PROGRAM facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Power Systems
Advanced Research

08/2008

NETL

Coal Utilization Science Program

Description

The Coal Utilization Science (CUS) Program sponsors research and development (R&D) in fundamental science and technology areas that have the potential to result in major improvements in the efficiency, reliability, and environmental performance of advanced power generation systems using coal, the Nation's most abundant fossil fuel resource. The challenge for these systems is to produce power in an efficient and environmentally benign manner while remaining cost effective for power providers as well as consumers.

The CUS Program is carried out by the National Energy Technology Laboratory (NETL) under the Office of Fossil Energy (FE) of the U.S. Department of Energy (DOE). The program supports DOE's Strategic Plan to:

- Promote America's energy security through reliable, clean, and affordable energy;
- Strengthen U.S. scientific discovery and economic competitiveness; and
- Improve the quality of life through innovations in science and technology.

Current research within the CUS Program targets the development of critical and enabling technologies that contribute to the design and operation of advanced near-zero emission power and fuel systems. These systems include the demonstration of multiple commercial-scale Integrated Gasification Combined Cycle (IGCC) or other clean coal power plants with cutting-edge carbon capture and storage (CCS) technology under the Department's restructured FutureGen approach.

Within NETL's Advanced Research organization, CUS performs a crosscutting function, serving as a bridge between basic science and the engineering of new technologies by identifying critical research needs and barriers, gaining a thorough understanding of the underlying chemical and physical processes involved, and developing the tools required to overcome those barriers. Program

Advanced Research — To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing — opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

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participants use state-of-the-art methods to explore novel concepts, perform theoretical investigations, examine critical processes and mechanisms, and generate high-quality data.

CUS Program participants include businesses, universities, and other national laboratories. Flexible teaming arrangements enable multi-laboratory teams to cooperate both formally and informally. The generic and noncommercial nature of the research has led to international collaboration through the annex to the International Energy Agency Implementing Agreement on Clean Coal Science, as a way of extending limited R&D budgets.

Program Focus Areas

NETL's CUS Program currently is conducting research projects in the two primary focus areas described below. These areas address the more complex operational requirements of advanced coal plants, which are designed to be integrated with CCS subsystems.

Sensors and Controls Innovations — Novel sensors and advanced process control are key enabling technologies for advanced near-zero emission power systems. CUS is leading the effort to develop sensing and control technologies and methods to achieve seamless, integrated, automated, optimized, and intelligent power systems. The performance of advanced power systems currently is limited by the lack of sensors and controls capable of withstanding high temperature and pressure conditions. Harsh environments are inherent to new systems that aim to achieve high efficiency with low emissions. In addition, these systems are complex, with operational constraints and system integration challenges that push the limits of traditional process controls. As R&D enhances the understanding of these evolving advanced power systems, it is clear that new, robust sensing approaches, including durable materials and highly automated process controls, are needed to optimize their operation and performance.

Computational System Dynamics — Simulating the complex processes that occur inside a coal gasifier, or across an entire chemical or power plant, is a powerful tool made possible by today's supercomputers and advanced simulation software. The Computational System Dynamics focus area provides such tools to the CUS Program. The goal is to help scientists and engineers better understand the fundamental steps in a complex process so they can optimize the design of the equipment needed to run it. Not only is this less costly than performing a long series of experiments under varying conditions to try to isolate important variables, but also it yields more information than such experiments can provide. Of course, the data are only as good as the computer model, but some of today's computer models have proven to be excellent when measured against as-built configurations.

Program Successes

CUS R&D has had numerous noteworthy successes, falling under Advanced Research's broad mandate to conduct research that supports the development of technologies for clean, efficient electric power generation. Success often is gauged by the ability to transfer a new technology or approach to the next level where demonstration or scale-up of a technique can be undertaken. In other cases, such as sensors, direct commercialization of the technology is a measure of success. With funding from NETL, for example, researchers at The Ohio State University developed a high-temperature oxygen micro sensor as part of a broad-ranging effort

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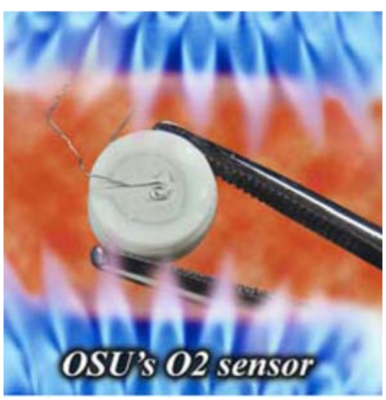

Ohio State University's reference-free potentiometric oxygen sensor capable of withstanding temperatures of 1,600 °C.

to more closely monitor total nitrogen oxides (NO_x), carbon monoxide (CO), and oxygen (O_2) during combustion. The oxygen sensor was selected by R&D Magazine in 2005 as one of the 100 most technologically significant products introduced into the marketplace over the previous year.

