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Report to Congressional Requesters

May 2005

CLEAN AIR ACT

Emerging Mercury Control Technologies Have Shown Promising Results, but Data on Long-Term Performance Are Limited

GAO-05-612

GAO Accountability·Integrity·Reliability

Highlights

Highlights of GAO-05-612, a report to congressional requesters

May 2005

CLEAN AIR ACT

Emerging Mercury Control Technologies Have Shown Promising Results, but Data on Long-Term Performance Are Limited

Why GAO Did This Study

In March 2005, the Environmental Protection Agency (EPA) issued a rule that will limit emissions of mercury—a toxic element that causes neurological problems—from coal-fired power plants, the nation's largest industrial source of mercury emissions. Under the rule, mercury emissions are to be reduced from a baseline of 48 tons per year to 38 tons in 2010 and to 15 tons in 2018.

In the rule, EPA set the emissions target for 2010 based on the level of reductions achievable with technologies for controlling other pollutants—which also capture some mercury—because it believed emerging mercury controls had not been adequately demonstrated. EPA and the Department of Energy (DOE) coordinate research on mercury controls. In this context, GAO was asked to (1) describe the use, availability, and effectiveness of technologies to reduce mercury emissions at power plants; and (2) identify the factors that influence the cost of these technologies and report on available cost estimates. In completing our review, GAO did not independently test mercury controls. GAO provided the draft report to DOE and EPA for comment. DOE said that it generally agreed with our findings. EPA provided technical comments, which we incorporated as appropriate.

www.gao.gov/cgi-bin/getrpt?GAO-05-612.

To view the full product, including the scope and methodology, click on the link above. For more information, contact John Stephenson at (202) 512-3841 or stephensonj@gao.gov.

What GAO Found

Mercury controls have not been permanently installed at power plants because, prior to the March 2005 mercury rule, federal law had not required this industry to control mercury emissions; however, some technologies are available for purchase and have shown promising results in field tests. Overall, the most extensive tests have been conducted on technologies using sorbents—substances that bind to mercury when injected into a plant's exhaust. Tests of sorbents lasting from several hours to several months have yielded average mercury emission reductions of 30-95 percent, with results varying depending on the type of coal used and other factors, according to DOE and other stakeholders we surveyed. Further, the most recent tests have shown that the effectiveness of sorbents in removing mercury has improved over time. Nonetheless, long-term test data are limited because most tests at power plants during normal operations have lasted less than 3 months.

The cost of mercury controls largely depends on several site-specific factors, such as the ability of existing air pollution controls to remove mercury. As a result, the available cost estimates vary widely. Based on modeling and data from a limited number of field tests, EPA and DOE have developed preliminary cost estimates for mercury control technologies, focusing on sorbents. For example, DOE estimated that using sorbent injection to achieve a 70-percent reduction in mercury emissions would cost a medium-sized power plant $984,000 in capital costs and $3.4 million in annual operating and maintenance costs. If this plant did not have an existing fabric filter and chose to install one—an option a plant might pursue to increase the efficiency of mercury removal and reduce related costs—capital costs would increase to about $28.3 million, while annual operating and maintenance costs would decrease to about $2.6 million. Most stakeholders generally expect costs to decrease as a market develops for the control technologies and as plants gain more experience using them. Furthermore, EPA officials said that recent tests of chemically enhanced sorbents lead the agency to believe that its earlier cost estimates likely overstated the actual cost power plants would incur.

Coal-Fired Power Plant

Source: U.S. Department of Energy.

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Abbreviations

ACI	Activated Carbon Injection
CEMS	Continuous Emissions Monitoring Systems
DOE	Department of Energy
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
FDA	Food and Drug Administration
FF	Fabric Filter
FGD	Flue Gas Desulfurization
MACT	Maximum Achievable Control Technology
MW	Megawatt
NESCAUM	Northeast States for Coordinated Air Use Management
NETL	National Energy Technology Laboratory

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Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, D.C. 20548

May 31, 2005

Congressional Requesters

Mercury, a toxic element that poses human health threats, enters the environment through natural and human activities, such as volcanic eruptions and fuel combustion. Coal-fired power plants release mercury into the air when burning coal to generate electricity and were, prior to March 2005, the largest unregulated industrial source of mercury emissions in the United States.[1] The Environmental Protection Agency (EPA) estimated that in 1999, the most recent year for which data were available, coal-fired power plants within the United States emitted 48 tons of mercury into the air, or about 42 percent of the total man-made emissions nationwide.[2] The Clean Air Act Amendments of 1990 required EPA to study the environmental and health effects of hazardous air pollutants from coal-fired power plants and determine whether it was "appropriate and necessary" to regulate emissions of these pollutants.

