



# Advanced Research

*Opening New  
Frontiers in Power*

# INTRODUCTION

The Advanced Research Program supports Vision 21 and is an integral part of the Central Systems, Distributed Generation, and CO<sub>2</sub> Sequestration programs. As such, the Advanced Research program is driven by many of the same market and environmental influences as other C&PS programs.

Utility deregulation, energy security, the growing global demand for energy, the aging fleet of U.S. coal-fired power plants, global climate change initiatives, and environmental compliance concerns all have implications for the long-term use of fossil fuels.

The Advanced Research Program serves as a bridge between basic research and the development of innovative systems capable of improving efficiency and environmental performance while reducing costs of fossil energy systems, both for electric power and liquid fuels production. Advanced Research provides the means by which advanced concepts are transformed into future working technologies for use in the United States and abroad. Improvement of the energy infrastructure, which includes power plants, power transmission systems, fuel production and transportation systems, coproduction of higher value products (such as chemicals), environmental protection and remediation efforts, is dependent on the products of advanced research.

The Advanced Research Program provides two major products. The first is a set of crosscutting studies and assessment activities in environmental, technical and economic analyses, coal technology export and international program support. The second identifies and guides

advanced research in new directions and provides a set of cross-cutting fundamental and applied research programs focused on developing the technology base in the enabling science and technologies needed for the 21st century. These areas are critical to the successful development of both ultra-clean, very high efficiency coal-based power systems, and coal-based fuel systems with greatly reduced or no net emissions of CO<sub>2</sub>. This second set of activities addresses the full spectrum of fossil utilization research and development, technology transfer, outreach, and private sector partnerships.

The Advanced Research Program is charged with coordinating and directing research that will lead the technological developments of the C&PS program. This is accomplished by identifying and nurturing innovative concepts, and with the aid of the basic research community, advancing the technology to achieve FE's program goals. The Advanced Research Program facilitates the transition of research to the appropriate program areas for development and marketing. With the export of U.S. coal and power systems technology abroad, the Advanced Research Program promotes the national goals of energy and environmental security, and increases the opportunity for U.S. technology use in the global marketplace.

## PROGRAM AREAS

- Materials and Advanced Metallurgical Research
- Bioprocessing
- Coal Utilization Science
- University Coal Research
- Historically Black Colleges and Universities/Other Minority Institutions
- Small Business Innovation Research
- International/Coal Technology Export

## BENEFITS

### CUSTOMER BENEFITS

- Ensures continued economic well-being for U.S. citizens by reducing energy costs resulting from advanced technologies.
- Improves the U.S. economy and increases the number of high-skill jobs for Americans by increasing international technology export.

### SUPPLIER BENEFITS

- Develops international markets for U.S. energy-related technologies, services, and energy resources by facilitating both new market entries and expansion in existing markets through the international program.
- Enables the production of advanced, high-efficiency power systems that better utilize domestic fossil fuel resources through development of advanced coal research.

### NATIONAL BENEFITS

- Provides Americans with a dependable domestic source of power by maintaining coal as the primary source of energy for electricity production.
- Mitigates the global environmental impact of the increased fossil fuel use by overcoming the obstacles to using clean fossil-powered systems.
- Captures the diverse research contributions of academia and industry and contributes to the Nation's scientific knowledge base by engaging universities, historically black colleges and universities/other minority institutions, and small businesses in fossil-related research.

## DRIVERS

- Climate change initiatives will likely require serious carbon reductions in the electrical generation and transportation sectors.
- Governments may enact new and, as yet, undefined environmental regulations that could require even further reductions in emissions from stationary and mobile sources.
- With deregulation, the utility industry is consolidating and keeping older plants on line to remain economically competitive. The question of how this will affect availability, reliability of electric supply, and the deployment of advanced technologies will probably remain unanswered for some time.
- The existing stock of US fossil-fueled power plants is growing older, and little new generating capacity is currently being added. After about 2010, this situation will result in the need for substantial new generating capacity over and above that required to meet the growing demand due to population and economic growth.
- Demand for electricity overseas is expected to grow substantially over the next several years. This will create a huge market for new electrical generation capacity that is well matched to regional characteristics.
- Coal not only faces environmental challenges, but faces competition from the other fossil fuels — oil and natural gas. With natural gas prices projected to be relatively stable through 2015, it could be the fuel of choice of electric utilities and independent power producers to satisfy future electric demand.
- U.S. dependence on imported oil and gas continues to grow. By 2015, imported oil is expected to amount to 61% of consumption, and imports of gas to 14% of consumption.

