ADVANCED COMBUSTION SYSTEMS PROGRAM

NATIONAL ENERGY TECHNOLOGY LABORATORY

BACKGROUND

The Department of Energy's (DOE) Advanced Combustion Systems (ACS) program is conducted under the Clean Coal and Carbon Management Research Program (CCCMRP). Fossil fuels account for more than 80 percent of total U.S. primary energy use because of their abundance, high energy density, and the relatively low costs associated with production, safe transport, and use. Ensuring that we can continue to rely on clean, affordable energy from ample domestic fossil fuel resources is the principal mission of DOE's Office of Fossil Energy (FE) research programs. As a component of that effort, the CCCMRP implemented by the National Energy Technology Laboratory (NETL) is engaged in research, development, and demonstration (RD&D) activities to develop and deploy innovative energy technologies and inform data driven policies that enhance U.S. economic growth, energy security, and environmental quality.

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The Advanced Combustion Systems program is focused on the R&D needed to enable generation of efficient, cost-effective electricity from coal with near-zero atmospheric emissions through the development of impactful near-term technologies to improve the existing fleet and transformational technologies that will modernize the coal-fired fleet. The Advanced Combustion Systems Technology Area includes three key technologies: (1) Existing Plant Combustion Technologies, (2) Transformational Technologies, and (3) Novel and Enabling Concepts. The research focus areas for each of these technologies are depicted in Figure 1. Impactful technology research is being conducted to bring about near-term reliability and efficiency improvements for the existing fleet. Transformational technology research is being conducted to bring about a modern, higher efficiency and lower cost coal-fired fleet. The projects that currently make up this area are pressurized oxy-combustion systems, chemical looping combustion (CLC) systems, supercritical carbon dioxide (sCO_2) power cycles, pressure gain combustion, and other novel concepts.