In 2000, the agency determined that it was appropriate and necessary to regulate emissions of mercury, a hazardous air pollutant, from coal-fired power plants by requiring these plants to meet specific emissions standards reflecting the application of control technology (the "technology-based" approach).[3] In January 2004, EPA issued a proposed rule with two options for controlling mercury from power plants—the technology-based approach and an alternative approach that would set a national cap on mercury emissions and allow power plants flexibility either to achieve reductions or to purchase allowances from plants that achieved excess reductions (the "cap-and-trade" option).[4]

[1]In this report, "power plants" refers to coal-fired electricity generating units larger than 25 megawatts in size that produce electricity for sale.

[2]The 48 ton emissions level reflects reductions in mercury emissions achieved by existing controls for other pollutants. In this report, we use the amount of mercury in coal that is burned by power plants (75 tons) as a baseline when discussing the effectiveness of mercury controls.

[3]The technology-based approach is commonly known as the Maximum Achievable Control Technology (MACT) approach.

[4]For information about EPA's economic analysis of the mercury control options, see our related report, GAO, *Clean Air Act: Observations on EPA's Cost-Benefit Analysis of Its Mercury Control Options*, GAO-05-252 (Washington, D.C.: Feb. 28, 2005).

In March 2005, EPA revised its finding that it was appropriate and necessary to regulate mercury emissions from power plants under the technology-based approach and issued a final rule based on the cap and trade option that established a mercury cap of 38 tons for 2010 and a second phase cap of 15 tons for 2018.[5] Although power plants were not previously required to control mercury emissions, some already captured mercury as a side benefit of using controls designed to reduce other pollutants such as sulfur dioxide. In developing the rule, EPA determined that technologies specifically intended to capture mercury were not adequately demonstrated and therefore were not "commercially available." As a result, the agency decided that it could not reasonably impose requirements to use these technologies in the near-term and set emissions targets for 2010 based on the level of mercury control it expects to result as a side benefit of another rule it issued in March 2005—the Clean Air Interstate Rule (the interstate rule)—that calls for further reductions in emissions of nitrogen oxides and sulfur dioxide.

Controlling mercury from power plants poses unique challenges because it is emitted in low concentrations, making removal difficult, and in several different forms, some of which are harder to capture than others. In addition, the relative ease of removal varies from plant to plant depending upon such site-specific factors as the type of coal burned.[6] EPA and the Department of Energy (DOE) coordinate research and development of mercury controls, with EPA conducting small-scale research on new technologies, while DOE partners with the power industry and other stakeholders to conduct field tests of mercury control technologies at power plants.

The DOE field tests have focused on (1) mercury controls known as sorbent injection technologies, in which powdered substances (known as sorbents) that bind to mercury are injected into a plant's exhaust; (2)

[5]EPA has estimated that power plants will achieve emissions reductions beyond the 38 ton cap in 2010 and then use the resulting emissions allowances to comply with the more stringent cap for 2018, resulting in actual mercury emissions of about 31 tons in 2010 and about 26 tons in 2018. Relative to the estimated 75 tons of mercury in coal, this equals a 59 percent reduction in 2010 and a 65 percent reduction in 2018.

[6]The main types of coal burned, in decreasing order of rank, are bituminous, subbituminous, and lignite. Rank is the coal classification system based on factors such as the heating value of the coal. High-rank coal generally has relatively high heating values (i.e., heat per unit of mass when burned) compared with low rank coals, which have relatively low heating values.

enhancements to existing controls for other pollutants to increase mercury removal; (3) multipollutant controls, which simultaneously capture mercury and other pollutants; and (4) oxidation technologies, which convert mercury to a chemical form that is easier to remove. As of February 2005, 13 of DOE's field tests were completed and 26 were planned or not yet completed.

