Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems

FINAL RESULTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 721045

SUMMARY

NEXTOWER PROJECT

The context: Concentrated Solar Power Technologies

Concentrated solar power (CSP) is an important building block in installing a secure, competitive and sustainable energy system.

Today, the diverse solar thermal energy solutions commercially available differ with respect to concentration technology, receiver type and shape, nature of the heat transfer fluid (HTF) and capability to store thermal energy, to turn it later into process heat or electricity on demand.

However, more cost-effective solutions are required for a wider-scale deployment of the CSP technology.

Novel functional materials and material combinations throughout the manufacturing chain are therefore needed to enhance the efficiency of solar energy harvesting beyond that of the current state-of-the-art technologies.

Solar towers using atmospheric air as heat transfer fluid for large-scale power generation

LIMITS:

CSP Tower systems using air as HTF are potentially capable of higher working temperatures than the current commercial technologies based on parabolic trough systems and towers using molten salts as HTF. However, their industrial exploitation has been so far hindered by limitations in the materials used for the central receiver - a key component in the system - and by the lack of efficient very high temperature thermal energy storage solutions, which dictate the maximum working temperature and the in-service overall durability against failure from thermal cycling and thermal shocks.

CHALLENGES/TECHNOLOGICAL NEEDS:

- Improving the central receiver
- Possibly re-engineering the whole systems downstream to work longer and at much higher temperature, especially in the thermal storage compartment.

NEXTOWER ADVANCED MATERIALS SOLUTIONS AND ARCHITECTURES

- Improved durable monolithic ceramic materials for open volumetric receivers of CSP systems of different size
- New thermal energy storage system for very-high-temperature (> 600°C) based on liquid lead
- Innovative corrosion-creep resistant steels for high temperature thermal storage > 600°C.

EXPECTED IMPACTS

- New material technologies for the CSP Market that will increase the appeal of air-based CSP tower systems in the energy market
- Enabling materials for more competitive CSP systems and power cycles
- CSP market open to new application areas

NEXTOWER ENABLING SOLUTIONS - **CERAMIC SOLAR RECEIVER**

Innovative all-SiC receivers: innovative ceramic for high-temperature open volumetric receivers based on all-SiC honeycomb design by VPS for more durability to oxidation.

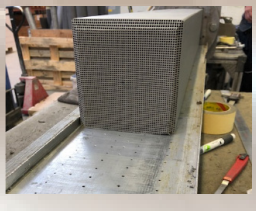
• Better ceramics for high-temperature receivers working at temperatures of 800°C, under extreme thermal cycling without failure with over 25 years of continued operations of the receiver in large CSP plants (>5MWe)

• Superior thermal properties and reliability: strong and thermally conductive SiC honeycomb structure.

• All-SiC ceramic receivers (recrystallized SiC monolithic component by a special joining of SiC at temperatures over 2000°C), optimized for oxidation:

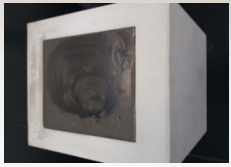
- Porosity of 30% in the cup
- Porosity of 43% in the square part
- Pore size of 17 µm

"Tile" production



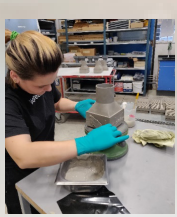
Extrusion and cut to the final shape

"Cup" production



Mix a slurry and cast the cup

Glue



Glue the two pieces with a paste of SiC

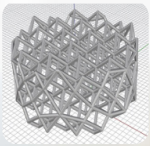
All-SiC solar receiver

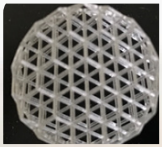
Sintering temperature above 2000 °C

Final all-SiC solar receiver for real application

New generation of SiSiC solar absorber lattices optimized for higher toughness and thermal conductivity: innovative ceramic for high-temperature open volumetric receivers based on more flexible multiparts Si-SiC 3D printed design with self healing glass ceramics and brazing alloys for higher toughness, higher thermal conductivity, and more open design.

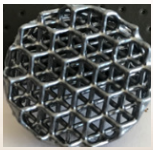
- Performance: higher air temperature by same radiation and flow
- Lifetime: 25 years with an inlet air flow at 900°C at concentrated solar flux density of about 2 MW/m^2 and maximum thermal gradient of 70 °C/cm.

