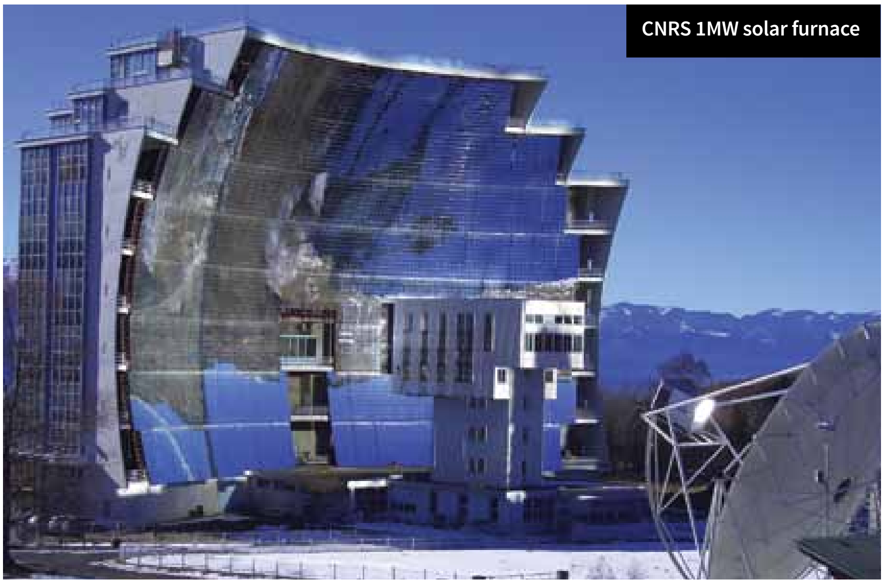
Harnessing the sun to clean up industrial processes

By using concentrated solar energy at high temperatures of about 900˚C, the solpart project aims to integrate a solar reactor into the processes of mineral industries, enabling the reduction of fossil fuel use and CO_2 emissions.

■ *by **CNRS and Euronovia**, France*

With a budget of €4,558,687 and 10 partners from seven different countries, the SOLPART project, funded through the Horizon 2020 European programme, is working on limiting CO_2 emissions from industrial minerals processing in sectors such as cement and lime production. For example, for every 10t of cement produced, nine tonnes of CO_2 are released from calcite decomposition (calcination) and fossil fuels combustion. Therefore, decarbonisation of these sectors is a key requirement in reducing industrial CO_2 emissions.


CNRS 1MW solar furnace

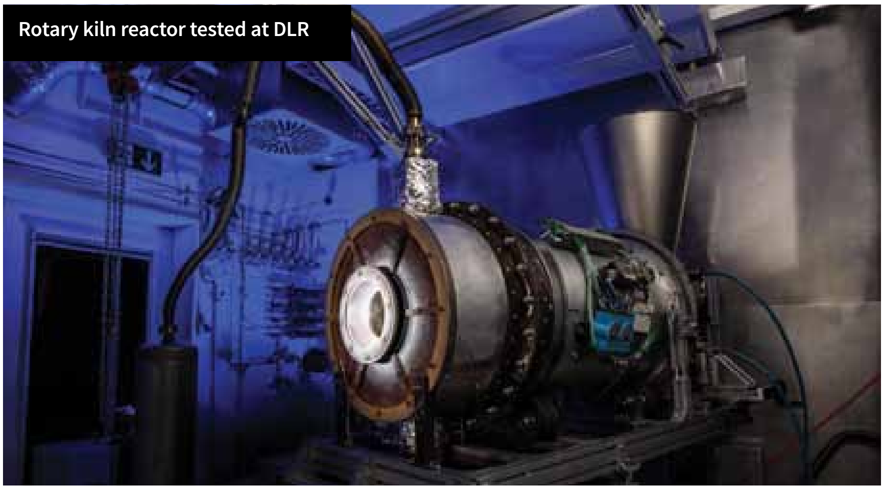
SOLPART project objectives

The SOLPART project aims to demonstrate ways of totally or partially supplying the thermal energy requirement for $CaCO_3$ calcination with high-temperature solar heat, thus reducing the lifecycle environmental impacts of the process and increasing the attractiveness of renewable heating technologies in process industries.

Researchers expect that the pilot-scale tests carried out in 2019 will prove that the solar reactor can replace between 60-100 per cent of fossil fuel consumption, depending on the targeted final material.

SOLPART opens new application domains for solar heat by addressing the following technology-specific challenges:

- How to heat particles to a high temperature to achieve a chemical reaction in the 800-1000˚C temperature range while meeting endothermic and kinetic requirements.
- How to enable a 24/7 process with solar heat.


Rotary kiln reactor tested at DLR

Main concept

To substitute fossil fuel firing of kilns, the SOLPART project is investigating the use of concentrated solar energy to supply the reaction heat. This will be achieved by the demonstration of a pilot-scale solar reactor suitable for calcium carbonate decomposition (calcination reaction: $CaCO_3 = CaO + CO_2$) and to simulate at prototype scale a 24h/day industrial process (TRL 4-5), requiring a high-temperature transport and storage system.