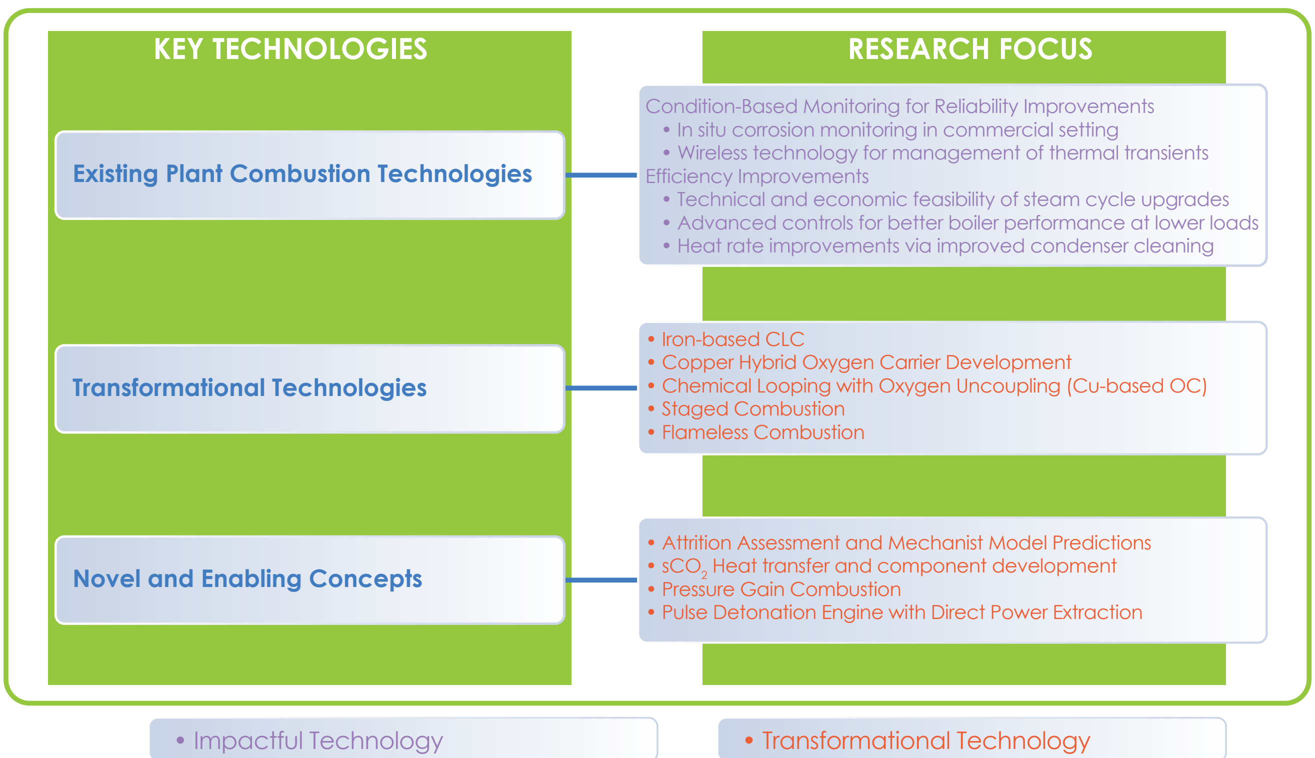

Figure 1: Key Technologies and Associated Research Focus in Advanced Combustion Systems

KEY TECHNOLOGIES

EXISTING PLANT COMBUSTION TECHNOLOGIES —

The existing fleet of coal-fired power plants underpins economic prosperity in the U.S. Coal-based generation has dominated the U.S. electricity supply for nearly a century. The benefits derived from the existing coal fleet have several components. These include the direct and macroeconomic benefit of low-cost electricity, the portfolio value of having a diverse mix of fuels and technologies for power generation, and the energy security value of a power generation option that is not dependent upon real-time fuel delivery/transport and is relatively immune to purposeful attack (terrorism). Studies have found that significant efficiency and reliability improvements are possible from a variety of measures.

The Advanced Combustion Systems program is supporting near-term research to improve the efficiency and reliability of existing coal fueled plants. The existing coal power generating fleet plays a critical role providing reliable on-demand power generation required for power grid stability, and it is important that these existing units can continue to operate in an efficient and reliable manner.

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Existing Plant Combustion Technologies R&D focuses on the identification of impactful, near-term opportunities applicable to the needs of the existing fleet, leading to increased reliability, operational flexibility, and improved efficiency. The current research focus includes condition-based monitoring and plant efficiency improvements. Other areas for potential near-term improvements to the existing fleet include advanced instrumentation and process control systems, advanced high temperature/pressure materials, topping cycles, dynamic data analysis, recovery of low-grade waste heat, improvements in water usage, and coal characterization studies and improvement to quality of coals.

Condition-Based Monitoring (CBM) is a maintenance philosophy that actively monitors the health condition of assets to predict and prevent failures and, in the case of power plants, maximize availability and generating capacity while saving cost. CBM can be utilized in all parts of the plant; however, currently the program is focused on the improvement of boiler reliability in the high temperature region of the boiler in pulverized-coal Rankine cycle power plants.

Three projects in this area were recently selected for award under the program:

- **Improving Coal-Fired Plant Performance through Integrated Predictive and Condition-Based Monitoring Tools—Microbeam Technologies Incorporated** (Grand Forks, ND) aims to demonstrate improvements to boiler performance and reliability in coal-fired power plants using condition-based monitoring. The approach develops a tool that alerts plant operators and engineers about poor boiler conditions. The goal is to integrate the operations of the tool into plant control systems and plant operating parameters. These improvements will potentially allow automation of coal selection and blending and will enhance the efficiency and long-term reliability of coal plants. DOE Funding: $1,384,560; Non-DOE Funding: $437,930; Total Value: $1,822,490.
- **Technology Maturation of Wireless Harsh-Environment Sensors for Improved Condition-Based Monitoring of Coal-Fired Power Generation—The University of Maine** (Orono, ME) will develop, adapt, implement, test, and transition wireless harsh-environment sensor technology in coal-fired power plants. The technology offers several advantages for inline monitoring of coal-based power generation systems—including accurate, battery-free, maintenance-free wireless operation. The small footprint of the sensors will potentially allow flexible placement and embedding of multiple arrays into a variety of components that can be sampled with a nearby interrogating antenna and radio frequency signal processing unit. DOE Funding: $1,999,703; Non-DOE Funding: $504,722; Total Value: $2,504,425.
- **High Temperature Electrochemical Sensors for In-Situ Corrosion Monitoring in Coal-Based Power Generation Boilers—West Virginia University Research Corporation** (Morgantown, WV) will validate the effectiveness of their previous electrochemical high-temperature corrosion sensor in coal-based power-generation boilers; optimize the high-temperature sensor; and develop a pathway toward commercialization. Sensors will be tested at bench and commercial scales. Commercial-scale sensors will be optimized for a specific type of advanced supercritical boiler. Bench-scale sensors will be tested under a range of operating conditions that would serve a variety of coal-fired combustion boilers. DOE Funding: $1,334,953; Non-DOE Funding: $341,734; Total Value: $1,676,687.

