Innovations for Existing Plants:
The AR&ET Program

Program Plan: FY 2000 - FY 2001

May 2000

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory
Pittsburgh, Pennsylvania
Morgantown, West Virginia

A Message to Our Stakeholders

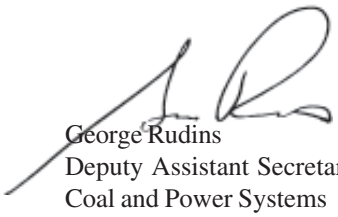
The availability of clean, affordable energy is essential for the prosperity and security of the United States and the world in the 21st century. In the United States today, over half the electricity comes from coal-fired boilers, and coal is projected to account for over half of U.S. electricity generation through 2020 and beyond. Internationally, the amount of coal used in developing nations for electricity generation is projected to more than double by 2020. Innovative emission-control technologies will be required to alleviate, at low cost, the environmental concerns associated with coal combustion.

This document is the Program Plan for the Advanced Research & Environmental Technology (AR&ET) Program. In FY 2001, the program name will change to "Innovations for Existing Plants." This name change recognizes that there are 300 GW of air-combustion coal-fired electric generation assets in the United States, and there is a continuing need to improve their environmental performance. The name change also recognizes that "existing" coal-fired power plant technology is and will continue to be deployed in the developing world. As environmental awareness grows in these countries, retrofit emissions control technology will be needed for those systems as well.

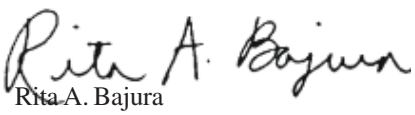
The Program Plan describes the program drivers and goals, the R&D portfolio, program strategy, and program benefits. It is the direct result of collaborative work with our stakeholders. Key interactions include:

- Collaborative cost-shared research on pollution control technologies to improve their performance and sharply reduce their cost.
- Collaborative work with the Tennessee Valley Authority, EPRI, and state and local environmental agencies to evaluate the impact of fine particulates on visibility.
- Collaborative efforts with EPA, the Office of Management and Budget (OMB), EPRI, the utility industry, and independent research organizations on establishing the procedures under EPA's Information Collection Request (ICR) initiative for collecting data related to emissions of mercury from coal-fired utility boiler systems.
- Partial sponsorship of NARSTO, a consortium of North American public and private organizations that are conducting research in support of air quality management, focusing on ozone and aerosols.
- A series of public meetings and one-on-one dialogues with key public and private sector stakeholders involved in $PM_{2.5}$-related research and decision-making.
- Cosponsorship with the Office of Surface Mining, Department of Interior, of an interactive forum on coal combustion by-product (CCB) utilization.
- Ongoing efforts to provide technical analysis and high-quality data for use in policy and regulatory determinations.

Only with your involvement and support can we succeed. Achieving our goals will not be easy. But with a history of success—and a cooperative partnership with industry, academia, and government—we will have the best chance. We welcome your comments and suggestions about the plan. Please respond directly to us or to the contacts listed on the back cover.



George Rudins
Deputy Assistant Secretary for
Coal and Power Systems



Rita A. Bajura
Director
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Table of Contents

List of Acronyms

AR&ET	Advanced Research and Environmental Technology
BAU	Business As Usual
BBA	Broad Based Agency Announcement
Btu	British Thermal Unit
CAAA	Clean Air Act Amendments
CCB	Coal Combustion By-product
CO_2	Carbon Dioxide
DOE	United States Department of Energy
ECBC	Emission Control By-products Consortium
EPRI	Electric Power Research Institute
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
FE	Fossil Energy
FGD	Flue Gas Desulfurization
HAP	Hazardous Air Pollutant
Hg	Mercury
IA	Interagency Agreement
ICR	Information Collection Request
NAAQS	National Ambient Air Quality Standards
NETL	National Energy Technology Laboratory
NO_x	Oxides of Nitrogen (NO, NO_2)
NSTC	National Science and Technology Council
OCDO	Ohio Coal Development Office
OMB	Office of Management and Budget
PM	Particulate Matter
Q	Quadrillion (10^{15})
RCRA	Resource Conservation and Recovery Act
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
SO_x	Oxides of Sulfur (SO_2, SO_3)
TRI	Toxics Release Inventory

Executive Summary

The World Tomorrow

The availability of affordable energy is, and will continue to be, essential to our nation's economic strength. Even with major advances in renewable energy use, energy forecasts agree that coal and other fossil fuels will be the dominant energy source for the foreseeable future. By 2020, the United States will still rely on coal for over half its electricity generation. Globally, developing countries such as China and India will use their abundant, domestic coal resources to fuel economic growth; the amount of coal used for electricity generation in the developing nations is projected to more than double by 2020.

The economic need for sustained coal use must be balanced by improved technology to eliminate the adverse impacts that emissions of certain chemical species can have on human health, the environment, and the global climate. Figure 1 shows that pollutant emissions per unit of coal burned have decreased significantly in the United States over the past 30 years. However, over the same period of time coal use has more than doubled. With increased coal use, emissions per unit of coal must be reduced further to limit aggregate pollutant emissions.

The United States needs new technology to improve the environmental performance of its coal-fired electric generation assets. Similarly, as world prosperity increases, other nations will seek to upgrade the environmental performance of their energy systems. Emissions control technology developed by the AR&ET program will greatly reduce the cost of this transition, providing sustained prosperity, energy diversity, and a cleaner global environment.

The Technical and Market Challenge

The coal power generation industry faces dual challenges: new requirements from increasing environmental regulation and the cost-cutting pressure of market deregulation.

Earlier pollution control systems for coal-fired power plants have proven effective in reducing emissions by a factor of two or three at low incremental cost. However, the clear trend in emissions regulations is removal of almost all (over 90%) of the species of concern to maintain the ambient air quality and visibility standards set forth by the U.S. Environmental Protection Agency (EPA). Pollutant species contained in flue gas—particulate matter, sulfur oxides (SO_x),

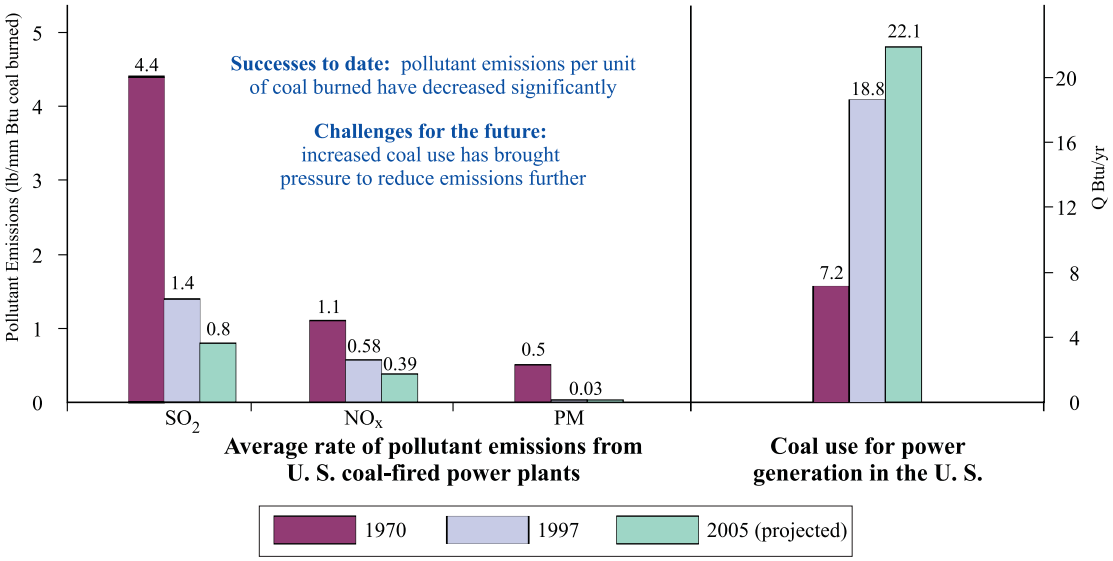


Figure 1. Since 1970, the Environmental Performance of U.S. Coal-Fired Power Plants has Improved while Coal Use has Increased

nitrogen oxides (NO_x), acid gases, and mercury—are present in dilute concentrations which greatly increase the technical challenge of near-complete removal (see Figure 2).

The Program Opportunity

The AR&ET Program focuses on innovations that will enable the continued use of existing coal-fired electricity generation assets, and the deployment of new coal plants, including the advanced generation technologies being developed as a part of the Vision 21 program. The program opportunities are threefold:

- Developing comprehensive environmental solutions that address all air emission and solid waste generation issues in an integrated manner
- Providing flexible systems that can be used with a wide range of plant configurations and sizes
- Providing technology solutions at or below current cost-of-electricity to ensure market use—in the United States and internationally.

R&D Portfolio

The program R&D portfolio has five primary elements:

- Systems Analysis and Integration
- Mercury
- Fine Particulate Matter
- Coal Combustion By-products
- Nitrogen and Sulfur Oxides

These elements cover the entire "life cycle" of emissions and technology, from source speciation through advanced emissions control technology development and testing. Data collected as "baseline" in control technology development can also be used in policy and regulatory processes.

Program Role and Strategy

The AR&ET program has two major focuses:

- Developing advanced environmental control technology for coal-fired power plants, and
- Providing high-quality scientific data and analysis for use in policy and regulatory determinations.

In conducting pollution control technology R&D, the program first seeks to obtain a fundamental understanding of the chemistry of the pollutant species of concern as they exist in flue gas. On that basis, research into control technologies is initiated. In addition to evaluating technologies on the basis of control performance and projected cost, consideration is given to 1) the ease with which a control technology can be integrated into both new and existing electricity generation systems, 2) the potential for the technology to capture or control more than one pollutant species, and 3) balance of plant issues such as ammonia slip, approach to saturation, etc. The ultimate goal is the development of fully integrated pollution control systems that address all of the environmental issues associated with coal-fired power generation in an optimal manner.