In this context, you asked us to (1) describe information on the use, availability, and effectiveness of technologies to reduce mercury emissions at power plants; and (2) identify the factors that influence the cost of these technologies and report on available cost estimates. To respond to these objectives, we reviewed data about technologies specifically designed to reduce mercury, including modifications to pollution controls already in use that would target and improve mercury capture.[7] We included test data on mercury controls used in field-scale tests but did not include test data on controls that were at earlier stages of development. We surveyed 59 key stakeholders—including mercury control vendors, representatives of the coal-fired power industry, technology researchers, and government officials—and received 40 responses. In addition, we reviewed technical documents addressing the performance of mercury controls and discussed technology research and development with 14 key stakeholders who view mercury reduction from a policy perspective. We did not independently test mercury control technologies. Finally, we interviewed vendors and researchers of mercury emissions monitoring technology to obtain and analyze information on the availability and reliability of mercury-monitoring devices; this information is presented in appendix II. (See app. I for a more detailed description of the scope and methodology of our review.) We performed our work between May 2004 and May 2005 in accordance with generally accepted government auditing standards.

Results in Brief

Mercury controls have not been permanently installed at power plants because, prior to the March 2005 mercury rule, federal law had not required this industry to control mercury emissions; however, some technologies are available for purchase and have shown promising results in field tests. Overall, tests of varying duration of the most developed mercury control, sorbent injection, have achieved average mercury reductions of 30 to 95 percent, with results depending on the rank of coal burned and other

[7]We did not assess the effectiveness of controls for other pollutants in capturing mercury as a side benefit because EPA had already conducted an extensive analysis of that topic.

factors, according to DOE and other stakeholders we surveyed. More recent DOE-funded monthlong tests, particularly those for chemically enhanced sorbents, have shown average removal rates of over 90 percent. However, data on the long-term performance of mercury controls or the effect that they have on the overall reliability and efficiency of power plants are limited, especially for plants using low-rank coals, because most field tests have lasted less than 3 months. Ongoing tests may better inform stakeholders within the next year about the longer-term capabilities of mercury controls for these coals.

The cost to install and operate mercury controls depends on a number of factors, including the extent to which controls already in place to reduce other pollutants also reduce mercury emissions. As a result, cost estimates vary widely. Available EPA and DOE cost estimates for mercury controls have focused primarily on sorbent injection and were based on modeling and data from a limited number of field tests, making them preliminary and uncertain. Nonetheless, DOE estimated that using sorbent injection to achieve a 70 percent reduction in mercury emissions would cost a medium-sized power plant—one that has the capacity to generate 500 megawatts of electricity and operates for about 80 percent of the time over the course of a year—$984,000 in capital costs and $3.4 million in annual operating and maintenance costs. If this same plant were to install a supplemental fabric filter—an option a plant might pursue to increase the efficiency of mercury removal and reduce related costs—capital costs would increase to about $28.3 million, while annual operating and maintenance costs would decrease to about $2.6 million. Regardless of the exact magnitude of costs, most stakeholders we contacted generally expect mercury control technologies to cost less over time as a market develops for the controls and as plants gain more experience using them. Furthermore, EPA officials said that recent tests of chemically enhanced sorbents lead the agency to believe that its earlier cost estimates likely overstated the actual costs power plants would incur.

We provided a draft of this report to DOE and EPA for review and comment. DOE said that it generally agreed with our findings. EPA's Office of Air and Radiation and Office of Research and Development provided technical comments, which we incorporated as appropriate.

