Supercritical Carbon Dioxide Power Cycles Crosscut Initiative

U.S. DEPARTMENT OF ENERGY | Fossil Energy

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) supports a broad portfolio of new fossil-based energy conversion systems integrated with carbon capture, utilization, and storage (CCUS) that are designed to improve the efficiency, flexibility, environmental performance, and affordability of power generation.

Supercritical Carbon Dioxide Power Cycles

Power cycles that use supercritical carbon dioxide (sCO_2) as the working fluid have the potential to deliver significantly higher thermal efficiencies at a lower cost than today's state-of-the-art, steam-based power plants. With successful development, sCO_2 power cycle technology will be able to generate lower-cost electricity from diverse heat sources (coal, gas, nuclear, concentrated solar, or industrial waste heat) while simultaneously reducing emissions and water withdrawals.

The high density of supercritical carbon dioxide enables order-of–magnitude smaller turbo machinery and components, reducing costs. (Image: General Electric)

The sCO_2 power cycles will also provide a much smaller physical footprint, enabling the required scalability and lower capital costs needed to facilitate distributed generation and improve regional energy security and resilience. In addition, the sCO_2 power cycle will offer significant benefits to fossil-fueled heat sources for topping and bottoming power conversion cycles, including waste heat recovery.

How sCO_2 Power Cycles Work

Above the critical point, CO_2 does not change phases (that is, change from gas to liquid). Instead, it undergoes a change in density in even small shifts in temperature and pressure. This property allows a large amount of energy to be extracted at a high temperature, using equipment that is relatively compact. The sCO_2 turbines may be an order of magnitude smaller than today's utility-scale combustion or steam turbines.

The sCO_2 Power Cycles Crosscut Team

To spearhead the development and commercialization of this promising technology, three DOE program offices—Nuclear Energy, Fossil Energy, and Energy Efficiency and Renewable Concentrating Solar Power—are working together to reduce technical hurdles and support foundational research and development of sCO_2 power cycles. The sCO_2 Power Cycles Crosscut team has drawn upon its collective expertise and resources to initiate the design and construction of a pilot-plant facility for Supercritical Transformational Energy Power (STEP).

STEP

The sCO_2 Power Cycles Crosscut team aims to design, build, and operate a 10 MWe indirectly heated sCO_2 pilot plant to demonstrate component performance, cycle operability, and progress toward a lower cost of electricity (COE). At the same time, staff belonging to four FE programs—Advanced Turbines, Advanced Combustion Systems, Crosscutting Technology Research, and STEP—are coordinating efforts to develop an sCO_2 power cycle base program. That program will enable development of FE power systems that are cleaner and have a more affordable COE, working toward two sCO_2 power cycle configurations:

1. Indirectly heated cycle for coal-fired boiler applications
2. Directly fired gaseous fuel (coal-based syngas or natural gas) that captures CO_2

Project funding to design, build, and operate a 10 MWe indirectly fired sCO_2 power cycle pilot facility has been awarded to the Gas Technology Institute, which is partnering with Southwest Research Institute and General Electric (GE). Additionally, Thar Energy is completing the design, fabrication, and testing of multiple 100 kW prototype recuperative heat exchangers, and GE Global Research has completed the designs for a subscale dry gas seal to be tested in conditions representative of a utility-scale sCO_2 power cycle turbo-expander.

Benefits of sCO_2 Power Cycles

- **Small Footprint** – High fluid density enables order-of-magnitude smaller turbo machinery and other components.
- **Higher Efficiency** – Cycle offers greater efficiency than state-of-the-art supercritical coal-fired steam with 90% capture and compression.
- **Reduced Water Use** – Indirectly heated sCO_2 cycle reduces water withdrawals by approximately 8%. Preliminary studies indicate that condensing sCO_2 cycles can have relatively small cost and efficiency penalties for dry cooling.
- **Lower CO_2 Emissions** – Direct-fire configuration provides intrinsic separation and compression.
- **Scalability** – sCO_2 turbomachinery is projected to maintain high efficiency when scaled to smaller sizes (<100 MWe), lowering capital requirements.

Key R&D Challenges Facing Development of the sCO_2 Power Cycle

- **Materials** – Identify cost-effective materials compatible with the sCO_2 working fluid at the high temperatures and pressures of the system.
- **Recuperators** – With the high degree of heat recuperation required by the cycle, reduce the size and cost of recuperators, balancing the tradeoffs in size, cost, pressure drop, effectiveness, and approach temperature.
- **Turbomachinery** – Design turbomachinery specifically for the high power density and high temperature of the cycle and for use with the sCO_2 working fluid. The low pressure ratio (3–4) leads to high sCO_2 flow rates. (8–12x greater than those in steam cycles). Also develop low-leakage turbomachinery shaft seals because leaked CO_2 must be recompressed, reducing efficiency.
- **Design** – Develop designs that will cost-effectively integrate the heat source with the sCO_2 power cycle, supporting high temperatures, high mass flow, and low pressure drop.

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