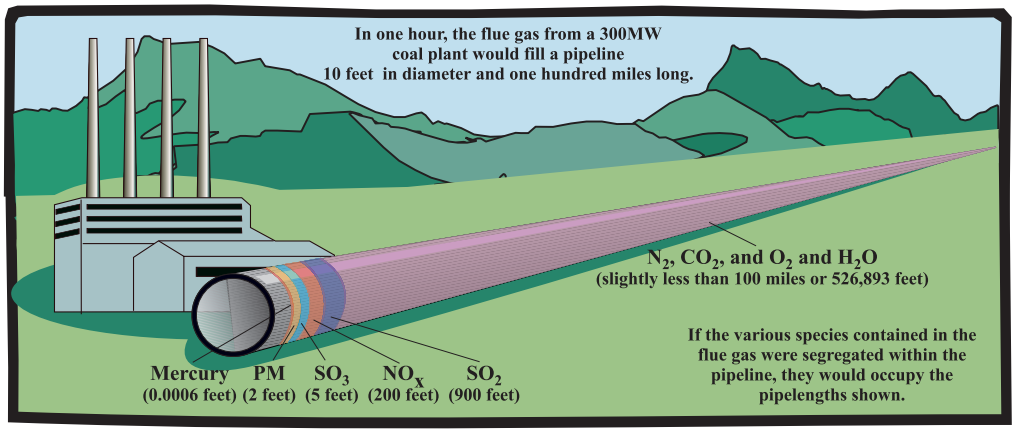


Figure 2. Pollutant Species are Contained in Flue Gas in Dilute Concentrations and Near-Complete Removal is Difficult

The AR&ET Program is in a unique position to serve as an unbiased provider of high-quality scientific data and analysis associated with emissions from coal-fired power plants and the performance of various control technologies. The program acquires such information as a part of conducting control technology R&D. Also, the program works closely with industry in developing control technology and has the contacts and relationships required to garner the high quality data needed for effective policy and regulatory determinations.

Program Benefits

Program benefits include: (1) Development of sound technical information on which appropriate regulatory decisions can be based; (2) Improvement of the performance and reliability of pollution control technologies; and (3) Reductions in the cost of such technologies. Because the first two types of benefits are so difficult to quantify, calculated program benefits are based on lowering the cost of environmental compliance for coal-fired electric generators. The aggregate cost of environmental compliance for coal-fired generators in the United States was 1.9 billion dollars in 1997 and is projected to balloon to over 13 billion dollars per year by 2010 as more stringent environmental regulations come into effect. One program goal is to reduce the overall cost of environmental compliance by 50%, through advanced technologies and integrated systems. A successful program will provide savings of over 6.5 billion dollars per year by 2010.

The program has a strong history of assisting in the development of useful commercial products. Low-NO_x burners, advanced SO_2 scrubbers, and other products have provided the United States with both billions of dollars of savings and a cleaner environment. Figure 3 shows that as competition in the electricity supply industry has lowered prices, generators have increased their use of coal. This trend is due, in part, to the R&D on advanced technologies conducted by the AR&ET Program. In collaboration with industry, the program seeks to continue R&D support to the electricity generation industry, this will result in:

- Continued consumer savings from the use of the most economic source of power—domestic coal
- Continued improvement in ambient air quality
- Technology solutions for large, emerging global market applications to maintain U.S. leadership in the export of electric-power generation technology and services
- Effective environmental technology that will enable the U.S. to maintain energy diversity in a deregulated electric supply industry.

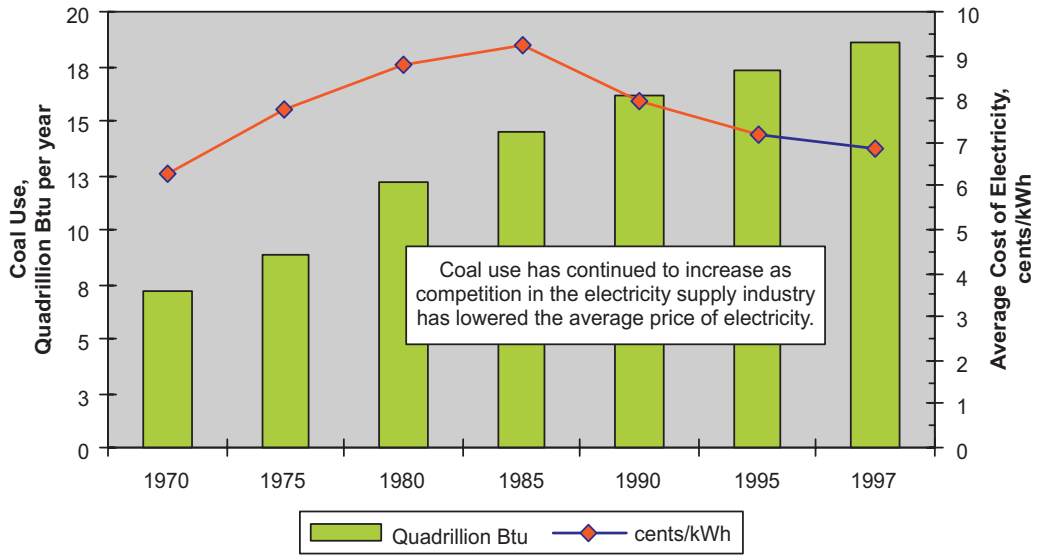


Figure 3. Coal Use and Electricity Cost in the United States

I. Introduction

Vision Statement

The program vision is to develop to the point of deployment advanced emissions control technologies for coal-fired power plants. These technologies will support the continued production of low-cost, environmentally sound coal-based electric power in the U.S. and help maintain U.S. leadership in the export of electric power technology and equipment.

This document presents the R&D plan for the AR&ET Program. It defines the role that the Office of Fossil Energy (FE) will play to ensure environmentally sustainable power production from fossil-based fuel systems in restructured power markets. The environmental issues of concern center around emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), hazardous air pollutants (HAPs), especially mercury and acid gases, and the utilization and proper disposition of coal combustion by-products (CCBs).

This program plan is based on an ongoing series of collaborative efforts with stakeholders. We welcome our stakeholders' comments and ideas. Please visit our web sites, or contact us via e-mail or telephone. (See the last page for details.)

A. Program Drivers

The program is driven primarily by environmental regulations pertaining to coal-fired electricity generation, and the economic need for low-cost compliance options. Reductions in the allowable air emissions of sulfur dioxide, nitrous oxides, particulate matter, acid gases, and mercury are being implemented or planned based on a number of issues including ambient air quality, acid rain, the health of aquatic ecosystems, and regional visibility in parks and other areas of interest. Also, the impacts of solid coal combustion by-products (CCBs) on groundwater are currently being assessed and standards for some uses and management practices may be developed in the future. Electric generators are now required to report releases of hydrochloric acid sulfuric acid, mercury and other HAPs under the TRI. The resulting heightened public awareness of emissions could lead to emissions limits more stringent than those determined by regulators. Finally, the status of a number of coal-fired generation facilities as grandfathered under the Clean Air Act has recently been questioned by EPA on the basis that certain repairs or replacements of equipment performed at those facilities. Figure 4 presents an historical overview of regulatory actions pertaining to coal-fired generation beginning with the passage of the Air Quality Act in 1967. A more detailed discussion of environmental drivers is contained in Appendix A.

Concurrent to the increasing stringency of emissions limits, the electric-generation industry is undergoing deregulation, prompting new efforts to maximize revenues and minimize operating expenses. Drivers for improving system performance for deregulated power markets include:

- Improving the efficiency of fossil-based electricity generation by lowering the parasitic load of environmental controls
- Reducing the operations and maintenance costs of environmental control systems
- Integrating power generation with other products and revenue sources.

Utilization of CCBs will, for example, provide power generators with opportunities to generate additional profits and decrease the waste disposal requirements associated with coal combustion. However, the inherent variation in the physical and chemical properties of CCB materials, combined with the high cost of transportation, will require site-specific applications development.

Against the backdrop of environmental regulation and the electric industry deregulation is the fact that coal-fired electric generation plants commissioned 20, 30, and even 40 years ago have turned out to be highly reliable, low-maintenance, long-lived, and extremely low-cost sources of electricity. These plants are strong assets that have fueled the United States' economic growth over the past decades. However, they were not designed and built to meet current air quality regulations, and new technologies are needed to improve their environmental performance if they are to continue to operate.

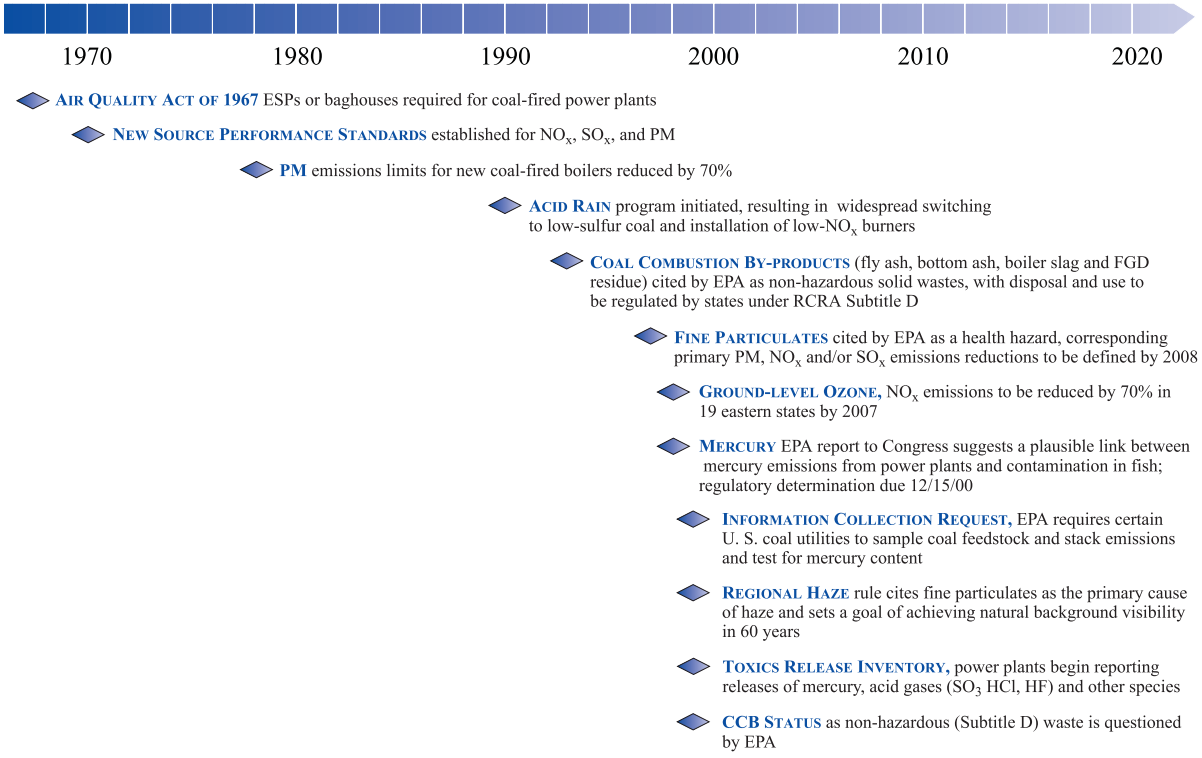


Figure 4. Environmental Regulation of Coal-Fired Electricity Generating Plants is Becoming Increasingly Stringent

B. Federal Role

New technologies will be needed to meet the environmental challenges of coming years. However, the movement toward deregulation of the electricity supply industry has resulted in a dramatic decrease in utility-based research, development, and demonstration of new technologies. Risk-aversion in a highly competitive power market means less likelihood of investment in R&D for new technology. For these reasons, Federal government collaboration is essential to enable industry to develop the needed technology. By making retrofit and new-plant environmental compliance options available and less expensive than they would otherwise be, the DOE/industry partnership can make continued operation of existing coal assets a viable option for power generation companies.