Background

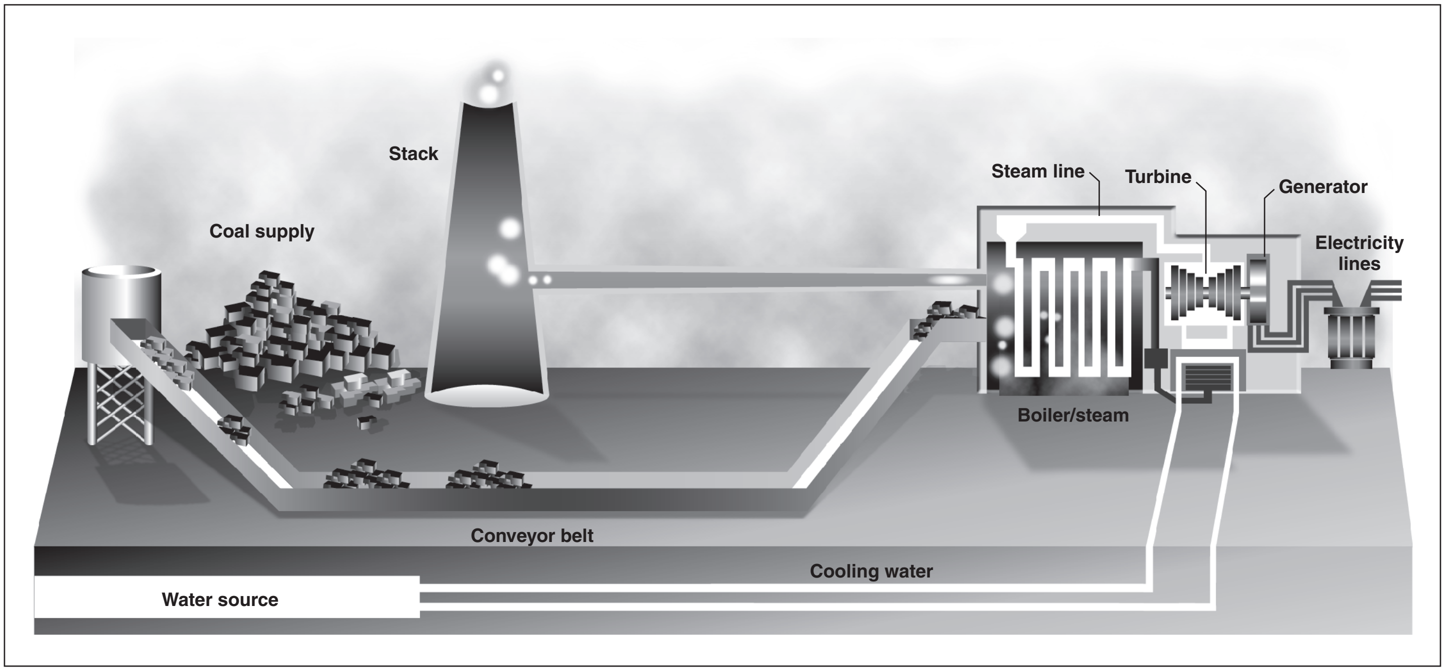
Mercury enters the environment through natural and man-made sources, including volcanoes, chemical manufacturing, and coal combustion, and poses ecological threats when it enters water bodies, where small aquatic organisms convert it into its highly toxic form—methylmercury. This form of mercury may then migrate up the food chain as predator species consume the smaller organisms. Through a process known as bioaccumulation, predator species may consume and store more mercury than they can metabolize or excrete.

Fish contaminated with methylmercury may pose health threats to people that rely on fish as part of their diet. Mercury harms fetuses and can cause neurological disorders in children, including poor performance on behavioral tests, such as those measuring attention, motor and language skills, and visual-spatial abilities (such as drawing). The Food and Drug Administration (FDA) and EPA recommend that expectant or nursing mothers and young children avoid eating swordfish, king mackerel, shark, and tilefish and limit consumption of other potentially contaminated fish. These agencies also recommend checking local advisories about recreationally caught freshwater and saltwater fish. According to EPA, 45 states issued mercury advisories in 2003 (the most recent data available).

According to the United Nations Environment Program, global mercury emissions are uncertain but fall within an estimated range of 4,850 to 8,267 tons per year. Of this total, EPA estimates that man-made sources in the United States emit about 115 tons per year, with about 48 tons emitted by power plants. Because mercury can circulate for long periods of time and be transported thousands of miles before it gets deposited, it is difficult to link mercury accumulation in the food chain with individual emission sources.

The United States has 491 power plants that rely in whole or in part on coal for electricity generation, and these plants produced 52 percent of all electricity generated in 2004, according to DOE's most recent data. These plants generally operate by burning coal in a boiler to convert water into steam, which in turn drives turbines that generate electricity. Figure 1 provides a general overview of a power plant's layout.

Figure 1: Overview of a Coal-Fired Power Plant



Source: Tennessee Valley Authority.

