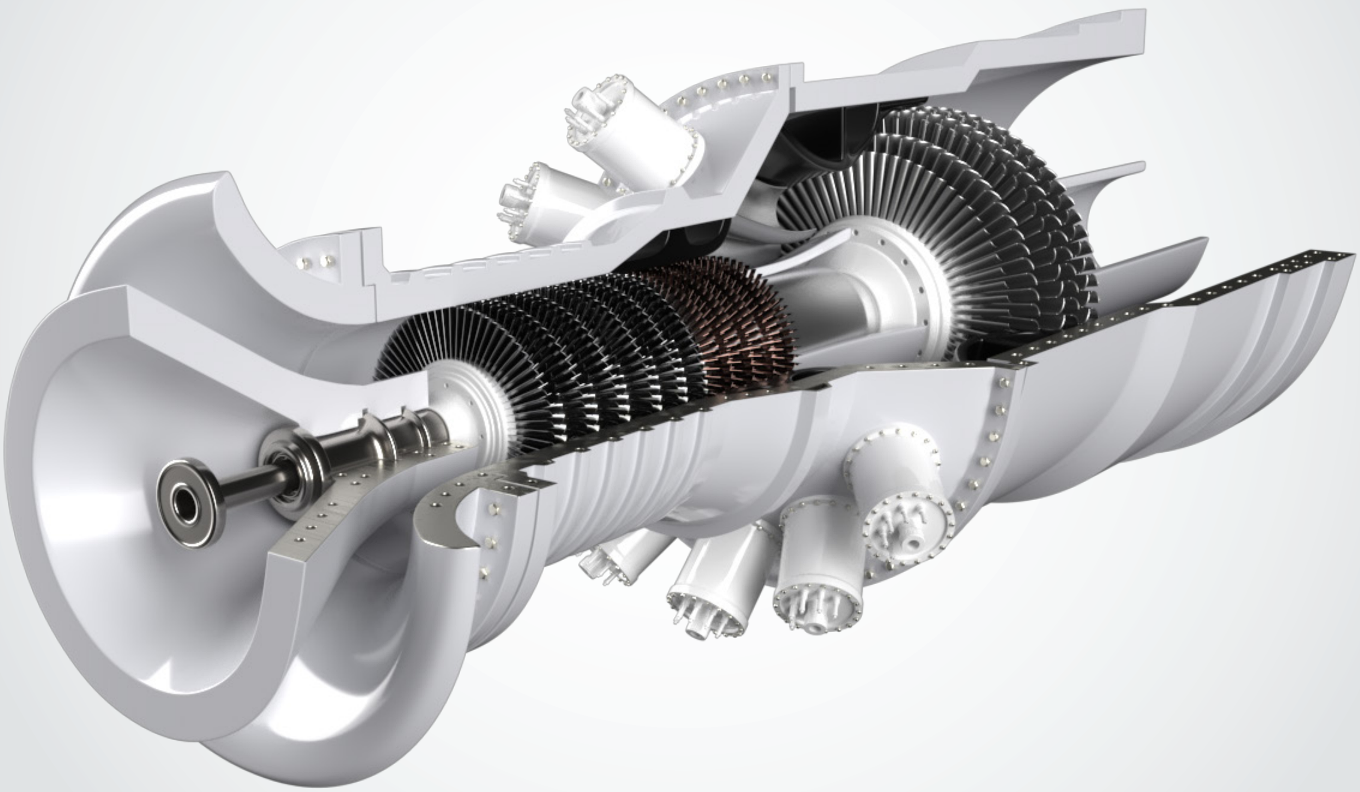
ADVANCED TURBINES



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BACKGROUND

The U.S. Department of Energy's (DOE) Advanced Turbines Program is conducted under the Office of Fossil Energy and Carbon Management's (FECM) Research Program. Fossil fuels account for approximately 79% of total U.S. primary energy use due to their abundance, high energy density, and the relatively low costs associated with production and use. However, the combustion of fossil fuels for electricity generation is the largest single source of carbon dioxide (CO_2) emissions in the nation, accounting for approximately one-third of total U.S. CO_2 emissions. Control and mitigation of greenhouse gases from energy production and industry is a national focus, as the Biden administration has set a goal of a 50% reduction in greenhouse gas emissions by 2030, zero emissions in the power sector by 2035, and net-zero emissions economy-wide by 2050.