Thanks to the European fund, a rotary kiln reactor and a fluidised bed of 10-20kW have already been tested at the German Aerospace Centre (DLR) and the National Centre for Scientific Research (CNRS) in France, respectively. A pilot-scale reactor with about 50kW of heating power, designed and manufactured by French SME COMESSA, has been commissioned and is currently being tested for limestone, dolomite, phosphate and cement raw meal calcination in the solar furnace of the CNRS-PROMES laboratory in Font-Romeu, France.

Pilot-scale fluidised bed reactor tested at CNRS laboratory

The proposed innovative concept develops and merges three advanced technologies: a high-temperature solar reactor, transport of high-temperature solid materials and a storage tank of high-temperature solid materials/intermediate products. The synergy between the technologies lies in using particles as a storage medium. The main idea of the approach is to develop an easily-scalable solar reactor concept that may be used for various types of solid-gas chemical reactions and be integrated into existing plants. Combined with modelling, experimental results are used to define the basic laws for scaling up. The design of a commercial-scale solar calciner and its integration in a cement plant is performed by Abengoa and Cemex.

For cement plants, the process consists of replacing the traditional fossil fuel-heated calciner by a solar-heated calciner. This solar receiver/reactor, which operates at 850-900˚C, is fed by the particles preheated in the cyclone train and the calcined mixture feeds either the kiln (working at about 1450˚C) or the storage tank (see Figure 1). This latter component is necessary to achieve a continuous operation after sunset. The environmental impacts of the solar-driven (SOLPART) calcination process have been compared with the conventional calcination process via lifecycle assessment. The results estimated by the University of Manchester show that, compared to the conventional process, the solar calcination system has the potential to reduce greenhouse gas emissions by nearly 40 per cent and fossil-based energy use by 57 per cent. This is due to the SOLPART system using solar thermal power as a substitute for fossil fuels.

For lime production (application studied by EPPT and NLD) the process can be solar-only because the calciner is the hottest component.

Main constraints

Considering the various constraints of the industrial process the main challenges include:

1. Particle heating

The only realistic way to "solarise" the calcination process is high-temperature particle heating using solar energy without a heat transfer fluid. Corresponding objective: development of new technologies (solar reactors) for solar heating particles up to 950˚C.

2. Continuous operation

In the production of cement or lime, plants must be able to operate 24h/day, seven days/week and 10-11 months/year without interruption. Corresponding objective: development of a high-temperature storage solution adapted to continuous solid processing to address the key issue of process integration of this new technology. Safety issues will be particularly studied because of the high temperature and the particle reactivity. A 100 per cent solar (solar-only) solution will be tested at pilot scale. On an industrial scale, a hybrid solution mixing solar and combustion heat will be examined during the scaling-up study. As a result, it will be possible to propose an industrially-feasible and economic solution with a realistic chance of application.

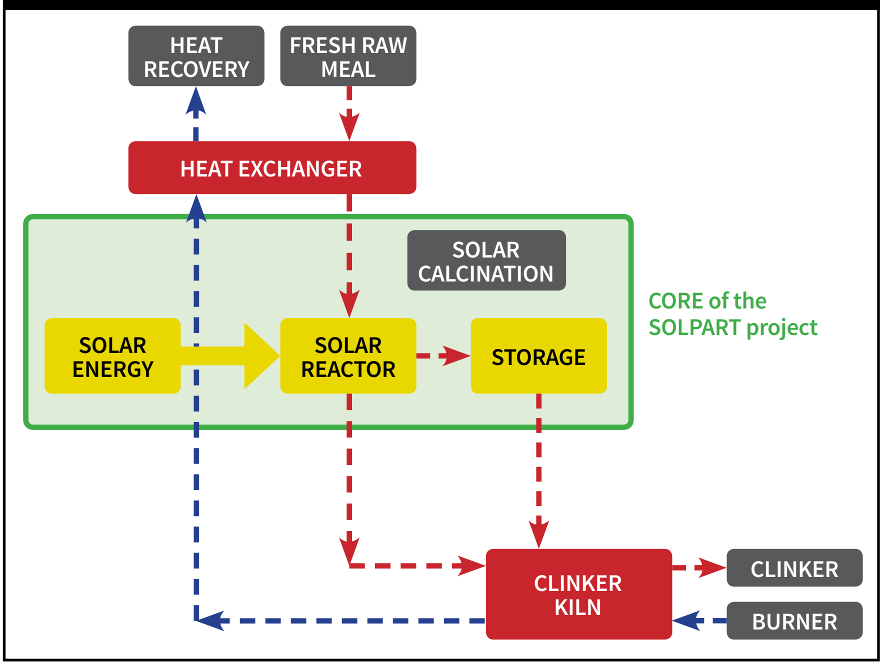
3. Particle conveying

This solarised process includes the high-temperature transport of a solid from the solar reactor to the storage tank and from storage to the kiln. This technological issue should be addressed carefully, because there are no transport technologies available for solids at such temperatures yet, and any temperature decrease will have a direct impact on the heat balance and the economics of the system. Corresponding objective: handling and conveying of solids at high temperature.