Power plants burn at least one of the three primary coal ranks—bituminous, subbituminous, and lignite—and plants may burn a blend of different coals, according to DOE. Of all coal burned by power plants in the United States in 2004, DOE estimates that about 46 percent was bituminous, 46 percent was subbituminous, and 8 percent was lignite. The amount of mercury in coal and the relative ease of its removal depend on a number of factors, including the geographic location where it was mined and chemical variation within and among coal ranks.

Coal combustion releases other harmful air pollutants in addition to mercury, including sulfur dioxide and nitrogen oxides.[8] EPA has regulated these pollutants since 1995 and 1996, respectively, through its program intended to control acid rain. In addition, the March 2005 interstate rule will require further cuts in these pollutants beginning in 2009.[9] To comply with these and other regulations, the coal-fired power industry has installed a variety of technologies that, while intended to control nitrogen oxides, particulate matter, or sulfur dioxide, may also affect or enhance mercury capture. Examples of such technologies include selective catalytic reduction (SCR) for nitrogen oxides, electrostatic precipitators (used by about 80 percent of all facilities) and fabric filters (used by the remaining 20 percent) to control particulate matter and wet or dry scrubbers to remove sulfur dioxide.

EPA estimates that power plants capture about 27 tons of mercury each year, primarily through the use of controls for other pollutants. In general, the exhaust from coal combustion (called flue gas) exits the boiler and may flow through a device intended to control nitrogen oxides before entering the particle control device and then through a scrubber prior to release from the smokestack. The combination of these devices in use at power plants differs greatly among facilities and is likely to change as a result of the interstate rule, which, according to EPA, will result in additional installations of equipment to control nitrogen oxides and sulfur dioxide. EPA believes that the steps power plants will take to control nitrogen oxides and sulfur dioxide under the interstate rule will enable them to meet the first phase mercury cap of 38 tons beginning in 2010.[10] As noted above, EPA determined that mercury control technologies were not commercially available and that the agency could not reasonably impose requirements to use them in the near-term.

[8]Nitrogen oxides and sulfur dioxide contribute to acid rain and the formation of fine particles that have been linked to aggravated asthma, chronic bronchitis, and premature death. Nitrogen oxides also contribute to the formation of ozone, a regulated pollutant, when they react with volatile organic compounds in the presence of heat and sunlight.

[9]The interstate rule requires further reductions in nitrogen oxide and sulfur dioxide emissions in 2009 and 2010, respectively.

[10]According to EPA, a large share of the mercury captured under the two rules will be its forms that are of greatest concern with respect to deposition in the United States and eventual uptake by freshwater aquatic organisms.

Nonetheless, a number of mercury control technologies have been developed over the past several years as a result of public and private investments in research and development, and these technologies generally fall into the following categories:

- **Sorbent (carbon-based, chemically enhanced carbon-based, and non-carbon based).** This technology involves injecting a powdered substance (sorbent) into the flue gas that binds to mercury prior to collection in a particle control device. Regardless of the chemical composition of the sorbent, this technology involves adding a silo or other structure containing the sorbent and a system that injects the sorbent into ducts that carry the flue gas.

- **Enhancements to existing controls for other pollutants to increase mercury capture.** This class of technologies focuses on retrofitting existing controls for other pollutants to improve their ability to capture mercury. Examples of enhancements include adding sorbents to wet scrubbers used for sulfur dioxide removal or modifying selective catalytic reduction devices used to reduce nitrogen oxides.

- **Multipollutant controls.** This class of technologies is designed from the outset to simultaneously control or enhance the removal of multiple pollutants, such as mercury, nitrogen oxides, or sulfur dioxide.[11] These technologies may also use sorbents.

- **Oxidation technologies.** This class includes methods, chemicals, or equipment designed to oxidize mercury into a form that is more readily captured.

