strengthen public participation and imbue a sense of social responsibility concerning water and energy use, especially regarding freshwater resources, and adapting to the above-mentioned threats. Innovative technologies are required by the water industry to develop products and services fuelling the European economy. The main goal is to reuse the heat from the existing novel SBBGR reactor at CNR-IRSA into a low-temperature air conditioning system capable of covering the heating/cooling and domestic hot water (DHW) demand of an experimental test laboratory (ETL); this will be constructed during the project at the CNR-IRSA site. The system will be backed up by short-term storage based on Phase Change Materials (PCM) to ensure year-round coverage of the experimental lab's heating/cooling and DHW demand. After obtaining satisfactory results from the developed prototype, we will analyse this innovative application's viability for incorporation into Almería's (Spain) and Bari's (Italy) tourist facility network. Our main goal will be to evaluate how much energy we can gain from a specific urban wastewater network to reduce energy consumption (coming from fossil fuels) for cooling/heating purposes in tourist buildings located in the cities. The project also intends to create new business opportunities, notably by supporting SME involvement in local water and solar-energy supply chains. THERBIOR comprises a consortium of four European organisations from Spain, Italy and Denmark, combining a wide range of technical, institutional and business expertise. THERBIOR aims to bring together all the specialists required to support and promote a novel technological solution to improve urban wastewater treatment process efficiency with an emphasis on model application under the European Water and Energy Directives.

### **Objectives:**

- Evaluating how much energy we can gain from a specific urban wastewater network to reduce energy consumption (coming from fossil fuels) for cooling/heating purposes in tourist buildings located in the cities.

### 2.5.8.2. Forecast of solar radiation at the receiver of a solar power tower

**Participants:**

University of Almería, University of Huelva and CIEMAT.

**Project Leader:**

Francisco Javier Batlles Garrido

**Contact:**

F.J. Batlles ([fbatlles@ual.es](mailto:fbatlles@ual.es)).

**Amount:**

300.000 €

**Funds:**

Ministry of Economy and Competitiveness.

**Time Period:**

January 2015 – December 2017

**Current Status:**

In progress

**Summary:**

Direct normal irradiance (DNI) forecast is a research topic of increasing interest in fields such as agriculture or solar power production. Power generation from Solar Power Towers (SPT) -where DNI is a critical input- is experiencing a rapid growth worldwide. SPT technology will be the main contributor to the future mix of renewable energies. The greater challenge posed by these large solar installations is the grid integration. To this end, it is crucial to have an accurate forecast of the DNI levels reaching the receiver, which affects not only the plant operation but the energy price market.

Clouds are the main source of DNI variability in the heliostat field. When solar radiation is not intercepted by clouds, aerosols are the atmospheric component accounting for the largest DNI variability. SPTs are usually located in arid or semi-arid areas, with high percentage of clear skies and a larger frequency of high turbidity episodes. The forecast need is then vital. However, none of the short or mid-term forecast techniques explicitly provide ground DNI. On the other hand, aerosols in the lowest layers of the atmosphere can reduce the solar power reflected by the heliostats up to 40% before reaching the receiver of a SPT. Although the actual attenuation is currently unknown, it is urgently demanded. SPT design software (e.g. HLFICAL or SolTRACE) is unable to reproduce said effects.

**Objectives:**

The project goal is to produce a short-term forecast of the DNI reaching the SPT receiver. To this end, we propose to forecast the DNI arriving to the heliostat field and develop techniques to determine and forecast the reflected solar radiation attenuation on its path to the receiver.

### 2.5.8.3. Thermal energy storage with phase change materials for solar cooling and heating applications: A technology viability analysis (PCMSOL)

**Participants:**

University of Almería (Spain), University of Antofagasta (Chile), Technical University of Wrocław (Poland), University of Cochabamba (Bolivia), y Phase Change Technologies, S.L. (Spanish company)).

**Project Leader:**

Antonio M. Puertas ([apuertas@ual.es](mailto:apuertas@ual.es))

**Amount:**

300.936 €

**Funds:**

European Commission (ERANET-LAC Joint call 2015-2016), MINECO (Ref. PCIN-2016-013)

**Time Period:**

December 2016 – December 2019

**Current Status:**

In progress

**Summary:**

Project PCMSOL is a coordinated project with the University of Antofagasta (Chile), Technical University of Wroclaw (Poland), University of Cochabamba (Bolivia), and the company Phase Change Technologies, S.L. The project is intended to develop and test new phase change materials for the storage of thermal energy in a cooling/heating system based on solar energy. Due to the time mismatch between solar radiation and energy demand, this kind of technology requires the storage of energy. In our case, energy is saved in the form of thermal energy using materials with the liquid-solid phase transition in the appropriate temperature range. For winter, the phase transition should take place around 50°C, while the phase transition temperature is sought around 5°C for the summer mode. In this project, we intend to study in the first place different materials that could be used for thermal storage. The materials must be characterized chemical and thermally, and using numerical simulations the kinetics of the melting is studied, to model the required storage system for a model building. Finally, storage tanks will be tested in CIESOL, to perform a viability analysis of the storage system based on phase change materials.

**Objectives:**

- Find new materials with potential use for thermal energy storage in both the winter and the summer mode (heating and cooling).
- Characterize the materials and model the kinetics of melting.
- Estimate a storage system for a cooling/heating system based on solar energy.
- Install the storage tanks and study the viability of the whole system.

**2.5.9 Activities and Courses, technical capacity**

- Plenary conference given by Francisco Javier Batlles Garrido in IWLIME, 2017. International Workshop. Lithium, Industrial, Minerals and Energy. Cochabamba (Bolivia), July de 2107.
- Several meetings with the company Hedera Helix Ingeniería y Biotecnología S.L., and the company Phase Change Technologies S.L., for the development of an energy recovery plant with phase change materials.
- Six months research stay of Francisco Javier Batlles Garrido (from July to December 2017) at the Solar Energy Research Centre (SERC) in Chile, collaborating with the University of Chile and the University of Antofagasta. Work was carried out in the modelling production of photovoltaic plants and characterization and encapsulation of phase change materials.
- Teaching of the doctorate course "Measurement and calculation of solar radiation". University of Antofagasta (Chile). November 2017.
- Meeting of the project "Thermal energy storage with phase change materials for solar cooling and heating applications: A technology viability analysis (PCMSOL)", in Cochabamba (Bolivia), September 2017.

#### **2.5.10 Project's applications in 2017**

- Call for State R & D + I Program Oriented to the Challenges of the Society. Title of the project "Short-term prediction of the production of energy in a photovoltaic plant and influence of the fouling of the panels in the production of the plant". Participants: University of Almería (Coordinator of the project), University of Huelva and CIEMAT. Main Researcher: Francisco Javier Batlles Garrido. Amount 320,000 €. Granted

## 2.6 ACTIVITIES OF THE DESALINATION AND PHOTOSYNTHESIS UNIT

### 2.6.1 Functional unit description

The "Desalination and Photosynthesis" unit is made up of researchers from the Chemical Engineering Department of the Universidad de Almería and from the Plataforma Solar de Almería who are starting a new independent research group with synergies from two fields. The researchers of this unit also are adscribed to the Plan Andaluz de Investigación research groups "Ingeniería de bioprocesos y tecnologías del agua, BIO263", "Biotecnología de microalgas marinas, BIO173", and to Plataforma Solar de Almería. This unit was started in 2014 and began with the set up and operation of new installations and facilities dedicated to water desalination with solar energy by using hydrophobic membranes as well as the application of solar energy in biological microalgae-based depuration processes. Both lines present ample opportunities for synergy and for collaboration with other units within CIESOL which raise frequent colaborations.

### 2.6.2 Main research lines

The group works in two parallel lines dealing with solar energy application in desalination using membrane systems and microalgal cultivation particularly oriented to recycling by solar energy-driven synthesis of commodities such as biofertilizers or biodiesel and value products such as carotenoids and essential fatty acids. Seawater is the main raw material the research deals with although other types of feed, such as freshwater, brines, rackish waters or wastewaters are also considered. The core research lines are:

- Development of membrane-based solar desalination and water treatment systems.
- Application of solar energy to the treatment of hypersaline media.
- Recovery of value compouds from brines and hypersaline effluents.
- Design of photobioreactors for the cultivation of microalgae.
- Applications of microalgae to the purification of wastewaters and industrial effluents
- Valorization of microalgal biomass obtained from wastewater.

### 2.6.3 Main researchers

**Jose M. Fernández Sevilla** (Scopus Author 6602856181)

Is a Professor of Chemical Engineering at Universidad de Almería, currently affiliated with the Engineering Department at Universidad de Almería. He obtains a Degree in Industrias Chemistry (Químico Industrial) at Universidad de Granada in 1991 and a PhD. In Cheminsty in 1995 at the Universidad de Almería. He has worked in in twelve I+D projects in the international and spanish national levels, as lead reseacher in five of them. He has participated also in 15 research contracts funded by companie, has also advised six PhD. Theses and is the co-author of seven patents and over one-hundred scientific publications in peer-reviewed internationa journals.

**Guillermo Zaragoza del Águila** (Scopus Author 6701505211)

PhD in Applied Physics by the University of Granada, Spain (1996). Has held academic positions in the Consejo Superior de Investigaciones Científicas of Spain (CSIC), the University of Oxford, and is currently a senior researcher in the Department of Energy of Spanish CIEMAT (Centre for Energy, Environment and Technology Research), at the Plataforma Solar de Almería (Solar Desalination Unit). Has published more than 60 papers

in peer-reviewed international journals, presented more than 100 papers on international conferences, authored 8 book chapters and co-authored 3 books. Teaches in international courses on Solar Desalination organized by the European Desalination Society and is presently coordinating the Renewable Energy Desalination Action Group of the European Innovation Partnership on Water of the European Commission, as well as the Working Group on the same subject in the European Water Platform WsTP.

