COAL AND POWER SYSTEMS:
INNOVATIONS FOR EXISTING PLANTS ROADMAP

Knowledge and Technology Products for Clean Power

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

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I. Introduction

Coal has provided the nation with an abundant and affordable source of power for decades. For electric power, coal provides well over half of our electricity supply, and is projected to be a major component of the energy mix for decades to come. Maintaining coal's position in the future, however, will require enhanced scientific knowledge and advanced technology products to enable improved environmental performance. The DOE Office of Fossil Energy, through the National Energy Technology Laboratory (NETL), conducts R&D in the Innovations for Existing Plants (IEP) Program to address these needs.

The extent and complexity of potential control requirements is increasing. Proposed "multi pollutant" approaches such as the Clear Skies Initiative would entail fundamentally different approaches to the regulatory process. Concerns such as fine particulates, air toxics, ground-level ozone, and regional haze further complicate traditional "single-pollutant" approaches to air quality. Similarly, complex interactions among air, water, and solid media require new integrated approaches.

Accordingly, the major focus of the IEP Roadmap is the development of knowledge and technology to support multi-pollutant, multi-media solutions for continued use of coal. This directly supports the approach of the Clear Skies Initiative and other legislative multi-pollutant approaches. The program has two major products.

- Knowledge: High-quality scientific data and analysis for use in policy and regulatory determinations
- Technology: Advanced environmental control systems for coal-based power plants.

Working collaboratively with technology developers, users, regulators, and others, the program seeks market-based technology solutions to environmental challenges.

A. Vision and Goals

The vision for the IEP Program is that coal is sustained as an abundant, affordable, and environmentally acceptable resource for satisfying the nation's need for energy throughout the 21st century. The program goal is to develop integrated, multi-pollutant control systems that address air, water, and solid waste effluents in an affordable manner. This will be achieved by pursuing market-based technology options that are based on sound scientific and technical information and provide the least-cost paths for effective compliance.

The program seeks to create technology options that will enable the current fleet of coal-fired combustion power plants to comply with future environmental regulations at a low cost, while simultaneously building the foundation for entirely new coal-based power systems. The scope of this roadmap includes combustion, gasification, and hybrid power systems. There are significant program synergies with all coal-power system programs, as well as for coal-based systems for fuels and hydrogen production.

B. The Benefits of Affordable Power

In the United States, over 300 gigawatts of coal-fired air combustion power plants are currently in operation. They are the baseload power supply—stable and affordable—that has fueled the nation's economic growth and prosperity for the past several decades. The majority of these power plants were designed and built well before current air emission requirements became law. Great progress has been made in improving their environmental performance, with this improvement based in large part on technology products sponsored by DOE. For example, the National Academy of Sciences reports that upwards of $60 billion in benefits have been gained from DOE's research in NO_x and SO_2 control technology. The emissions rate of U.S. coal plants has been dramatically reduced while coal use has increased.

Air-quality requirements for control of currently unregulated species and implementation of emissions caps will require a new generation of multi-pollutant compliance technology. There are also opportunities to combine air-quality control with improved water management and the environmentally acceptable use of solid by-products for value-added applications. Achieving multi-pollutant, multi-media solutions will underpin the continued use of coal for affordable power. The prospective benefits of this technology are shown below.

IEP Program: Prospective Benefits

Technology Area	Performance Goals	Annual Economic Benefit	
		2010	2018
Mercury	2005 – 50-70% removal; ¾ cost of current technology	$550-$800 million	$800 million - $1.24 billion
	2010 - >90% removal; ½ to ¾ cost		$1.65 - $2.47 billion
NO_x	2005 - ≤0.15 lb/mmBtu; ¾ cost of SCR	$296 million	$448 million
Acid Gases	2005 – 95% removal; ¾ cost	$75 million	$90 million
Particulate Matter	2005 – 99% capture (10 - .01 micron particles); ¾ cost	$150 million	$150 million
Byproducts	66% increase in current utilization	$500 million - $1 billion $13 billion*	$500 million - $1 billion $13 billion*

* Avoided cost of designating by-products as RCRA Subtitle C hazardous waste.

