Case study

Developing supercritical CO_2 technologies to increase the flexibility of power-generation plants

sCO₂-flex is an EU-based consortium of 10 key industry organizations and academic institutions, and the project has received funding from the EU's Horizon 2020 research and innovation program. Its main objective is to make fossil-fuel-based electricity production more flexible to foster integration of renewable energy sources. Its use of supercritical CO_2 (sCO_2) technology will increase the efficiency of conventional power plants—enabling significantly smaller footprints while reducing greenhouse gas emissions, residue disposal, and water consumption.

Why supercritical CO_2?

The EU 2050 Energy Strategy demands significant reduction of greenhouse gas emissions, and calls for an increase of renewable sources in the energy mix. It becomes fundamental in this context to find new and cost-effective ways to guarantee grid stability in the event of large power output fluctuations.

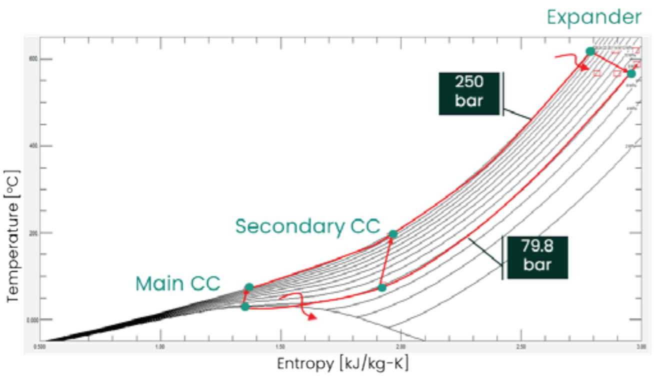
Supercritical carbon dioxide (sCO_2) can play a major role. Compared to other closed-loop bottoming cycles, properties of CO_2 at pressure and temperature higher than the critical values can enable higher efficiencies of both plant and turbomachinery. In addition, extremely compact machines and main components can be achieved thanks to the high fluid density.

The sCO_2-flex project

sCO_2-flex is proposing a new closed-loop thermodynamic cycle, with turbine driven by supercritical CO_2, to improve the flexibility and efficiency of existing conventional power plants while minimizing water usage. The system is based on the Brayton cycle and includes an axial expander and two centrifugal compressors working in parallel. It will provide 25 MWe at 100% load and have the flexibility to reduce load down to 20%. Compared to a water/steam plant, sCO_2-flex can reduce greenhouse gases emissions by 8%.

Baker Hughes' deliverables for the project include:

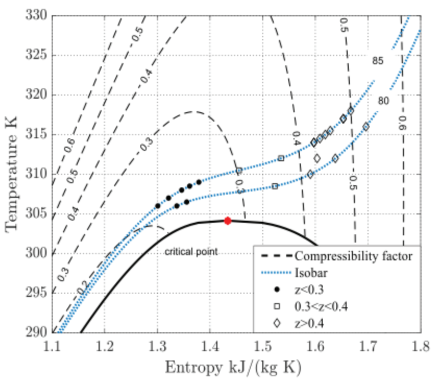
- Design of two compressors and one turbine expander
- Test of prototype compressor working close to CO_2 critical point
- Material selection and relevant tests
- Plant simulation for design and off design conditions
- Cost-effectiveness of the project, including auxiliaries
- Scale-up of the system to 100 MW



Technical challenges and solution

Centrifugal compressor aerodynamic design

Suction conditions very close to CO_2 critical point were selected for the main centrifugal compressor to enhance the cycle's efficiency. These posed the main challenges for the machine's design: in this area the fluid behavior is far from ideal, and it shows large gradients in thermodynamic properties. Special care had to be taken in performance predictability, and a dedicated CFD analysis method was developed in collaboration with Politecnico di Milano. This approach enabled identification of a specific design for the first impeller to mitigate effects of phase change while maintaining the performance targets for pressure ratio and efficiency.