#### **2.6.4 Summary of the functional unit's activities carried out during 2017**

In the microalgae production line during 2017 two national projects have been completed: (i) the PURALGA project focused on the treatment of wastewater from the livestock industry, mainly animal purines through microalgae, and (ii) the EDARSOL project also focused in treatment by microalgae but in this case of urban wastewater. Other previous projects related to microalgae during 2016 have been continued, such as (i) the ERANET-LAC GREENBIOREFINERY project in collaboration with universities and research centers in Portugal, Argentina and Colombia, and (iv) the BACAGRO collaboration Challenges project in collaboration with the Biorizon Biotech company and the Cajamar Foundation. The first is related to the production of compounds of interest from microalgae using the waste from the brewing industry as a substrate, while the second relates to the production of bacteria for agricultural use for commercial application.

In addition, during 2017 we continued with contracts related to the development of treatments to upgrade of biogas to biomethane by biological methods such as the project (i) GREENUPGAS coordinated by Estrella Levante and (ii) the METINGREEN project led by Sacyr and Biorizon Biotech. In addition, (iii) the SETEC contract has been developed in collaboration with the SETEC company in France, focused on the development of a biological process for the production of biopolymers from flue gases with microalgae, (iv) the BIOREFINA contract coordinated by AZUD and focused on the recovery of agricultural waste through anaerobic digestion systems and microalgae, and (v) the European SABANA project led by the University of Almeria and focused on the implementation of a demonstration plant for the production of microalgae for agricultural and aquaculture applications in Almeria. In all the work in these projects continues the implementation of new processes based on microalgae especially for large market applications such as biopolymers, biofertilizers and feed for aquaculture, especially integrating with wastewater treatment of urban and / or livestock origin. It is also worth mentioning the opening of a new line of work at the request of some companies interested in it, such as the treatment of biogas to biomethane, especially by biological methods using microalgae.

Regarding the results in water desalination, the RED Heat-to-Power project has continued. The objective is to generate electricity from a salinity gradient using a reverse circuit electro dialysis process with a contribution of thermal energy to regenerate the salinity gradient. Our task in the project is to evaluate thermal regeneration systems with different salts, and during this year the work has been focused on evaluating the membrane distillation operation for the construction of a pilot plant. As part of the REWACEM project, the activities continued with the design of a pilot plant to be built at the facilities of the Electroníquel company in Gijón. The objective is to evaluate a combination of diffusion dialysis and membrane distillation for recovering sulfuric acid and copper from the exhausted baths of the copper plating processes and, on the other, reduce the consumption of rinsing water by reusing it after treatment. In the Zero Carbon Resorts project (ZCR2), the activities done were focused on the preparation and publication of results on the



evaluation of commercial membrane distillation modules for seawater desalination, as well as for the treatment of wastewater contaminated by heat-resistant pathogens. The activities of the national project EFFERDESAL, subproject of the coordinated project ENERPRO, whose main objective is the analysis, design and application of modeling, control and optimization techniques for the efficient management of energy, water and CO<sub>2</sub> generation in productive systems have also continued. Among the most important activities during 2017 are the determination of optimal operating points for MED plants fed with static solar thermal collectors, the development and validation of distillation production models for solar membrane distillation plants, dynamic modeling of parabolic trough collector plants of small opening and the analysis of optimal conditions of operation of MED-DEAHP plants (exergoeconomic analysis).

During 2017, the research activities within the framework of the European STAGE-STE project have been completed. Within WP10 (Solar Thermal Electricity + Desalination) the development of cogeneration plant models (electricity + desalinated water) has been completed and the techno-economic analysis of different configurations (CSP + MED and CSP + MD) has been carried out for different scenarios in order to study its viability against the CSP + RO option. Also during 2017, the European project activity H2020 INSHIP (Integrating National Research Agendas on Solar Heat for Industrial Processes), coordinated by the Fraunhofer Institute (Germany) was started. The researchers of the PSA Desalination Unit participate in work packages related to the technology of static solar collectors and emerging process heat technologies (including membrane distillation). Among the activities planned is the study of the feasibility of solar collector technology for the drying of microalgae.

The WASCOP project, coordinated by the CEA research institute (France) and whose main objective is to develop a revolutionary innovation in water management (both for cooling the power block and for cleaning the optical surfaces of the solar field) in Concentrating Solar Power (CSP) plants. During 2017, the Desalination Unit of the Plataforma Solar de Almería has been working together with the French company Hamon d'Hondt and the University of Cranfield in the design of a test loop to characterize hybrid cooling systems and their comparison with conventional systems. This test loop will be installed in the Plataforma Solar de Almería, where the tests will be carried out during 2018 and 2019. Likewise, in 2017, the technical prescriptions of all the necessary equipment have been drawn up and most of the purchase orders have been accomplished. Another new project H2020 is REWACEM, coordinated by the Fraunhofer Institute and with the aim of reducing the use of water and energy, reducing the generation of wastewater and recovering valuable metal resources in the galvanizing industry and the production of printed circuit boards. Our task is to implement a combination of dialysis by diffusion and membrane distillation in a copper electroplating process in close collaboration with the Spanish SME Electroniquel and the German company SolarSpring.

#### **2.6.5 New staff: pre and post-doctoral fellowships, contracts, scholarships**

During the year 2017 new hired researchers have joined the working group. The people hired are: Martina Ciardi, Elvira Navarro, Cynthia González, Rafael Cubero and Alessandro Solimeno. During 2017, two researchers were left the group: Azahara Martínez and Pablo Fernandez del Olmo. In addition, during the

year 2017 there have been frequent visits by researchers from other research centers and universities, both national and international.

### 2.6.6 Publications (Journal articles, doctoral theses, conference communications, book chapters etc.)

#### Papers:

- A. Ruiz-Aguirre, J.A. Andrés-Mañas, J.M. Fernández-Sevilla, G. Zaragoza Modeling and optimization of a commercial permeate gap spiral wound membrane distillation module for seawater desalination. *Desalination* 419, 160-168, 2017.
- M. Papapetrou, A. Cipollina, U. La Commare, G. Micale, G. Zaragoza, G. Kosmadakis. Assessment of methodologies and data used to calculate desalination costs. *Desalination* 419, 8-19, 2017.
- A. Altaee, J. Zhou, A.A. Al Anezi, G. Zaragoza. Pressure retarded osmosis process for power generation: Feasibility, energy balance and controlling parameters. *Applied Energy* 206, 303-311, 2017.
- B. Ortega-Delgado, M. Cornali, P. Palenzuela, D.C. Alarcón-Padilla. Operational analysis of the coupling between a multi-effect distillation unit with thermal vapor compression and a Rankine cycle power block using variable nozzle thermocompressors. *Applied Energy* 204 (2017) 690-701
- A. Cipollina, M. Agnello, A. Piacentino, A. Tamburini, B. Ortega, P. Palenzuela, D. Alarcon, G. Micale. A dynamic model for MED-TVC transient operation. *Desalination* 413 (2017) 234-257
- A. Chorak, P. Palenzuela, D. C. Alarcón-Padilla, A. Ben Abdellah. Experimental characterization of a multi-effect distillation system coupled to a flat plate solar collector field: empirical correlations. *Applied Thermal Engineering* 120 (2017) 298-313
- A. Altaee, G. Zaragoza, E. Drioli, J. Zhou Evaluation the Potential and Energy Efficiency of Dual Stage Pressure Retarded Osmosis Process. *Applied Energy* 199, 359-369, 2017.
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- A. Altaee, G.J. Millar, G. Zaragoza, A. Sharif. Energy Efficiency of RO and FO-RO system for High Salinity Seawater Treatment. *Clean Technologies and Environmental Policy*, 2017, 19 (1), 77-91.
- J.A. Andrés-Mañas, P. Palenzuela, L. Cornejo, D.C. Alarcón-Padilla, G. Ación, G. Zaragoza. Preliminary evaluation of the use of vacuum membrane distillation for the production of drinking water in Arica (Chile). *Desalination & Water Treatment* 61 (2017) 160-169.
- Ruiz-Aguirre, J.A. Andres-Mañas, J.M. Fernández-Sevilla, G. Zaragoza. Comparative characterization of three commercial spiral-wound membrane distillation modules. *Desalination and Water Treatment* 61, 152-159, 2017.