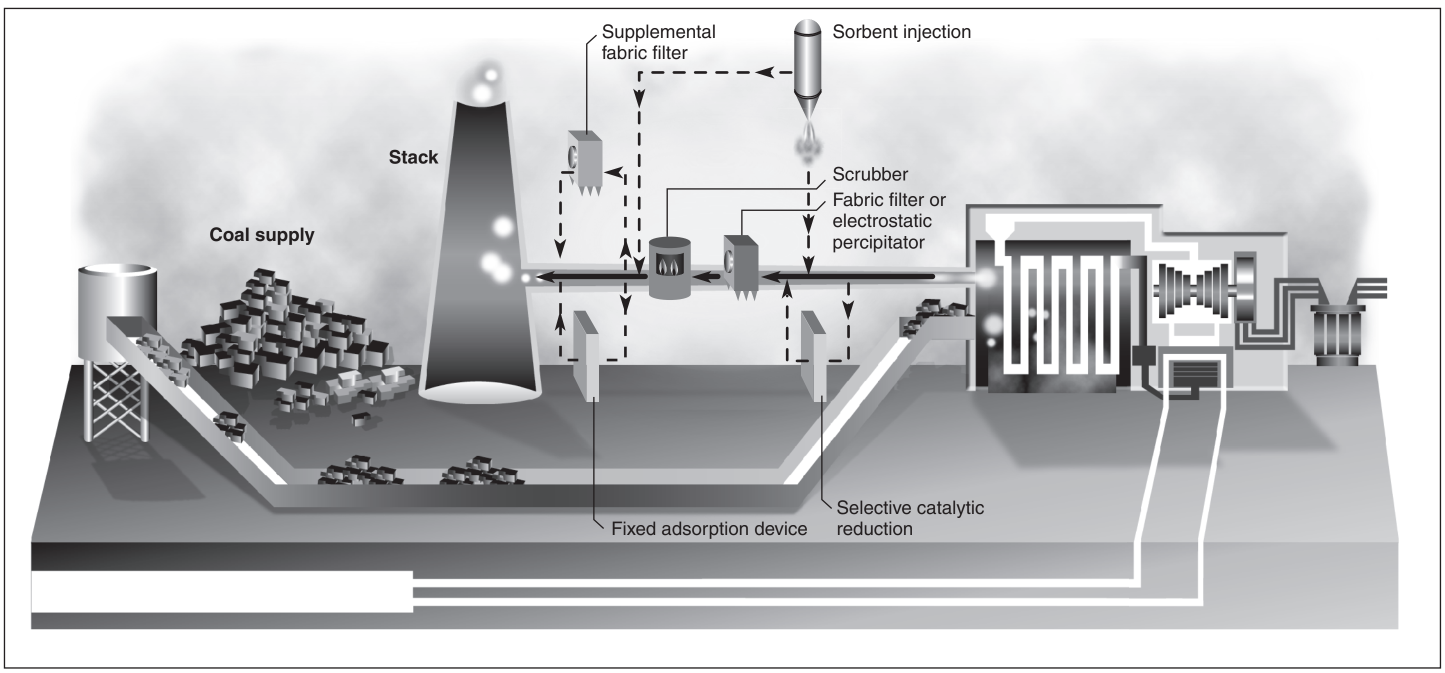
- **Other technologies.** This category includes other technologies that capture mercury using approaches such as removing mercury from coal prior to combustion and fixed adsorption devices that rely on precious metals such as gold to separate mercury from flue gas.

The intended location of these technologies in a power plant's overall layout may vary. As shown in figure 2, some may be located between the boiler and the particulate matter collection device, while others may be located further downstream in a plant's process. This figure also shows that

[11]Multipollutant controls do not include those that are intended to capture other pollutants that may also remove some mercury.

some plants can either install sorbent injection upstream of the existing particulate matter removal device or downstream of the device using a supplemental filter to collect the spent sorbent, keeping it separate from the fly ash collected in the particulate matter collection device. The latter configuration may be relevant for those facilities that sell their fly ash as a raw material for use in other applications, such as cement manufacturing, because carbon-based sorbent can render fly ash unsuitable for some of these applications. According to EPA, power plants sell about 35 percent of their fly ash for use in other applications, with 15 percent going to uses, such as cement manufacturing, where carbon contamination could pose a problem.

Figure 2: Sample Layout of Mercury Controls at a Coal-Fired Power Plant



Source: Electric Power Research Institute.

The Department of Energy's (DOE) National Energy Technology Laboratory partners with the private sector to evaluate the use of mercury control technologies at power plants in tests lasting up to 5 months. The testing program focuses on mercury controls, such as sorbent injection, and ways to better and more consistently capture mercury with technologies for other pollutants. Participants in DOE's program evaluate concepts in laboratories and develop promising technologies in progressively larger-scale applications, including actual power plants.[12] The duration of the tests that have been completed has varied from several hours to 5 months, with most of the completed DOE-funded tests lasting between 1 week and several months.[13] The most recent phase of DOE testing has focused on the longer-term performance of mercury control technologies. Appendix III provides more information on the DOE tests completed, ongoing, or planned as of February 2005.