C. The Path Forward: Collaboration and Partnerships

The roadmap provides a snapshot of our current knowledge and understanding, which is based on extensive collaboration with technology users, developers, regulators, and others. Ongoing collaboration will serve two purposes:

- Refining the technology roadmap to reflect new opportunities for *what* technology pathways should be explored and
- Supporting the ongoing, iterative process of program planning and analysis on *how* the FE/NETL programs interact with other implementing organizations (industry, national laboratories, universities, and others) in pursuing various pathways.

The roadmap will be a "living" document, with the R&D framework evolving as new data, information, and opportunities are examined.

II. Drivers and Challenges

A. Regulations and Compliance

The compliance landscape is undergoing the most significant changes since the passage of the original Clean Air Act. The potential for regulatory change includes the following:

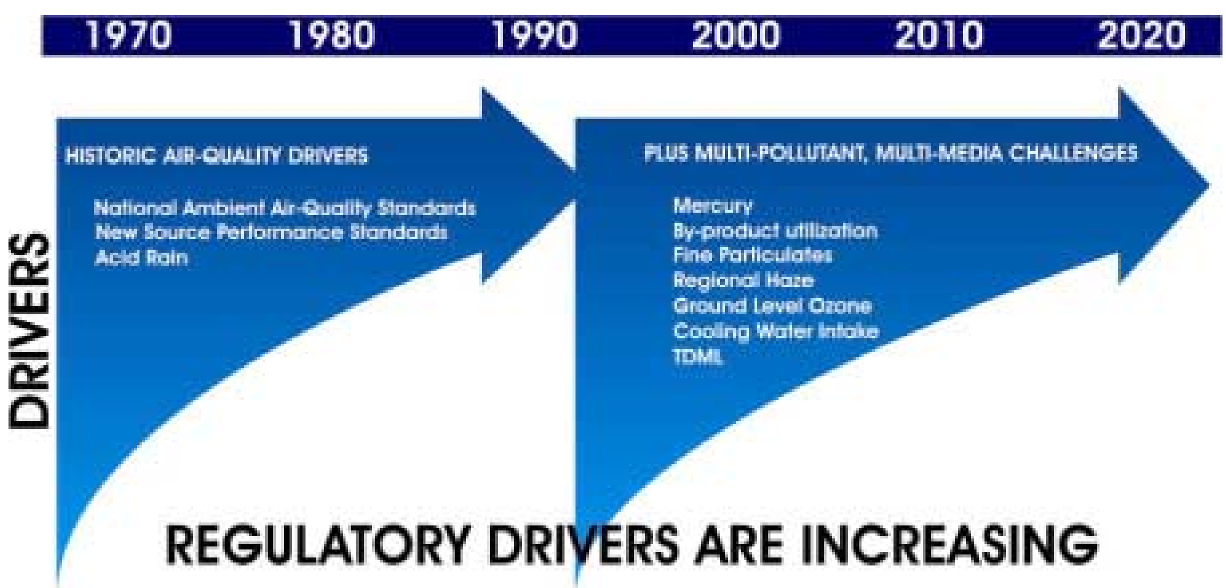
Clear Skies Initiative

Annual U.S. Power Plant Emissions

	Current	Mid-Term 2008-2010	2018
SO_2	11 million tons	4.5 million tons	3 million tons
NOx	5 million tons	2.1 million tons	1.7 million tons
Mercury	48 tons	26 tons	15 tons

- National emissions caps, similar to the current SO_2 cap, under a multi-pollutant control strategy such as the Clear Skies Initiative (CSI);
- Control of mercury and other hazardous air pollutants under Title III of the Clean Air Act Amendments;
- Water management issues associated with power production, including air pollutant loading to surface water, constraints in water availability, and cooling water intake structure regulations; and
- Solid residue and by-product issues, including increased volumes and assurance of the acceptability of alternatives to disposal.