- J.A. Carballo, Javier Bonilla, Lidia Roca, Alberto de la Calle, Patricia Palenzuela, Manuel Berenguel. Optimal operating conditions analysis of a Multi-effect distillation plant. *Desalination & Water Treatment* 69 (2017) 229-235
- L. Cornejo, L. Martín-Pomares, D. Alarcon, J. Blanco, J. Polo. A thorough analysis of solar irradiation measurements in the región of Arica Parinacota, Chile. *Renewable Energy* 112, 197-208, 2017.
- R. Leiva-Illanes, R. Escobar, J.M. Cardemil, D. Alarcón-Padilla. Thermo-economic assessment of a solar polygeneration plant for electricity, water, cooling and heating in high direct normal irradiation conditions. *Energy Conversion and Management* 151, 538-552, 2017.
- A. Solimeno, F. Gabriel Acien, J. García. Mechanistic model for design, analysis, operation and control of microalgae cultures: Calibration and application to tubular photobioreactors. *Algal Research* 21 (2017) 236–246.
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- L. Terumi Arashiro, N. Montero, I. Ferrer, F. Gabriel Acien, C. Gómez, M. Garfí. Life cycle assessment of high rate algal ponds for wastewater treatment and resource recovery. *Science of the Total Environment* xxx (2017) xxx-xxx
- P. Fernández-Del Olmo, J.M. Fernández-Sevilla, F.G. Acien, A. González-Céspedes, J.C. López-Hernández, J.J. Magán. Modeling of biomass productivity in dense microalgal culture using computational fluid dynamics. *Acta Horticulturae* 2017, 1170 ,pp.111
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  - Chapter: Solar photocatalytic disinfection of water for reuse in irrigation. Fernández-Ibáñez, P., M.I. Polo-López, S. Malato, A. Ruiz-Aguirre, and G. Zaragoza. En: "Geothermal, Wind and Solar Energy Applications in Agriculture and Aquaculture", Eds: Bundschuh, Piechocki, Chandrasekharam, Chen; CRC Press/Balkema Taylor & Francis Group; 2017. ISBN: 9781138029705.
  - Book: Evaluación de sistemas comerciales en espiral de destilación por membranas y su aplicación al tratamiento de aguas. A. Ruiz-Aguirre, G. Zaragoza, J.M. Fernández-Sevilla. Colección Documentos CIEMAT. ISBN: 978-84-7834-781-0. DL: M-31485-2017.
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  - Chapter: F.G. Acién, J.M. Fernández-Sevilla, E. Molina. Microalgae on the basis of mankind sustainability" in the book "Case Study of Innovative Projects - Successful Real Cases".. Edited by Bernardo Llamas ISBN 978-953-51-5535-5. InTech, Croatia 2017.
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  - Chapter: E. Posadas, C. Alcántara, P.A. García-Encina, L. Gouveia, B. Guieysse, Z. Norvill, F.G. Acién, G. Markou, R. Congestri, J. Koreiviene, R. Muñoz. Microalgae cultivation in wastewater. En Economics of Microalgae Biomass Production. Microalgae-based biofuels and bioproducts. Edited by Gonzalez C, Muñoz R. Elsevier (2017). ISBN: 978-0-08-101023-5.
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  - Chapter: Felix L. Figueroa, Nathalie Korbee, Roberto Abdala-Diaz, Felix Alvarez-Gomez, Juan Luis Gomez-Pinchetti and F. Gabriel Acien. Growing algal biomass using wastes. En Bioassays Advanced Methods and Applications. Edited by Donat-P. Hader and Gilmar S. Erzinger. Elsevier, Amsterdam, Netherland.

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**Congress:**

- 2017 EU-China Workshop on Research and Application of Membrane - Membrane Systems for Water Treatment and Reuse. Weihai (China), 17-18 noviembre 2017
  - a. State of the art of membrane distillation at industrial scale (oral). G. Zaragoza, J.A. Andrés-Mañas, A. Ruiz-Aguirre
- The International Desalination Association World Congress on Desalination and Water Reuse 2017. Sao Paulo, Brazil, October, 15-20, 2017.
  - a. Shaping the future of thermal desalination with high performance heat conducting polymer tubes (oral). T. Orth, D.C. Alarcón-Padilla, G. Zaragoza, P. Palenzuela, P. Mueller
- SolarPACES 2017. Solar Power & chemical Energy Systems. Santiago de Chile (Chile). September, 26-29, 2017
- 2<sup>nd</sup> International Symposium on Innovative Desalination Technologies. Gyeongju (Corea del Sur). 20-21 septiembre 2017
  - a. Comparative analysis of commercial MD modules based on flat sheet membranes (oral). G. Zaragoza
- 25<sup>th</sup> Mediterranean Conference on Control and Automation. Valetta (Malta), 3-6 julio 2017.
  - a. Using a Nonlinear Model Predictive Control Strategy for the Efficient Operation of a Solar-powered Membrane Distillation System. J.D. Gil, L. Roca, A. Ruiz-Aguirre, G. Zaragoza, J.L. Guzmán, M. Berenguel.
- 5<sup>th</sup> International Scientific Conference on Pervaporation, Vapor Permeation and Membrane Distillation. Torun (Poland), 20-23 junio 2017.
  - a. Membrane distillation at industrial scale: state of the art of current modules (oral). G. Zaragoza, J.A. Andrés-Mañas, A. Ruiz-Aguirre
- EuroMed 2017. Desalination for Clean Water and Energy. Tel Aviv (Israel). 9-12 May, 2017
  - a. Membrane distillation for the treatment of high-salinity aqueous solutions in the regeneration of salinity gradient resources (oral). J.A. Andrés-Mañas, P. Palenzuela, D.C. Alarcón-Padilla, F.G. Acién, G. Zaragoza
  - b. Multi-effect distillation for regeneration of saline solutions used in a RED close-loop process (oral). P. Palenzuela, D.C. Alarcón-Padilla, G. Zaragoza.
- 3<sup>rd</sup> International Conference on Desalination using Membrane Technology. Gran Canaria (Spain), 2-5 abril 2017.
  - a. Modeling spiral-wound commercial modules for applications of membrane distillation (oral). G. Zaragoza, A. Ruiz-Aguirre, J.A. Andrés-Mañas, P.A. Davies.
- 1<sup>st</sup> IWA Conference on Algal Technologies for Wastewater Treatment and Resources Recovery. Delft, Netherland 2017

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- a. Light-dark respirometry as tool to characterize microalgae/bacteria consortia (POSTER). C. Gómez, M. Morales, J.M. Fernández, F.G. Acien, E. Molina
  - b. Optimization of operational conditions for manure treatment using microalgae (POSTER). C. Gómez, M.M. Morales, I. Martín, F. G. Acien, E. Molina, J. M. Fernández
  - c. Harvesting of microalgae biomass from wastewater treatment processes (POSTER). A. Martínez-García, Ismael Martín, Cintia Gómez, J.M. Fernández, I. Ferrer, M. Garfí and F.G. Acien
  - 7<sup>th</sup> International Conference on Algal Biomass, Biofuels and Bioproducts. Miami, USA 2017
    - Analysis of vertical mixing in raceway photobioreactors using CFD and modelling of microalgal productivity. P. Fernández del Olmo<sup>1</sup>, A. M. González-Céspedes<sup>2</sup>, F. G. Acien<sup>1</sup>, J. M. Fernández-Sevilla.
    - On the contribution of microalgae to wastewater treatment processes as Oral presentation by C. Gómez, A. Reis, L. Gouveia, N. Giraldo, V. Busto, L. Atehortua, J. Romo, J. M. Fernández, F. G. Acien.
    - Sustainable integrated algae biorefinery for the production of bioactive compounds for agriculture and aquaculture (SABANA) as Poster presentation by F. G. Acien, J. M. Fernández-Sevilla, E. Molina-Grima.
    - Production of biofertilizers from microalgae biomass: Optimization of cell disruption step" (Poster). L. Barboza Fallas, I. Martín Cara, M. Guerrero Barrantes, F. G.
    - Comparison of standard harvesting methods for microalgae biomass recovery at large scale (Poster). A. Martínez García, I. Martín Cara, J. M. Fernández-Sevilla, E. Molina-Grima, F. G. Acien.
  - 8<sup>th</sup> Symposium on Microalgae and seaweed products in plant/soil systems. Mosonmagyaróvár, Hungria 2017
    - a. Production of microalgae coupled to wastewater treatment for the production of biofertilizers (POSTER) C. Gómez-Serrano, J. Peña-Martín, F. G. Acien-Fernández, J. M. Fernández-Sevilla, E. Molina-Grima
    - b. Effect of foliar application of microalgae (*Spirulina* sp. and *Scenedesmus* sp.) on *Petunia x hybrida* growth (POSTER) Minguez-Durban, A.; Plaza, B.M.; Acien-Fernández, F.G.; Jiménez-Becker, S.
    - c. The influence of microalgae (*Spirulina*) on the growth of *Petunia x hybrida* cuttings (POSTER) Fernández-Rueda, F.J.; Plaza, B.M.; Acien-Fernández, F.G.; Jiménez-Becker, S.
    - d. Microalgae based plant stimulants applications in intensive agriculture (Oral) presentation E. Rojas, F.G. Acien, J.J. Garcia, J. Pozo
    - e. Comparative in vitro protein hydrolysis microalgae by digestive enzymes of *Sparus aurata* and *Solea senegalensis* (POSTER) A.J. vizcaino, M. Saez, A. Galafot, T.F. Martinez, F.G. Acien, F.J. Alarcon.
    - f. Hydrolysate of the microalga *Arthrospira platensis* in feed for gilthead sea bream (*Sparus aurata*) Effect on growth and intestine functionality (POSTER) A.J. vizcaino, A. Oshiro, M. Saez, A. Galafot, T.F. Martinez, F.G. Acien, F.J. Alarcon.
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- g. In vitro evaluation of *Ulva rigida* protein hydrolysis by digestive proteases of Senegalense sole (*Solea senegalensis*) (POSTER) A.J. vizcaino, M. Saez, A. Galafot, T.F. Martinez, F.G. Acien, F.J. Alarcon.
  - h. The potential inhibitory effect of *Ulva rigida* on digestive proteases of Senegalense sole (*Solea senegalensis*) (POSTER) A.J. Vizcaino, M. Saez, A. Galafot, T.F. Martinez, F.G. Acien, F.J. Alarcon.
  - i. Major challenges in the production of microalgae at large scale (ORAL) F.G. Acién, J.M. Fernandez Sevilla, E. Molina Grima
  - j. Sustainable algae biorefinery for agricultura and aquaculture SABANA project (ORAL) F.G. Acién, J.M. Fernandez Sevilla, E. Molina Grima
- 15<sup>th</sup> International Conference on Environmental Science and Technology, CEST2017. Rhodes, Greece 2017
  - a. Evaluation of the dynamics of microalgae population structure and process performance during piggery wastewater treatment in algal-bacterial photobioreactors, (POSTER) Garcia D., Posadas E., Blanco S., Acien G., Bolado S. and Muñoz R
- 10<sup>th</sup> World Congress of Chemical Engineering, Barcelona, Spain. 1-5 October 2017.
  - a. R&D Platform "Las Palmerillas" for industrial development of microalgae based processes" (Oral) J.M. Fernandez-Sevilla, E. Molina Grima, F.G. Acién Fernandez.
  - b. Harvesting of microalgae biomass from wastewater treatment processes. A. Martínez-García, Ismael Martín, Cintia Gómez, J.M. Fernández, I. Ferrer, M. Garfí and F.G. Acién
- Desafios y oportunidades para el desarrollo acuícola del Norte de Chile. Antofagasta, Chile 2017
  - a. Sustainable production of aquafeed from microalgae SABANA project (ORAL) F.G. Acien-Fernandez
- Jornada Técnica Agroalimentaria Produccion sostenible de hortalizas (Sociedad Española de Ciencias Hortícolas) Almeria, España 2017
  - o Procesos biotecnológicos basados en bacterias aplicados a la producción sostenible de hortalizas (ORAL) F.G. Acien-Fernandez

