sCO_2 on the horizon in the EU

As reflected in a current series of webinars organised by ETN Global (with the ETN, previously European Turbine Network, now standing for Energy & Turbomachinery Network), there is some very interesting R&D going on in Europe in the area of supercritical CO_2, much of it with EU funding coming from the Horizon research and innovation programme. Nine leading European sCO_2 research & development projects are outlined here, with additional R&D initiatives to be profiled in a future article. sCO_2 power cycles are a promising research area due to potential benefits such as higher thermal efficiencies, reduced costs, lower emissions, and more compact components compared to conventional power generation technologies

Applications for supercritical CO_2 envisaged by European R&D projects include solar power (particularly CSP (concentrated solar power)), waste heat recovery, and nuclear plant decay heat removal.

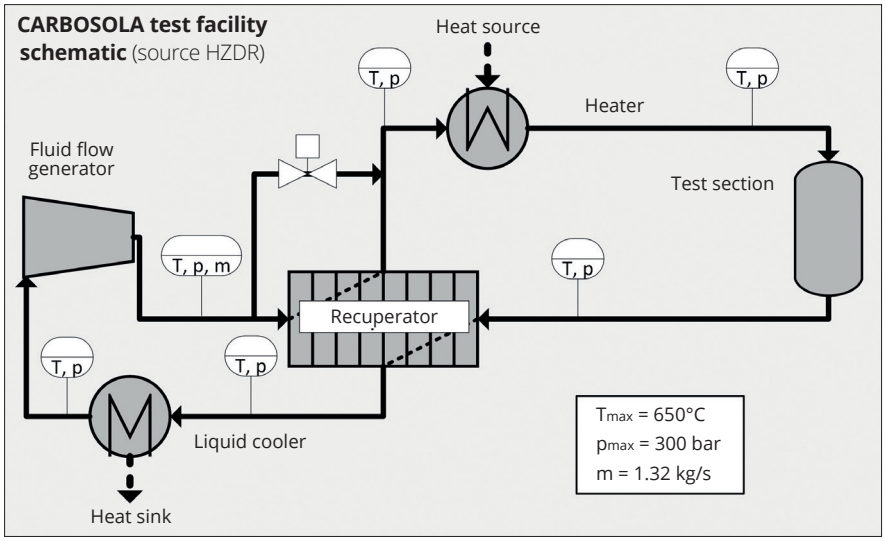
Below is a summary of nine key European projects: CARBOSOLA; COMPASsCO2; CO2OLHEAT; DESOLINATION; iSOP; SCARABEUS; sCO2-Efekt; sCO2-4-NPP; and SOLARSCO2OL.

CARBOSOLA

CARBOSOLA, funded by the German government, is focused on use of sCO_2 as the working fluid in a Brayton cycle, with potential applications in CSP and waste heat recovery.

A key part of the project is a MWt-scale test facility, with sCO_2 as the working fluid, constructed at Helmholtz-Zentrum Dresden-Rossendorf (HZDR), with temperatures planned for up to 650°C at 300 bar and mass flow rate 1.32 kg/s.

Project duration October 2019 to March 2023, budget 2.2 million euro, participants: TU Dresden; Siemens Energy; DLR Institute of Solar Research; HZDR. *Funded by the Bundesministerium für Wirtschaft und Energie (BMWi), indication 03EE5001D.*