Mercury Controls Have Not Been Permanently Installed at Power Plants but Are Available for Purchase and Have Shown Promising Results in Field Tests

Power plants in the United States do not currently use mercury controls, but some technologies are available for purchase and have shown promising results in full-scale tests in power plants. These tests have shown that mercury controls known as sorbent technologies—which involve injection of a powdered material that binds to mercury in the plant's exhaust—have shown the greatest effectiveness in removing mercury during tests at power plants. However, long-term test data are limited because most of these tests have lasted less than 3 months.

Mercury Controls Are Not Currently Used by Power Plants, but Some Technologies Are Available for Purchase

According to all 40 survey respondents, coal-fired power plants were not, as of November 2004, using mercury controls, although several plants have subsequently announced plans to install them. The coal-fired power industry has not used mercury controls because, prior to EPA's March 2005 rule, federal law had not required mercury emissions reductions at power

[12]As stated in appendix I, we focused our data collection on tests at actual power plants. The tests at power plants were conducted on varying scales, with some controls applied to a diverted fraction of the flue gas and other controls—primarily the sorbents—applied to the entire stream of flue gas, e.g., full-scale tests.

[13]The longest continuously operating test lasted for 5 months as part of a yearlong project at a plant in Wilsonville, Alabama.

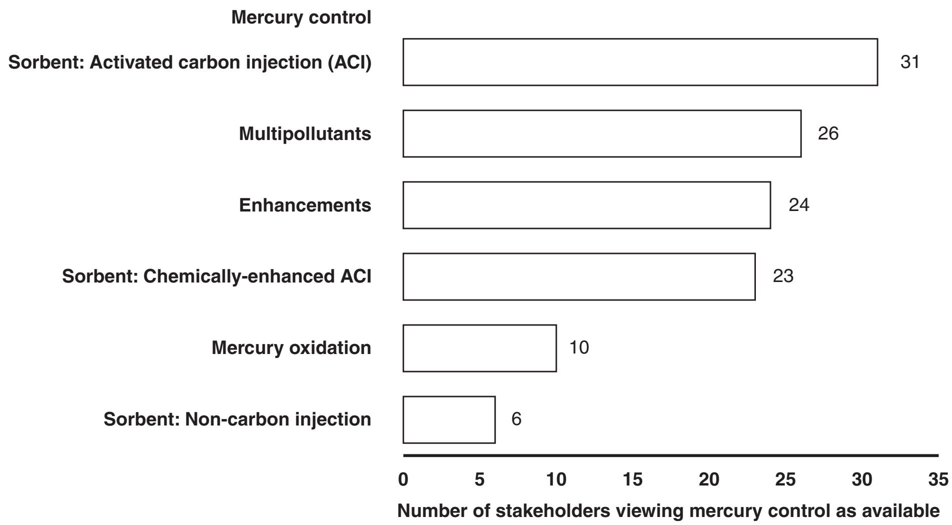
plants.[14] In fact, most of the power industry survey respondents (13 of 14) cited uncertainty about future regulations as one of the top three reasons for not installing mercury controls. Thus, in the absence of federal requirements to reduce mercury emissions, limited demand existed for mercury controls.

We found that although some mercury controls, such as activated carbon injection, are currently available for purchase from vendors, perceptions about their availability vary widely among stakeholders, primarily because stakeholders do not consistently define "availability." That is, some stakeholders believe that mercury controls become available when they have been demonstrated in long-term tests under normal commercial operations, rather than when they are available for purchase. Thus, some stakeholders' views on availability reflect more of a judgment about the proven effectiveness of a control technology than their availability for purchase.[15] In this context, we found that views regarding the availability of mercury controls generally varied by stakeholder group and by the type of control. A greater portion of the vendors described mercury controls as available than either of the other two groups we surveyed, with the power industry group citing these controls as available least frequently. As shown in figure 3, the stakeholders were overall most optimistic about the availability of activated carbon injection technologies, followed by multipollutant controls and enhancements to existing controls for other pollutants.