These factors augment existing air-quality concerns such as regional haze, ozone, ground-level acid gases, and fine particulates. Whatever regulatory requirements are ultimately enacted, the products of the IEP Program will provide two necessary components for effective compliance: improved scientific knowledge to support decision making and technology solutions to support cost-effective, timely implementation.



B. Markets and Competition

The basis for coal's importance to power generation is powerful and pervasive: coal is abundant, affordable, and enjoys the distinct market advantage of long-term price stability. In addition to the installed base of coal-fired plants, over 30 gigawatts of new coal-based generation is expected to be built over the next 20 years. Maintaining the cost advantage of coal, however, must be based on the ability to resolve a range of potential environmental issues.

The leading competitor for power generation is natural gas, which has an inherent cleaner-burning capability, but is a more expensive resource with greater price volatility. Domestically, the competition with gas means that coal technologies must be able to achieve high environmental performance at less cost than the price "premium" of natural gas. Internationally, the potential market for coal technology is very large. For example, India and China represent large markets for coal power and ancillary low-cost environmental control systems. The challenge will be to provide technologies where there is presently little market incentive to improve environmental performance.

C. Building Technology and Policy Linkages

The availability of high-quality information and knowledge is key to the development of cost-effective control technology and the formulation of balanced regulatory policy. Knowledge that is accepted by all stakeholders has multiple benefits. It can:

- Clarify potential contributions of power systems to air, water, and solid-waste pollutants;
- Provide a scientific basis for control needs; and
- Guide the direction of subsequent technology development and policy decisions.

The result is improved policy and regulatory approaches that can yield the greatest public benefits at the least cost to the power sector of the economy and to society at large.

To achieve the transfer of knowledge and technology products, the program works closely with power producers, the EPA, state and local agencies, and other stakeholders. The program has made significant contributions through the Interagency Review process to the formulation of policy addressing toxic releases, coal byproduct disposal, mercury regulations, and cooling water intake structures.

III. Technology Pathways

The Innovations for Existing Plants roadmap has six major pathways.

- **Advanced NO_x Emissions Control**
- **Mercury Emissions Control**
- **Particulate-Matter Emissions Control**
- **Coal Utilization By-Products**
- **Air Quality Research**
- **Water Management for Power Production**

The pathways address both of the main product types: 1) advanced environmental control technology and ancillary systems and 2) high-quality scientific data and analysis for policy and regulatory planning purposes. These products will help ensure coal's continued role as an abundant, affordable, and environmentally acceptable resource for the nation's power. Figure 1 provides an overview of the six major pathways and their drivers, goals, and outcomes.

Figure 1. Innovations for Existing Plants Roadmap

<table>
<tr><th>DRIVERS</th><th colspan="2">R&D PATHWAYS</th><th>GOALS</th><th>OUTCOMES</th></tr>
<tr><td rowspan="6">• Demand for low-cost power as a foundation of economic strength
• Increasing scope and complexity of environ-mental regulation
• Need to increase the efficiency of generation by minimizing parasitic load of environ-mental controls
• Multi-media interrelation-ships</td><td>Advanced NOx Emissions Control</td><td>• Advanced combustion control
• Post-combustion control</td><td>• < 0.15 lb NOx/mmBtu at less than ¾ cost of Selective Catalytic Reduction</td><td rowspan="6">• Integrated control systems with high efficiency and low cost
• Reduced cost of compliance with environ-mental requirements
• Continued reliance on low-cost domestic resources
• Improved regional, national, and international environmen-tal quality</td></tr>
<tr><td>Mercury Emissions Control</td><td>• Advanced control technologies
• Emissions characterization</td><td>• 50-70% reduction by 2005 at <3/4 cost of commercial Activated Carbon Injection (ACI)
• >90% capture by 2010 at <3/4 cost of commercial ACI</td></tr>
<tr><td>Particulate-Matter Emissions Control</td><td>• Advanced primary fine particulate control
• Advanced acid gas control</td><td>• 99.99% capture of primary PM in the 10 micron to 0.1 micron size range</td></tr>
<tr><td>Coal Utilization By-Products</td><td>• Environmental impact characterization
• Utilization research
• Separation technologies</td><td>• Increase utilization from 30% to 50% by 2010
• Develop solutions to future environmental issues</td></tr>
<tr><td>Air Quality Research</td><td>• Emissions characterization
• Ambient monitoring
• Atmospheric transport and deposition
• Predictive modeling and evaluation</td><td>• Address scientific uncertainties associated with the formation and distribution of coal-plant emissions</td></tr>
<tr><td>Water Management for Power Production</td><td>• Advanced water management technology
• Watershed science and technology</td><td>• Identify and develop technology solutions to fossil-energy-related water issues</td></tr>
</table>

