U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

Robust Combined Heat and Hybrid Power (CHHP) for High Electrical Efficiency Cogeneration

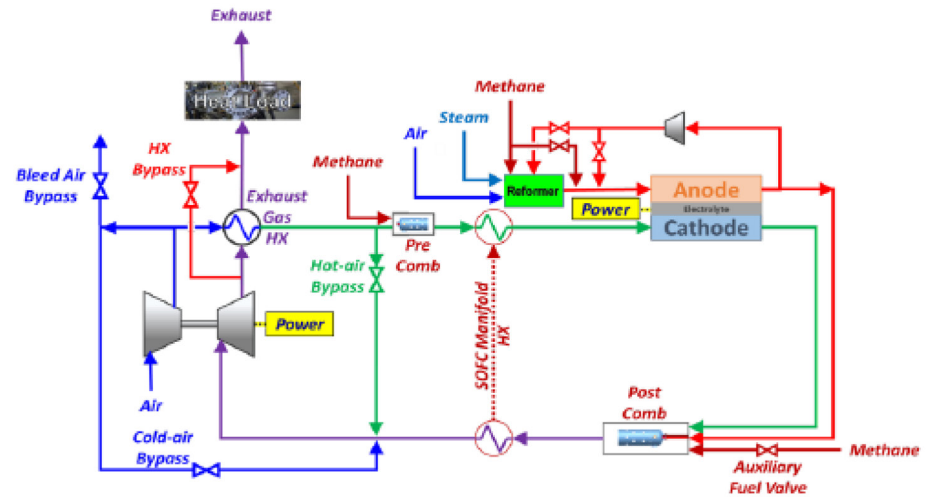

Diagram of a hybrid solid oxide fuel cell/gas turbine (SOFC/GT) cycle as a combined heat and hybrid power (CHHP) system for both robust and high power-to-heat ratio (P/H) cogeneration. *Diagram courtesy of Georgia Institute of Technology.*

According to the U.S. Department of Energy Combined Heat and Power Installation Database, approximately 80 GW of electrical power is produced in the United States using combined heat and power (CHP) systems. Studies have also shown that a potential market for CHP applications is larger than the existing market. Since fuel consumption is the most significant part of the operating cost for a CHP plant, higher efficiency translates to increased power output for the same quantity of fuel. Therefore, more efficient power conversion will decrease the price of electricity generated and improve the economic feasibility of new CHP applications.

A large part of the untapped CHP market is in the smaller scale applications (i.e., less than 20 MW). Of the installed CHP capacity in the United States, gas turbines account for more than 60%. Electrical efficiency of large turbines can exceed 43%, while smaller turbines (less than 20 MW) are typically less than 35% efficient. Combining gas turbines and fuel cells into a hybrid system is one strategy to achieve greater system efficiency in smaller turbines and improve their cost-effectiveness.

Solid oxide fuel cell/gas turbine (SOFC/GT) systems are hybrid power systems that have projected electrical efficiencies of more than 70% (lower heating value, or LHV). Researchers in laboratories and industry have spent years and resources developing these SOFC/GT cycles into highly efficiency power cycles; however, not as much attention has been placed upon developing these systems into cogeneration cycles, namely combined heat and hybrid power (CHHP) systems. Such systems would be especially attractive for high electrical efficiency cogeneration.

The intent of this project is to facilitate the development of such high electrical efficiency cogeneration cycles by leveraging and extending SOFC/GT hybrid power system research conducted by the U.S. Department of Energy's National Energy Technology Laboratory (NETL), which houses the nation's only fuel cell/gas turbine cycle cyber-physical system (CPS) testbed facility, Hybrid Performance (Hyper).

Benefits for Our Industry and Our Nation

Specifically, the goal of this project is to determine what variable heat and power loads the cycle can meet while maintaining a 70% LHV electrical efficiency and an 80% LHV cogeneration efficiency. The overall success of the research focuses on meeting these efficiency goals for versatile and dynamic loading. Such success will help improve manufacturing/industrial energy efficiency because the proposed, elevated efficiencies of the system meet or exceed the efficiencies of heat outputs derived from combustion processes onsite at the manufacturing facility and electrical power obtained by the manufacturing facility from the grid, and with the added benefit of onsite CHP generation. In addition, the dynamic versatility being sought can be a key asset in accommodating the new transient operability requirements that are evolving given the growing penetration of renewable energy sources within the electric grid.