Taking a longer view, federal government involvement in improving operations of the existing fleet of coal plants ensures that the coal infrastructure will be intact when Vision 21 systems are ready for commercial application–projected for the 2015 time frame.

C. Program Goals

The overall goal of the AR&ET program is to develop integrated, advanced environmental control technologies for achieving near-zero emissions of SO_x, NO_x, particulates, and HAPs, and to maximize the beneficial use of solid and liquid residual by-products from the use of fossil fuels. The program's cost goal is to reduce environmental compliance costs for coal-fired power plants by 50%, through both advanced technologies and integrated systems.

Specific objectives include:

- Develop new technologies to meet existing and potential regulations on mercury and other hazardous air pollutants, particulate matter, acid gases, and nitrogen oxides by 2004-2005.
- Provide a better understanding of the contribution of both primary and secondary fine particulate emissions from coal-fired electric-utility boilers to ambient concentrations $PM_{2.5}$ by 2002-2004.
- Demonstrate the acceptability of large-volume uses of coal combustion by-products, such as in road construction and mine reclamation, by 2000 with the ultimate goal of increasing the overall utilization of solid coal combustion by-products from 30% to 50% by 2010.

D. Program Relationships

The AR&ET Program's portfolio of activities is closely linked to both the Vision 21 Program and the Carbon Sequestration Program.

- The "Vision 21" concept is a new approach to 21st century energy production from fossil fuels. It will integrate advanced concepts for high-efficiency power generation and pollution control into a new class of fuel-flexible facilities capable of co-producing electric power, process heat and high-value fuels and chemicals with virtually no emissions of air pollutants. It will be capable of a variety of configurations to meet differing market needs, including both distributed and central power generation. The integrated pollution abatement systems being developed as a part of the AR&ET Program will be compatible with Vision 21 concepts and may enhance their commercial viability.
- The Carbon Sequestration Program is developing systems for capturing greenhouse gas emissions (especially CO_2) from fossil-fuel production and utilization systems and other anthropogenic emissions sources and sequestering the carbon either by converting it into useful by-products or storing it in underground formations or in the deep ocean. Parallel research will explore enhancing natural carbon sinks. Many of the options for capturing CO_2 from flue gas will also capture SO_x, NO_x, particulates, and HAPs. "One box" concepts that would combine CO_2 capture with reduction of criteria pollutant emissions could provide highly cost-effective solutions.
- The AR&ET Program is focused on environmental controls for existing power plants that convert coal to electricity via air-fed combustion. Such power plants represent a tremendous asset base for the United States both in terms of generation capacity (300 GW) and associated infrastructure. Technologies developed for the U.S. systems will eventually be needed abroad, as environmental awareness increases in developing nations.

The AR&ET, Carbon Sequestration, and Vision 21 Programs will combine synergistically to provide a portfolio of retrofit and new coal-fired electricity generation options that cost less, use less fuel, and emit near-zero levels of emissions into the atmosphere. The most recent program plans for the Carbon Sequestration Program and the Vision 21 Program can be downloaded from the DOE Office of Fossil Energy website (http://www.fe.doe.gov/programs_coalpwr.html).

II. Program R&D Portfolio

The overarching objective of this research and development effort is to achieve cost-effective coal combustion systems that have no adverse impacts on human health and the environment. Within that objective, individual technology efforts are aimed at either preventing the generation of certain species in the combustion process or capturing them from gaseous effluents before they are emitted to the atmosphere. Species of concern include SO_2, NO_x, fine particulate matter, mercury, and acid gases.

Another important concern is the management of the solid by-product materials (coal combustion by-products, CCBs) of systems that capture species from the gaseous effluents. Currently, 70% of CCBs are disposed of in landfills; the program activities are aimed at finding more productive and environmentally benign uses for CCB materials. This activity is closely related to the development of post-combustion treatment systems since different systems produce characteristically different solids, which affects management options.

A final element of the AR&ET Program, systems analysis and integration, involves examining the interrelations of the various pollution control system components, looking for opportunities to combine functions and optimize and simplify the overall system. The systems analysis and integration element is crucial to achieving the program's cost goal of reducing environmental compliance costs by 50% for coal-fired power generation systems that meet tighter environmental requirements.

As shown in Figure 5, the AR&ET Program elements span the life-cycle of technology development, from the characterization of emissions through the deployment of integrated systems. Some program elements are relatively mature, while others are in the earlier stages of the technology development cycle. The current program portfolio has five main elements:

- System Analysis and Integration
- Mercury and other HAPs
- Fine Particulate Matter
- Coal Combustion By-products
- Nitrogen Oxides and Sulfur Oxides

Each is discussed in following sections.

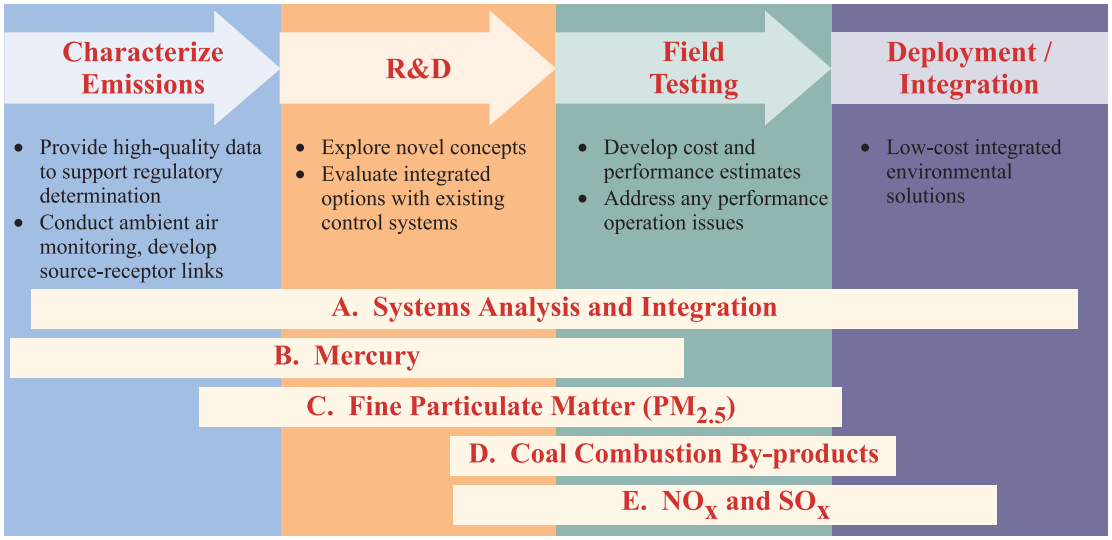


Figure 5. Program R&D Spectrum

A. Systems Analysis and Integration

GOAL:
Identify and evaluate opportunities to combine control of multiple pollutants in integrated systems.

There are many different emissions control options along the coal utilization pathway, from feedstock preparation to combustion modification to flue gas treatment (see Figure 6). The objective of systems analysis and integration is to examine the interrelations among the various options, looking for ways to combine functions and create a simplified and optimized overall system. In doing this, it is important to take a long-term view and anticipate regulation of mercury, particulate matter, and CO_2 emissions, and also to focus on the existing assets and how they can be best utilized. Examples of integration options include:

- Evaluating the effect of SCR catalysts on mercury oxidation and subsequent capture in an ESP, baghouse or scrubber.
- Improving the efficiency of wet scrubbers to remove more SO_2 and to generate less CCBs.
- Augmenting the capture of SO_3 and other acid gases in advanced control systems designed primarily for NO_x, SO_2, particulates, and/or mercury.

Compared to the predominantly single-pollutant control approaches typical of most present-day systems, integrated systems offer notable potential benefits:

- Lower costs due to fewer components and subsystems and reduced parasitic power requirements
- Smaller plant footprint, particularly important for retrofit applications.

Accordingly, systems analysis and integration will be a key factor in achieving pollutant removal to very low concentrations and at an acceptable cost.

Some of the technology control options shown in Figure 6, such as feedstock preparation, are already covered by other parts of the FE program. Also, CO_2 sequestration is addressed in a separate R&D program plan (the *Carbon Sequestration Program Plan*). This systems analysis and integration program element is new and is intended to identify and evaluate the technology opportunities for integrated systems across the R&D portfolio.

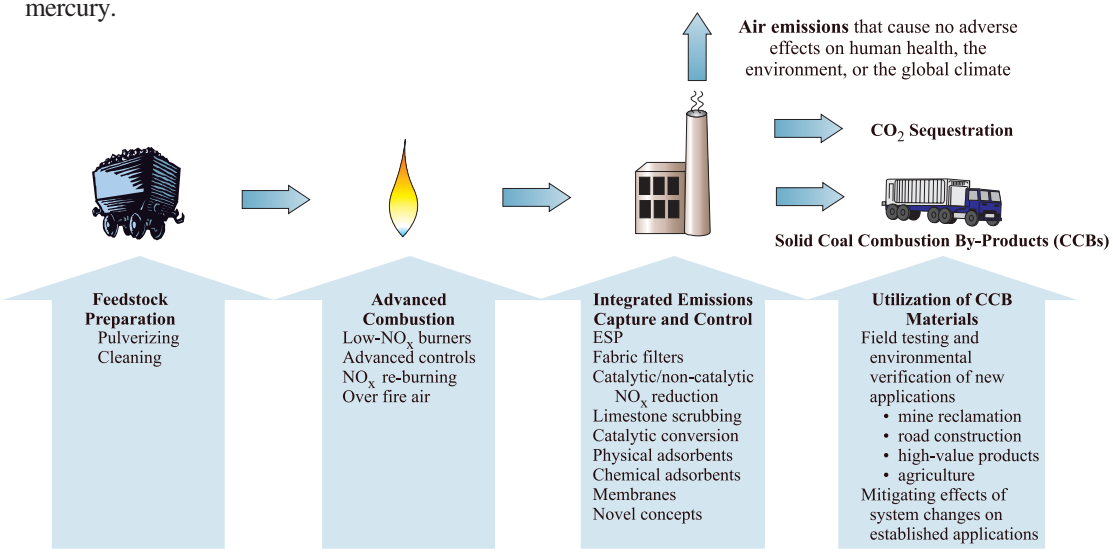


Figure 6. The Portfolio of Emissions Reduction Technologies in the Full Life Cycle of Pulverized Coal Electricity Generation

B. Mercury

GOAL:
Develop control strategies for reducing the current annual coal-fired utility mercury emissions by 50 to 70% by 2005 and by 90% by 2010 at a cost between one-quarter and one-half of the current cost-estimates.