FECM recognizes that to meet the nation's climate goals, we must manage the carbon that comes with the legacy use of fossil fuels and make addressing the climate crisis a primary goal. FECM will use its extensive research capabilities to minimize the climate and environmental impacts of fossil energy and to advance carbon management in order to achieve a net-zero carbon power sector by 2035. This includes research and development (R&D) in point-source carbon capture, CO_2 removal, CO_2 conversion into products, CO_2 storage, blue hydrogen production, carbon-free power generation, and critical mineral production from industrial and mining waste.

ADVANCED TURBINES PROGRAM

The Advanced Turbines Program is focused on the development of advanced turbine technologies that will accelerate turbine performance, efficiency, and cost effectiveness beyond current state-of-the-art. The program will provide tangible benefits to the public in the form of options for eliminating CO_2 emissions, lowering cost of electricity (COE), and reducing emissions of criteria pollutants. The efficiency of combustion turbines has steadily increased as advanced technologies have provided manufacturers with the ability to produce highly advanced turbines that operate at very high temperatures. Further increases in efficiency are possible through the continued development of advanced components, combustion technologies, material systems, thermal management, and novel turbine-based cycles.

KEY TECHNOLOGIES

The Advanced Turbines Program supports four key technologies that will advance clean, low-cost power production from fossil energy resources while providing options for CO_2 mitigation. These key technologies include: (1) Advanced Combustion Turbines, (2) Pressure Gain Combustion (PGC), (3) Turbomachinery for Supercritical Carbon Dioxide (sCO_2) Power Cycles, and (4) Modular Turbine-Based Hybrid Heat Engines. DOE's R&D in advanced turbines technology develops and facilitates low-cost advanced energy options for carbon-negative energy ecosystems.

ADVANCED COMBUSTION TURBINES — Research in this key technology addresses component development to advance the efficiency of combustion turbine systems. The objective is to reduce the overall cost of carbon capture and utilization in energy systems by increasing the capability and efficiency of these turbines while simultaneously minimizing or altogether eliminating the emissions of CO_2. By enabling turbines to combust carbon-free fuels with higher efficiency and lower cost, we will make headway towards achieving a carbon-free power sector by 2035.

Combustors and hot section parts are a primary interest. This target will be achieved in part by optimizing turbine technology for various low-carbon fuels to include natural gas, and hydrogen blends, along with carbon-free fuels such as ammonia, hydrogen, renewable natural gas, and synthetic fuels with low-carbon intensity. Additionally, combined-cycle turbine systems will be optimized for post-combustion carbon capture applications.

Efficiency targets will be addressed by developing advanced components. Component R&D is being conducted that will allow higher turbine inlet temperatures; manage cooling requirements; minimize leakage; advance compressor and expander aerodynamics; advance the performance of high-temperature, load-following combustion systems with low emissions of criteria pollutants, including oxides of nitrogen (NOX); and, overall, lead to improved efficiency of the gas turbine machine in a combined-cycle application. The program currently applies combustion turbine R&D to large-frame, aeroderivative, and industrial-scale machines.

The efficiency goal for the program is 65% for large combined-cycle machines (lower heating value [LHV], natural gas benchmark). Efficiency goals will be achieved by conducting R&D on gas turbine hot section components and technology, including, but not limited to, materials, advanced cooling, leakage control, advanced aerodynamics, and altogether new turbine design concepts. This research will discover and exploit the potential for new designs and operation offered by advanced manufacturing, machine learning, and artificial intelligence. To achieve the efficiency goal, special emphasis will be placed on combustor development to support high-temperature, stable, and low-NOX combustion on a range of fuels. Combustion turbine technology will have an additional role in energy storage and decarbonizing industry. Overall, similar R&D will be used to develop simple-cycle aeroderivative and industrial class machines to advance efficiency and the use of low carbon and carbon-free fuels.