NETL Sensors and Controls R&D has yielded a number of additional successes to date, among them:

- A new, robust, accurate temperature measurement system that can withstand the harsh conditions found in commercial gasifiers for an extended period;
- Pilot-scale testing of a number of novel sensors to assess commercial feasibility, including fiber optic temperature and strain sensors on the superheater tubes of an oxygen-fired combustion facility , a silicon carbide temperature sensor on the turbine burner test rig operating up to 1,200 °C, and high-temperature micro gas sensors in exhaust gas environments;
- First demonstration of the viability of constructing high–temperature, fiber-based gas sensors capable of selectively detecting gases at or near 500 °C; and
- A field-portable kit for screening halogenated volatile organic compounds from soil and water samples, providing a streamlined method for testing redevelopment sites for environmental contamination.

Additional research in sensors and controls is underway to develop:

- A suite of high-temperature, harsh environment sensors to measure temperature, pressure, and other process variables;
- Novel sensors to measure synthesis gas (e.g., hydrogen), flue gas constituents (e.g., NO_x), and trace contaminants (e.g., mercury); and
- Advanced process control strategies for near-zero emissions in processes such as gasification and chemical looping.

Examples of successes in the Computational System Dynamics area include the following:

- **M**ultiphase **F**low with **I**nterphase e**X**changes (MFIX) software, which is internationally recognized as the pre-eminent software for modeling gas-solids (multiphase) flow, and which won an R&D 100 Award in 2007. MFIX works on optimizing one functional unit, such as a coal gasification reactor, at a time; and
- **A**dvanced **P**rocess **E**ngineering **C**o-**S**imulator (APECS) software, which combines commercial process simulation and computational fluid dynamics to help industries design highly integrated plants. APECS won an R&D 100 Award in 2004 and a Federal Laboratory Consortium Excellence in Technology Transfer Award in 2007. APECS coordinates many functional units across an entire plant to optimize its operational efficiency.

Continuing research in Computational System Dynamics focuses on:

- Projects related to steady-state simulations, the framework that supports the simulations, and the reduced-order models to carry out the simulations for carbon capture demonstrations;

PROGRAM PARTICIPANTS (CONT.)

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University of Colorado
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University of North Dakota Energy and Environmental Research Center (EERC)
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University of Utah
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Virginia Polytechnic Institute and State University
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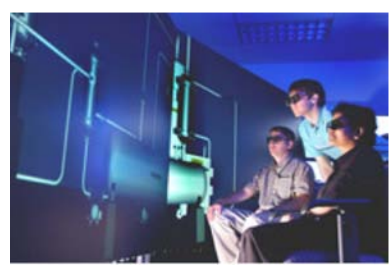
Western Research Institute
Laramie, WY



APECS software enables virtual plant simulations that follow complex thermal and fluid flow phenomena from unit to unit across the plant.

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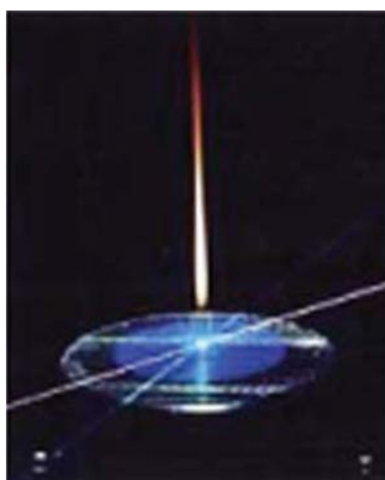
- Integration of co-simulator models with virtual engineering plant walk-through environment models;
- Efforts to expand and validate multiphase fluid flow models for simulation of advanced coal-based power systems; and
- Investigation of basic combustion and gasification chemistry to determine mechanisms that affect emissions behavior or coal under advanced and conventional combustion/gasification.

The computational system dynamics information is used to validate combustion/gasification models, thereby enabling the use of these integrated modeling and simulation packages to aid in the design and evaluation of advanced power systems, including those under development for carbon capture demonstrations.

Benefits

The CUS Program has produced important advances in the science of coal utilization. R&D from this program, for example, has led to the first one- and two-dimensional combustion-capable Computational Fluid Dynamics code in the United States. The program also has provided insights into coal devolitization, char reactivity, and ash behavior that have led to new mechanistic models now used in several commercial and research-oriented combustion codes. Many of today's low-NO_x burners and advanced reburning technologies are based on the kinetic data and models developed through this program.

Such advances have translated to enhanced technology transfer and commercial availability through industrial participation, lower costs through reduction of initial investment and operating expenses, and the creation of new jobs and investment opportunities. Support for national research capabilities and facilities has enabled highly skilled scientists and engineers to promote fuel diversity and helped to maintain a competitive U.S. economy.



CUS projects are using laser diagnostics to probe the way coal burns.

Additional Information

Additional information may be accessed electronically through the following link to the NETL Advanced Research Reference Shelf:

http://www.netl.doe.gov/technologies/coalpower/advresearch/ref-shelf.html