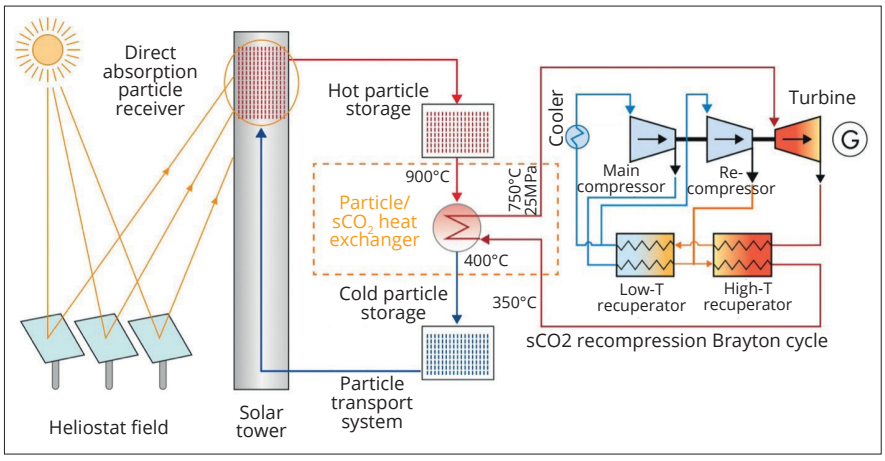
COMPASsCO$_2$

COMPASsCO_2 (COmponents' and Materials' Performance for Advanced Solar Supercritical CO_2 powerplants) is looking at the integration of CSP particle systems into sCO_2 Brayton power cycles (see below).The principle aim is validating the key component for such an integration, the particle/sCO_2 heat exchanger, "in a relevant environment." To reach this goal, the consortium plans to produce tailored particle and alloy combinations that meet the extreme operating conditions in terms of temperature, pressure, abrasion and hot oxidation/carburisation of the heat exchanger tubes and the particles moving around/across them.

Planned scope can be summarised as follows:

- Investigate, design, develop and test highly durable and effective particles for CSP receivers that can withstand the conditions for indirect integration with the sCO_2 Brayton cycle, in particular high temperatures (over 700°C).
- Investigate, design, develop and test metal alloys and coatings that guarantee reliable and efficient operation of the particle/sCO_2 heat exchanger.
- Model the degradation of the materials developed.
- Design, engineer and construct a heat exchanger section to validate the applicability of the components under the harsh conditions of a CSP sCO_2 power plant.
- Assess the economic competitiveness of a CSP sCO_2 Brayton power plant using the materials and components developed as part of the project. It is envisaged that sun-to-electricity efficiency of the overall system will be improved by 30% relative to current state-of-the-art CSP plants.

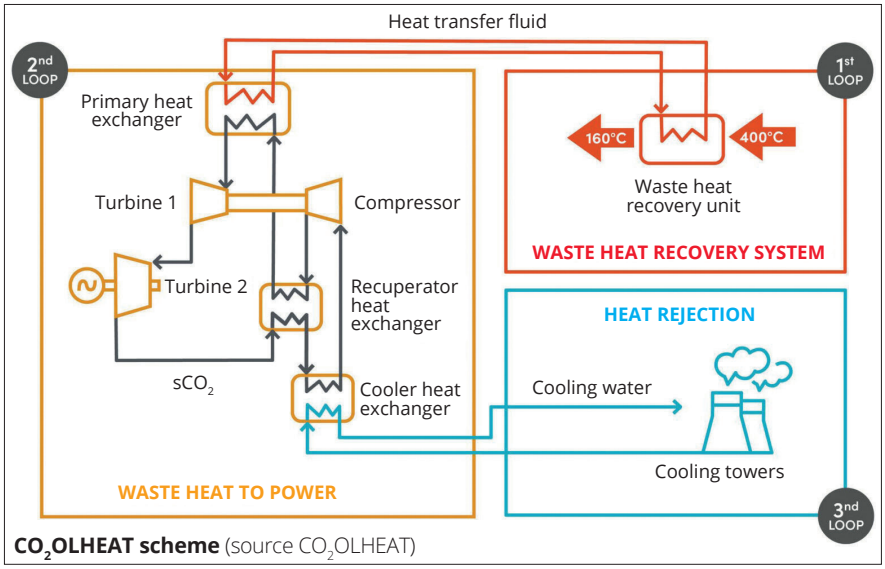
Duration November 2020 to October 2024, Horizon funded, budget 6 million euro, participants: DLR (co-ordinator); Ciemat; John Cockerill Renewables; CVR; Dechema Forschungsintitut; Forschungszentrum Jülich; OCAS; Ome; Saint Gobain; Sugimat; University of Birmingham; VTT. *Funding received from the EU's Horizon 2020, grant agreement (GA) No. 958418.*



CSP with particle receiver and sCO_2 Brayton cycle (source COMPASsCO_2)

CO$_2$OLHEAT

CO_2OLHEAT (supercritical CO_2 power cycles demonstration in Operational environment Locally valorising industrial waste HEAT) is



CO_2OLHEAT scheme (source CO_2OLHEAT)

focused on "unlocking the potential of industrial waste heat and its transformation into electricity via sCO_2 cycles", with design and demonstration of an EU "first-of-its kind sCO_2 plant in a real industrial environment", namely in a CEMEX cement plant in Prachovice, Czech Republic. This facility has significant untapped waste heat potential, which is currently not exploited and rejected by means of water-cooling towers.