Applications in Our Nation's Industry

This project is likely to increase the efficiency of onsite heat and power generation, which will decrease manufacturers' energy costs and reliance on the grid for power and external heat sources, such as fuels. The types of manufacturers that are expected to benefit from this project include those with power-to-heat ratios (P/H) between 0.75 and 1.5, possibly up to 2. Manufacturers with loads resulting in 0.75-1.5 P/H ratios may not use existing thermally driven CHP technology because it cannot satisfy these ratios. The use of CHHP systems will be beneficial to these target manufacturers, which include animal/poultry processing, bakeries and milk/flour/pastry manufacturing, tire/rubber manufacturing, textile mills, dry/frozen food manufacturing, electrochemical processing (alkalis and chlorine manufacturing), and newsprint mills.

Project Description

The goal of this project is to develop a hybrid SOFC/GT cycle as a CHHP system for both robust and high P/H cogeneration. The system concept will entail a "direct" hybrid arrangement wherein a high temperature SOFC stack will be inserted within the pressurized side of a recuperative Brayton cycle. Fuel (e.g., methane from natural gas) will be reformed and then primarily oxidized in an electrochemical manner for direct power generation, while residual reformate and byproduct thermal energy will flow into a "bottoming" post-combustion turbine assembly for additional power generation.

Additionally, turbine exhaust thermal energy will flexibly support recuperative preheating of the airstream entering the fuel cell stack and/or bottoming thermal loads that span various heating needs (e.g., sensible temperature gains of process streams and thermally driven absorption cooling). This versatility in heat reclaim will be enabled by a novel, high-temperature valve technology that will allow the recuperator bypass to be immediately downstream of the turbine expander. This project will determine what versatile and dynamic heat and power loads can be met at elevated efficiencies (70% LHV electrical and 80% LHV cogeneration) through the operation of this bypass valve and given different configurational and operational design possibilities.

Barriers

- Ensuring the physical appropriateness of using piezoelectric material as the enabling technology for a CHHP recuperator bypass valve
- Simulating the fuel cell/gas turbine CHHP concept, inclusive of the virtual hot gas bypass valve, in a cyber-physical platform
- Resolving viable scenarios wherein the targeted electrical and cogeneration efficiencies can be met across a domain of targeted sectors and in a robust, dynamic manner

Pathways

In the first part of this project, team members will enhance the NETL Hyper simulator to address cogeneration. Dynamic heat exchanger behavior will be developed for real-time simulation in the CPS platform. This will allow for cogeneration to be modeled based upon measured turbine exhaust temperature and flow in conjunction with simulated thermal loads. The thermal loads will be simulated based upon heat profiles within strategic industrial sectors that require high P/H CHP. Piezoelectric materials development will transition from lab-scale reduction-to-practice to pilot implementation as a "flap" within the Hyper recuperator. This flap initiation will serve as a precursor to the bypass valve.

In the second part of this project, team members will utilize the piezoelectric flap to insert a computational representation of the envisioned recuperator bypass within the Hyper platform. Then, they will perform design space exploration to optimize dynamic electrical and cogeneration efficiencies within strategic industrial sectors that require high P/H cogeneration (e.g., assembly plants and electrochemical plants), but this time, inclusive of computationally represented hot air bypass valve technology.

Milestones

This three-year project began in late 2020:

- Hyper facility simulation (in real-time) of dynamic CHP given variable heat stream "source" and heat stream "sink(s)" (2021)
- Simulation and exploration of system performance (e.g., electrical and cogeneration efficiencies) across dynamic power and heat demand profiles (2022)
- Progression of piezoelectric technology from academic fabrication tests to national lab testbed implementation (2022)
- Development of virtual recuperator bypass within Hyper platform (2023)
- Design space exploration to optimize dynamic electrical and cogeneration efficiencies with virtual recuperator bypass (2023)

Technology Transition

The project is likely to make an impact on commercial technology and public use. The current focus of hybrid fuel cell/gas turbine technology is on high efficiency electricity generation. This project will expand the focus to an even higher efficiency electricity generation and heat cogeneration system to embrace and optimize CHP merits. Upon successful development and cyber-physical demonstration of the CHHP system for both robust and high P/H cogeneration, this project will aim to spark follow-on and complementary investments from an interested power and energy private sector.

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DOE/EE-2672 • December 2022