## 2.6.7 Staff members

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## 2.6.8 ONGOING PROJECTS IN 2017

### 2.6.8.1 Development of a biological upgrading technology for the production of biometan in agroindustrial environments (GREENUPGAS)

**Participants:**

ESTRELLA DE LEVANTE, AQUALGAE, ENEVIA, BIONET, AINIA, AIJU, Universidad de Almería, AROSA I+D

**Contacts:**

Dr. F. Gabriel Acien Fernandez (facien@ual.es)

**Funding source:**

INTERCONNECTA, CDTI EXP - 00083180 / ITC-20151346

**Expected Duration:**

January 2016 – December 2017.

**Situation:**

On going

**Summary:**

The main objective of the project is to develop the GreenUpGas technology or biological process for the purification of agro-industrial biogas to obtain biomethane suitable for injection in gas networks or use as biofuel in vehicles. GreenUpGas technology consists of three modules: biogas conditioning with microalgae culture, H<sub>2</sub> production by electrolysis of water from photovoltaic solar energy, and biocatalytic methanization with hydrogenotrophic methanogenic microorganisms.

**Objectives:**

The overall objective of GreenUpGas is the development of a new biological upgrading technology for the production of biomethane in agro-industrial environments.

### 2.6.8.2 Zero Carbon Resorts towards Sustainable Development of the Tourism Sector in the Philippines and Thailand (ZCR2)

**Participants:**

Gruppe Angepaste Technologie GrAT (AT) (Coord.)  
 Palawan Council for Sustainable Development PCSD (PH)  
 Green Leaf Foundation GLF (TH)  
 Health Public Policy Foundation HPPF (TH)  
 PSA-CIEMAT (ES).

**Contact:**

G. Zaragoza (gzaragoza@psa.es)

**Source of funding:**

European Commission, SWITCH-ASIA programme

**Duration:**

May 2014 – April 2018.

**Status**

Ongoing

**Abstract:**

This project builds upon the success and achievements of the ZCR in the Philippines (2009-2014) for replication and upscaling. Regional approach will be implemented through ZCR intervention in Thailand and Green Certification in the Philippines, while increasing the access to green finance and improving policy exchanges on SCP in tourism in both countries.

**Objectives:**

The overall objective is to contribute to sustainable development of the tourism sector in the Philippines and Thailand with a focus on reduction of fossil fuel use and CO<sub>2</sub> emissions through improved energy and resource efficiency of SME companies and increased availability of renewable energy. The goal is to enable SME companies in the tourism industry in the Philippines to be a model of sustainable consumption and production for the tourism sector through certified Zero Carbon practices and efficient innovative technologies in a cross-border approach with Thailand, providing incentives and access to finance in both countries.

The specific objectives of the participation of CIESOL are:

- Design an autonomous solar system for supplying water and energy to remote isolated tourist installations.
- Research and characterize the technology of membrane distillation with solar energy.

- Evaluate commercial systems of membrane distillation.
- Research on the application of membrane distillation to treat contaminated waters.
- Dissemination of results and elaboration of scientific reports.

### 2.6.8.3 Processing of brewery wastes with microalgae for producing valuable compounds (GREENBIOREFINERY)"

**Participants:**

Departamento de Ingeniería, Universidad de Almería (España)  
Laboratorio Nacional de Energía y Geología (LNEG) Portugal  
Universidad de Antioquia (Colombia)  
Universidad Nacional Tecnológica (Argentina)  
Cervecería la Unión (Colombia)  
Mahou-San Miguel (España)

**Contact:**

F. Gabriel Acién (facien@ual.es)

**Source of funding:**

ERANET LAC 2014

**Duration:**

October 2015 – September 2018.

**Status**

In progress

**Abstract:**

The main objective of GREENBIOREFINERY is to develop new strategies to generate bioproducts with the integration of both the brewery wastes' treatment and the production of microalgal biomass, enhancing this way the economic and environmental sustainability of the process as a whole. This integration will enable the transformation of these wastes of the brewery industry into biomass of interest. Therefore, this will allow not only the reduction of the environmental impact of beer fabrication processes, but also a recovery of the nutrients (C, N, P) contained in the wastes and their conversion to high-value compounds. To achieve this objective, the wastes (liquids and gases) produced will be characterised to be used as feedstock into the microalgae's production by previously selected companies. Several procedures for salvage these wastes will be compared to identify the most suitable to be coupled with microalgae production. After this, several microalgae strains will be evaluated to establish which is the best in accord with both its capacity of growth and its biochemical composition. The characterisation previously cited, will be carried out under laboratory conditions yet simulating real ones, while the selected strain will be tested outdoors too, employing different growth systems and operational modes. Both the production and quality of the biomass produced, as well as the depuration of the brewery wastes used (liquids and gases) will be analysed. From the biomass characterisation proper processes for the complete valorisation of the biomass will be developed. The production of high-value compound as could be pigments and fatty acids, as well as the utilization of the biomass as animal feeding and biofertiliser production will be consider. Finally, the developed technology will be escalated to pilot-scale with 1m<sup>3</sup> photobiorreactors to validate and assess the process as a whole. In this project four organisation with great experience in bioprocess engineering, microalgae biotechnology and in vitro cell culture are taking part, with the aim of developing innovative bioprocesses for high-value biomass production from nutrient-rich wastes (C, N, and P) unused currently in brewery industry. As a result, we aims to develop flexible and adaptable processes of integral exploitation of the microalgal biomass which could be applicable in different breweries taking into account local necessities and possibilities.

**Objectives:**

- Characterization of liquid and gaseous wastes derived from brewery industry in terms of its feasibility as raw material for microalgae production Design of a strategy for the treatment and use of brewery wastes using microalgae cultures
- Evaluation of productivity and composition of microalgae grown in brewery wastes at laboratory scale, in addition to its depuration capacity
- Development of biorefinery concept for the integral valorization of produced biomass minimizing the release of wastes.
- Demonstration of the process at pilot scale and evaluation of its economy and feasibility.

**2.6.8.4 Efficient technology for biomethanization of biogas (METINGREEN)****Participants:**

Biorizon Biotech,  
University of Almeria

**Contact:**

F.G. Ación (facien@ual.es)

**Source of funding:**

Ministerio de Economía y Competitividad. CDTI

**Duration:**

June 2016 - December 2017.

**Status**

On going

**Summary:**

This project is focused to develop a new product, a series of prototypes (in the METinGREEN will reach the scale of demonstration) that will allow to treat the biogas product of the anaerobic digestion. For this, technology and prototypes will be developed for (1) upgrading and (2) refining. Parallel to the project presented by VALORIZA Agua, called SMART · Met · Value, will seek to optimize the process of valorization of biomethane, adding a new prototype based on blending. The final product obtained will be a biomethane, with similar properties to the Natural Gas at a competitive cost for its commercialization.

**Objective:**

The objective of the project is to develop a set of prototypes capable of refining and fine-tuning the biogas from Wastewater Treatment Plants (EDARs) and / or Wastewater Treatment Plants (RSU). The overall objective of the project in this case is to test on a sufficient scale (near the demonstration scale) the principle of biogas cleaning under real conditions, and to produce biomethane under conditions of sufficient quality for commercialization (injection into the distribution network or biofuel)

**2.6.8.5 Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis (RED-Heat-to-Power)****Participants:**

WIP (D)  
University of Palermo (IT)  
FUJIFILM (NL)  
REDSTACK (NL)  
UNIVERSITY OF EDINBURGH (UK)  
UNIVERSITAT POLITECNICA DE CATALUNYA (ES)

PSA-CIEMAT (ES)  
Universidad de Almería (ES)

**Contact:**

Dr. Guillermo Zaragoza (guillermo.zaragoza@psa.es)

**Source of funding:**

European Commission, Horizon 2020 programme

**Duration:**

May 2015 – April 2019.

**Status**

Ongoing

**Abstract:**

The concept is based on the generation of electricity from salinity gradient using Reverse Electrodialysis with artificial saline solutions operating in a closed-loop. The original salinity gradient is regenerated by a separation step that uses heat at 40 - 100 °C.