The envisaged 2 MW CO_2OLHEAT power block will be able to cover about 10% of the site's electricity needs, amounting to 750 000 € savings per year, thus promising a short payback period (4-8 years).

Project duration June 2021 to May 2025, budget 18.8 million euro, with 14 million euro coming from Horizon. Project participants: ETN Global (project co-ordinator); RINA; Siemens Energy; University of Duisberg-Essen; Baker Hughes; Politecnico di Milano; SimeROM; CEMEX; Brunel University; MAS; Roma Tre University; CERTH; Leitat; Heatric; ENEA; Engie Laborelec; EDF; Mytilineos; Sisecam; Bosal; Celsa Barcelona. *Funding received from the EU's Horizon 2020, GA No. 101022831.*

DESOLINATION

The aim of DESOLINATION (DEmonstration of concentrated SOLar power coupled wIth advaNced desAlinaTion system in the Gulf region) is development of an innovative process coupling CSP with desalination, resulting in co-production of renewable electricity and fresh water.

The project will include development and demonstration of a 2 MW power cycle based on CO_2 blends, to be located in Saudi Arabia. The new technology will be tested for one year at an existing CSP plant, that at King Saud University, Riyadh.

The CO_2 blends concept is expected to result in an increased thermal-to-electric conversion efficiency relative to both conventional steam cycle and pure sCO_2 cycle, as well as reduced power block specific costs with respect to both conventional steam cycle and pure sCO_2 cycle.

The desalination system is a novel combination of direct osmosis and membrane distillation. Forward osmosis (osmotic pressure) induces a flow of seawater through a membrane that will only let freshwater through, but will block salt. Using waste heat from the CSP plant, the diluted solution is heated until the fresh water can be recovered through a second membrane.

Main project goals are the identification of the best CO_2 blend for the working fluid, selection of the most suitable materials for the working fluid and optimisation of heat exchanger design.

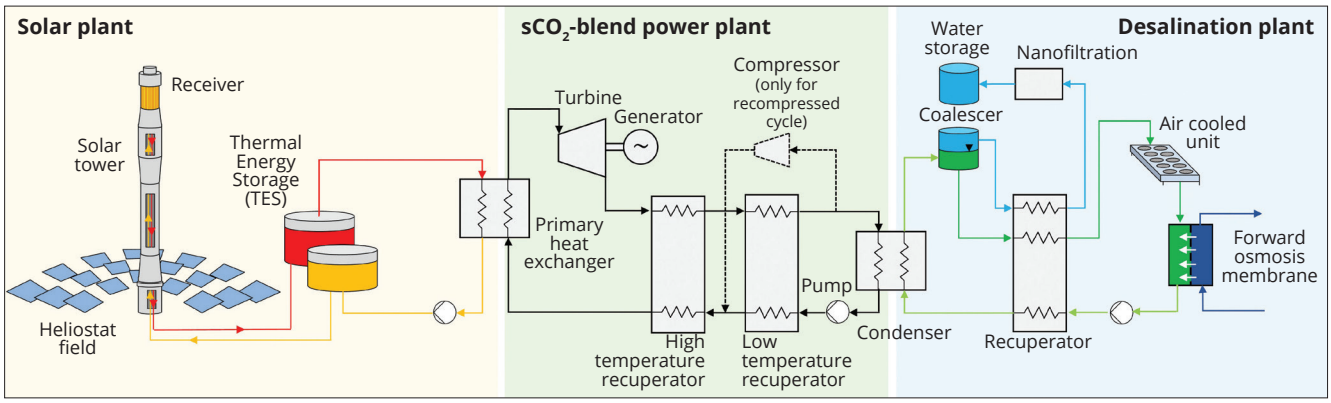
Project duration June 2021 to end September 2026. Source of funding Horizon and Gulf Cooperation Council. Budget 14.5 million euro, with 10 million euro coming from Horizon.