Most flue gas streams from coal-fired electricity generation systems contain trace amounts of mercury, on the order of 1 part per billion. Mercury, some forms of which bioaccumulate, is a neurotoxin. The effects of mercury emissions on human health, especially related to ingestion of mercury-contaminated fish, have recently become an issue of concern. In 1997, EPA submitted a report to Congress suggesting a "plausible link" between mercury emissions from coal plants and mercury contamination in fish. The EPA report also found that coal-fired electricity generation systems represent 32.6% of all U.S. anthropogenic mercury emissions.

The mercury issue is relatively new. Rigorous study of mercury emissions from power plants began with the Clean Air Act Amendments of 1990 (CAAA), which directed EPA to examine mercury contamination and anthropogenic emissions. The scientific understanding of issues such as mercury transport in the environment and the acceptable level of mercury contamination in fish and other wildlife is evolving.

The mercury element of the program has three primary thrusts:

- Characterize mercury emissions from coal-fired boilers,
- Develop cost-effective mercury control systems, and
- Provide comprehensive cost and performance data on mercury control technologies for use in regulatory determinations.

Each is described in the following:

Characterize mercury emissions

The program pursues characterization of mercury emissions from coal-fired boilers in order to provide reliable information that can serve as the underpinning for a successful control technology R&D effort. The characterization thrust has three components: 1) measuring the levels of various forms of mercury in flue gas, 2) studying the chemical interactions of each form of mercury with other flue gas components, and 3) developing correlations between the levels of various forms of mercury in flue gas and both combustion conditions and types of coal. The goal of the characterization effort is to provide data of the necessary quality and scope to support effective decision-making about viable technology development pathways.

Develop cost-effective mercury control systems

Economical capture of mercury from flue gas is a daunting challenge. The R&D effort is a three-pronged approach:

- Improve the mercury capture of existing pollution abatement systems through
  - conversion of elemental mercury to water-soluble forms
  - additives to enhance mercury capture across ESPs and fabric filters
- Add adsorbents to the flue gas to capture the mercury using
  - carbon-based adsorbents
  - flyash carbon
  - noble metals
- Identify and evaluate novel concepts

As researchers have studied the problem and experimented with options for mercury reduction, the estimated cost of emissions reduction have come down. Recent cost estimates for a 90% reduction in mercury emissions from all U.S. coal-

fired boilers are $2.5 to $6.5 billion per year, half of what they were three years ago. While the reductions are encouraging, the cost estimates are still high and continued R&D is needed.

In 1995 the program initiated a number of pilot studies with the goal of obtaining a fundamental understanding of the chemistry of mercury species in flue gas and developing new mercury control technologies. This R&D phase will be completed in 2000.

Starting in FY 2000, the AR&ET Program will acquire field test data for promising mercury control technologies and will also initiate smaller pilot-scale investigations of newer concepts. This effort will provide opportunities to further collaborate with other government agencies, the utility industry, organizations representing the utility industry, and technology developers. Research objectives are to:

- Determine mercury removal or efficiency of promising mercury control technologies at a larger scale
- Assess the portion of U.S. electricity generation industry to which each mercury control technology is amenable, based on systems integration issues
- Identify the possible negative and positive impacts of retrofitting these mercury control technologies
- Rate the various technologies on the basis of emissions control performance per cost, taking into consideration real-world deployment factors that increase cost and degrade performance.

Provide comprehensive cost and performance data on mercury control technologies

The program is working closely with EPA and EPRI to ensure the regulatory development process for mercury emissions has the benefit of high-quality up-to-date information regarding both mercury emissions from coal-fired boilers and available emissions control options. The program has undertaken the following major efforts in support of the regulatory development process.

- Provided EPA with mercury emissions data from 16 coal-fired boilers–the data that formed the basis for the Mercury Report to Congress.
- Assisted EPA by developing the Quality Assurance and Quality Control Plan for its Information Collection Request (ICR) in which additional mercury emission data was gathered from coal-fired utilities.

The program will also participate in the statistical analysis of the ICR data. The data collection phase of the ICR will end in June 2000.

EPA is scheduled to determine if mercury emissions from coal-fired power plants should be regulated by December 15, 2000. If EPA decides to regulate utility mercury emissions, compliance would be required by 2007. The program plans to continue its collaboration with EPA as the regulatory development process proceeds. The program will supply EPA with updated information as understanding of mercury emissions chemistry improves and as better cost and performance data from control technologies become available.

90% Removal of Mercury from Flue Gas is a Challenge

Mercury is present in flue gas at a concentration of approximately 1 part per billion. In the pipeline example earlier, one hour of operation of a 300 MW coal plant fills a 100-mile-long pipe with 41 million cubic feet of flue gas. This is roughly equivalent to the volume of the Houston AstroDome. Consider that the AstroDome could hold roughly 30 billion ping pong balls. So, analogously, 30 of the 30 billion ping pong balls are "mercury" and the technology challenge is to sift through the AstroDome full of ping pong balls and capture 27 of the 30 "mercury" ones (90% removal).

C. Fine Particulate Matter ($PM_{2.5}$)

GOAL:
Ensure that the best science and technology are available for any regulatory decision-making related to the health and environmental impacts of ambient fine-particulate matter and regional haze.

Ambient concentrations of ultrafine particulate matter—particulate matter with a diameter of 2.5 microns or less ($PM_{2.5}$)—may be linked to both adverse human health effects and the loss of visibility in national parks and other areas. Fine particulate matter can be associated with potential HAPs such as trace metals or organic compounds. As Figure 7 shows, there are two types of particulate matter emissions, primary and secondary. The program activities address both types.

Control of larger primary particulates has improved dramatically over the past 30 years in response to the original Clean Air Act and associated New Source Performance Standards (see Figure 8). For the future, EPA's revision of the National Ambient Air Quality Standards in 1997 and promulgation of the Regional Haze Rule in 1999 make future regulatory limits on anthropogenic emissions of $PM_{2.5}$ and $PM_{2.5}$ precursors a real possibility. In 1998 Congress called for DOE to initiate a research program to address these technical and scientific issues from the standpoint of the potential impact of the new $PM_{2.5}$ standard on coal-based power systems.

Objectives

The $PM_{2.5}$ element of the AR&ET program has three specific research objectives:

- Elucidate source-receptor relationships and emission trends through evaluation of the concentration and chemical and physical composition of ambient fine particulate matter and precursor gases, and possibly other pollutants of concern (e.g., ozone, mercury).
- Characterize both primary and secondary fine particulate emissions from fossil-based power systems to better understand their potential impacts on ambient air quality.
- Develop and evaluate technologies to cost-effectively control $PM_{2.5}$, should further reductions in fossil-based power systems be necessary to address $PM_{2.5}$ health or visibility concerns.

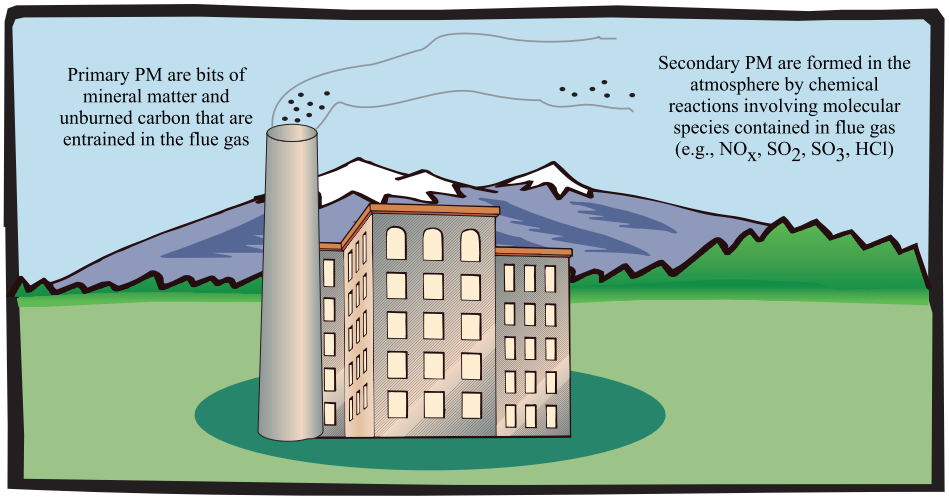


Figure 7. Two Types of Particulate Matter Emissions from Coal-Fired Boilers

These objectives are closely related. For example, the development of source-receptor relationships will determine the degree to which emissions from coal-fired boilers must be limited to achieve ambient air quality and visibility standards. Further, the research supports the National Academy of Sciences recommendation to determine the link between ambient air quality and human health. Developing an understanding of the relative impacts of the different types of $PM_{2.5}$ will also enable a prioritization of control technology R&D activities.

The program's R&D activities are strongly leveraged with funds from industry and other state and federal agencies. In addition, the program conducts a significant amount of outreach, recently becoming a sponsoring member of NARSTO, a tri-national organization that addresses scientific and policy issues related to ozone and aerosols.

The $PM_{2.5}$ element conducts research in the three main areas. These areas and their major activities follow:

Ambient monitoring: $PM_{2.5}$ sampling and chemical analysis

The new fine-particulate NAAQS will establish a nationwide network of 1,500 $PM_{2.5}$ monitors by 2000. A small but critical subset of these stations will include "supersites" that will sample for an array of chemical species on a more frequent sampling interval. DOE has worked with key stakeholders, including the EPA, local and state environmental agencies, academia, and industry, in establishing and operating several of these $PM_{2.5}$ sites. Project sites include the Upper Ohio River Valley Region, the Great Smoky Mountains National Park in Tennessee, and the Bravo project in Big Bend National Part in Texas. The program is working to expediate sharing of data and other collaborative activities among the different facilities. Figure 9 shows the location of these and other projects in the Ambient Monitoring effort.