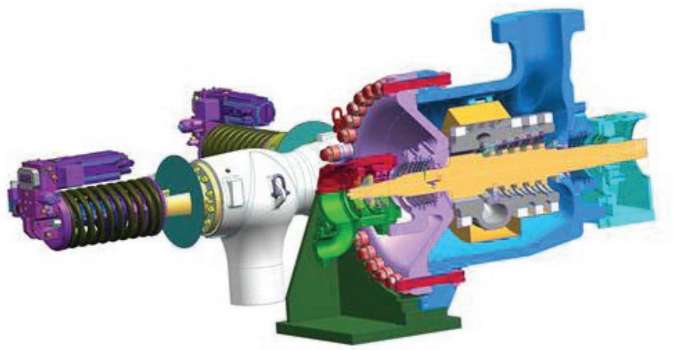


Selected compressor inlet conditions

Another main challenge of the selected cycle was the flexibility in terms of net power: turbomachinery is required to operate from 100% (nominal operating point) to 20% load. To achieve this level of flexibility, design choices such as compressor inlet guide vanes (IGV) and variable-speed drivers have been implemented.

Turbine

A five-stage axial turbine was designed to carry out the expansion. We performed a thorough optimization to balance conflicting requirements like efficiency, rotor-dynamic behavior, and limitation of thermal stresses to maximize operating flexibility. The stability of the rotor-bearings system has been achieved by adopting conventional tilting-pad journal bearings. The expander has been equipped with dry-gas seals (DGS) to minimize leakage without impacting efficiency of the overall cycle. Current DGS technology doesn't work at the expander's operating temperature, so a cooling system has been designed to limit operating temperatures in the areas of the DGS within their allowable limits.



Longitudinal section of the sCO_2 turbine

For partial-load operation, sliding-pressure operation was identified as the most effective method to maximize efficiency.

Compressor prototype and test rig

Design concepts for the main centrifugal compressor have been fully tested at our Florence site in a 5.4 MW prototype reaching supercritical conditions at the inlet.

Off-design conditions were tested, including dual phase and liquid phase at suction, with continuous monitoring of the compressor rotordynamic behaviour thanks to vibration probes. We performed a complete exploration of its operating map, varying rotating speed from 100% to 60%, modifying IGV opening from -60° to +10°, and reaching up to 6.2 MW.

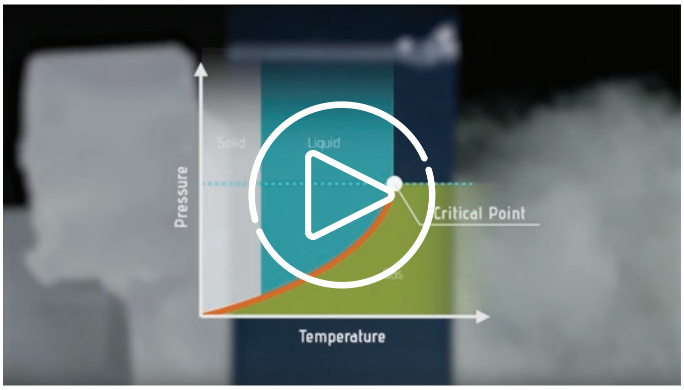
Achievements and benefits

This is likely the first time a compressor of this size has been tested with CO_2 in these conditions—and it fulfilled all requirements. The innovative sCO_2-flex calculation method enables accurate performance predictions for centrifugal compressors working close to the CO_2 critical point.

This is a unique milestone for the validation of sCO_2 cycles, bringing key learnings in terms of efficiency, manufacturability, and controllability of one of the crucial components, the main compressor.

The sCO_2-flex experience has enabled us to design turbomachinery to operate with supercritical CO_2—for selection and production of the most efficient, flexible, and cost-effective supercritical CO_2 cycles to help drive the energy transition.

Compressor prototype installed on the test rig at the Baker Hughes facility in Florence, Italy



Watch the sCO_2-flex video: https://youtu.be/-eNqOqcEGow


Prototype compressor test rig at the Baker Hughes facility in Florence, Italy

The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement 764690 sCO_2-Flex

Baker Hughes