## GOALS

- Overall, to deliver the scientific understanding and technological innovations that are critical to the success of C&PS programs as well as FE and DOE missions.
- Leverage research opportunities through science partnerships and pursue international science collaborations.
- Generate fundamentally-based knowledge and data to make significant improvements in power plant efficiency and environmental performance.
- Develop advanced materials and enabling technologies for Vision 21 power systems having no negative impact on the environment.
- Promote strong relationships between DOE and the academic community through research activities directed toward advancements in advanced power systems.
- Support Fossil Energy in developing collaborative technical activities with international performers in the coal and advanced power system area.

## STRATEGIES

Vision 21 is the guiding principle that defines the activities of the Advanced Research program by setting priorities for the next century. Many elements of what must be contained in the Vision 21 concept already exist and are part of the C&PS technology portfolio. Some of the strategies for achieving Vision 21 through the Advanced Research Program include:

- Identify next generation of advanced fuel and power systems that can operate at greater efficiencies and at an economic cost that is lower than for the present state-of-the art.
- Support the research necessary to graduate new technologies to the development stage.
- Initiate research that is likely to lead to entirely new technology areas.
- Provide sustained support to fund high-risk work in anticipation of technological advances or as key experiments that facilitate development of breakthrough technologies.
- Develop an effective Center of Excellence for Advanced Research at NETL.
- Search opportunities for power systems in targeted countries.

## MEASURES OF SUCCESS

- Make available high-temperature corrosive, erosive-resistant materials to increase the durability and extend the operating envelope of advanced power systems.
- Facilitate both new international market entries and expansion in existing markets for U.S. energy-related technologies, services, and energy resources.
- Award approximately 20 research grants annually to provide the fundamental research and novel approaches to successfully develop advanced power systems and clean fuels for transportation.
- Explore novel aspects of fuels and their production from coal and other energy resources in combination with coal.

## LINK TO VISION 21

The Vision 21 concept defines the activities of FE's Advanced Research Program by setting priorities for the 21st century. The research thrusts of FE's Advanced Research activities include identifying a next generation of advanced fuel and power systems that can operate at greater efficiencies on coal and at an economic cost that is lower than for the present state-of-the-art, while emitting practically no criteria pollutants, and with sequestration, having no net emissions of CO<sub>2</sub>. The major goal of the Advanced Research Program is to develop, by 2015, a series of advanced materials, subsystem technologies, and breakthrough process concepts that are essential to the success of Vision 21. To achieve these goals, a NETL Center of Excellence for Advanced Research is being developed. This center will allow applied research to be conducted now to produce a technology base from which the energy plants of the future will be designed, built, and operated.

In order to achieve the perfor-



Vision 21 energy plant of the future.

mance goals of Vision 21, a number of challenging R&D issues must be addressed by the FE Advanced Research Program. Though not meant to be an exhaustive list of critical research needs to achieve Vision 21, these needs include:

- Lower-cost oxygen separation technology
- Advanced carbon products, such as nano-structural materials
- High-temperature hydrogen separation technology
- Heat exchanger materials capable of operating at combustion temperatures
- Approaches to effectively capture and sequester CO<sub>2</sub>

The Advanced Research Program is directly related to the other programs within C&PS. Advanced Research is key to innovation and progression in its commercial program areas because it: (1) supports the research necessary to graduate new technologies to the development stage, and (2) initiates research that is likely to lead to entirely new technology areas, and possibly to entirely new program areas.

It should be noted that often the processes and materials that advance one C&PS program may well have application in another, with little or no modification. A major advantage of the Advanced Research Program is its ability to see and foster applications of a given technology across a number of programs, and leverage scarce resources to accomplish common goals.

### CENTER OF EXCELLENCE FOR ADVANCED RESEARCH – ENERGY PLANTS OF THE FUTURE (COMPUTATIONAL ENERGY SCIENCE)

#### Strategy

Conduct computational research on advanced energy plants to provide:

- Insight into the complex interaction of physical and chemical systems involved.
- Direction to experimental research that addresses key technical barriers.