Participants: Politecnico di Milano (project co-ordinator); Protarget; Cobra Instalaciones y servicios; Baker Hughes; Aalborg CSP; Fraunhofer IKTS; Cranfield University; Lund University; Lappeenranta University of Technology; Fundación Tekniker; Lulea University of Technology; German University of Technology in Oman; Euroquality; Technical University of Eindhoven; TEMISTh; Maribor University; King Saud University; University of Bahrain; University of Brescia; Teesside University; University of Derby. *Funding received from the EU's Horizon 2020, GA No. 101022686.*

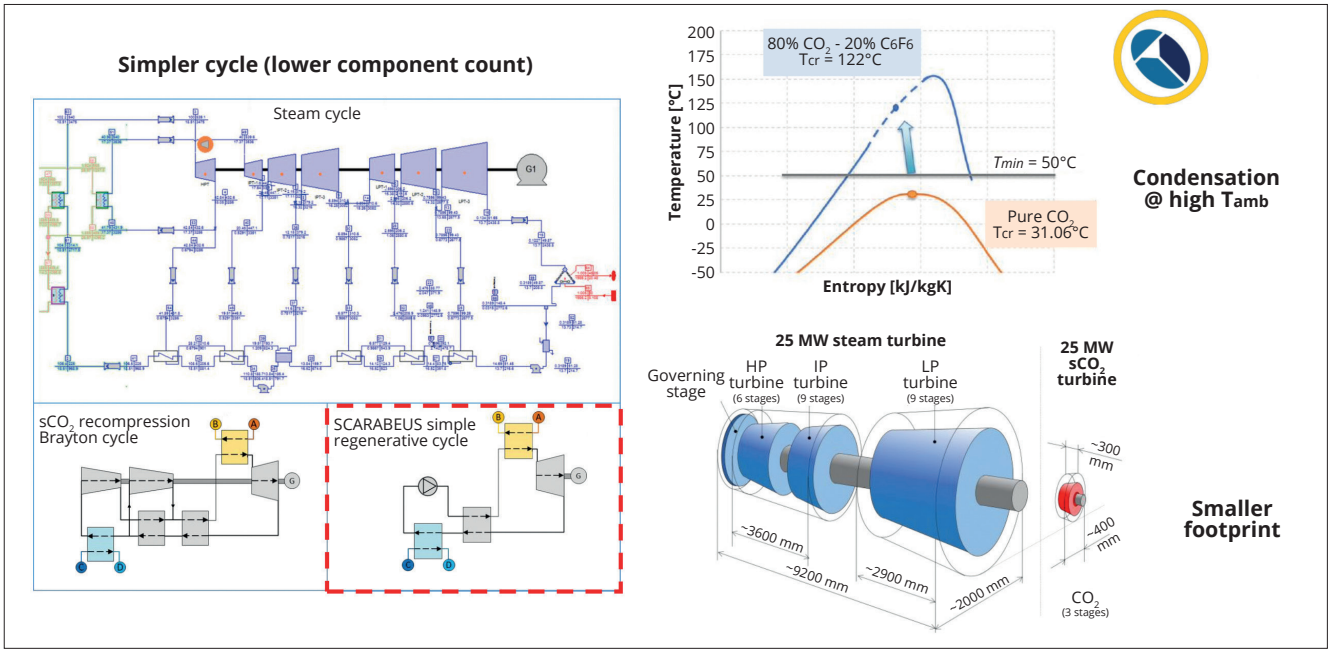
ISOP (Innovation in Supercritical Carbon Dioxide Power Generation Systems) aims to "undertake cutting edge multidisciplinary research and development" to bring about "a step change in understanding and advancing supercritical CO_2 based power", while "providing specialised training for 17 doctoral researchers to help establish the backbone of an important industry."

The objectives of the research are:

- Development of advanced models and design tools that enable the optimal integration of sCO_2 power systems components for various thermal energy sources and end use applications.
- Development of accurate prediction tools for the simulation of transient operation of sCO_2 power cycles and and investigation of innovative concepts for control and optimisation of operation.
- Development of innovative methods to enhance aerodynamic and mechanical performance, reliability, and operability of key sCO_2 system components.
- Development of advanced modelling and experimental methods that enable selection and development of materials, coatings and manufacturing techniques.