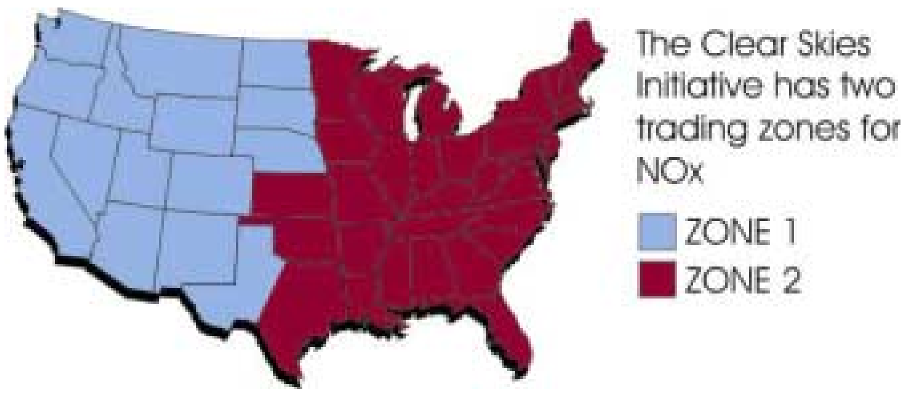
The following sections describe each of the major pathways, including barriers and issues, technology approaches, technology targets, and implementation strategy (collaboration, milestones, and decision points).

A. Advanced NOx Emissions Control

National NOx emissions may be capped at levels well below current emissions under proposed multi-pollutant control initiatives to address continued concerns about secondary fine particles (including those formed by reactions with NO_x) and ozone. Such proposals would essentially extend the current NO_x State Implementation Plan Call to twelve months and expand it to all 48 contiguous states. While selective catalytic reduction (SCR) is the workhorse for meeting current NO_x regulations, future requirements drive the need for lower-cost technology. For example, the Clear Skies Initiative divides the country into two zones with less stringent reduction requirements in the West. Accordingly, advanced technology that is cheaper and has fewer balance-of-plant issues than SCR could offer lower-cost options for western power plants and smaller eastern plants.

Figure 2 shows the advanced NOx emissions control roadmap. There are two major pathways.

- **Advanced Combustion Control**
- **Post-Combustion Control**



The major focus is the development of enhanced combustion control technologies that: 1) have negligible impact on balance-of-plant, 2) apply to a wide range of boiler types and configurations, and 3) maintain performance over a wide range of feed coals and operating conditions.

Figure 2. Advanced NOx Emissions Control

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Advanced Combustion Control *Reduce NO_x formation in the combustion process*	• Multi-pollutant controls may require deeper cuts in NOx emissions • Potential emissions trading may facilitate new technology options	• Ultra-low NO_x burners • Pre-combustion modifications • Oxygen-enhanced combustion	• Achieve <0.15 lb/mm Btu at less than ¾ cost of current methods	• Complete pathway with advanced combustion control technology available for full-scale demonstration of technologies to provide cost and performance validation by 2005

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Post-Combustion Control *Convert NO_x to N_2 after combustion*	• SCR systems have high capital costs and can create balance-of-plant issues	• Integrate ultra-Low NO_x burners and advanced combustion control with selective non-catalytic regeneration and SCR • Assess alternative reducing agents	• Achieve <0.10 lb/mm Btu at less than ¾ cost of current methods (i.e., SCR)	• Complete pathway with availability of SCR-alternative technologies available for full-scale demonstration to provide cost and performance validation by 2010