**Objectives:**

The overall objective is to prove this revolutionary concept, develop the necessary materials, components and know-how for bringing it to the level of a lab prototype generating electricity from low-grade heat at higher efficiencies and lower costs than ever achieved to date. Specific objectives:

- Select the most suitable technologies for the regeneration process and the combinations of salts and solvents that can maximise the system performance.
- Create new knowledge for developing: membranes for the selected solutions; membrane manufacturing concepts that can be scaled-up for high volume and low-cost production; efficient stacks suitable for this application; energy efficient regeneration processes.
- Implement and validate a process simulation tool to analyse the performance under different configurations and operating conditions.
- Evaluate and improve the performance of the overall system through tests on a lab-prototype, identifying potential up-scaling and operational issues

The specific objective of CIEMAT-PSA is to select the most suitable technologies for the regeneration process and the combinations of salts and solvents that can maximise the system performance.

#### 2.6.8.6 Sustainable Algae Biorefinery for Agriculture and Aquaculture (SABANA)

**Participants:**

MIKROBIOLOGICKY USTAV - AVCR, V.V.I., Czech Republic  
GEA WESTFALIA SEPARATOR GROUP GMBH, Germany  
UNIVERSITA DEGLI STUDI DI MILANO, Italy  
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA, Spain  
SZECHENYI ISTVAN UNIVERSITY, Hungary  
KARLSRUHER INSTITUT FUER TECHNOLOGIE, Germany  
A.I.A. S.p.A., Italy  
FCC AQUALIA SA, Spain  
BIORIZON BIOTECH S.L., Spain  
CIB-CONSORZIO ITALIANO BIOGAS E GASSIFICAZIONE  
UNIVERSIDAD DE ALMERIA, Spain

**Contact:**

F. Gabriel Acién (facien@ual.es)

**Source of funding:**

This project has received funding from the European Union's Horizon 2020 Research and Innovation program under the Grant Agreement No. 727874

**Duration:**

December 2016 – November 2020

**Status**

In progress.

**Abstract:**

SABANA aims at developing a large-scale integrated microalgae-based biorefinery for the production of biostimulants, biopesticides and feed additives, in addition to biofertilizers and aquafeed, using only marine water and nutrients from wastewaters (sewage, centrate and pig manure). The objective is to achieve a zero-waste process at a demonstration scales up to 5 ha sustainable both environmentally and economically. A Demonstration Centre of this biorefinery will be operated to demonstrate the technology, assess the operating characteristics of the system, evaluate environment impacts and collaborate with potential customers for use.

**Objectives:**

The objective of SABANA is to develop and demonstrate an integrated microalgae-based sustainable biorefinery to produce a range of value-added products (biostimulants, biopesticides and aquafeed additives) and low-value products (biofertilizers, aquafeed) for agriculture and aquaculture, using marine water and recovering nutrients from wastewaters (sewage, centrate and pig manure), accomplishing market (quality, price, regulations) and social (acceptance, capacitation, skills) requirements. It provides a solution for three current key issues in the EU: (i) improvement of the safety and sustainability of food production in agriculture and aquaculture, (ii) contamination problems resulting from nutrients dissemination and scarcity (phosphorous), and (iii) minimization of greenhouse gas emissions from wastes (wastewater and flue gases).

### 2.6.8.7 Control and energy management strategies in production environments with support of renewable energy (ENERPRO)

#### Subproject title: Efficient energy control and management of solar thermal desalination systems (EFFERDESAL)

**Participants:**

Universidad de Almería (ENERPRO)  
CIEMAT-PSA (EFFERDESAL)

**Contact:**

Dr. Diego-César Alarcón-Padilla, [diego.alarcon@psa.es](mailto:diego.alarcon@psa.es)

**Source of funding:**

Ministerio de Economía y Competitividad, Plan Estatal. I+D+i 2013-2016 orientada a los retos de la sociedad.

**Duration:**

January 2015 – December 2017.

**Status**

In progress.

En coordinación con la Unidad de Modelado y Control Automático. Ver sección XXX

**Abstract:**

Due to increasing demand for energy and water, most countries are promoting the efficient use of these resources to reduce costs and increase sustainability. Generally, energy efficiency is not only associated with technological improvements, but also with the improvement of control and energy management. This is the main framework of this research project ENERPRO, which is a natural evolution of a previous project, POWER, where both UAL and CIEMAT-PSA subprojects focused on heat/cooling and water management.

**Objectives:**

The main objectives of the EFFERDESAL subproject are:

- Dynamic modeling of solar-gas hybrid desalination plants supplied with novel industrial solar collectors.
- Development of prediction models for environmental variables, disturbances, sources and loads.
- Analysis and modeling of energy storage systems and other auxiliary systems for energy cost reduction
- Development of simplified models for control purposes
- Development of MPC strategies (hierarchical, hybrid and economic) for desalination plants
- Coupling of solar desalination plants as a water and energy supply to greenhouses and buildings.
- Testing of control algorithms both in simulation and in the real installations.

**2.6.8.9 Agroindustrial effluents valorization through the use of microalgae to obtain bio-products (PURALGA)**

**Participants:**

Coordinated research Project funded by INIA (Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria) with FEDER participation. The Project is being carried out by the Instituto Tecnológico Agrario de Castilla y León (ITACyL) (coordinator) the Universidad de Valladolid and UAL (subproject RTA 2013-00056-C03).

**Contact:**

Jose María Fernandez Sevilla (UAL), [jfernand@ual.es](mailto:jfernand@ual.es)

**Source of funding:**

Funded by INIA (Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria) with FEDER funds. Reference RTA 2013-00056-C03.

**Duration:**

September 2014 – September 2017.

**Status**

In progress.

**Abstract:**

This project aims at obtaining bioproducts from microalgae biomass, through the recycling of nutrients from agrofood processing wastewater, for a more economical and environmentally sustainable process; integrating the production and valorization under the biorefinery concept, and determining the economic viability by the Life Cycle Analyses (LCA).

Two different strategies about biomass uses are considered in this project. First, the direct utilization of the whole biomass as feed in aquaculture, or in the production of biofertilizers or biogas. Second, the processing of the biomass to obtain different commodities of industrial interest. Because microalgae biomass is mainly composed of proteins, carbohydrates and lipids, the bio-products to be obtained are: 1) proteins to be used in animal nutrition through incorporation into feed, 2) alcohols that will be obtained from pre-treatment and fermentation of microalgae biomass, 3) oils from the lipid fraction that can be used to formulate feeds for

animal uses, and 4) biogas that will be obtained from the anaerobic digestion of residual algal biomass. To close the cycle of biomass production, the CO<sub>2</sub> generated from the anaerobic digestion of residual microalgae will be recycled for algal biomass production step, thus production system will act as a sink for CO<sub>2</sub> reducing the emission of greenhouse gases. Therefore, this holistic approach will allow obtaining bio-products from the recycling of nutrients from agro-industrial wastewater while contributing to mitigate greenhouse gas emissions.

This study will be carried out in coordination with the research groups involved in the project: the Agricultural Technological Institute of Castilla y León (ITACyL) with the University of León, the University of Valladolid and the University of Almería with the Fundación Cajamar.

**Objectives:**

The objective of this project is the valorization of wastewaters by the complete use of microalgal biomass to obtain bioproducts from of nutrients from agrofood processing wastewater, for a more economical and environmentally sustainable process; integrating the production and valorization under the biorefinery concept, and determining the economic viability by the Life Cycle Analyses

The main products the Project aims to obtain are:

- Protein for animal feed to be incorporated in feedstocks;
- Production of bio-alcohols from the glucidic fraction of the microalgal biomass to be used as fuels by means of hydrolysis/fermentation treatments;
- Production of oils and fats from the lipidic fraction of the microalgal biomass to be used as animal feed.
- Conversion of the residues in biogas through anaerobic digestion.

To enhance the recovery of by products, the Project plans to use the CO<sub>2</sub> generated in the digestion process as the source of inorganic carbon for the microalgae, which will make these depuration systems act as a sink of atmospheric CO<sub>2</sub> effectively decreasing the emission of greenhouse gases while generating products from the nutrients in wastewater.

**2.6.8.10 Valorization of wastewater with microalga-bacteria consortia (EDARSOL)****Participants:**

Universidad de Almería.

Universidad politécnica de Cataluña

**Contact:**

F. Gabriel Acien Fernández (UAL), [facien@ual.es](mailto:facien@ual.es)

**Source of funding:**

Proyecto RETOS INVESTIGACIÓN, Ministerio de Economía y Competitividad CTQ2014-57293-C3

**Duration:**

January 2015– January 2017.

**Status**

In progress

**Abstract:**

The objective of the EDARSOL project is to develop sustainable processes for the treatment of wastewater using microalgae and bacteria consortia, thus enabling the transformation of contaminants from wastewater



(C, N, P, etc.) into valuable products (fertilizers, biogas), and resulting in regenerated water of sufficient quality for its reuse. The goal is to develop a portfolio of tools to ease the implementation of these processes in a more effective and safer way.

**Objectives:**

- To characterize and modelize microalgae-bacterial consortia those develop during the treatment of wastewaters.
- To develop wastewater treatment processes using low cost reactors either open (raceway and thin layer) or closed (polyethylene tubular reactors).
- To develop industrial methods to enable the separation and concentration of the produced biomass, including methods such as electroflocculation/coagulation capable of rising the concentration of the harvested biomass up to 100 g/L, and with an improvement on the reclaimed water quality sufficient to meet the specifications of the Directive 91/271/CE.
- Developing valorization processes for the obtained biomass. Among the products proposed are biofertilizers to recover the nitrogen fraction in the effluents and biogas to partially recover the carbon content of the wastewaters.
- The techno-economic viability of the developed processes will be analyzed. Special attention will be given to the critical points of the technologies used and in particular to the costs and the scale-up options. The sustainability of the whole optimized process will be assessed by a life cycle analysis).

