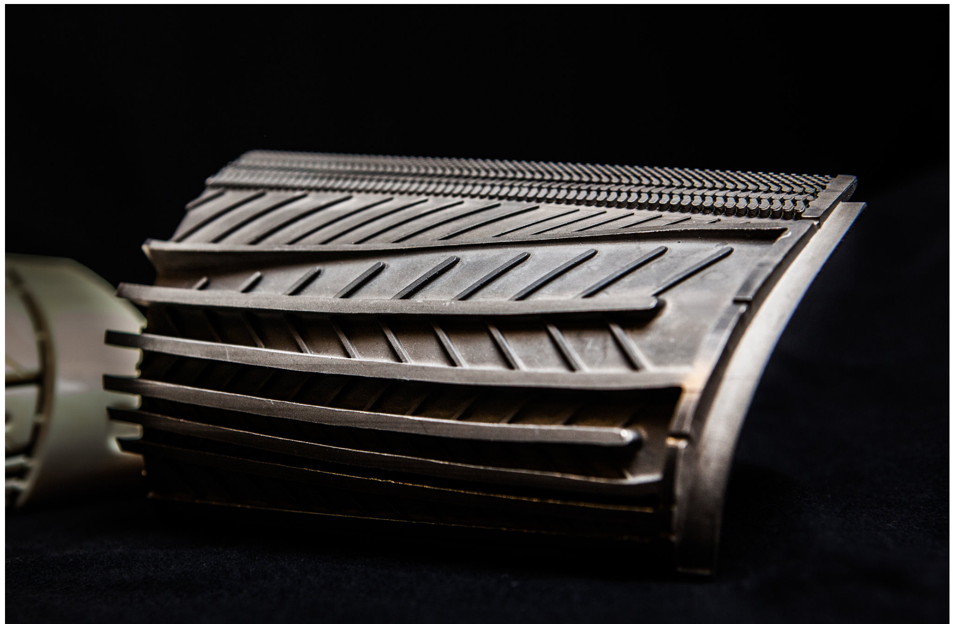
Advanced Turbine Airfoils for Efficient Combined Heat and Power Systems



This project explores the use of advanced airfoil materials and designs as well as additive manufacturing approaches to increase system efficiency of gas turbines with less than 20 MW capacity. *Image courtesy of National Energy Technology Laboratory*

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. Increasing turbine inlet temperatures is one strategy to achieve greater system efficiency in smaller turbines and improve their cost-effectiveness.

This project seeks to evaluate how a combination of new materials, additive manufacturing (AM) technologies, and airfoil cooling design can raise the efficiency of turbines used in CHP systems by demonstrating how to increase the turbine firing temperature by 100°C compared to a 2015 baseline. The project team will also estimate the economic benefits from these efficiency gains in CHP systems that use turbines smaller than 20 MW.

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 gigawatts (GW) of currently installed CHP capacity. If the technologies developed as part of this project enable 5 GW of additional CHP power generation, the potential environmental and economic benefits are significant, including:

- 22 million tons of carbon dioxide emissions would be avoided
- Approximately $500 million in fuel costs would be saved annually

The technologies developed under this project could also be utilized in turbines used in other markets, such as naval, aerospace, and other power applications. These other markets represent an estimated $80 billion per year in business. 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 improvements to smaller—under 20 MW—gas turbines suitable for CHP applications. The increased gas turbine efficiency will improve the business case for the installation of smaller CHP systems that match the potential domestic CHP markets. CHP technology is broadly applicable across a variety of industrial sectors, including the chemicals, food and beverage, plastics, and fabricated metals industries. Advancements in the airfoil materials, manufacturing, and design will also benefit other types of gas turbines, including larger stationary engines and turbines used in naval and aerospace applications.

Project Description

This project aims to develop new materials, additive manufacturing approaches, and airfoil cooling designs that enable a 100°C increase in the gas turbine firing temperature relative to a 2015 baseline. The ability to raise the turbine inlet operating temperature will increase the efficiency of the engine, which in turn will result in lower fuel costs for operating the turbine. Before building a fully functional airfoil demonstration unit, the viability of the identified new materials, system design, and manufacturing approaches will be evaluated using coupon tests, modeled engine performance, and technoeconomic analyses.

Barriers

- Airfoil geometries and cooling designs are proprietary information, so no public baseline design currently exists for reference.
- The creep-resistant, high temperature alloys used for gas turbine hot gas components have been optimized for casting manufacturing methods and these materials will crack when welded; therefore, simply substituting these materials into a Direct Metal Laser Sintering (DMLS) additive manufacturing process is not feasible.
- Material behavior during AM processing is not fully understood and documented.
- The yield, precision, and process steps needed for AM airfoils manufacture have not been optimized or defined.

Pathways

A technical advisory panel of commercial turbine manufacturers will be established. It will guide the research direction and provide insight into candidate technology solutions being considered throughout this project.

The project will proceed in two separate phases. Phase 1 is the current focus of this effort, and Phase 2 is an option that will be considered at a later date.

In Phase 1, the project team will demonstrate the potential of AM airfoils to achieve the turbine efficiency and temperature goals. A baseline state-of-the-art airfoil cooling design will be defined. Additionally, advanced cooling designs, materials, and AM methods will be identified and evaluated. Of particular interest are new cooling geometries enabled by the use of AM approaches. After down-selection of technology alternatives, AM test articles that have features representative of airfoils will be manufactured and tested for durability and cooling characteristics. Numeric models of turbine and airfoil performance will be used to project installed engine efficiency. A technoeconomic analysis will also be conducted to estimate market penetration of the new airfoil design for CHP applications.

The optional Phase 2 effort will be contingent on the ability of the best airfoil design to meet the prerequisite performance targets for a larger scale demonstration. If Phase 1 is successful, an agreement will be established with a turbine manufacturer to incorporate the airfoil in an actual engine and test its performance during Phase 2.

Milestones

This three-year project began in 2019:

- Complete baseline cooling design to be used as reference (2020)
- Identify most promising AM materials and manufacture coupons for materials testing (2020)
- Use model predictions to estimate system performance and market for the advanced CHP turbine (2020)
- Complete coupon testing and preliminary airfoil design (2021)
- Manufacture a demonstration airfoil and complete prerequisite performance testing of the airfoil at engine representative temperatures (2022)

Technology Transition

This project will provide a basis for future technology development by defining public baseline conditions for small gas turbines and baseline airfoil designs. In this context, baseline will be defined as "representative of gas turbine engines in a specific size category, but not specific to any commercial engine."

Through the technical advisory panel, gas turbine manufacturers will engage with the research team from the beginning of this project to improve the value and eventual technology transition to the end-users. Gas turbine manufacturers have also expressed interest in utilizing AM approaches to develop new cooling geometries for gas turbine engines, but the technical barriers are significant. If the project is successful, the technology will be available to all equipment manufacturers.

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