B. Mercury Emissions Control

Mercury is a neuro-toxin that can bio-accumulate in the foodchain. Coal-fired power plants currently represent roughly one third of all man-made U.S. mercury emissions and have been targeted for reduction. Effective control options that can be retrofitted cost effectively are needed in anticipation of proposed regulations under the EPA Maximum Achievable Control Technology process or through implementation of the Clear Skies Initiative.

The program has been working over the past decade to develop technology to lower the cost of mercury emissions reductions. It recently completed the first phase of field tests of activated carbon injection and enhanced flue gas scrubbing for mercury control. In addition, the program seeks to bring continuous mercury monitors to the state of commercial readiness.

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. For example, one hour of operation of a 300 MW coal plant produces a gas volume 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 (achieving 90% removal).

The mercury control effort involves partnerships with EPA and the electric-utility industry. This helps to ensure that policy and regulatory processes benefit from the program's information on mercury-emission characteristics and reliable cost and performance data on control-system options. Figure 3 presents the mercury emissions roadmap. There are two major pathways.

- **Advanced Control Technologies**
- **Emissions Characterization**

Figure 3. Mercury Emissions Control

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Advanced Control Technologies *Develop cost-effective options for new and retrofit applications*	• Elemental and oxidized forms of mercury require different control strategies • Flue gas contains very dilute concentrations of mercury making capture difficult and expensive	• Develop comprehensive cost and performance data from field testing of state-of-the-art advanced systems • Conduct pilot and bench-scale development of novel control concepts	• Retrofit options for two reduction targets (50-70% and >90%) at less than ¾ the cost of baseline technology (activated carbon injection) • Technology to enable reduction of compliance costs by $1-3.5 billion per year	• Have advanced technology available for commercial demonstration to achieve 50-70% reduction by 2005 • Complete pilot-scale testing of novel concepts in 2004 • Have novel technology available for commercial demonstration to achieve 90% capture by 2010

Figure 3. Mercury Emissions Control

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Emissions Characterization *Develop methods and data to support control system needs*	• Variability in the amounts of mercury in different coal feedstocks • Variability in the speciation of mercury in coal flue gas	• Methods development for total and speciated mercury	• Reliable data on emissions from coal-based power systems • Real-time measurement (i.e., continuous emission monitors - CEMs) to enable systems for process feedback and control	• Commercial readiness of total mercury CEMs by 2005 • Commercial readiness of speciated-mercury CEMs by 2008

C. Particulate-Matter Emissions Control

Ultra-fine particulate matter (particles with a diameter of less than 2.5 microns, or PM2.5) can cause localized plume opacity, visibility impairment, and has been linked to adverse human health impacts. In addition, they can be reportable under the Toxic Release Inventory. The particulate matter released by coal-based power systems can be placed in three broad categories: (1) primary – bits of mineral matter and unburned carbon that are entrained in flue gas, (2) secondary – particulates formed in the atmosphere by chemical reactions involving NO_x and SO_2, and (3) fine acid aerosols – such as those created by the reaction of SO_3 and water vapor.

The goal of this pathway is to develop cost-effective control technology to address both primary particulates and associated trace metals (e.g., lead, arsenic, etc.) and acid gases. Advanced control technology for the gaseous precursors to PM2.5 is being carried out under the Advanced NO_x Emissions Control pathway.

Figure 4 presents the particulate–matter emissions control roadmap. There are two major pathways.