**2.6.8.11 Production of bacteria for use in agriculture soil fertility enhancers and as anti-pathogen protective agents. (BACAGRO)**

**Participants:**

Universidad de Almería.  
Biorizon Biotech S.L.  
Fundación Cajamar

**Contact:**

F. Gabriel Acién Fernández (UAL), [facien@ual.es](mailto:facien@ual.es)

**Source of funding:**

Proyecto RETOS COLABORACIÓN, Ministerio de Economía y Competitividad

**Duration:**

October 2015 – September 2017.

**Status**

In progress.

**Abstract:**

The goal of the Project BACAGRO is to develop bioproducts containing bacteria to be applied in agriculture as soil stabilizers and fertility enhancers with a protective function against plant pathogens. It is an applied research project led by the Biorizon Biotech, a company deeply involved in applied biotechnology, with the additional participation of Universidad de Almería and Fundación Cajamar as technological partners. Biorizon Biotech is involved in the development and marketing of new and innovative products for agricultural use in order to favour sustainability and increase rentability mainly in environments of intensive

agriculture in greenhouse as well as in other types of extensive cultures. For this, the company has been developing, manufacturing and is currently selling different biofertilizers, bio-stimulants and protective agents. Among these, the company is now developing bacteria-based growth promoters containing symbiotic bacteria that improve the radicular function. This kind of bacteria have received intense attention and its beneficial effects have been frequently reported in the literature but, in spite of this, the production of these type of agents is currently very limited. The reason for this is that this bacteria are currently expensive to produce and difficult to stabilize, store and thus distribute. Project BACAGRO aims at solving all these issues by tackling successively the tasks of characterization and selection of strains, designing mass culture systems and methods of application, ending with a demonstration in field experiments of the efficacy and enhancement potential of these bacteria used as additives.

**Objectives:**

- Selection and identification of beneficial bacteria for soils and plants:
- Development of scalable production processes of the selected bacteria with a price low enough for agricultural applications.
- Development of technologies for the stabilization, storage, preservation and application of the bacteria-based bioproducts.
- Evaluation of the effect in soil and plants of the stabilized bioproducts containing bacteria.

**2.6.8.12 Bioplastics production from carbon captured in household waste incineration fumes (SETEC)**

**Participants:**

Universidad de Almería.  
SETEC Environnement (France)

**Contacts:**

F. Gabriel Acién Fernández (UAL), [facien@ual.es](mailto:facien@ual.es)

**Source of funding:**

Private contract

**Duration:**

May 2016– May 2017.

**Status:**

In progress

**Summary:**

Setec Environnement has concluded a research and development contract (hereinafter referred to as « MAIN CONTRACT ») with Sycdom, the Paris Metropolitan Intercommunal household waste treatment and recycling Syndicate (hereinafter referred to as « Sycdom »), the purpose of which is to provide within the framework of the project for bioplastics production from carbon captured in household waste incineration fumes (hereinafter referred to as « PROJECT »)

Setec Environnement requests that the UNIVERSIDAD DE ALMERIA, which agrees, provide its support as a subcontractor for the implementation of experimental missions to select microalgae strains.

**2.6.8.13 BIOREFINERY A SMALL SCALE OF IN-SITU APPLICATION IN RURAL ENVIRONMENTS WITH MIXED AGRICULTURAL ACTIVITY AND LIVESTOCK (BIOREFINA)**

**Participants:**

Universidad de Almería.  
SISTEMA AZUD S.A.

MIGUEL GARCÍA SÁNCHEZ E HIJOS, S.A.

BIORIZON BIOTECH S.L.

J. BOUZADA INGENIEROS S.L.U.

Fundación Cajamar

**Contacts:**

F. Gabriel Acién Fernández (UAL), [facien@ual.es](mailto:facien@ual.es)

**Source of funding:**

INTERCONNECTA 2016, Ministerio de Economía y Competitividad

**Duration:**

November de 2016– November 2018.

**Status:**

In progress

**Summary:**

The project aims to develop "bioREFINA" technology or agroindustrial waste treatment process for its transformation into bioproducts that can be reused in fruit and vegetable farms, according to the biorefinery model. The three bioproducts to be obtained are: a "functional" organic amendment to improve the quality of cultivated soil, a liquid fertilizer for fertigation and a biofertilizer rich in amino acids and plant hormones of microalgal base. In this way, the horticultural exploitation would go from buying fertilizers to third parties, to produce their own biofertilizers made from the waste generated, improving their economic and environmental sustainability. One of the characteristics of bioREFINA fertilizers will be its high hygienic quality, essential for the safety of fruits and vegetables sold in markets in central and northern Europe, especially demanding in this area. In addition, bioREFINA generates a biofuel, biogas, which will be used as a source of renewable heat to achieve the energy self-sufficiency of the transformation processes.

**Objective:**

The general objective of the project is to develop an agricultural biomass treatment plant based on the concept of biorefinery to be installed in fruit and vegetable farms, allowing the production and self-consumption of bioenergy and biofertilizers of low environmental footprint and high hygienic quality.

#### 2.6.8.14 WATER SAVING FOR SOLAR CONCENTRATED POWER (WASCOP)

**Participants:**

CEA

DLR

CIEMAT

Cranfield University

Fundación Tekniker

Moroccan Agency for Solar Energy SA

Rioglass Solar S.A

Archimede Solar Energy S.r.l.

OMT Solutions B.V

Hamon d'Hondt

AMIRES s.r.o.

**Contacts:**

Dra. Patricia Palenzuela (CIEMAT), patricia.palenzuela@psa.es

**Source of funding:**

European Commission, Horizon 2020 programme

**Duration:**

January 2016-December 2019

**Status:**

In progress

**Summary:**

The main goal of this Project is to develop a revolutionary innovation in water management of CSP plants- flexible integrated solution comprising different innovative technologies and optimized strategies for the cooling of the power block and the cleaning of the solar field optical surfaces. WASCOP main advantage consists in the ability to reflect and adapt to the specific conditions prevailing at individual CSP plants, unlike other competitive approaches proposing a single generic solution applicable only on some referenced cases. The WASCOP holistic solution provides an effective combination of technologies allowing a significant reduction in water consumption (up to 70%-90%) and a significant improvement in the water management of CSP plants. To demonstrate the benefits (whether economic or environmental), the developed system will be tested and validated in real conditions of four testing sites in France, Spain and Morocco after preliminary demonstration in laboratory environment.

**Objectives:**

The main objectives of this project are:

- Development and optimization of a heat storage reservoir added to the turbine heat exhaust, and prior to the power block cooling loop, which will lower the dry cooling loss of efficiency down to 5% but give the potential for cooling water saving of 100%.
- Development of a cost effective hybridized dry/wet cooling system and its advanced operating strategy for use at peak ambient temperatures, which will bring an increase in the overall plant efficiency of 5%.
- Development of an unique concept of adiabatic versatile cooler, based on a dry cooling approach with an adjustable amount of water addition, heat exchanger redesign and air handling redesign. This approach will lead to total water saving of 90%.
- Optimization of the traditional cleaning methods to reduce the water consumption.
- Development of a cleaning device based on ultrasound cavitation effect and consuming nearly zero water (98% reduction in comparison with common cleaning methods) to remove adhered particles from reflectors surfaces.
- Development of a cleaning device consuming no additional water but utilizing the condensate dew reflectors.
- Validation of the whole system under real conditions, with each sub-system tested in at least one of the four CSP testing facilities.

**2.6.8.15 RESOURCE RECOVERY FROM INDUSTRIAL WASTE WATER BY CUTTING EDGE MEMBRANE TECHNOLOGIES (REWACEM)**

**Participants:**

Fraunhofer Institute (Germany)

CIEMAT-PSA (Spain)

AEE (Austria)  
VDEH GmbH (Germany)  
Universita Degli Studi Di Palermo (Italy)  
Deutsche Edelstahlwerke GmbH (Germany)  
SolarSpring GmbH (Germany)  
AT&S (Austria)  
Electroniquel SAU (Spain)  
DEUKUM GmbH (Germany)  
Associazione Italiana Zincatura (Italy)  
Universitaet Stuttgart (Germany)  
Tecnozinco Srl (Italy)  
PSE AG (Germany)

**Contacts:**

Dr. Guillermo Zaragoza (CIEMAT), guillermo.zaragoza@psa.es

**Source of funding:**

European Commission, Horizon 2020 programme

**Duration:**

October 2016-October 2019

**Status:**

In progress

**Summary:**

The ReWaCEM project aims at reducing water, energy use and wastewater production, recovering valuable metal resources and decreasing water footprint by between 30-90% in the metal plating, galvanizing and printed circuit board industry. In order to achieve these goals, ReWaCem will adopt two cutting edge membrane technologies suitable for the requirements of closed material cycles approaches and recovery concepts in metal processing industry: Diffusion Dialysis (DD) and Membrane Distillation (MD) as an integrated hybrid process.

**Objectives:**

The main objective of the proposed project is the application and demonstration of innovative and efficient water treatment technologies with the effect of a significant reduction of water use, waste water production, chemical consumption and energy use for the metal production, processing and coating industries. By combination and integration of existing but highly innovative technologies valuable resources such as metals and process fluids will furthermore be recovered, thus reducing raw material consumption, closing process chain loops and bringing existing processes in the metallurgical industry a large step closer to sustainability.

