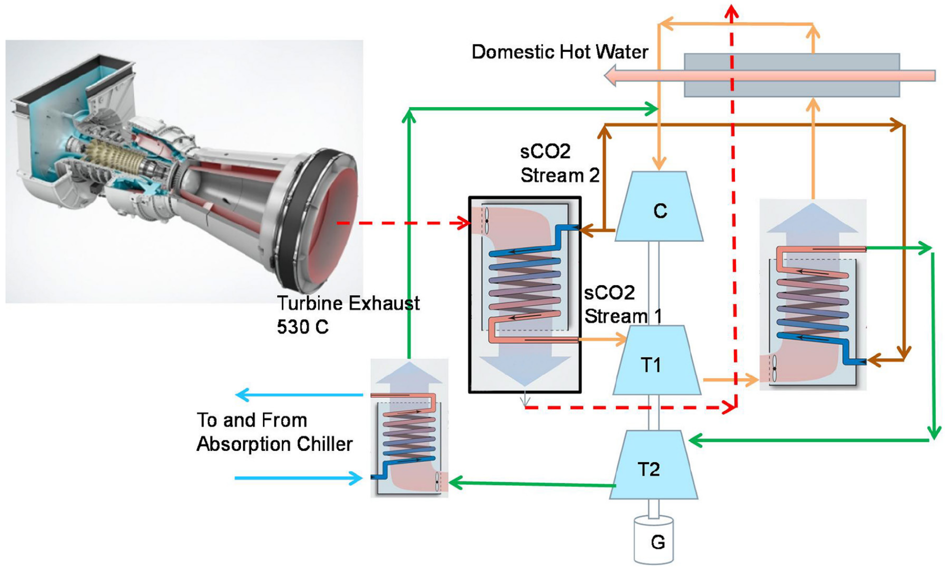
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Flexible CHP System Utilizing Improved Gas Turbine and sCO_2 Cycles



To achieve full-load and partial load efficiency targets, the CHP system will incorporate two cascading bottoming cycles that utilize supercritical carbon dioxide (sCO_2) as the working fluid. *Image courtesy of Siemens Corporation*

Combined heat and power (CHP) systems provide both electricity and heat for their host facilities. CHP systems have mostly saturated the large industrial facility market, where economies of scale and the presence of needed technical staff make the deployment of large systems greater than 20 megawatt (MW) electrical capacity cost effective and practical. There remains, however, substantial room for growth of smaller CHP systems suited for small and mid-size manufacturing facilities.

In addition to manufacturing facility energy benefits, the needs of the modern electric grid are other potential drivers for further deployment of CHP systems. As intermittent renewable generation resources constitute a growing and increasingly significant portion of electricity generation, the need for dispatchable generation resources to maintain the stability of the grid grows. Many small and mid-size manufacturing facilities would be ideal hosts for flexible CHP systems that can provide needed grid services.

In order for CHP systems to be seamlessly integrated with the grid and provide more advanced grid services, further technical development is needed. For such CHP systems to be cost-effective and able to respond to changing grid conditions, they must be able to maintain high system efficiency at partial load conditions and have the ability to ramp up or down quickly.

This project seeks to enable a new type of a flexible CHP system by adding a supercritical carbon dioxide (sCO_2) bottoming cycle and a steam injection system to an existing 5.3 MW gas turbine to increase its peak electrical efficiency to 50% and maintaining 30% electrical efficiency at 50% of load. The new turbine configuration will provide approximately 8 MW of electric capacity, and total CHP system efficiency is projected to remain at 85% both at rated capacity and 50% of load.

Benefits for Our Industry and Our Nation

Because of the projected high system efficiency at part load conditions and the ability of the gas turbine to ramp up or down quickly, the new technology would contribute to the development of flexible CHP systems that could be used to provide needed grid services, such as additional generating capacity during times of peak demand and voltage regulation. Having such highly efficient flexible CHP systems could provide significant financial benefits to the host facility, but also to the grid system operator and all ratepayers. According to a 2018 manufacturing sector analysis conducted for the U.S. Department of Energy, widespread deployment of flexible CHP systems that are able to provide grid services could result in annual financial benefits of approximately $1.4 billion in the state of California alone. These savings consist of lower industrial site energy costs, reduced grid operating costs, and capacity value of the new electric generators.