- **Advanced Primary Fine Particulate Control**
- **Advanced Acid Gas Control**

Figure 4. Particulate-Matter Emissions Control

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Advanced Primary Fine Particulate Control *Capture 0.01-10 micron particles from flue gases*	• Future controls required to address potential link to health effects • Deteriorating performance of older electrostatic precipitator systems (ESPs) • Integration of particulate and mercury control	• Enhance efficiency of existing ESPs through flue gas conditioning and concentration • Develop advanced particulate collectors and separation systems	• Achieve 99.99% capture of fine particles in the 0.01-10 micron size range	• Complete pathway with technology available for commercial demonstration in the 2003-2005 time frame
Advanced Acid Gas Control *Develop acid-gas control strategies*	• Localized plume opacity and impacts on air quality • Toxics Release Inventory reporting required of power producers • No current continuous acid gas analyzers	• Injection of alkaline sorbents • Identify and characterize acid-gas production (e.g., from SCR systems) • Develop continuous SO_3 analyzers	• Achieve 95% control of acid gases (H_2SO_4, HF. HCl) • Continuous SO_3 analyzers with EPA Test Method sensitivity of 0.05 mg/m^3	• Complete pathway with technology available for commercial demonstration in the 2003-2005 time frame • Have field rugged SO_3 analyzer commercially available by 2005

D. Coal Utilization By-Products

In 2001 coal-fired power plants generated approximately130 million tons of solid by-product materials, 70% of which were disposed in landfills with the remaining 30% recycled. The program has established a goal of increasing the commercial use of coal utilization by-products (CUBs) by 66% to a total utilization of 50% by 2010. This goal will be challenging due to three main issues: (1) increased scrutiny of by-products due to concerns about the fate of mercury and other trace elements removed from flue gas; (2) future SO_2 regulations could double the amount of scrubber solids currently generated; and (3) mercury controls can negatively impact the value of flyash as a by-product.

The program seeks to address these emerging issues through an integrated approach to information, markets, and technology. Research is carried out to characterize the fate of mercury and trace metals in CUBs (including by-products from both combustion and gasification technologies), to expand existing and develop new commercial markets for CUBs, and to develop advanced separation technologies. Figure 5 presents the Coal Utilization By-Products roadmap. There are three major pathways.

- **Environmental Impact Characterization**
- **Utilization Research**
- **Separation Technologies**

Figure 5. Coal Utilization By-Products

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Environmental Impact Characterization *Characterize environmental acceptability of by-products*	• Development of standards and protocols for acceptance of use • Occurrence of toxics at very low levels from process streams • Future air regulations will increase scrutiny of coal by-products	• Determination of fate of mercury in residues (including both leaching and volatilization pathways) • Evaluate by-products from advanced power technologies such as gasifiers and fluidized-bed combustors	• Reliable characterization of mercury and other trace metals in by-products • Validated data set accepted by industry, regulatory, and other stakeholders • Knowledge products that enable avoidance of potential hazardous waste costs of ~$13 billion per year	• Attain state regulatory acceptance of alternative uses
Utilization Research *Technology and processes to expand by-product use*	• Need to increase the number of uses that are allowable under state and Federal regulations • Ammonia carryover from NO_x reduction • Increased unburned carbon due to loss-on-ignition and mercury control • Future air regulations will increase scrutiny of coal byproducts	• Identify and evaluate options for by-product recycling • Novel methods for large-scale utilization • Mercury sorbents with low foaming index • Mine-land reclamation and enhancement of carbon sequestration	• Increase utilization rate from 30% in 2002 to 50% by 2010 • Provide economic benefits of $500 million to $1 Billion per year through by-product sales	• Collaborate through government/industry Combustion By-products Recycling Consortium to demonstrate technologies

Figure 5. Coal Utilization By-Products *(continued)*

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Separation Technologies *Technology to cost-effectively separate contaminants from fly ash*	• NOx and mercury control can negatively impact sale and disposal of fly ash and scrubber solids	• Develop advanced technologies for separating carbon from fly ash • Integrate separation of carbon materials with mercury controls	• Produce low-carbon, saleable fly ash from all pulverized-coal boilers at cost less than ash-sale revenues	• Complete pathway by having technology available for commercial demonstration in the 2005-2010 timeframe

E. Air Quality Research

The air quality research pathway is designed to expand the scientific data and understanding related to the ultimate fate of coal system air emissions. The goal is to provide information that can guide future policy decisions, by providing improved information on both the impacts of control requirements and control technology options. For example, the knowledge products from this research would directly support the "mid-course" correction review of emissions-reduction progress under current Clean Air Act provisions as well as target-attainment reviews under the Clear Skies Initiative. Further, research on atmospheric chemistry will be invaluable for further debate on a global mercury strategy as well as global transport and deposition of other emissions.