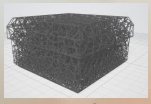

3D model


Polymeric template

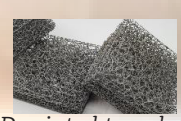

Coating


Debinding


Si-Infiltration


Voronoi design


Final items with cups


3D printed template

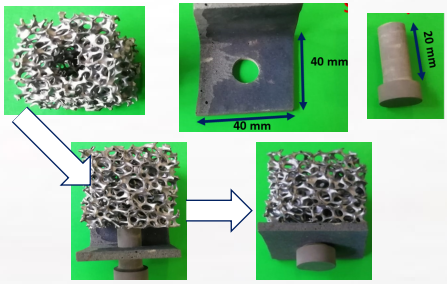

Coated template (green body)

Optimization and validation of pressure less-techniques of joining together SiC based ceramic pieces with proven scalability able to avoid interfacial cracking of the receiver made of three pieces.

RM-Wrap is a new brazing technology named after the Refractory Metals (RM) combined in a wrap containing silicon. It is a pressure-less tailorable joining technique made of two steps:

- Si coat on SiSiC disk to improve wetting
- Mo-Wrap joining

SiSiC FOAM *SiC SUBSTRATE* *SiSiC PIN*



SiSiC FOAM *SiSiC DISC*

Development of a brazing process suitable for the production of Si-SiC solar receivers

Coating and surface treatments to improve thermomechanical properties and emissivity: increased thermal conductivity and durability of porous SiC receivers and reduction of their emissivity in order of magnitude of 20% to boost performance at higher temperatures (900°C).

- For increased thermal conductivity and thermal shock resistance: introduction by CVI of highly thermal conductive aluminium nitride (AIN)
- For reduced emissivity:
  - innovative metal-oxide coating by sol-gel deposition
  - engineering surface roughness by micropatterning
  - engineering surface coatings filled with nanocavity by plasmonic technology based on nanoparticles

A proposal of amendment to the ISO 18755:2005: a proposal of amendment to the ISO 18755:2005 current standard on thermal diffusivity determination with the Laser/Light Flash Method (LFA) has been drafted and submitted to the ISO Standardization Body.

The objective is to propose to employ a single standard and only the LFA method to characterize the whole thermal behaviour of the ceramic materials under investigation, in terms of thermal diffusivity, specific heat and thermal conductivity.

A correct evaluation of the specific heat by means of the LFA has been demonstrated by comparison with the results achieved by the standard DSC technique. In this way, the acceptance and utilisation by the market of the developed solutions can be favoured.

A CEN Workshop Agreement (CWA 17726) titled "High temperature accelerated ageing of advanced ceramic specimens for solar receivers and other applications under concentrated solar radiation" has been promoted by NEXTOWER partners and published in open access on CEN-CENELEC website in June 2021(link >>)**.**

Focusing on the lack of guidelines for the standardization of high-temperature accelerated aging of high-tech ceramic components, this progress brings a tangible advantage to the industrial partners in NEXTOWER, as well across the entire ceramic industry, to facilitate the development & certification of their products to boost high-temperature applications in energy and aerospace, thus ushering in a real economic advantage for society.

Solar accelerated ageing of materiales under high solar energy fluxes in controlled and extreme thermal conditions

Two novel tests benches have been developed to carry out accelerated ageing testing of SiC ceramic slabs and volumetric cups under concentrated solar radiation at Plataforma Solar de Almeria Solar Furnaces. Accelerated ageing tests have been carried out:

- *up to 10,000 cycles and in ranges from 300 to 1200ºC on SiC ceramic slabs at SF40,*
- *up to 900ºC at the outlet air of the SiC cups at SF60.*

Accelerated ageing testing of ceramic slabs under concentrated solar radiation can predict the behaviour under CSP real conditions.

CUSTOMER SEGMENTS

Durable components working at high temperatures for

Automotive industries

Chemical plants

Mills

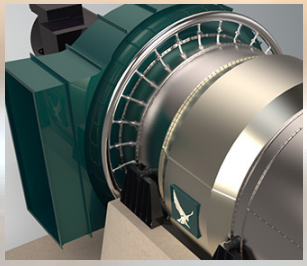
Expanders

Extruders

Nuclear sector

Manufaturing of ceramic materials

Fuel production



CO_2 supercritical power plants

NEXTOWER ENABLING SOLUTIONS - **THERMAL STORAGE MATERIAL**

Liquid lead as heat transfer fluid as technology transfer from nuclear fission to CSP of high-temperature lead-based thermal fluid.

Because of the higher stability and continuity of the heat supply ensured by the lead storage, the solar heat collected can be used also as high-temperature process heat, significatively extending the range of possible applications of concentrated solar thermal plants.