Other projects recently selected under the program focused on near-term applications for existing coal based plants include:

- **Low Load Boiler Operation to Improve Performance and Economics of an Existing Coal-Fired Power Plant—Alstom Power Inc.** (Windsor, CT) intends to improve the performance and economics of existing coal-fired power plants by extending boiler operation to lower loads. The objective is to develop and validate sensor hardware and analytical algorithms to lower plant operating expenses for the pulverized coal utility boiler fleet. The focus is on relatively inexpensive new interconnected technologies to minimize capital investment. DOE Funding: $851,664; Non-DOE Funding: $212,916; Total Value: $1,064,580.
- **Evaluation of Steam Cycle Upgrades to Improve the Competitiveness of U.S. Coal Power Plants—The Electric Power Research Institute** (Charlotte, NC) will examine the technical and economic feasibility of a series of steam cycle upgrades to subcritical and supercritical pulverized coal units, the two most prevalent types of U.S. coal power plants. The project will develop and evaluate nine separate retrofit options and will examine the business case for raising steam temperatures of existing units within the U.S. coal fleet. DOE Funding: $1,179,839; Non-DOE Funding: $302,157; Total Value: $1,481,996.
- **Advanced Anti-Fouling Coatings to Improve Coal-Fired Condenser Efficiency—Oceanit Laboratories, Inc.** (Honolulu, HI) plans to improve the performance and economics of coal-fired utilities and industrial-scale boilers through the reduction of fouling and the promotion of dropwise condensation using a composite coating mater ial that has demonstrated adhesion and abrasion resistance, which may be used on heat conducting surfaces without impacting heat transfer. DOE Funding: $2,000,000; Non-DOE Funding: $500,000; Total Value: $2,500,000.

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TRANSFORMATIONAL TECHNOLOGIES — The Advanced Combustion Systems program is pursuing R&D into technologies with the potential to transform and modernize the coal-fired fleet. Currently Transformational Technologies R&D focuses on chemical looping combustion and pressurized combustion, including iron-based CLC, chemical looping with oxygen uncoupling (CLOU), development of copper hybrid oxygen carriers, staged combustion, and flameless combustion.

Oxy-combustion technology is applicable to new and existing conventional pulverized coal (PC)-fired power plants. In oxy-combustion, pulverized coal is combusted in an enriched oxygen and carbon dioxide stream, instead of air. This eliminates most, if not all, of the nitrogen (N_2) found in air from the combustion process, resulting in flue gas composed of CO_2, water (H_2O), contaminants from the fuel (including coal ash), and has the potential for reduced equipment size and higher temperature thus more efficient power cycles. The high concentration of CO_2 (≈70 %) and absence of nitrogen simplify separation of CO_2 from the flue gas for storage or beneficial use.

Chemical looping combustion systems produce the oxygen necessary for combustion internal to the process via the oxidation-reduction cycling of an oxygen carrier, usually a solid, metal-based compound. This allows the combustion process to be split into reduction and oxidation reactions in different reactors. The advantage of this technology is that oxygen can be separated from air without the large capital and energy costs associated with conventional oxygen production. Furthermore, combusting the fuel via oxygen supplied by the oxygen carrier prevents the introduction of nitrogen, resulting in a flue gas stream of concentrated CO_2 with water that can be purified, compressed, and sent for storage or beneficial use.

NOVEL AND ENABLING CONCEPTS — The Advanced Combustion Systems program is pursuing R&D opportunities in Novel and Enabling Concepts to evaluate and develop technologies that could provide innovative new options for the transformation of the coal-based power generating fleet.

The focus of Enabling R&D is to address critical technology gaps and improve overall system performance by decreasing unit operation energy requirements. To achieve these objectives, projects consist of applied R&D focusing on technologies that can enable scale-up and set the stage for Transformational Technology benefits. These projects will reduce technical risk, improve performance, and reduce cost to assist the technologies supported by the ACS program to meet the Program goals. Enabling R&D research currently includes attrition assessment and mechanistic model predictions, high-efficiency supercritical CO_2 power cycles, and pressure gain combustion.

Novel R&D is defined as technologies that could provide dramatic improvements in the cost and performance of advanced combustion systems and who's development time horizon are longer term. An advanced technology investigated as part of this research focus area that offers significant promise after preliminary analysis and laboratory testing could then be transitioned into its own R&D focus area, if applicable. Activities range from scoping studies and systems analysis to focused R&D.

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