4. Product quality

The solar-produced particles should exhibit equivalent properties to conventional industrial ones. In particular, CaO reactivity is the key property that governs the applications. Moreover, it is expected

Figure 1: concept of the project with integration into a hybrid cement plant as an example



to achieve better qualities, since product contamination from fossil fuel combustion or RDF/biomass (sulphur, organics) will be avoided. Corresponding objective: characterisation of the product properties.

5. CO_2-rich flue gas

One of the specific features of a solar calcination process is its theoretical capacity to produce a pure flow of CO_2 without pollution by the combustion products and excess air. However, the real flue gas composition needs to be measured in detail. Moreover, even if the solar process reduces CO_2 emission by avoiding combustion, CO_2 emissions are not completely eliminated because calcium carbonate decomposition results in a large production of CO_2. This issue will also be addressed in the project. Corresponding objective: measurement of the CO_2 flue gas content and options for CO_2 capture, without additional large capture systems.

6. Integration

The proposed technology should be integrated into existing plants, thus this constraint will be taken into account during the choice of the technologies to be tested at pilot scale: solar reactor, particle conveying device and particle storage. Corresponding objective: evaluation of integration of the solar technology into industrial plants.

7. Environmental impact

The solar option should result in a significant reduction of environmental impacts, including the carbon footprint, in terms of current standard technologies. The extent will be investigated in the project with a detailed lifecycle assessment analysis. Corresponding objective: lifecycle and environmental impacts of the solar-based solution in comparison with the standard processes.

8. Risks

High-temperature solar processing of minerals is a new field of development for concentrating solar technology. Therefore, it is necessary to understand and analyse the risks associated with this new technology. Corresponding objective: identification and management of risks associated with the innovative solar technology developed during the project.

9. Costs

The economics of high-temperature solar heat integration depend on various parameters such as site location, size of the plant and fossil fuel cost. Therefore, the technological and environmental approaches will be completed by a detailed economic analysis. Corresponding objective: economics of high-temperature solar heat integration in the cement and lime industry based on case studies.

Key innovations

The SOLPART project includes several key innovations:

- design and comparative testing of various innovative solar reactor concepts based on rotary kiln, fluidised bed or moving bed principles at laboratory scale
- quantification of performance of one selected solar reactor concept at pilot scale (>30kWth) for calcination of calcium carbonate-based materials at about 900˚C. The expected product flow rate is about 30kg/h of CaO, which correspond to about 7.5 times the state-of-the-art technology
- online characterisation of flue gas composition and solid product
- quantification of the pilot solar reactor performance for calcination of various solids such as cement raw meal, dolomite and phosphate ores
- development of a 900˚C/160kg particulate storage system combined with the solar reactor and able to deliver 10kg/h CaO
- assessment of the complete loop – solar reactor + storage – 24h/day during several days
- particle handling solutions at high temperature (>900˚C)
- concept for integration of high-temperature solar heat in a large industry at the scale of 300tpd lime, 1500tpd phosphate and 3500tpd (and also lower mass flow rate) cement production plan. The study will also consider hybrid solutions in which a variable proportion of thermal energy provided by fossil fuel combustion is substituted by solar energy to find the best economical solution for each region
- complete environmental, risk and economic assessment of the solarised process with respect to the traditional route (business as usual)
- business analysis on the basis of case study.

Workplan

The workplan of the SOLPART project is divided into nine work packages (WP), of which seven are devoted to science and technology development and two are related to communication, dissemination and exploitation of results, and management, respectively.

The first three packages of the workplan address a complete state-of-the-art of the standard and solar technologies for processing and storing particles, and the development and testing of laboratory-scale high-temperature solar reactors and particle storage. This has led to a critical milestone of choosing the technologies to be developed on a pilot scale. On this basis, WP4 and WP5 are devoted to the design, construction and testing of the pilot unit (30kW solar reactor and 16h particle storage). The current performance evaluation of the pilot unit, which is being carried out in 2019, includes product characterisation, and heat and mass balance during continuous operation. The results of this critical step will then be used in WP6 and WP7 to finalise the environmental lifecycle assessment of the solar process and the scaling-up of the solar technology for three main applications: calcite (and dolomite) and cement raw meal decarbonation, and phosphate ores calcination.

Final steps

The final step will consist of mainly operating the pilot-scale solar reactor to process calcium carbonate, phosphate from Morocco (a collaboration between OCP and University of Cadi Ayad) and cement raw meal with a production of several 10kg/h. The quality of the product will be analysed for each material.

In parallel, the scaling-up of the solar process will be finalised. It includes sizing the solar subsystem (heliostats and tower) and the particle thermal treatment subsystem, as well as estimating the cost.

Finally, the environmental assessment will emphasise the main advantages of the solar process in terms of the decarbonisation of the mineral processing industry. ■

Acknowledgments

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