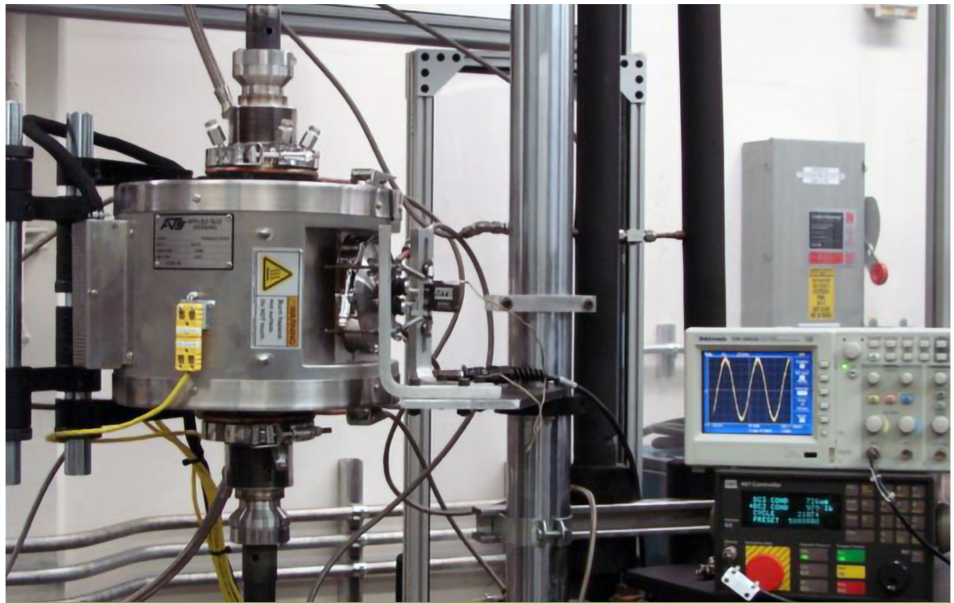
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

High Performance, High Temperature Materials to Enable High Efficiency Power Generation



The project team uses an environmental fatigue rig to evaluate the performance of advanced materials at high temperatures. The identified new materials enable CHP systems that are more efficient and less expensive to maintain.
Image courtesy of Oak Ridge National Laboratory

According to the U.S. Department of Energy Combined Heat and Power Installation Database, approximately 80 gigawatts (GW) of electrical power is produced in the United States using combined heat and power (CHP) systems. Studies have also shown that the potential market for CHP applications is larger than the existing market. A large part of this untapped CHP market is in smaller-scale applications of less than 20 megawatts (MW). 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.

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. Identification and development of new high performance materials can play a significant role in improving the efficiency and other project economics of gas turbines and other CHP technologies. Improved materials used in critical components—such as heat exchangers and combustion liners—can allow CHP systems to operate at higher temperatures, which enables higher system efficiency. In addition, new materials that perform better in demanding high temperature conditions will last longer and reduce operating costs, and, if the new materials can be produced at lower cost, the capital cost of CHP systems will go down.

This projects seeks to evaluate advanced materials and develop lifetime modeling tools to enable a greater than 100°C increase in gas turbine inlet temperature compared to a 2015 baseline and improve the durability and reduce maintenance costs of high temperature components in current CHP systems. The targeted components include heat exchangers, combustion liners, and hot corrosion-resistant coatings for disk applications with high sulfur opportunity fuels.

Benefits for Our Industry and Our Nation

Combined-cycle and simple-cycle gas turbines are the most common onsite electrical generation technologies utilized in the industrial and commercial sectors, representing approximately 50 GW of installed capacity. If the materials and models developed as part of this project enable a 10% increase in the installed capacity of onsite CHP systems, it would result in a 5 GW increase in total CHP capacity. Such increase in CHP installations would avoid 22 million tons of carbon dioxide emissions and save approximately $500 million in fuel costs annually. If the developed technologies enable the sale of an additional 200 turbine units, the value of these increased sales would be approximately $2 billion.

Applications in Our Nation's Industry

This project focuses on material improvements that are applicable to smaller—under 20 MW—gas turbines and other CHP prime mover technologies. The increased system efficiency, lower maintenance costs, and decreased production cost will improve the business case for the installation of such smaller CHP systems. Many small- and mid-sized manufacturing facilities and data centers with both electrical and thermal loads are suitable hosts for CHP systems of this size. CHP technology is broadly applicable across a variety of industrial sectors, including the chemicals, food and beverage, plastics, and fabricated metals industries.

Project Description

This project aims to identify and evaluate new advanced high-performance, high-temperature materials that enable the development of CHP technologies with higher efficiency and lower maintenance and operating costs. A key objective of the project is to identify advanced materials that enable a greater than 100°C increase in gas turbine inlet temperature compared to a 2015 baseline without a reduction in component durability. In addition, the projects seeks to identify materials and coatings that improve the durability and reduce the maintenance costs of high temperature components in CHP systems.

Barriers

- Need to identify new materials that are cost-effective and meet the high performance targets
- The new flexible CHP paradigm, in which the systems are expected to provide grid services on an as-needed basis, is likely to result in more frequent cycling; this may significantly impact material degradation
- New coating solutions can potentially lead to sensitivity to fatigue cracking and thereby reduce component life

Pathways

To identify advanced materials that enable a greater than 100°C increase in gas turbine inlet temperature, the project team will investigate new oxidation resistant Ni-based alloys for turbine combustor liners and lower cost steel materials for turbine recuperators. This work will build on previous materials research conducted at Oak Ridge National Laboratory (ORNL). The project team will also work to improve lifetime models for predicting the long-term behavior of high performance alloys as a function of component thickness, operating temperature, and service conditions.

In a separate effort, mechanical properties of candidate coatings that resist hot corrosion at approximately 700°C will be evaluated. Durable, high-temperature coatings will enable the use of lower cost alloys in harsh environments, such as those created by combustion of certain opportunity and renewable fuels.

To conduct some of the needed advanced characterization tasks, the project team will utilize the Advanced Photon Source (APS) at Argonne National Laboratory. APS provides ultra-bright, high-energy x-ray beams that are capable of evaluating subsurface material features. It is also able to conduct in-situ characterizations over a wide range of time scales to study the evolution and progression of key phenomena.

Milestones

This three-year project began in 2019:

- Evaluate at least three alloys in foil form at 850°C to identify reaction rates less than 2 μm/year in simulated exhaust gas based on more than 5,000 hours of cumulative laboratory testing (2020)
- Identify at least one coating material with corrosion rate at least 10 times lower and fatigue life more than 2 times higher compared to an uncoated alloy in corrosive environment at 700°C (2021)
- Validate, based on input data from more than 10,000 hours of experimental data, a lifetime model that includes growth, spallation, and evaporation of the oxide scale and predicts chromium loss behavior within ±1 standard deviation of the measured experimental data (2022)

Technology Transition

For some of the materials that are being evaluated in this project, including the alumina-forming austenitic (AFA) steels and Ni-based alumina-forming wrought alloy, patents have been awarded and they are available to license from ORNL. Once the performance of the new materials is validated in this project, it is expected that alloy manufacturers willing to produce the new materials can be identified.

For the coatings task, the work is conducted with feedback from industry partners. The corrosion-resistant coatings being evaluated have been identified as very promising by the gas turbine industry, but further fatigue analysis of the coated materials is needed before more expensive engine testing is warranted.

The lifetime materials model being developed by the project team will be freely available and publicized to the industry through journal publications and conference presentations.

Project Partners

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