Further specific objectives of the project are:

- Adaptation of a combined treatment system including proven membrane selective separation technologies for application in the metal processing industry for minimising their liquid waste streams by 70-90%, minimising water usage by 50-90% and maximizing the recovery of valuable resources, leading to environmental and economic benefits
- Utilization of available low grade waste heat at 70-90°C for the thermal powered membrane process
- Testing and evaluation of the technology in real conditions and integration into the production process demonstrating technical and economic performance

- Facilitate the market uptake of the project results by active engagement with the industry from an early stage, first taking their feedback during the development phase and then communicating effectively to them the project achievements and further opportunities for the exploitation of the project results
- Implementation of an effective communication and transfer of knowledge strategy aiming to policy making, business and to the general public

#### 2.6.8.16 NETWORKING FOR EXCELLENCE IN SOLAR THERMAL ENERGY RESEARCH (NESTER)

##### **Participants:**

The Cyprus Institute (Cyl)

CIEMAT-PSA (Spain)

ENEA-UTRINN (Italy)

CNRS-PROMES (France)

RWTH Aachen (Germany)

##### **Contacts:**

Dr. Diego Alarcón (CIEMAT), diego.alarcon@psa.es

##### **Source of funding:**

European Commission, Horizon 2020 programme

##### **Duration:**

January 2016-December 2018

##### **Status:**

In progress

##### **Summary:**

The NESTER TWINNING Project aims in upgrading the scientific performance and innovation capacity of the Cyprus Institute (Cyl) in the field of Solar-Thermal Energy (STE) and related technologies. The upgrade will be achieved by embedding the Institute's activities in a network of excellence, which will provide access to the latest know-how and facilities, train Cyl's scientific and technical personnel, and link it with the European Industry. Within this network the substantial investments already made by Cyl in this field, but also the ones planned, will result in a harmonization and optimization of activities in STE with other leading institutions of the field, thus international excellence can be achieved. The proposed network of excellence is defined by four institutions in the field with proven track record in solar thermal research (ENEA-UTRINN, CNRS-PROMES, CIEMAT-PSA and RWTH – Aachen), partners in this project. The NESTER consortium collectively possesses a formidable know-how in the STE area and operates some of the most important experimental facilities, worldwide. The consortium institutions together with their partners and links in research, education and innovation define a network of unparalleled opportunities for Cyl to grow in, and allow it to emerge as centre of excellence in its own right.

##### **Objectives:**

The overarching objective of the NESTER Project is to firmly embed the solar energy division of the Cyprus Institute (Cyl) as a member of the community of the leading research groups in the field of Solar Thermal Energy, and to establish it as a regional leader in The Eastern Mediterranean and Middle East (EMME region). The specific objectives of this project are:

- Elevate the research output of the Cyprus Institute, in terms of quality and quantity.

- Reinforce and create durable linkages between Cyl and the relevant academic partners and networks.
- Increase the prestige and visibility of the Cyprus Institute, in particular in the field of STE.
- Establish Cyl as a regional hub for knowledge transfer in the field of STE in the Eastern Mediterranean.
- Improve the success of Cyl in competitive grant applications in the field of STE.
- Attract better Doctoral Candidates, Researchers and Faculty.
- Engage with the local, regional and European industry.
- Interact with local and regional policy makers, associations and press.

#### 2.6.9 Activities and Courses, technical capacity

##### CONFERENCES AS INVITED SPEAKER:

- F.G. Acien-Fernandez. TITLE: Products and processes with microalgae. International Workshop Biotechnology in Energy Production. Madrid, España, 2016
- F.G. Acien-Fernandez. TITLE: Contribution of microalgae to wastewater treatment processes. IWA Leading edge conference on water and wastewater technologies. Jerez, España, 2016
- F.G. Acien-Fernandez. TITLE: Producción de microalgas sobre digerido de plantas de biogás. Jornada Biorefinerías Agroalimentarias (AINIA). Madrid, España, 2016
- F.G. Acien-Fernandez. TITLE: Desarrollo de una tecnología de upgrading biológico para la producción de biometano en entornos agroindustriales. Jornada Biorefinerías Agroalimentarias (AINIA). Madrid, España, 2016
- F.G. Acien-Fernandez. TITLE: Success stories: SABANA Project. Infoday and proposal workshop on WP2016-2017 calls 2017 (CDTI). Madrid, España, 2016
- G. Zaragoza. TITLE: Desalación de agua de mar mediante destilación por membrana. Workshop "Obtención de agua potable mediante tecnologías de desalación acopladas a energía solar" (Solar Energy Research Center, Chile) Arica, Chile, July 2016.
- G. Zaragoza. TITLE: Applications of membrane distillation to water treatment. Desalination for the Environment Clean Water and Energy. Sitges, Barcelona (Spain), September 2016.
- G. Zaragoza. TITLE: State of the art of solar desalination. MIT "Low Carbon Desalination" Workshop. Cambridge, Boston (USA), October 2016.
- G. Zaragoza. TITLE: Uso de energía solar térmica para refrigeración y riego de invernaderos. Jornadas "Aplicación de energías renovables a la agricultura intensiva". El Ejido, Spain, November 2016.
- G. Zaragoza. TITLE: Membrane distillation: a review of commercial modules and their performance. International Membrane Science and Technology Conference. Adelaide (Australia), December 2016.

### 2.6.10 Project's applications in 2017

#### Solving Water Issues for CSP plants (SOLAWATT)

##### Participants:

TSK Electrónica y Electricidad S.A., Spain  
 Commissariat A L Energie Atomique et aux Energies alternatives, France  
 Deutsches Zentrum Fuer Luft-Und Raumfahrt EV, Germany  
 Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas-CIEMAT, Spain  
 Cranfield University, United Kingdom  
 Fundación Tekniker, Spain  
 Rioglass Solar S.A., Spain  
 Arquimede Solar Energy SRL, Italy  
 Ingeniería para el desarrollo tecnológico, S.L., Spain  
 Feniks Cleaning & Safety S.L., Spain  
 Barcelona Supercomputing Center-Centro Nacional de Supercomputación, Spain  
 AMIRES SRO, Czech Republic

##### Contacts:

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##### Funding:

European Commission, Horizon 2020 programme

##### Duration:

4 years.

##### Status:

Under evaluation

##### Abstract:

The SOLWATT Project aims to significantly reduce the amount of water used in CSP plants (over 35% in the case of plants with wet cooling and over 90% in plants with dry refrigeration). The project proposes to demonstrate the efficiency of the innovations in the cleaning of the solar field, in the cooling of the power block, in a water recycling system and in the operation strategy of the plant. Among these innovations there is an optimization software that includes the prediction of dirt build-up in mirrors, a multi-effect evaporation system for water recovery that is powered by the energy left over from the solar field, and a refrigeration concept that stores the excess of heat when the ambient temperature is too high, then releasing that heat during the night. All these solutions will be implemented in two operational sites of CSP plants, a cylinder-parabolic plant in Spain "La Africana" and a central tower receiver plant in Israel, "Ashalim".

##### Objectives:

- Reduction of cleaning operations
- Night cooling to condense turbine steam
- Application of a water recovery technology.
- Development of an optimizer that includes the prediction of the speed of fouling buildup in the mirrors.
- Conducting environmental and socio-economic studies.
- Demonstration and validation of all technologies in real CSP plants.

#### Optimal desing and operation conditions of closed photobioreactors for the production of biofertilizers coupled with treatment of manure

##### Participants:

Universidad de Valladolid.  
 Universidad de Almería / CIESOL



ITACyL

**Contacts:**

José María Fernandez Sevilla (jfernand@ual.es)

**Funding:**

MINISTERIO DE ECONOMIA, INDUSTRIA Y COMPETITIVIDAD. Programa Estatal de I+D+i Orientada a los Retos de la Sociedad

**Duration:**

3 years.

**Status:**

Granted (provisional, notified 28/12/2017)

**Summary:**

GREENFARM project aims at designing and optimizing a process for the treatment of manure using microalgae that will allow transforming this waste into high-value bio-fertilizers, thus avoiding the environmental problems and costs associated with the inadequate management of this effluent transforming it into a resource. The challenge is to achieve a "zero emissions" process, developing technologies avoiding the release of wastes and enhancing the sustainability of the overall process. Livestock farming is a social and economic pillar in Spain and EU, the release of manure being inherent with this activity. Manure can be used as a fertilizer but in situation where a high density of farms exists, there is not enough fertile land available to consume the large amounts of manure produced, becoming an environmental and economic problem. In the previous project PURALGA it was demonstrated that manure can be used to produce microalgae biomass, but the biomass productivity and the quality of water released were not optimized. Moreover, it was demonstrated that microalgae biomass produced from manure can be used to produce biofertilizers rich in biostimulants for agricultural uses, but the quality of the biomass was not optimized and the quality of produced biofertilizers was not evaluated in field trials. Moreover, the bottleneck of the process was the high water loss by evaporation, whereas from the different technologies evaluated the utilization of thin-layer reactors was the optimal one. GREENFARM project aims to optimize the design and operation of thin-layer reactors for the treatment of manure, evaluating different materials and configurations to minimize the water losses while maximizing the performance of the reactors in terms of biomass production and treatment of manure. Moreover, the quality of produced biomass and treated water will be also optimized for further agricultural uses. Concerning biomass quality the objective is to optimize its composition, proteins content and amino acids profile but also phytohormones content, for agricultural uses which will be evaluated by in vitro and field assays. Concerning water quality, the compliancy of the released water to regulation for agricultural uses will be evaluated in addition to field trials to be performed. GREENFARM also includes the analysis of emerging pollutants and heavy metals inlet and outlet to the system, and especially those accumulated into the biomass that at the end can determine the application of the biomass for different uses. GREENFARM is a project of high interest at national and international level because the problem to solve is common at many different geographic areas, thus companies related with the project are interested both into the technologies and the products to be developed, at the same time GREENFARM project being related with other international projects on which the research group is involved.