Emissions characterization and $PM_{2.5}$ atmospheric chemistry

The program seeks to 1) characterize fine particulate emissions from fossil-fuel-based power systems with the goal of producing a well-defined source emissions inventory, 2) continue to develop and evaluate new fine particulate emissions sampling methods to gain the most accurate results, and 3) study plume and atmospheric chemistry to better understand the reaction pathways of secondary fine particulates.

Control technology research and development

A critical component of the $PM_{2.5}$ element is the development of cost-effective control technology to be implemented should further restrictions be placed on emissions from coal-based power systems. The control system development effort is focused on three types of emissions: primary particulates, NO_x, and acid gases.

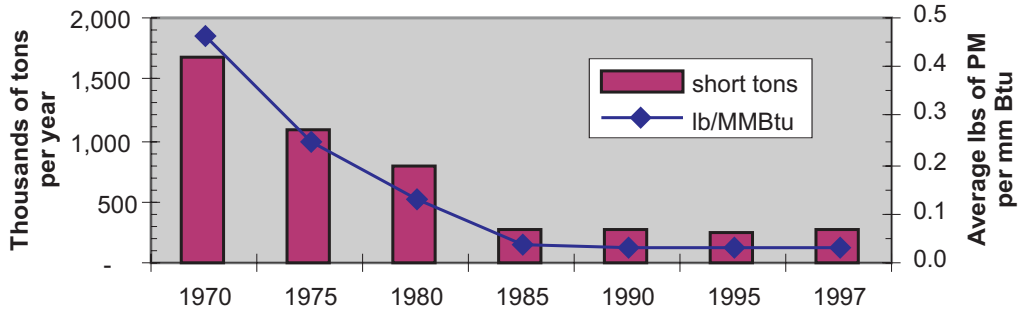


Figure 8. Emissions of Particulate Matter from Coal-Fired Power Plants

Primary particulate matter. The majority of coal-fired electric utility boilers in the United States control primary particulates with ESPs. A smaller but growing number of boilers employ fabric filter collectors (baghouses). However, even with high-performance particulate-control systems, collection is less efficient in the submicron particle size range. Also, increased age of existing systems has led to decreased collection efficiency, as has switching to higher resistivity low-sulfur coals. The R&D efforts encompass both stand-alone $PM_{2.5}$ capture systems and upgrades/add-ons to commercial control systems.

NO_x (secondary particulate precursor). Flue gas contains various levels of NO_x depending on the type of boiler, coal type, existence of combustion controls (e.g., low NO_x burners) and other factors. NO_x emissions are regulated as a part of the Clean Air Act and, in addition to causing formation of secondary fine particulates, NO_x is linked to ground-level ozones and eutrophication of lakes. Several NO_x control R&D projects have been funded under the auspices of the fine particulates program. NO_x emissions and controls are discussed further in the NO_x, SO_x program summary.

Acid gases (secondary particulate precursors). Flue gas from coal-fired boilers contains trace amounts of acid gases such as SO_3/H_2SO_4, HCl, HF, and related condensable vapors that can form ultrafine particles upon cooling and/or exposure to moisture within the combustion system or after release from the stack. Such species, which can adversely affect plume opacity, are not typically controlled in coal-fired boilers.

In the area of NO_x emissions control, the program will investigate ways to improve the performance of advanced low NO_x burners through over fire air and staged air configurations, as well as through hybrid systems with selective non-catalytic reduction and other post-combustion control technologies. The program will also investigate oxygen and methane-enhanced combustion as a means of NO_x control. In addition, the program will carryout full-scale demonstration of a Selective Non-Catalytic Reduction unit (in collaboration with the Ohio Coal Development Office, EPRI, American Electric Power, and 14 other utilities).

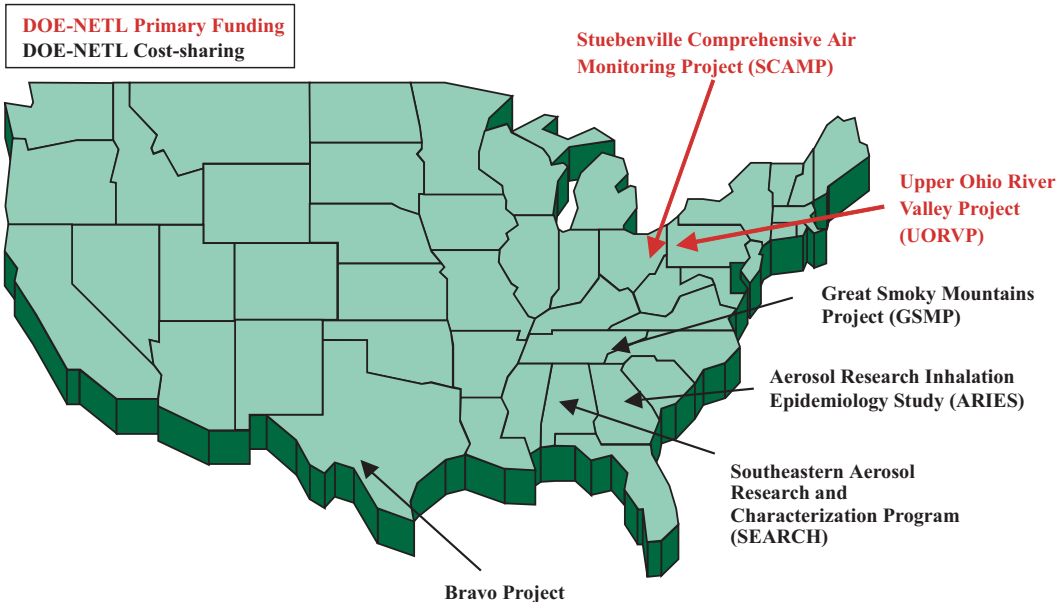


Figure 9. DOE Ambient $PM_{2.5}$/Air Toxics Sampling and Analysis Projects

LSR Technologies' Core Separator

In the early 1990's, the AR&ET Program provided funding to LSR Technologies, Inc. for the development of its Core Separator, a mechanical particulate control system. The research was a success, and in 1996 the Core Separator earned LSR Technologies one of R&D Magazine's prestigious R&D 100 Awards. Initial commercial applications for the Core Separator have been mostly industrial boilers. Recently, LSR Technologies developed the ElectroCore system which is designed to be retro-fitted into coal-fired electricity generation systems with ESP units. In the ElectroCore system, an ESP is integrated with a Core Separator to achieve a high degree of particulate separation (especially fine particulates) at low incremental cost. In August of 1999, the AR&ET Program awarded LSR Technologies $1.2 million to demonstrate its ElectroCore fine-particulate-separation technology at the pilot scale at Alabama Power Company's Gaston Stream Plant.

In the area of primary particulate emissions control, the program will investigate flue gas conditioning agents to improve ESP performance, hybrid ESP/fabric filter systems, and electrostatically enhanced core separator retrofit systems (see box on the next page). In the area of acid gas emissions control, the Program will investigate in-furnace injection of alkaline chemicals.

For more information on the R&D performance targets, solicitation activity, and background information related to the $PM_{2.5}$ element, visit the Particulate Matter and Air Toxics Research Program website at www.netl.doe.gov/products/power/enviro/pm25.

GOAL:
Increase the utilization of solid coal combustion by-products from 30% to 50% by 2010.

The removal of fly ash, sulfur dioxide, and other species from flue gas results in the production of solid materials, referred to as coal combustion by-products (CCBs). CCBs have many interesting and useful properties. However, due to both liability concerns and the limited number of proven utilization options, electricity generators have historically opted to landfill CCBs rather than try to sell them as a commodity. Figure 10 shows that the generation of CCBs in the United States has been increasing steadily with both increasing coal use and more stringent environmental regulations, and that only a small percentage of the total generation is utilized. In 1998 seventy-seven million tons of CCBs were disposed of landfills in the United States, roughly 71% of the total production, at a cost of roughly $1 billion.

With increased focus on cost-cutting in a competitive market, electricity generators have recently become more interested in utilizing CCBs. From the perspective of DOE, value-added CCB applications can reduce the overall cost of environmental controls and maintain low-cost energy production. Also, the utilization of CCBs can reduce CO_2 emissions by avoiding the energy needed to produce displaced virgin material.

The activities of the CCB program element can be broken into three interrelated thrusts:

- Developing new applications for CCB materials
- Evaluating the impact of air emission control technologies on CCB properties
- Providing field test data for use in regulatory matters pertaining to disposing of or using CCBs.

Developing new applications for CCB materials

The program efforts on developing new options for CCB disposition are broken into three categories.

- Construction materials
  - Lightweight aggregate
  - Road construction
- Beneficial land application
  - Agricultural lime substitute/soil amendment
  - Surface mine reclamation
  - Livestock feedlot stabilization
- Underground mine emplacement
  - Surface mine highwall stabilization
  - Underground mine subsidence control
  - Acid mine drainage abatement

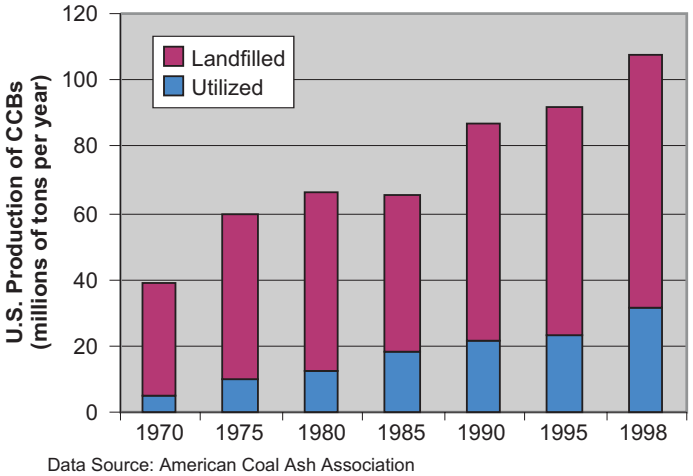
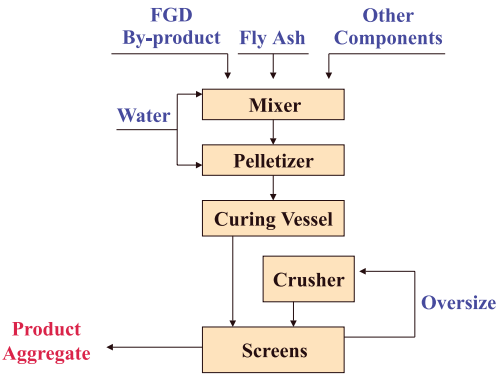


Figure 10. Utilization of CCBs

It is anticipated that additional SO_2 scrubbers will be deployed over the next 10 years to comply with CAAA and other air emission regulations, resulting in the production of significantly more flue-gas desulfurization (FGD) by-products. Based on projected scrubber capacity, the annual generation rate of FGD material could increase from 25 MM tons (25% of all CCBs) in 1998 to 75 MM tons (50% of all CCBs) in 2010. In 1998 only 10% of FGD material generated was utilized. Finding useful applications for FGD material is a key focus of the CCB program.