DESOLINATION demo concept (source DESOLINATION)



Goals of the SCARABEUS project (source SCARABEUS)

The project also aims to train "a new generation of creative, entrepreneurial and innovative early-stage researchers", who can face future challenges and "convert knowledge and ideas into products and services for economic and social benefit."

Project duration is from January 2023 to December 2026. Total budget is 4.45 million euro, of which 3.84 million euro comes from Horizon and 0.61 million euro from UK Research and Innovation.

Participants: University of Seville (project co-ordinator); Instituto Superior Tecnico (Portugal); University of Stuttgart; Baker-Hughes; Fives Cryo; ETN Global; Empresarios Agrupados Internacional; CiTD Engineering; SoftInWay; Technical University Wien; Técnicas Reunidas; Czech Technical University Prague; Politecnico di Milano; Siemens Energy; RPOW Consulting; City, University of London; INERCO; EASY Energy; Rosswag; Doosan-Skoda Power; Azzero CO_2; Plataforma Solar de Almería; Aalborg CSP. *Funding received from the EU's Horizon Europe, GA No. 101073266.*

SCARABEUS

The SCARABEUS (Supercritical CARbon dioxide/ Alternative fluids Blends for Efficiency Upgrade of Solar power plants) project aims to demonstrate that sCO_2 blends used as the working fluid in CSP plants can significantly reduce the size and increase the efficiency of the power block, potentially reducing CAPEX by 30% and OPEX by 35% relative to state of the art steam cycles, thus exceeding the reduction achievable with standard sCO_2 technology. This translates into 30% lower LCoE than currently possible.

The project scope included identification of the optimal additive for a new working fluid employing a supercritical CO_2 blend and development of tailored heat exchanger designs, particularly for the air-cooled condenser, to operate with the new fluid.

Another objective of the project was to run the newly developed heat exchanger for 300 h in a CSP-like operating environment (employing a validation test rig at TUW).

The project participants note that the LCoE of CSP (currently about 150 €/MWh) has not attained the target level of 100 €/MWh except for a few installations in exceptionally good locations. Many ongoing research projects aiming at enhancing the efficiency of the CSP power block and reducing costs are based on sCO_2. However, high ambient temperatures remain the Achilles heel of sCO_2 cycles as their efficiency drops dramatically in warm environments, where ambient temperatures are close to or higher than the critical temperature of CO_2 (31°C), not allowing the adoption of condensation (Rankine) cycles with their expected higher efficiencies.

The SCARABEUS project aims to address this critical hurdle for the future commercialisation of CSP plants by employing a modified working fluid in which carbon dioxide is blended with additives to enable condensation at temperatures as high as 60°C. This represents a major breakthrough for CSP as it increases the thermomechanical conversion efficiency from the current 42% to above 50%. Both actions will lead to a significant reduction of CAPEX and OPEX with respect to conventional CSP.

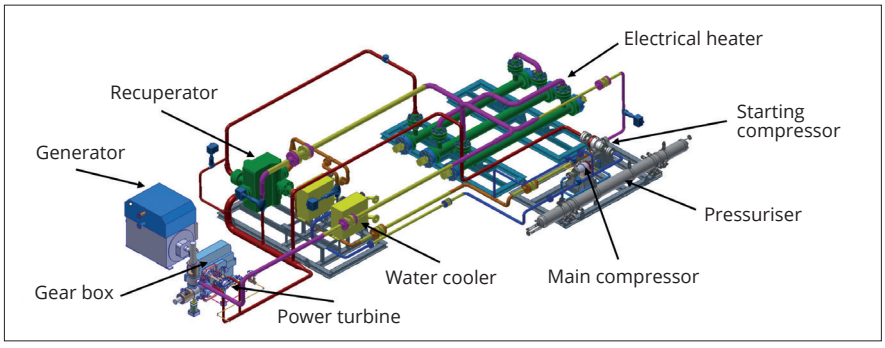
Duration: April 2019 to January 2024. Budget: € 4 950 266.25. Source of funding: Horizon. Participants: Politecnico di Milano (project co-ordinator); Laboratorio Energia Ambiente Piacenza; Technische Universitaet Wien; Kelvion; Exergy; University of Seville; City, University of London; Quantis; Abengoa; University of Brescia; Nuovo Pignone. *Funding received from the EU's Horizon 2020, GA No. 814985.*

sCO_2-Efekt

The sCO_2-Efekt project is focused on the application of supercritical CO_2 in thermal energy storage. The project scope envisages installation of a compressor and turbine test rig (called Sofia) at the Melnik heating plant, with operation scheduled for 2024.