**Objectives:**

- Use microalgae to process manure.
- Recovery of nutrients.
- Ammelioration of enviromental impacts of cattle farming.
- Recycling by turning manure into biofertilizers.
- Use of thin-layer photobioreactors as mainstream techology.
- Zero-emission processess using microalgae.

**2.3.11 Others**

### 3. CIESOL FACILITIES

Since its inception, the center has gradually increased the number as well as capabilities of its scientific and technological facilities. This extensive and advanced equipment, allows it to offer a quality and highly competitive service.

Our center is always trying to improve our facilities as much as possible and remodeling deteriorated or obsolete infrastructures.

Thanks to the collaboration of the Dirección General de Infraestructuras of the UAL and the PSA, the following improvements and repairs have been implemented:

- A new electrical panel with greater capacity and multiple improvements, correcting the enormous electrical problems that affected CIESOL
- A new boiler of the Center's air conditioning system to replace the damaged one
- A new air compressor with lower consumption and greater flow and pressure

#### 3.1 SOLAR ENERGY CHEMICAL FACILITIES

**Autotrace.** Autotrace is an automated solid-phase extraction (SPE) system for use with large samples (20 mL–20 L) to isolate trace organics in water or aqueous matrices. The compounds of interest are trapped on SPE adsorbents (cartridge or disk format), then eluted with strong solvents to generate an extract ready for analysis. AutoTrace instruments offer many advantages for sample preparation over traditional techniques including solid-phase extraction technology to save time, solvent, and labor.



**XcelVap.** The XcelVap Automated Evaporation and Concentration System is a modern, compact nitrogen blow-down system that provides rapid, gentle evaporation of up to 54 sample extracts ranging in size up to 200-mL each. Evaporation is accomplished by combining consistent heat, controlled nitrogen flow, and active venting of the solvent vapors. With the XcelVap System, less time and attention are required to prepare reproducible extracts for chromatography analysis (GC/MS, LC/MS, GC, LC), improving laboratory productivity.



**Micromolar photochemical system.** The micromolar photochemical reactor is a system that allows the controlled irradiation of small volumes containing photoactive species in both homogeneous and heterogeneous phases. Its irradiation source can be sunlight or an artificial halogen lamp and it is used to study photochemical reactions in real time, avoiding perturbations in the reaction medium and allowing external factors that might influence the reaction to be controlled.

#### Spectrophotometers

- Fluoromax-4 Horiba Jobin Yvon Fluorometer
- JASCO V650 UV-Vis spectrophotometer

- Hach Lange UV-Vis spectrophotometer

**Monochromator-coupled deuterium lamp.** It is mainly used to study photochemical reaction mechanisms, identification of reaction intermediates and kinetics.

**Reaction carousels.** Each one can host up to 12 reaction tubes with Teflon caps to work in different kinds of atmospheric conditions and temperatures. Condensation of vapour is permitted by a chilling circuit in the upper part of the system. The working temperature ranges are from room temperature up to 300°C. They are mainly used to study catalytic reactions versus time and temperature along with varying the atmosphere.

**UPLC Agilent Technologies series 1200.** This equipment allows the analysis of substances present in aqueous and organic media with high precision and with a relatively short time analysis by reverse chromatography due to their ability to work at high pressure. This device is used for the detection of contaminants in water and allows the removal of these contaminants to be studied with the different processes studied in the CIESOL.

**SHIMADZU GC-2010 Gas chromatograph.** The gas chromatograph is equipped with a capillary column Supelco SP-2330 with a FID detector, with the possibility of sample injection split/splitless. It is mainly used to separate and identify organic substances produced in catalytic processes with organometallic compounds and using sunlight and/or heat as the energy source.

**Espectrómetro de masas AB SCIEX QTRAP 5500 LC/MS/MS.** The QTRAP is designed to excel at metabolite identification, detection and confirmation of low-level pesticides, It also houses a high sensitive ion trap along with offering ultra-fast scan speeds and full MS3 capabilities. Perform multiple reaction monitoring (MRM) scans for quantitation using this high-sensitivity triple quadrupole system. Identify, characterize, and quantitate metabolites more quickly and easily. Enable high-sensitivity, full-scan MS, MS/MS, and MS3 with high-selectivity from true triple quadrupole precursor ion (PI) and neutral loss (NL) scans.

**TripleTOF™ 5600+.** The TripleTOF 5600+ System is innovative in LC-MS/MS performance that uniquely integrates comprehensive, qualitative exploration, rapid profiling, and high-resolution quantification workflows on a single platform. It combines high-sensitivity detection, high resolution with fast acquisition speeds and stable mass accuracy over days of acquisition.

**BRUKER 320MS Mass spectrometer triple quadrupole coupled to BRUKER 450GC gas chromatograph.** This chromatographic system complements the previously mentioned ones because it allows analysis of organic compounds of low/medium polarity. It is used especially for the determination of trace levels of contaminants such as synthetic fragrances, and pesticides, among others.

**Ion chromatograph (Metrohm 881 Compact IC Pro).** This equipment allows the accurate analysis of anions or cations in concentrations from µg/L to g/L, with detection limits of <1 µg/L. This system is essential

for the characterization of the aqueous effluents used for experimentation, since the presence of certain cations as phosphates and chlorides affects various processes of water decontamination conducted at CIESOL (Fenton and solar photo-Fenton).

**Total organic carbon analy (TOC).** These analysers allow the dissolved carbon and nitrogen to be determined. In the laboratory they are used for the determination of inorganic and organic carbon and nitrogen dissolved in liquid samples of wastewater to evaluate their purification when oxidative treatments are applied.

**Biochemical oxygen demand analyzer (BOD).** Biological oxygen demand (BOD mg O<sub>2</sub>/L) determines the relative oxygen requirements of wastewater effluent and contaminated water for biological degradation. This measure expresses the degree of contamination due to potentially biodegradable organic matter (under aerobic conditions) of wastewater. It is used to control the improvement of biodegradability of toxic effluents treated with photocatalytic processes.

**Chemical oxygen demand analyzer (COD).** It is used to estimate the amount of organic matter and its oxidation state. The combination of this measure with BOD and TOC allows good overall quality characterization of a wastewater.

**Atlas Suntest cPS+ solar simulator.** This device simulates the solar spectrum, allowing laboratory scale experimentation. It is essential in pre initial scale pilot tests.

**Pilot plants.** We have four pilot plants for contaminated water treatment by photo-Fenton (usually). They operate using solar irradiation and are equipped with radiometers to record the incident radiation. Pilot plant to evaluate the reuse of regenerated solar photocatalytic treatment water for irrigation. The plant is covered with an anti-pest 20x10 mm protector, and has twelve pots or containers with a mixture of coconut fibre and peat as substrate, where the tests are performed. It is equipped with two independent automated irrigation systems.

**Bioreactors.** They are used to simulate different biological water purification processes

- Membrane bioreactor (MBR)
- Hollow fiber bioreactor (MBR)
- Batch bioreactor (SBR)
- SiClaro® 8PE Membrane bioreactor from Martin Systems AG

**Membrane distillation using solar energy test plant facility,** on the UAL central building rooftop.

### 3.2 SOLAR ENERGY EXPLOITATION FACILITIES.

During 2017 project entitled "multipurpose pilot assessment optimization and improvement of agrifood systems with renewable energy refrigerated Module" (UNAM13-1E-2532) has been gradually

implemented, a pilot module was installed in the CIESOL courtyard. It is composed of three complementary core modules, a common control and supervision room where there is an expert data acquisition system, with monitoring and flexible remote control as a management tool. The aforementioned facilities can be described as follows:

- Refrigerated pilot camera No. 1 with a thermal energy storage phase change system (ice accumulation), hybrid power solar photovoltaic system and wind turbine.
- Refrigerated pilot camera No. 2 for controlling environmental parameters, equipped with expert control system, pattern No. 1 camera, being of the same size and have the same cooling capacity installed.
- Refrigerated pilot camera No. 3 for testing cooling by harnessing water accumulation cycle solar absorption CIESOL building, whose primary objective is to test local cooling through use of cold water absorption cycle of the building CIESOL.



CIESOL Courtyard with the three refrigerated cameras and the control room.



Hybrid system consisting of a wind turbine (left) and PV system, installed opposite the main entrance of the CIESOL building and its courtyard respectively (right), forming an integral part of UNAM13-1E-2532 project.

The modeling and automatic control unit has the following equipment:

- Cameras and image processing systems: camera Marlin F-033C ½"; camera Intel VC4018/C; embedded data acquisition system with onboard image processing system National Instrument CompactRIO.

- Development environment for FPGA based embedded electronic systems from Altium Designer and Hard Real Time Systems development tools from Keil for 8, 16 and 32 bits processors.
- PC104 form factor development platform with soft real time operating systems: Embedded-Linux and WindowsXPEmbedded.
- Advanced tools for mathematical modelling and advanced control systems algorithms development: Dymola, Matlab/Simulink, NAG and Mathematica.
- Electronic instrumentation engineering desk, formed by:
  - Programmable power supply Metrix AX3222.
  - High accuracy multimeter Grundig DM100 and Metrix MTX3281 (portable).
  - Logic analyzer PC AT-LA500.
  - High accuracy timer and counter Pendulum CNT-90.
  - Welding station AOYUE 701.
  - Resistors decade box Chauvin & Arnoux P03197528A.
  - Tektronix TDS3014B Digital Oscilloscope.
  - Tektronix TDS2014 Digital Oscilloscope.
  - AFG3022C Function Generator.
- Cluster Beowulf formed by 13 nodes for distributed simulation and control in solar thermal power plants.

## 4. COMMITTEES AND ACTIVITY RESPONSIBLES.

### 4.1 CIESOL MANAGEMENT

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