Research along this pathway is focused on bringing additional clarity to the scientific uncertainties associated with the emission, transport, transformation, and deposition of emissions from coal-based power systems. Figure 6 shows the four major pathways in the air quality research roadmap.

- **Emissions Characterization**
- **Ambient Monitoring**
- **Atmospheric Transport and Deposition**
- **Predictive Modeling and Evaluation**

Figure 6. Air Quality Research

Pathway	Issues and Barriers	Science and Technology Approaches	Technology, Policy, and Regulatory Targets	Implementation Strategy
Emissions Characterization *Determine the chemical characteristics of emissions*	• Accurate source characterization is required to establish emission baselines • Data needed to update and validate source-receptor models	• Collection and analysis of primary particulates • Collection and analysis of secondary particulate matter and precursors • Develop dilution sampling methods	• Validated data sets on stack emissions • Provide emission "signatures" to determine sources	• Conduct targeted regional studies in collaboration with EPA, states, and others • By 2010, provide technical and cost input to PM2.5 National Ambient Air Quality Standards and Clear Skies Initiative regulatory reviews
Ambient Monitoring *Develop reliable database on the composition and characteristics of ambient particulate matter and gaseous species*	• Need for updated information on the characteristics of ambient fine particulate matter • Ambient air quality issues are driving calls for further reductions in coal-fired power plant emissions	• Establish collaborative regional monitoring networks working with EPA and industry • Apply advanced monitoring and analysis procedures and protocols • Support mercury deposition monitoring site(s)	• Develop reliable high-quality data on emissions fate • Assess trends in air quality relative to reductions in emissions	• Provide set of high-quality data on ambient air quality to EPA for regulatory determinations • By 2004, have available to public via web site PM2.5 and other parameters from upper Ohio River Valley

Figure 6. Air Quality Research *(continued)*

Pathway	Issues and Barriers	Science and Technology Approaches	Technology, Policy, and Regulatory Targets	Implementation Strategy
Atmospheric Transport and Deposition *Assess transport and fate of mercury and other emissions*	• Reliable information on atmospheric transport and deposition is needed • Improved understanding of movement and fate in ecosystems is needed	• Joint sponsorship of mercury plume chemistry and deposition research • Develop more detailed understanding of atmospheric chemical reactions involving SO_2, NOx, PM and mercury	• Information on mercury transport and deposition for use in development of mercury trading programs	• Provide support to U.S. position on United Nations Environmental Program global mercury assessment through validated information base
Predictive Modeling and Evaluation *Evaluate the effects of different reduction strategies*	• Lack of understanding of the action/response results from different control strategies	• Incorporate advanced knowledge of atmospheric chemistry into model algorithms • Develop and validate advanced emissions—specific protocols and models • Conduct modeling and analysis of mercury deposition	• Knowledge of the impacts of different control strategies for use in policy and regulatory determinations	• Collaborate with regional stakeholders to define and validate market-based compliance options

F. Water Management for Power Production

Electricity production is water intensive; thermoelectric power generation uses over 70 trillion gallons of water per year and is second only to irrigation as the largest user of freshwater in the United States. Recently proposed Clean Water Act regulations could potentially limit the amount of water used by power plants and other steam-generating units. Further, growing concerns about water availability and quality could place further constraints on water usage by power plants.