Production of Construction Aggregates from FGD By-product Material Shows Promise

In a cost-shared effort with CONSOL Incorporated, DOE is demonstrating conversion of a mixture of FGD by-product and flyash into manufactured aggregates that are suitable for high-volume construction purposes (see process diagram at right). Initial results are promising, and CONSOL is designing and building a 500 lb/hr pilot plant to demonstrate its proprietary process on a larger scale.



There are three main challenges to be overcome in the development of an application for a CCB material.

- Environment: CCBs may contain trace amounts of heavy metals and other regulated chemical species. The degree to which these regulated species are released into the environment, if at all, must be carefully measured for each application.
- Performance: The CCB materials must meet the performance requirements (e.g., strength, durability) of the application.
- Economics: The costs of any needed processing and transport of the CCB material must not outweigh the revenue benefit.

In the past, the CCB program has enjoyed numerous successes in collaborative projects with industry. To continue and build upon those successes, DOE has established the Emissions Control By-products Consortium (ECBC), an industry/government/academia partnership, to aid in managing the R&D effort and specifically to assist in the evaluation of proposals. The consortia will enable DOE to 1) collaborate with the utility industry and other federal agencies, 2) consider region-specific CCB utilization opportunities, and 3) leverage funds with other entities.

Evaluating the impact of air emission control technologies on CCB properties

Air emissions abatement technologies can affect the composition of flyash and other solid by-product streams. For example, low NO_x control systems may increase the carbon content of flyash and/or contaminate it with trace amounts of ammonia, in some cases making it unsuitable for use in concrete. Also, systems used to capture mercury from flue gas may increase the mercury content of CCBs, causing potential environmental concerns in certain applications. In the future, the CCB utilization program will focus on characterizing any changes that occur in CCB materials and maintaining the utilization of CCBs in key applications.

Providing data for use in regulatory matters pertaining to disposing of or using CCBs

In some cases perceived environmental risks associated with CCB use are a significant barrier to CCB utilization. To overcome this barrier, the program has performed numerous field tests with rigorous monitoring of the degree to which species of concern are released into the environment. The program supplies such information to EPA and other federal agencies.

EPA is currently determining the environmental acceptability of using CCB materials and what management/utilization practices are allowable. The program has supplied EPA with high-quality data obtained from field tests that show minimal environmental impacts. It will continue to provide EPA with data as it becomes available.

E. NO_X and SO_X

GOALS:
90% or greater NO_x emissions reduction from coal-fired boilers at low cost and 95% removal of SO_x from flue gas.

The term NO_x refers to oxides of nitrogen (NO, NO_2); similarly SO_x refers to both SO_2 and SO_3. The emissions of SO_2 and NO_x from electricity generation boilers are directly regulated as a part of Title IV of the CAAA. As a result of advanced control technologies and coal switching, emissions of NO_x and SO_2 from coal-fired power plants have been reduced (see Figure 11). Emissions of SO_3 and other acid gases may be regulated in the future, and the program element name has been changed from NO_x and SO_2 to NO_x and SO_x to reflect the significance of SO_3 emissions.

The Department of Energy, in partnership with industry, has been successful in developing retrofit technologies that have enabled existing coal plants to comply with CAAA at relatively low cost. Most notably, low-NO_x burners offer a 50% reduction in NO_x emissions at an incremental cost of roughly 0.03 cents per kWh ($200/ton NO_x). The program has also developed technology that enhances the performance of SO_2 scrubber systems (see page 15).

Although the technologies employed to comply with Phase I of Title IV (e.g., wet scrubbers, low-NO_x burners) are considered mature, tighter restrictions on NO_x and SO_x emissions are on the horizon. Two points demonstrate that this will be the case. First, the SO_2 emissions limits imposed by Title IV are an absolute cap. Over the coming years as stockpiled allowances expire and as coal use increases along with economic growth,

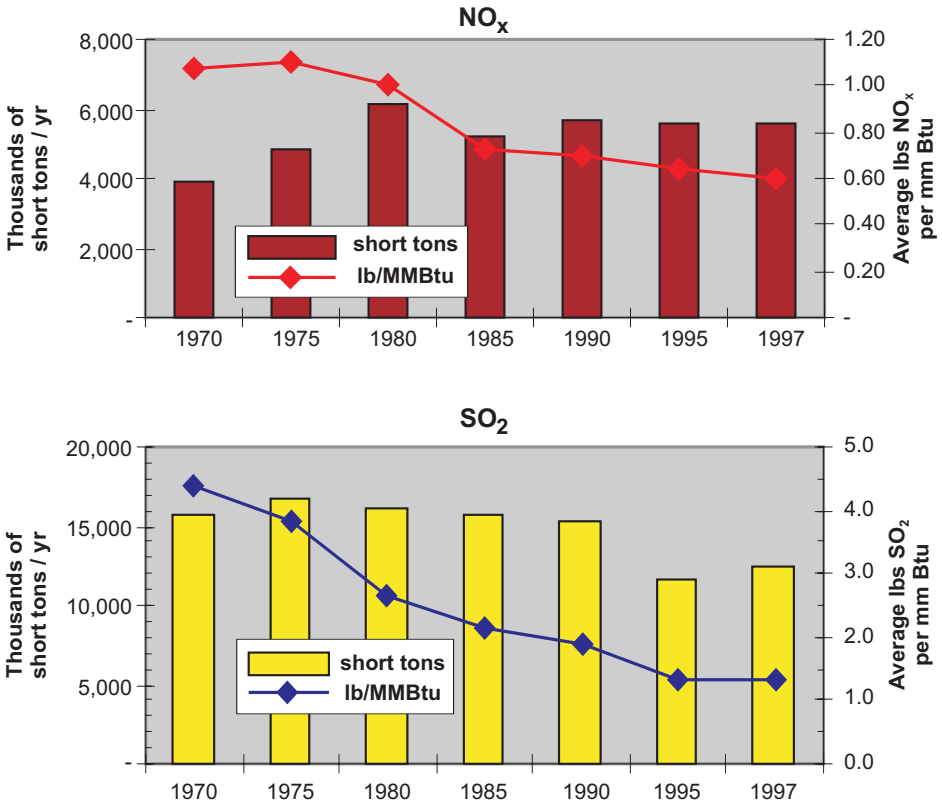


Figure 11. NO_x and SO_2 Emissions from Coal-Fired Power Plants in the U.S.

Title IV limits will become more restrictive. Second, NO_x and SO_x have been identified as precursors to fine particulate matter, and NO_x as a precursor to ground-level ozone; regulations designed to improve ambient air quality may require cuts in NO_x and SO_x emissions well below the proposed Title IV levels. For example, as a part of a State Implementation Plan to reduce ground-level ozone (NO_x SIP), 19 eastern states are required to reduce NO_x emissions from existing boilers to 0.15 lb/mm Btu coal during the summer-time ozone season (May-September). As a comparison, the NO_x emissions limits under the Acid Rain Program range from 0.4-0.86 lbs/mm Btu, depending on the boiler type.

Finally, the emissions of acid gases including SO_3 may become a regulatory target as a result of electricity generators reporting under the Toxics Release Inventory. Control of acid gases would in effect reduce the allowable emissions of SO_2 because of the similarity of the chemical species' reactivity. (99% of sulfur emissions from coal-fired boilers are in the form of sulfur dioxide, but the remaining 1% is mostly SO_3, which forms sulfuric acid upon contact with water.)

Because NO_x is a precursor to ambient fine particulate deposition, advanced NO_x control technologies are also being developed under the auspices of the fine particulate matter program. The technologies are to be ready for commercial deployment by 2002-2004, which would enable them to be utilized by U.S. utilities for compliance with the NO_x SIP call. Specific requirements for the NO_x reduction technology development are to 1) reduce NO_x emissions to 0.15 lb/ mm Btu at a cost 25% lower than an SCR, 2) have negligible impact on balance-of-plant issues, 3) be applicable to a wide range of boiler types and configurations, and 4) maintain performance over a wide range of feed coals and operating conditions.

Coal-fired power plants will likely be required to reduce SO_2 and SO_3 emissions below Title IV requirements over the next 5-10 years. Concerns over the effects of NO_x emissions may prompt lower year-round NO_x emissions standards as well. The AR&ET Program will continue to discuss technology development needs and opportunities regarding SO_2 and NO_x control with technology developers, utility companies, and other stakeholders.

A possible basis for tighter emissions standards is the deposition of NOx from power plant emissions to water bodies. Nitrogen in fresh water causes eutrophication (nutrient overloading), which causes algae to grow rapidly and deplete the oxygen in the water. Low oxygen concentration causes fish kills, odor, and other problems. The agriculture industry was first identified as the primary source of nitrogen overloading in fresh water systems, and initial action to lower nitrogen concentrations focused on regulating the storage and use of animal wastes. However, a 1998 report *National Acid Precipitation Assessment Program Biennial Report to Congress: An Integrated Assessment* by NSTC found that between 10 and 45% of nitrogen in estuaries along the Atlantic and Gulf Coast is caused by atmospheric deposition. Thus future regulations designed to protect fresh water resources may be focused on sources of atmospheric nitrogen, such as power plants and automobiles.

Field Test of Advanced Scrubber Technology at Duquesne Power and Light's Elrama Power Station is a Big Success

The addition of thiosufate to the scrubbing liquor of a flue gas desulfurization system inhibits sulfite to sulfate oxidation and the formation of gypsum scale. A field test cosponsored by DOE demonstrated that increasing the concentration of thiosulfate in the scrubbing liquor from 500 ppm (the established operating level) to 2000 ppm, improved the scrubber efficiency 1%, reduced the amount of lime used by 10%, and virtually eliminated scale buildup. The project is saving the plant $574,000 per year: $84,000 in extra sulfur dioxide allowances from the improved scrubber efficiency (based on current market value); $220,000 from reduced lime use, and $270,000 from reduced maintenance cost. Says Egon Klatt a 35-year veteran at Duquesne Light, "Some people would call it a home run. I call it a grand slam."

III. Program Management

This section presents the management objectives of the AR&ET Program, including the program strategy, R&D portfolio, portfolio criteria, and stakeholder outreach activities. It provides the program timing and major milestones.