#### Activities

- Modeling sub-elements in energy conversion devices.
- Combining sub-element models to describe the steady state operation and dynamics of a complete energy conversion device.
- Integrating devices into a model of an overall energy plant.
- Developing a manufacturing model to aid in commercialization of materials and devices produced from the research.

#### Benefits

- More rapid and efficient scale-up of new processes.
- Reduced need for large, expensive experimental units.
- Reduced operational risks at commercialization.
- Experiments and tests conducted for model validation.

## PROGRAM AREAS

### MATERIALS AND ADVANCED METALLURGICAL RESEARCH

Advanced materials are vital to enhancing the cost and performance of fossil energy systems. Today, research is focused on developing high-temperature, corrosion-resistant structural ceramic composites and alloys, and materials that perform specific functions in advanced fossil energy systems. The activities included in this program area focus on developing a technology base in the synthesis, processing, life-cycle analysis, and performance characterization of advanced materials. The program area funds exploratory research designed to develop new materials that have the potential to improve the performance or reduce the cost of existing fossil

fuel technologies. Also funded is the development of materials for new systems and capabilities.

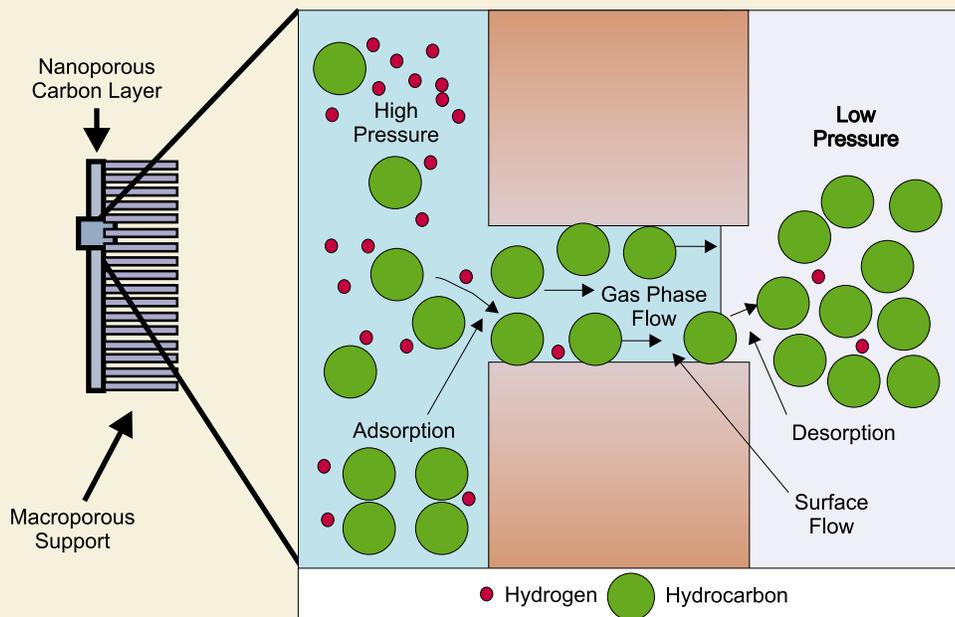
New materials and components are being developed under the Materials and Advanced Metallurgical Research program area to address the special needs of Vision 21. The ceramic materials required for novel membrane applications (including low-cost oxygen separation and hydrogen separation) and special alloys for high temperature heat exchangers are examples of products of this activity that are critical to the timely deployment of Vision 21 energy plants.

Partnering and cost-sharing with industry are central components of this program area. FE's materials research program area includes the Advanced Research Materials Program at Oak Ridge National Laboratory and the Advanced Metallurgical Research Program at Albany, Oregon, as well as related activities within the Office of Science and Technology at NETL.

### BIOPROCESSING

This program area sponsors research into the biology, biochemistry, microbiology, and bioengineering technologies. Activities are focused on developing the bioprocesses capable of fostering innovative uses for coal and its by-products, developing alternative fuels, identifying biomass sources of potential value in burning or co-burning technologies, developing biological processes to sequester and/or recycle greenhouse gases, addressing environmental issues affecting the power industry, and biologically mitigating fossil fuel mining and utilization issues. An example of current projects in bioprocessing include investigation of marine mechanisms of CO<sub>2</sub> sequestration, and sequestration effects on marine ecology to further the sequestration goals of Vision 21.