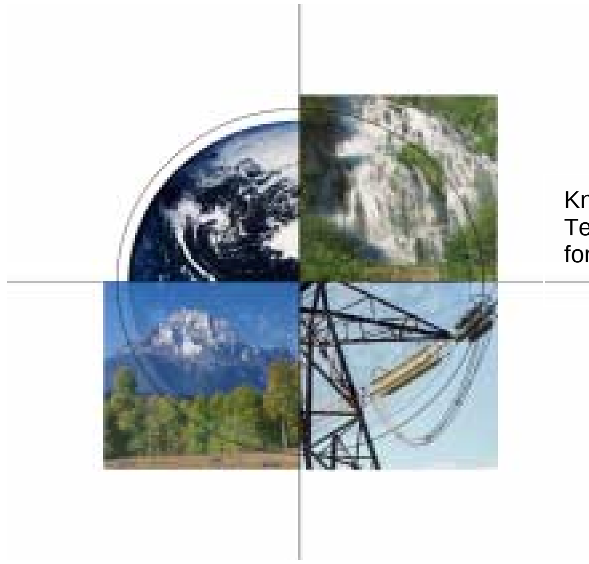
The program seeks to address these emerging water issues proactively by developing a water strategy that integrates advances in technology with innovative approaches to water and watershed management. Figure 7 shows the two major pathways in the energy-water interface roadmap.

- **Advanced Water Management Technology**
- **Watershed Science and Technology**

Figure 7. Water Management for Power Production

PATHWAY	BARRIERS AND ISSUES	TECHNOLOGY APPROACHES	TECHNOLOGY TARGETS	IMPLEMENTATION STRATEGY
Advanced Water Management Technology *Improve the efficiency and quality of water use by power plants*	• Power generation uses 70 trillion gallons of water/year, second only to agriculture • Use has impacts on overall water resource availability and quality • Regulations could further constrain water use by coal-based power systems	• Treatment and reuse of alternative water sources, such as mine-pool waters, produced water from oil and gas production, and industrial "grey" waters • Condensing low-pressure steam form turbines • Novel wet cooling systems • Novel dry cooling systems • Advanced cooling water intake structures • Advanced treatment and monitoring systems for plant process waters	• Reduce amount of freshwater consumption per kWh of power production by 25% by 2010 • Technology options for market-based compliance strategies	• Evaluate and communicate options for new technology with power producers and regional and state water-management organizations • Have available advanced technology for commercial demonstration by 2010
Watershed Science and Technology *Improve scientific understanding through advanced analytics*	• Improved watershed characterization needed to provide reliable baseline data • Need improved measurement and tracking of atmospheric deposition	• Develop geophysical remote sensing systems • Identify and characterize mine pools as potential sources of power plant water • Integrate energy and non-energy processes	• Accepted baseline information to support market-based approaches, including allowance-trading frameworks	• Test and validate new analytic tools to address specific regional problems • Evaluate suite of technology options to support market-based water-management strategies

IV. The Path Forward



Roadmapping is an iterative process that incorporates new information as it becomes available. In order to guide technology development along market-based options, the roadmapping effort relies on widespread collaboration to develop a scientific and technical consensus. Collaboration and communication are essential to integrate different perspectives on the intersection of regulation and technology development. Information exchange and collaborative planning enhances the IEP Program's public benefits through:

- Identifying current or potential roadblocks to progress,
- Identifying and assessing opportunities for technology advances,
- Developing action plans for implementation of collaborative programs and projects, and
- Communicating current status and developments in markets, regulations, and technology development.

To facilitate this collaboration, key efforts of the IEP Program include the following:

- Working with federal, state, and local regulatory groups to identify and resolve scientific data gaps,
- Working with environmental non-governmental organizations and others to elucidate perspectives and opportunities for improved environmental acceptability,
- Engaging in jointly-sponsored research programs to achieve common objectives, and
- Continuing public outreach activity to provide information and educational materials about technology options for compliance.

As this effort progresses, some pathways may not be viable due to environmental, economic, technical, or other reasons. Particularly in multi-pollutant approaches, new concepts may open new pathways. Through the process of roadmap development, these new pathways can be identified and explored.

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For more information on NETL coal-compliance programs, please visit our Environmental and Water Resources web site:

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