PRESSURE GAIN COMBUSTION — Pressure gain combustion (PGC) has the potential to significantly improve gas turbine performance by realizing a pressure increase versus a pressure loss through the combustor of the turbine. Hydrogen is a particularly attractive fuel for PGC and is being explored in this program. In accordance with the Biden Administration's 2035 net-zero carbon emissions goal in the power sector, PGC is a way to further increase H_2 turbine efficiency. Concepts for PGC utilize multiple physical phenomena—including resonant pulsed combustion, constant volume combustion, or detonation—to affect a rise in effective pressure across the combustor, while consuming the same amount of fuel as the constant pressure combustor.

PGC projects focus on assessing the potential benefit of PGC system technology for combined-cycle gas turbines. Researchers are focused on combustion control strategies and fundamental understanding of pressure wave-flame interaction that will lead to lab-scale testing and component prototyping for turbine integration with PGC. Project participants are developing system models for combined-cycle turbine systems to define the path to configurations that exceed 65% combined-cycle efficiency. These models will be validated against experimental data. In addition, these projects will document the technical gaps for PGC development and turbine integration in order to focus continued R&D.

TURBOMACHINERY FOR sCO_2 POWER CYCLES — Power cycles that use sCO_2 as the working fluid offer efficiency benefits and can be optimized for power generation with nearly 100% carbon capture. Indirectly heated closed sCO_2-based power cycles have applications in "boilers" and as energy storage heat pumps. DOE's Supercritical Transformational Electric Power (STEP) 10 MWe pilot project is a specialized example of this indirectly heated cycle. Directly fired oxyfuel cycles use sCO_2 as the working fluid at high pressure and offer options for high CO_2 capture rates. The higher efficiency and unique performance characteristics of sCO_2 power cycles provide broad applications that can potentially supplant other less efficient and more challenging working fluids, such as cycles based on steam and organic working fluids. To support technology development for these two general cycles, R&D will be conducted in oxyfuel (gaseous) combustion systems, sCO_2 expanders and compressors, and other cycle-supporting subsystems.

MODULAR TURBINE-BASED HYBRID HEAT ENGINES — Projects seek to develop modular turbine-based hybrid heat engines for FECM applications that integrate with modular gasifiers, promote the clean use of stranded fuels, support energy storage cycles, make hydrogen generation more affordable, improve the efficiency and environmental performance of natural gas compression stations, and provide an affordable COE. A goal will be to develop modular heat engines that can be used to decarbonize energy and industry ecosystems.

INNOVATIVE ENERGY SYSTEMS

TECHNOLOGY AREA	KEY TECHNOLOGIES	RESEARCH FOCUS
ADVANCED TURBINES FECM's Advanced Turbines Program provides the technology to manage carbon and meet the nation's climate goals while providing dispatchable and base load electricity. The program will do this by investing in hydrogen combustion and advanced gas turbine components R&D.	Advanced Combustion Turbines	• Increasing H_2 Fuels • Ceramic Matrix Composites • Low NO_x combustion
	Pressure Gain Combustion	• Cycle studies • Turbine integration
	Supercritical CO_2 Turbomachinery	• High-pressure, high-temperature oxy-combustion • Turbomachinery component development
	Modular Turbine-Based Hybrid Heat Engines	• Improve efficiency • Modular scalability

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NETL is a U.S. Department of Energy national laboratory that drives innovation and delivers technological solutions for an environmentally sustainable and prosperous energy future. By leveraging its world-class talent and research facilities, NETL is ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while developing technologies to manage carbon across the full life cycle, enabling environmental sustainability for all Americans.

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