### Selective Flow Membranes



## STRENGTH THROUGH SCIENCE

The following state-of-the-art virtual demonstration capabilities being performed by the Advanced Research Program strengthen the scientific base of design and demonstration tools.

**3-D Visualization.** 3-D solid model, compatible with 2-D drawing, allowing interactive Virtual Reality (Semi-immersive or Immersive).

**Information System.** A multi-modal (graphical, textual, alpha-numeric, video, etc.) Data Management System. This will allow One-Step/One-Time data entry and guarantee data integrity.

**Communication System.** Internet capabilities will allow collaboration between a geographically separated work team.

**CAD/CAE.** Will provide engineering drawings (schematic diagrams, P&IDs, loop diagrams, termination drawing, structural) to generate reports with total integrity with 3-D model.

**Process Simulation.** Process optimization, economic valuation, component sizing, sensitivity analysis are integrated with visualization, CAD, and other components of the virtual demo, utilizing a unit operations library physical properties database.

**Control Systems.** Tightly coupled Vision 21 systems will require sophisticated transients control strategies for normal operation, load following, start up/shut down, and safety.

**Mechanistic Modeling.** Models are physics-based. Included are Computational Fluid Dynamics (including single/multi-phase, heat transfer, chemical reactions, radiation), Finite Element Structural simulation, material simulation, and event-based simulation.

## COAL UTILIZATION SCIENCE

Creating efficient, economic and environmentally acceptable advanced fossil energy systems requires new knowledge of the fundamental mechanisms and processes that influence and control these systems. The acquisition of this information — needed by developers, designers, manufacturers, and operators — is a primary objective of the Coal Utilization Science (CUS) program area.

This program area supports research that develops technologies for clean, efficient power generation from coal and other fossil fuels. Experimental research and theoretical investigations are conducted to address technological barriers, and novel processes are developed to overcome the barriers.

The CUS program area continues to be heavily involved in modeling efforts, and is developing advanced designs and visualization software necessary to design, evaluate, and optimize the performance of next generation power systems. Research activities are integrated among industry alliances, National laboratories, and the university community including (1) advanced concept and system studies of an analytical, computational or experimental nature for testing novel concepts or evaluating promising power systems components, configurations or integrated issues; (2) visualization capability that utilizes immersive, interactive, and distributed visualization technology in the design of next generation power plants; (3) mechanistic model development of versatile, reliable models, based on the fundamental laws of science for

the performance of power production processes; and (4) the development of system tools for integrated use of information technology in power plant design.

## UNIVERSITY COAL RESEARCH

The Office of Fossil Energy conducts an annual competition to select and fund the best coal science and technology research proposals from the Nation's academic institutions. Grants are provided by the University Coal Research program area to U.S. universities in order to support fundamental research and develop improved fossil energy technologies. Novel and innovative approaches are sought to solve national and global environmental and energy-related issues. This research sustains U.S. global preeminence in the areas of fossil fuel science and engineering by supporting fossil energy research at our Nation's universities. The result is a developing and expanding knowledge base in disciplines relevant to fossil fuels.

## HISTORICALLY BLACK COLLEGES AND UNIVERSITIES/OTHER MINORITY INSTITUTIONS

This program area was established to provide a mechanism for cooperative research between historically black institutions and other minority institutions with U.S. industries and federal agencies. This program area strives to support the education of scientists and engineers, and sponsors research in support of the Office

of Fossil Energy's product lines. The Historically Black Colleges and Universities/Other Minority Institutions program area has emphasized improving the environmental compatibilities of advanced coal, oil, gas, and environmental technology concepts.

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## SMALL BUSINESS INNOVATION RESEARCH/SMALL BUSINESS TECHNOLOGY TRANSFER

Small businesses have historically played a key role in introducing revolutionary innovations which have led to competitive advantages in world markets. FE's Small Business Innovation Research/Small Business Technology Transfer program area makes competitive grants to small businesses for fossil-related technology research projects that interest small businesses while advancing the mission of FE. Research supports FE goals of obtaining clean fuels and energy from fossil resources.

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## INTERNATIONAL/COAL TECHNOLOGY EXPORT

Worldwide, the demand for power is increasing exponentially. The foreign market for electric power systems has been estimated at nearly \$180 billion by 2030. At the same time, the energy sectors of many countries are undergoing major transformations. Increasingly stringent environmental regulations, growing international concerns over global climate change, and increased competition among fuels drive the need for advanced power technologies that deliver electricity efficiently, cleanly, and economically both in the U.S. and abroad.