Applications in Our Nation's Industry

A CHP system consisting of a high-efficiency gas turbine and sCO_2 bottoming cycle will be suitable for many small and mid-size manufacturing facilities with both electrical and thermal loads. The increased gas turbine cycle efficiency will improve the business case for the installation of such CHP systems in the 5-10 MW size range.

Flexible CHP systems that can provide grid services are expected to be financially attractive investments in markets with high penetration of intermittent renewable resources, such as California, Texas, and several Midwestern states.

Project Description

This project seeks to integrate a sCO_2 bottoming cycle with a 5.3 MW gas turbine to develop a CHP system that is able to transition rapidly between 50% and 100% load by engaging or bypassing the bottoming cycle while maintaining electrical system efficiency above 30% at all times. The project team will engineer an optimized design of the power systems. The needed new key components, such as advanced heat exchangers and a steam injection system for the gas turbine, will be developed and their performance demonstrated in rig tests. The feasibility of the whole integrated CHP system will be validated through a cyber-physical approach.

Barriers

- Integration of the different technologies so that operating conditions and system component sizing is optimized for waste heat recovery
- Identification of cost-effective materials for the primary heat exchanger that do not degrade prematurely in high-moisture exhaust gas at 550°C
- Design for a secondary heat exchanger that can tolerate sCO_2 on one side and saturated steam on the other

Pathways

The new CHP system configuration will use an existing 5.3 MW aero-derivative gas turbine as its starting point. It is a proven turbine with capability for fast cold-starts, fast ramping up and down, and multiple starts and shutdowns per day.

The turbine currently has an electrical efficiency of 32% at rated power, but with additional steam injection this efficiency can be increased to approximately 37%. Incorporating a sCO_2 bottoming cycle will increase total electrical efficiency to around 50%. The project team will explore different cycle designs to find the best possible system configuration. Special emphasis will be placed on thermo-economic optimization of the cycle, to ensure commercial viability and marketability of the developed system.

To inject additional steam into the turbine, a new fuel nozzle variant will be designed, built, and tested. Additive manufacturing approaches, which allow intricate designs not feasible with conventional manufacturing technologies, will be utilized to build the modified nozzle.

A major focus of the project will be the development and demonstration of novel heat exchangers. To achieve project goals, a new heat exchanger design is needed for the primary cycle between the gas turbine and the sCO_2 system as well as the secondary cycle between the sCO_2 and process steam systems. The new advanced heat exchanger designs need to be optimized for low pressure drops, have the ability to withstand multiple cycles at high temperature and pressure, include integrated control systems, and be cost effective. Suitable low-cost materials will be identified and alternative manufacturing techniques pursued.

Milestones

This three-year project began in late 2018.

- Initial selection of CHP system components and modeling to confirm feasibility of system design meeting electrical efficiency goal of 50% at rated power (2019)
- 2,000 hours of materials testing for candidate heat exchanger materials under sCO_2 conditions (2020)
- Validation of performance improvement (from 32% to 37% in efficiency) utilizing additively manufactured steam injection nozzle (2020)
- Demonstration of performance for new heat exchanger designs and verification of 25% reduction in projected heat exchanger cost (2021)
- Validation that CHP system performance meets project efficiency goals at rated power and 50% of load (2021)

Technology Transition

The developed CHP system will build on an existing 5.3 MW Siemens gas turbine that has a proven track record of service and more than 1,600 installed units worldwide. Marketing a new, advanced version of an existing gas turbine is expected to be easier than a completely new system design. If the new gas turbine integrated with a sCO_2 bottoming cycle is successfully demonstrated, Siemens will conduct a detailed market study, develop a market entry plan, and identify an initial group of likely interested customers and technology partners. Besides small and medium-size manufacturing facilities, likely host sites for the developed system include large hotels and apartment complexes, hospitals, and universities.

Project Partners

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