This system is based on the P2H2P (power to heat to power) concept, also called the "Carnot battery", employing a Brayton cycle for heat to power conversion. Sofia rig operating conditions: up to 550°C; maximum test pressure 25 MPa; flow rate about 25 kg/s; max turbine power 1.5 MWe.

The project is being funded by the Czech government. Participants are: CVR (Research



sCO_2-Efekt Sofia test rig (source sCO_2-Efekt)

Centre Rez), lead; Doosan Škoda Power; Inpraise Systems; UJV Rez. Budget 4 million euro. Duration May 2019 to October 2024. *Supported by Czech Technology Agency.*

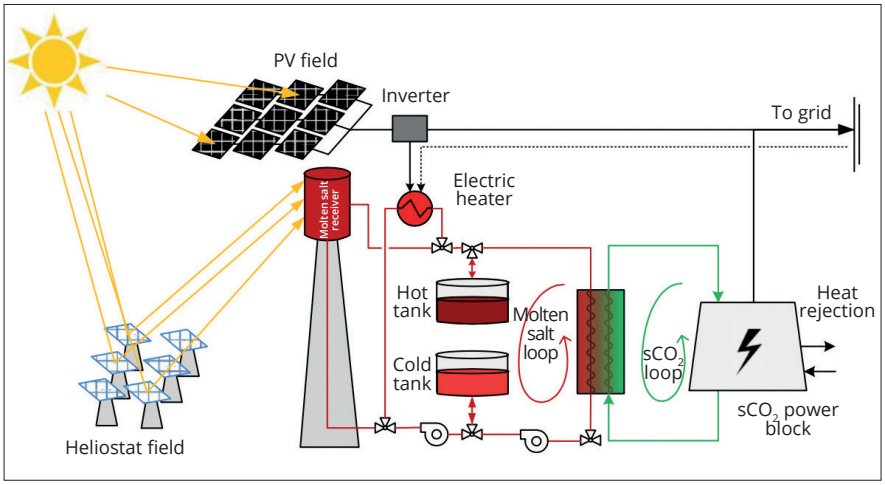
The main aim of the sCO_2-4-NPP project was to bring an innovative technology based on supercritical sCO_2 for heat removal in nuclear power plants closer to the market (to TRL5). The sCO_2-4-NPP project built on the results of a previous Horizon 2020 project sCO_2-HeRo, where the technology was first developed and brought to experimental proof of concept stage (TRL3).

The sCO_2-4-NPP technology would be a backup cooling system, attached to the principal, steam-based, cooling system, able to considerably delay or eliminate the need for human intervention (>72 hours) in case of accidents such as station blackouts.

The proposed backup cooling system is based on a closed Brayton cycle. In case of an accident, a safety valve opens to enable the release of the steam produced by the steam generator (PWR case) into the CHX (compact heat exchanger). The supercritical CO_2 is heated up in the CHX and flows then through the turbine which is linked to the compressor and the generator on the same shaft. The supercritical CO_2 flows through the DUHS (diverse ultimate heat sink) to be cooled by heat exchange with ambient air, and then goes through the compressor to restore its initial pressure, returning to the CHX.

Validation of the sCO_2-4-NPP cycle has included use of the Reactor Glass Model and Konvoi simulator at the KSG|GfS simulator centre, Germany.

Thanks to the compact size and modularity of the envisaged system, it would be retrofittable into existing nuclear plants and incorporated in future plants under development.



The SOLARSCO2OL vision: PV/CSP hybrid integrated with sCO_2 cycle (source SOLARSCO2OL)

The project was EU-funded via EURATOM. Budget 2 786 971 euro. Duration September 2019 to August 2022. Project participants: EDF (project co-ordinator); University of Stuttgart; Baker Hughes; Fives Cryo; KSG/GfS simulator centre; CVR (Research Centre Rez); Jozef Stefan Institute; University of Duisberg-Essen; UJV REZ (Nuclear Research Institute); Arttic. *Funding received from Euratom, GA No. 847606.*

The basic goal of the SOLARSCO2OL (SOLAR based SCO_2 Operating Low-cost plants) project is to demonstrate a 2 MW sCO_2 cycle and MW-scale electric heater, paving the way for near-term cost-competitive hybrid CSP– PV plants (first of a kind in the EU).