The Bilaspur Coal Washery Project in the state of Madhya Pradesh is India's first private commercial coal washery for electric power generation.

The International program area within the Advanced Research program has four major strategies:

- **Provide leadership in international organizations.** FE holds leadership roles in several international organizations: the International Energy Agency, Latin America Energy Organization, Asia Pacific Economic Cooperation's Regional Energy Cooperation Working Group, United Nations Economic Commission for Europe Clean Coal Technology Initiative, and the World Energy Council.
- **Maximize export opportunities.** The U.S. is the world leader in the development of clean fossil-powered technologies. The International program area works to ensure that U.S. companies get a share of the global market for clean power systems, thereby securing jobs, driving economic growth for the U.S., and contributing to global environmental protection.
- **Establish effective partnerships.** Partnerships play an important role in overcoming barriers facing U.S. companies pursuing export opportunities. Such barriers include inadequate understanding of U.S. clean power systems and unfair competitive trade practices. Through its partnerships, the program facilitates business solutions to remove these barriers.
- **Facilitate electricity transactions across international borders.** The International program area ensures reliability and open-access transmission through international border systems. FE authorizes exports of electricity, collects and analyzes information on international electricity trade, conducts country-specific studies on electric power systems and the construction of international transmission lines, and provides electric power regulatory assistance.

To ensure that U.S. companies get a share of the global market for clean fossil-power systems, bilateral efforts are ongoing in seven regions: Africa, Eastern Europe, the Pacific Rim, Russia and the Newly Independent States, South Asia and Near East, Western Europe, and Western Hemisphere. In each region, countries are assisted with adapting their power sectors to meet local demands and environmental pressures. This assistance facilitates dialogue between financial institutions and U.S. companies.

## PROGRAM SUCCESSSES

### Hot Gas Filter Materials

The difficult issue of removal of particulate matter from hot gas streams in pressurized fluidized-bed combustion (PFBC) and integrated coal gasification combined-cycle (IGCC) systems has been addressed by two developments of the Advanced Research Materials program area. In industry/DOE cost-shared collaborations, the 3M Company and Pall Corporation have, respectively, commercialized ceramic composite and metal alloy filters. The 3M Ceramic Composite Filter is a lightweight ceramic composite filter made of woven Nextel™ fibers coated with silicon carbide, which was produced under license of the DOE-developed technology. 3M has extended and patented its development to an all-oxide filter of similar design.

Pall Corporation's iron aluminide filter is a porous metal filter made of a highly oxidation- and sulfidation-resistant iron aluminide alloy. The application of this alloy as a filter material was explored in the Materials program area and extended to demonstration scale under the hot gas cleanup research.

Both the 3M and Pall filters are being demonstrated at the Power Systems Development Facility in Wilsonville, Alabama, as well as in numerous installations in Europe and Asia. These are developments of considerable importance, both with respect to enabling technologies for PFBC and IGCC systems, and commercialization. For 300-MWe systems, over 3,000 of these filters would be required for an oxygen-blown IGCC and over 30,000 would be required for a PFBC.

### International

Since 1982, the NETL has managed six coal-related projects in India for the U.S. Agency for

International Development. The total value of these projects, including contributions from the various Indian partners, is about \$80 million, with about \$15 million of the total brought to NETL for direct implementation.

One of these projects, the U.S.-Asian Environmental Partnership's Indo-U.S. Coal Preparation and Beneficiation Project, supported deployment of an advanced coal-cleaning circuit (based on U.S. technology supported by DOE) at the first commercial non-coking coal washery in India. The objective of this project was to demonstrate production of coal with less than 30% ash in the 2.5-million-ton-per-year commercial washery. Two U.S. firms, Spectrum Technologies, and CLI (a U.S. coal preparation design company), have been awarded a \$12-million engineer, procure, and construct contract and a \$4-million-per-year operation and maintenance contract.



A lightweight ceramic hot-gas filter material developed by the Advanced Research Program is now widely used to remove hot gas particulates in fossil-fueled power generation and industrial systems.



NETL's Solids Processing Research Facility is a one-of-a-kind, state-of-the-art center. Located in Pittsburgh, Pennsylvania, it is used to test a wide variety of advanced coal cleaning, processing, and handling methods.