Corrosion resistant alumina forming steels: innovative FeCrAl-alloys with better performance than reference commercial ones (good corrosion resistance in liquid lead at 750°C, minor oxidation, self-healing properties) used for the construction of steel piping and plates of the full-scale demo.

- Raw material reduction: partial substitution of chrome through both composition (lowering Cr by replacement of 4% Al) and by increased performance (increasing oxidation resistance) as compared to standard stainless steels and Ni superalloys.
- Liquid lead applications up to 750°C enabled, thus achieving increased thermal efficiency of CSP plants.
- Results in terms of characterization of FeCrAl steels transferrable to the Lead-cooled Fast Reactor (LFR) community.

Some FeCrAl manufactured components

Innovative welding feedstock and procedures: innovative welding feedstock based on the newly developed FeCrAl alloy and optimized robotic GTAW welding procedures and SAW Strip Cladding used with NEXTOWER innovative alloy allowed for overlay welding of FeCrAl alloy

- Greater repeatability and faster execution of the welding process compared to a semi-automatic procedure
- Welding feedstock based on the newly developed FeCrAl alloy will help welding companies and manufacturers of large parts for corrosive environments to achieve longer service lives and higher operating temperatures. A FeCrAl alloy weld overlay provides resistance to many environments where other alloys would quickly fail.

Weld-overlay activity of the 1st course

Weld-overlay activity of the 2nd course

CUSTOMER SEGMENTS

Sectors looking for durable components working at high temperatures:

Automotive industries

Chemical plants

Mills

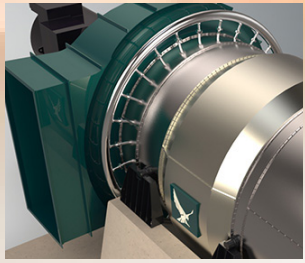
Expanders

Extruders

Nuclear sector

Manufaturing of ceramic materials

Fuel production



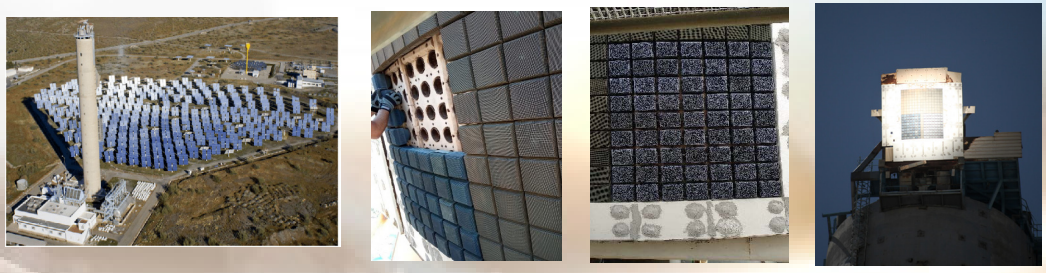
CO_2 supercritical power plants

NEXTOWER ENABLING SOLUTIONS - **SOLEAD DEMONSTRATORS**

The improved open volumetric receiver has been installed and tested at Plataforma Solar de Almeria (Spain).

An innovative single-tank thermocline indirect thermal energy store (TES) system using liquid lead as heat storage medium has been developed and installed at ENEA Brasimone (Italy).

- Compact and efficient thermal energy storage system based on a liquid heat storage medium.
- Flexible plant operation and dispatchable production
- Ease of integration with high-temperature power cycles using compressed gases or supercritical fluids as working media



Demo Plant in Plataforma Solar de Almeria

Demo Plant at ENEA Brasimone

CUSTOMER SEGMENTS

Sectors looking for durable components working at high temperatures:

Pharmaceutical companies

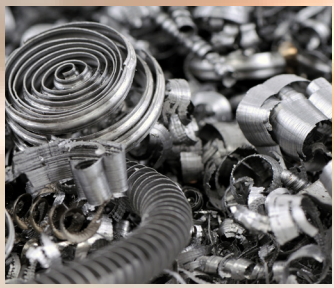
Breweries

Stem gas turbines

Biomass plants

Calcium looping plants

Cement plants



Metal industries

Glass industries

Solar enhanced oil recovery and desalination of sea water

Chemical storage plant

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PROJECT DETAILS

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TOPIC: NMBP-17-2016 - Advanced materials solutions and architecure for high efficiency solar energy harvesting

FUNDING SCHEME: IA - Innovation action

PROJECT WEBSITE: http://www.h2020-nextower.eu

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MORE INFO:

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