A. Program Role and Strategy

A program that encompasses R&D on a diverse portfolio of technologies offers the best chance of success for reducing risks and ultimate environmental-control costs to the United States. In implementing this portfolio, significant industry participation is essential for all phases of the program, through workshops, advisory panels, competitive awards, and cost-shared partnerships.

The AR&ET program has two major roles:

- Developing advanced environmental control technology for coal-fired power plants
- Providing high-quality data and analysis to EPA, OMB, Congress, and others for use in regulatory determinations.

A major portion of the program's R&D is awarded through competitive solicitations involving industry, universities, and national laboratory performers. For example, in 1999 the program issued a major solicitation titled *Emission Control Technology for Fine Particulate Matter ($PM_{2.5}$) Ozone, and Related Environmental Issues* for technologies, processes, and concepts that can be retrofitted to existing coal-based power systems. In March 2000, the program issued a solicitation for field-testing of promising mercury control technologies. Through these solicitations the program seeks to partner with industry to develop innovative technical approaches to ensure that domestic coal can remain an environmentally sound component of the United States' overall energy mix well into the 21st century.

High-quality data is critically important to ensure that regulations provide improvements in health and the environment and that those improvements are commensurate with the cost of compliance. The AR&ET program provides valuable input because it is both objective and technically capable of developing the pertinent data and analysis.

B. Portfolio Approach to Management

The program activities are managed as a portfolio, recognizing that knowledge about this field of science and technology is rapidly evolving. By applying portfolio theory to the management of program resources, the probability of success in achieving program goals is increased.

The portfolio will be managed with an increasing emphasis on the critical outcomes of flexibility and integration potential, because integration of controls for multiple emission species is the most likely path to achieve environmental acceptability at low costs.

C. Stakeholder Outreach and Partnerships

Environmental compliance of existing coal-fired boilers is an important issue for U.S. utilities, and there is strong support and interest for the program within the power generation industry. Through cost-shared R&D projects, industry/government consortia, and informal advisory relationships, the private sector is tangibly involved in the program. As new environmental issues affecting the power industry arise, the program funds workshops to garner industry input and works with other agencies of the Federal Government to identify R&D needs and other opportunities for the program. Also, coordination and cooperation with other governmental entities enables the program to leverage funds.

Recent outreach activities include:

- Provided technical and programmatic information to the National Research Council in its review of the DOE Fine Particulate Research Plan

Program Portfolio Criteria

Critical Outcomes

- *Low cost.* The expected cost of the commercial technology, in terms of both capital costs and operations and maintenance costs.
- *Environmental acceptability.* The expected compatibility with the environment, including protection of human health and sensitive ecosystems.
- *Control of multiple pollutants.* The ability of the technology to simultaneously control different emission species.
- *Flexibility Potential*. The ability of the technology to be used with a wide range of plant configurations and sites, both new and retrofit.

Supporting Outcomes

- *Likelihood of success.* The probability of meeting the performance objectives of the research activity.
- *Multiple benefits.* The degree to which the activity is likely to produce other benefits (e.g., international market competitiveness for technology products and services) in addition to environmental acceptability.
- *Program balance.* The degree to which the activity complements the scope, timing, risk, and diversity of the portfolio.
- *Program enhancement.* The degree to which the activity identifies and makes progress on new concepts, thereby increasing the likelihood of a successful program.
- *Partnerships.* The participation (financial, intellectual, and programmatic) of other research sponsors, including industry and international partners.
- *Leveraging.* The aggregate cost-sharing by non-FE participants.
- *Visibility*. The potential for the activity to attract favorable attention to the FE R&D program.

- Launched a $PM_{2.5}$ web page which provides background information on the fine particulate issue, a discussion of the program's goals and objectives, and updates on ongoing R&D projects, the ambient air monitoring program, and solicitation activity
- Published a technical review of the Environmental Protection Agency's Mercury Report to Congress, focusing on EPA's evaluation of mercury control technology and cost
- Published a critical review of mercury measurement and control technology in the *Journal of the Air & Waste Management Association*

Planned outreach activities include:

- Participate in the Air Quality Subcommittee, a Congressionally mandated group that coordinates all Federal activities in air quality
- Cosponsor, with the Office of Surface Mining, Department of Interior, an Interactive Forum on CCB Utilization in Mining.

D. Program Timing and Milestones

In the near term (less than five years), the program will continue to examine emissions-specific technology needs and solutions while assessing the opportunities for integrated control strategies. In the mid term (five to ten years), the program will focus on the evaluation and development of integrated control strategies and systems that can yield the cost-effective technologies that are required. The long-term (beyond ten years) focus is on ground-breaking concepts for a cost reduction in systems, including systems with both low capital cost and very low operations and maintenance costs. Figure 12 shows major activities and milestones for the program over the next five years.

E. Program Costs

The AR&ET program budget for FY 2000 is 23.8 million dollars, which includes 9.2 million dollars for carbon sequestration R&D activities. The non-sequestration budget, 14.6 million dollars, is nearly double the 1998 funding level. Future program funding will depend on regulatory activity and the level of national interest in reducing the detrimental effects of coal utilization to ensure its continued use as an energy source.

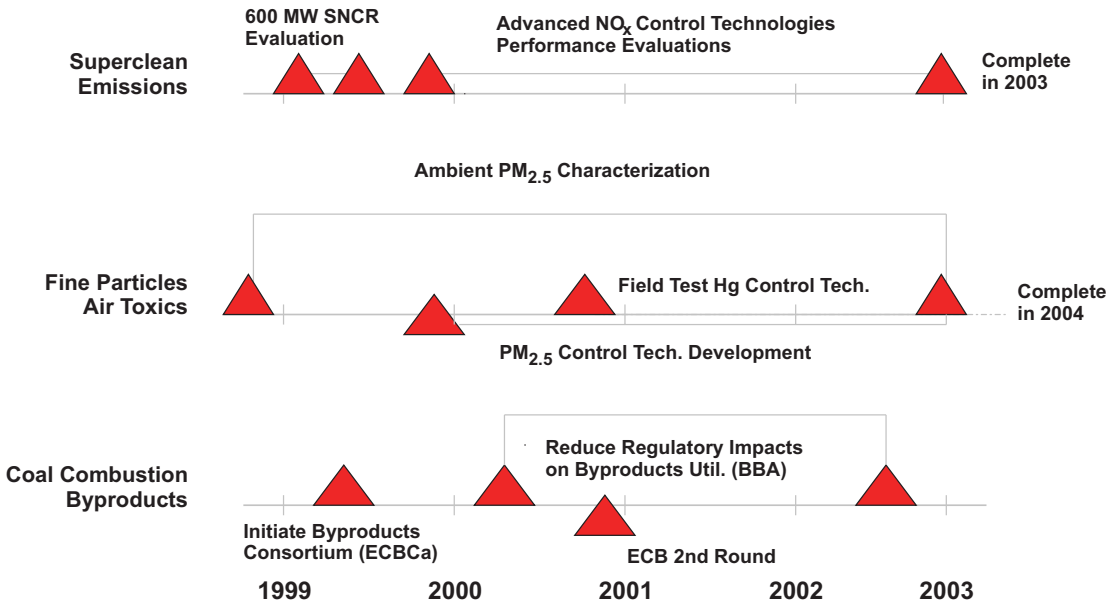


Figure 12. AR&ET Program Milestones

IV. Program Benefits

The aggregate cost of environmental compliance for coal-fired electric generators in the United States was 1.9 billion dollars in 1997 and is projected to balloon to more than 13 billion dollars per year by 2010 (see Figure 13). Regulations of HAP emissions and the Regional Haze Rule, which are not included in the 2010 estimate, could raise compliance costs higher. Thirteen billion dollars per year in 2010 is roughly equivalent to 0.6 cents per kWh of electricity generated from coal, which would be a 60% increase over the baseline average fuel cost of 1.0 cent per kWh.

The AR&ET program benefits are based on lowering the cost of environmental compliance for coal-fired electric generators. If the program goal of a 50% reduction is achieved it will save 6.5 billion dollars per year.

A. Retrospective

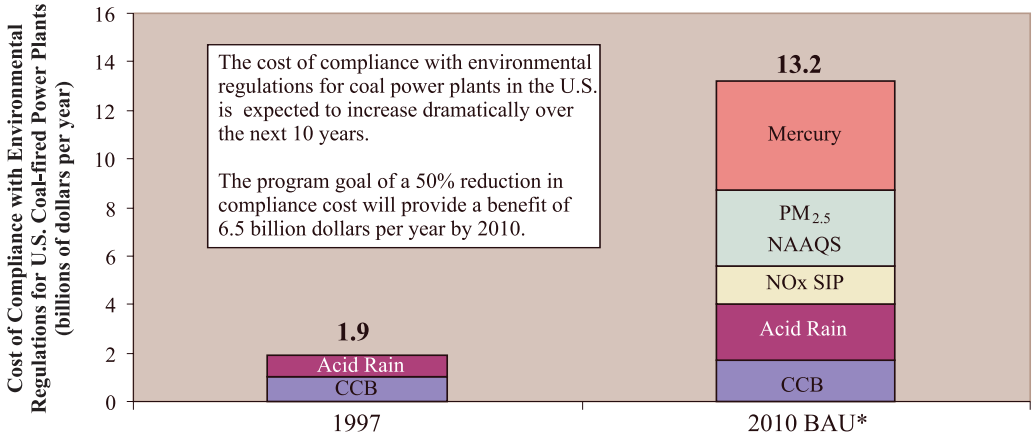
As shown in Figure 14, the cost of electricity has decreased from an average of 9.2 cents per kWh in 1985 to 6.9 cents/kWh in 1997 while coal use has increased. Cost reductions continue, and the increased reliance on coal plays a large role in enabling the lower energy prices.

Over the past 20 years, technologies developed by the program have helped keep the cost of coal-fired generation low. The following are examples.

- *Low-NO_x burners*. In 1997 over half the coal burned in the United States was burned in a Low-NO_x burner. Developed with DOE funding, this technology provides a 50-65% reduction in NO_x emissions at a cost of roughly 200 $/ton. As a comparison, a selective catalytic reduction system costs 1,500-2,000 $/ton.

- *Advanced SO_2 Scrubbers*. The AR&ET Program conducted field tests demonstrating that very minor operational changes to a limestone scrubber could improve the sulfur dioxide removal efficiency. The incremental cost of sulfur dioxide capture from such changes can be as low as 50 $/ton. With the soft market for SO_2 allowances and other pressing environmental and deregulation issues, commercial interest in advanced scrubber technology has been low. However, this technology will be critical in keeping the cost of sulfur emissions reductions low as Title IV comes into effect and as more stringent SO_2 emissions regulations are promulgated to meet $PM_{2.5}$ and ozone air quality standards.