The project says it will develop an innovative, economically viable and easily replicable supercritical CO_2 power block for integration with CSP plants, increasing flexibility and reducing LCOE, promoting an innovative water-free power plant cycle layout, with fast-reactive electric heaters and highly efficient heat exchangers.

Compared to organic and superheated steam-based Rankine cycles, sCO_2 cycles achieve high efficiencies over a wide temperature range (thus giving the opportunity to couple sCO_2 power blocks with molten salt CSP plants, existing and newly built), with lower CAPEX, lower OPEX, no use of water as operating fluid (a plus for CSP plants in arid locations), smaller system footprint, and greater operational flexibility.

SOLARSCO2OL aims to demonstrate the first MW Scale EU sCO_2 power block operating in a real CSP plant.

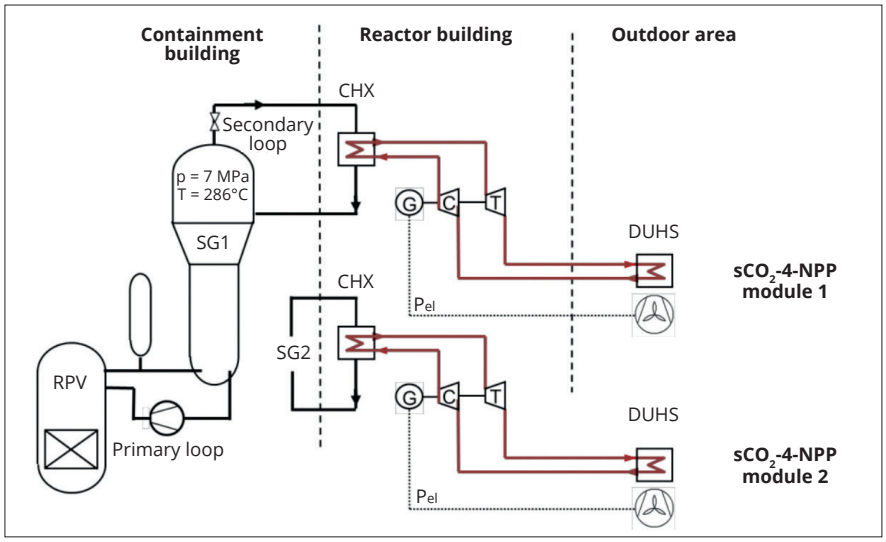
Project objectives:

- Demonstration of MW scale sCO_2 cycle (integrated with molten salt loop);
- Development of MW-scale simple-recuperated cycle, including new turbomachinery and heat exchanger designs;
- Demonstration of MW scale molten salt electric heaters;
- Techno-economic investigations of high temperature hybrid PV-CSP-sCO_2 power plants.

The initial plan was direct integration of a sCO_2 cycle with an operating CSP plant in southern Spain, taking advantage of an existing molten salt system, with cooling and infrastructure (utilities). But this was frustrated due to new facility ownership, and a new site had to be found, resulting in project delays. The new site is the Evora Molten Salt Platform (EMSP) in Portugal.

The project says it is adopting a conservative approach to the sCO_2 cycle: turbine 565°C, 185.5 bar; compressor T = 33°C, P= 83:188 bar.

Project duration Oct 2020 to July 2025. Budget 15 million euro, with 10 million euro coming from Horizon. Participants include: RINA (project co-ordinator); KTH (Kungliga Tekniska Hoegskolan); University of Evora; Moroccan Agency For Sustainable Energy; Ikerlan; University of Genova; Magtel; Franco Tosi; European Solar Thermal Electricity Association; Mas; Lointek; Baker Hughes; Seico; Abengoa; Ocmiotg; Certh; Ethniko Kentro Erevnas Kai Technologikis Anaptyxis; Bruno Presezzi Spa; Deutsches Zentrum Fur Luft - Und Raumfahrt; Build To Zero Energy Sociedad Limitada. *Funding received from the EU's Horizon 2020, GA No. 952953.*



sCO2-4-NPP cycle, PWR case (source sCO2-4-NPP)