- *High-quality information on toxics emissions*. Working with EPRI, DOE developed much more accurate air emissions factors for heavy metals and other toxic species than were currently available. These correlations showed much lower emissions of toxic materials in the flue gas from coal-fired boilers than the correlations



*The estimated cost of compliance under the 2010 BAU scenario varies between $7.8 and $22.4 billion/yr. The numbers presented are mid-range estimates.

Figure 13. The Cost of Compliance with Environmental Regulations is Projected to Increase Sharply Over the Next Ten Years

sanctioned by EPA. Based on the rigor and validity of the new emissions factors, the power industry was able to avoid both unwarranted regulations due to overreporting toxic emissions and expensive stack testing estimated to cost $50 million.

- *High-quality information on CCB utilization.* Working with a wide variety of partners, DOE demonstrated that CCBs do not release significant quantities of hazardous constituents into the environment, leading EPA to determine that regulation of large-volume CCB materials as a hazardous waste was not warranted. Utilization rather than disposal of CCBs can result in a cost savings ranging from $2/ton to $30/ton. At a current utilization rate of 30 million tons per year, the total savings due to CCB utilization ranges from $60 million to $900 million per year.

B. Future

The AR&ET Program looks forward to providing similar successes in the future as the electricity generation industry addresses the challenge of increasingly stringent air emissions regulations. The program goal is to reduce the cost of compliance by 50% through the development of new abatement technologies and integrated systems. If this goal is achieved, it will provide savings of 6.5 billion dollars per year by 2010.

Benefits are expected to be even greater internationally. Developing nations are currently deploying inexpensive coal-fired power plants with relatively poor environmental performance. As the standard of living rises in these nations, environmental awareness will increase, creating a substantial need for retrofit systems to improve the environmental performance of existing generation assets. Low-cost, environmentally clean coal-fired power systems will also be needed to meet future growth in demand.

A successful program will produce great benefits:

- Continued consumer savings from the use of the most economic source of power—domestic coal
- Continued improvement in ambient air quality
- Technology solutions for large, emerging global market applications to maintain U.S. leadership in the export of electric-power generation technology and services
- Effective environmental technology that will enable the U.S. to maintain energy diversity in a deregulated electric supply industry.

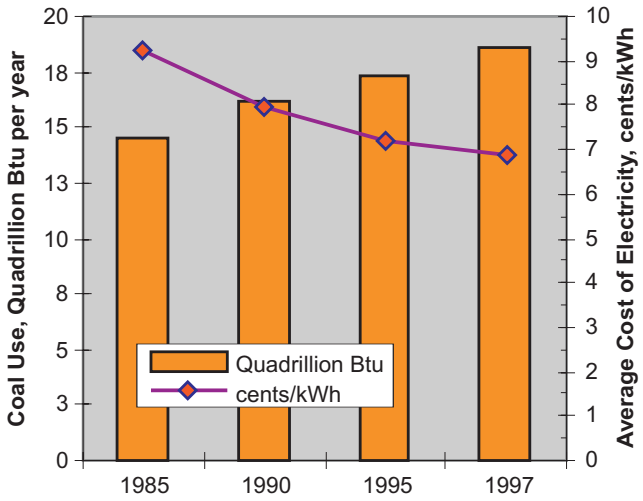


Figure 14. Since 1985 Coal Use has Increased While the Cost of Electricity has Gone Down

Appendix A. Key Regulatory Drivers

The development of emissions abatement technology for coal-fired boilers is driven by emissions regulations. The original Clean Air Act was passed in 1963 but no significant actions occurred until the passage of the **Air Quality Act in 1967**, which required all coal-fired units to install either electrostatic precipitators or baghouses to capture particulate matter from their flue gas. Within 15 years, the total U.S. emissions of particulate matter from coal-fired boilers was reduced by 85%.

The **Clean Air Act Amendment of 1970** set limits on the amount of particulate matter (0.1 lbs/mmBtu), sulfur dioxide (1.2 lbs/mmBtu), and oxides of nitrogen (0.7 lbs/mmBtu) that could be emitted by newly constructed or re-powered coal-fired boilers, so called New Source Performance Standards (NSPS). Also, Congress gave EPA the authority to determine National Ambient Air Quality Standards (NAAQS) which are the allowable concentrations of certain chemical species in ambient air that do not pose a significant threat to human health. Each state was to develop a State Implementation Plan (SIP), for limiting air emissions to meet the air quality standards, but EPA was given a strong oversight role in the development of these plans.

In response to legislative directives in the **1984 Amendments to the Resource Conservation and Recovery Act**, EPA published a final determination in 1993 that regulation of large-volume coal combustion by-product streams as a hazardous waste was **not** warranted. Under a consent decree EPA was to determine the status of the remaining CCB wastes in 2000. In the 1999 Report to Congress, Wastes from the Combustion of Fossil Fuels, EPA recommendations indicated that these materials would **not** be listed as hazardous. EPA did question the acceptability of two otherwise attractive and potentially high-volume applications of CCBs, acid mine remediation and agricultural soil amendment. Due primarily to environmental concerns about the release of HAPs, indications in early 2000 were that EPA might considering regulating these wastes as hazardous under RCRA Subtitle C. Under considerable pressure from legislators and certain government agencies, **EPA's final ruling was not to regulate the materials as hazardous**, but instead to develop standards under RCRA subtitle D (non-hazardous solid waste) for the disposal of fly ash, boiler ash and scrubber sludge.

Title IV of the **Clean Air Act Amendments of 1990** established the **Acid Rain Program**, a phased, allowance-based system for achieving reductions in emissions of NO_x and SO_2 from coal-fired boilers. Phase 1 of the Acid Rain Program regulations came fully into effect on January 1, 2000. In response to this program, industry has made significant changes to existing plants including widespread switching to low-sulfur subbituminous coal and installation of low-NO_x burners as well as the retrofit installations of a number of limestone scrubbers and selective catalytic reduction units. More investments are expected as Phase II comes into effect. In the 1990 Amendments, Congress also directed EPA to take regulatory action on regional haze and to study anthropogenic emissions of mercury in the United States.

EPA recently promulgated two air regulations under the CAAA that could have significant impacts on coal-fired boilers. In 1997, EPA tightened the **NAAQS for ground level ozone**, and also established an **air quality standard for ultrafine particulates** (i.e., less than 2.5 microns in diameter, $PM_{2.5}$). Separately, in 1999 EPA issued the **Regional Haze Rule**, setting a goal of reaching natural background visibility conditions in national parks and other mandatory Class I federal areas within 60 years. The rule cites ultrafine particulate matter as the primary cause of haze. **NO_x is a precursor to both $PM_{2.5}$ and ground-level ozone**, so both of these regulations imply more stringent limits on NO_x emissions from coal plants. The eastern United States has particularly acute problems with ozone in the ground-level air, and a recently approved SIP for ground-level ozone requires all coal-fired electricity generation units in 19 eastern states to achieve an average NO_x emissions rate of 0.15 lb NO_x/MMBtu by 2003, effectively mandating widespread retrofit installations of selective catalytic reduction units over the next several years. **Sulfur trioxide and other acid gases have been**

identified as precursors to fine particulates as well. As a result, the regional haze and $PM_{2.5}$ air quality regulations may require sulfur emissions reductions below the Acid Rain Program limits.

In 1997, EPA expanded the **Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA)** reporting requirements to include electricity generating facilities, among others. EPCRA requires certain facilities that manufacture, process, or otherwise use listed toxic chemicals to report their environmental releases of such chemicals annually. The results are produced in the **Toxic Chemical Release Inventory (TRI)**, and in the past have lead to significant public attention and pressures to further reduce limits on the releases. The first reports from coal-fired facilities on the release of toxic chemicals were due to EPA on July 1, 1999, the results of which have not yet been published by EPA. However the large quantities of acid gases (hydrochloric acid (HCl) and sulfates (SO_3)) released in the generation of electricity may cause public reaction and lead to tightened restrictions or reporting requirements.

In a 1997 report to Congress, EPA suggested a plausible link between mercury emissions from coal-fired power plants and mercury contamination in fish. The report stated that EPA has set a goal of reducing U.S. anthropogenic emissions of mercury by 50% by 2005. Because coal-fired electricity generation units represent 32.6% of all U.S. mercury emissions, future regulation of these emissions from coal-fires boilers is likely. In 1998, EPA issued an **Information Collection Request (ICR)** requiring all U.S. coal utilities to sample their coal once per week for one year and test for mercury content. Also, 75 randomly selected coal utilities had to conduct a series of four stack tests to measure their emissions of mercury. In **1999 EPA lowered the deminimis** reporting requirement for certain **persistent bioaccumulative toxic chemicals (PBTs),** including mercury and dioxins. The requirements for mercury were decreased from 10,000 to 10 pounds, which will now compel most coal-fired facilities to report mercury releases.

Under the Clean Air Act, certain facilities are "grandfathered" or made exempt from CAA regulations due to age and technology. Under the law these facilities are allowed to conduct routine maintenance, but according to **New Source Review (NSR)** requirements they must install emissions control technologies if plant modifications result in overall emissions increases. On **Nov 3rd, 1999 EPA announced major legal action** against 32 coal-fired power plants in ten states for alleged violations of the NSR rules. At issue are activities at the facilities that have been filed as routine maintenance, but which EPA claims constitute repowering. The alleged violations of the eight companies span several decades and could amount to extraordinary fines. In settlement discussions, EPA is seeking commitments to repower to new fuels, close down the more polluting units, enforce tighter emissions, and establish environmentally-friendly projects. Tampa Electric Company (TECO) is the only company to reach an agreement with EPA, the remaining seven are still in negotiations or court. The agreements or settlements when reached could have an effect on the **New Source Performance Standards (NSPS)**, resulting in more stringent emissions requirements, greenfield facilities, and fuel switching.

Clearly, environmental regulations of coal-fired generators have become more stringent over the past 30 years, and the trend is toward further tightening of emissions limits. New ideas and integrated solutions are needed to address both present and future environmental requirements in a cost-effective manner.

For more information on the AR&ET Program, please visit our web sites:

- DOE Office of Fossil Energy @
  http://www.fe.doe.gov/coal-power/environ/environ.sum.html
- DOE National Energy Technology Laboratory @
  http://www.netl.doe.gov/products/power/environ.html

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