[14]Thirteen of the 14 power industry respondents also identified inadequate performance guarantees and the belief that technologies are unproven as reasons for not installing mercury controls.

[15]In our survey, we asked respondents separate questions about mercury controls addressing their availability for purchase, their effectiveness, and the need for further testing.

Figure 3: Stakeholder Perceptions about Availability of Mercury Controls



Source: GAO analysis of survey responses.

Note: This figure is based on responses from the stakeholders that participated in either our surveys (40) or structured interviews (14). In asking survey respondents and interview participants about their views on the availability of all mercury controls, we categorized sorbent injection technologies as activated carbon, chemically enhanced carbon, and non-carbon injection in order to reflect the research and development of various sorbent materials.

Appendix IV provides more detailed information on stakeholder perceptions of the availability of mercury controls.

In evaluating the availability of mercury controls prior to finalizing the March 2005 mercury rule, EPA found that mercury controls were available for purchase but concluded that they had not been sufficiently demonstrated in long-term tests, and therefore were not available for permanent installation at power plants before 2010. As a result, EPA set the 2010 mercury reduction targets at a level that power plants could achieve as a side benefit of using technologies for other pollutants that the agency expects many plants will install to comply with the interstate rule, and set more stringent limits for 2018. Thus, power plants will not need to install mercury-specific controls until well after 2010. According to an EPA white paper assessing test results as of February 2005, the agency expects that mercury control technologies will be available for commercial application on most, if not all, key combinations of coal type and control technology to provide mercury removal levels between 60 and 90 percent after 2010 and between 90 and 95 percent in the 2010-2015 time frame.[16]

Some Mercury Controls Have Shown Promising Results in Short-Term Field Tests, but Data on Long-Term Performance Are Limited

Because mercury controls have not been permanently installed at power plants, the data on the performance of these technologies come from field tests. We obtained data from 29 completed field tests, including 13 which were part of DOE's mercury control research and development program, and 16 other tests identified by survey respondents.[17] Most of the available test data (21 of 29 tests) related to the effectiveness of sorbents. According to DOE and EPA, the tests have shown promising results, although the extent of mercury removal varies at each plant.

Tests of varying duration have identified sorbent technologies as the most developed mercury controls, which show promising results in achieving high mercury reductions. For example, tests of activated carbon and chemically enhanced carbon-based sorbents at power plants using a variety of air pollution controls have shown average reductions of 30 to 95 percent overall, providing the following average mercury reductions for each coal type:[18]

- 70-95 percent average removal on bituminous coals;
- 30-90 percent average removal on subbituminous coals;
- 63-70 percent average removal on lignite coals; and[19]
- 94 percent removal on blends of bituminous/subbituminous coals.

[16]EPA, Office of Research and Development, *Control of Mercury Emissions from Coal Fired Electric Utility Boilers: An Update* (Research Triangle Park, N.C., Feb. 18, 2005).

[17]We obtained data about 55 field tests, 39 of which are part of DOE's mercury control research and development program. As of February 2005, long-term testing was either planned or had not been completed at 26 of the 39 DOE-funded field tests. Sixteen of the 55 field tests we reviewed were identified by survey respondents and did not correspond to DOE-funded tests.

[18]These data consider the amount of mercury in coal—75 tons—as the baseline for estimating the percent mercury reduction.

[19]One test on lignite coal also used a sorbent enhancement, i.e. additional chemicals to improve mercury capture.

As the scale and duration of testing has increased, researchers have gained a better understanding of site-specific variables that affect results, and more recent full-scale, monthlong tests, particularly those using chemically enhanced carbon-based sorbents, have shown sustained high removal rates. For example, a monthlong test conducted in 2004 showed that a chemically enhanced sorbent reduced mercury emissions from a primarily subbituminous blend of coal by 94 percent, and a monthlong test of another chemically enhanced sorbent at a different plant burning subbituminous coal achieved a 93 percent reduction.

A number of the stakeholders we surveyed pointed out that the results of a particular test cannot be generalized or extrapolated to estimate potential reductions at other power plants because the reductions achieved during a test may have resulted in part from factors unique to that facility, such as its size, the type of boiler used, the temperature of its flue gas, or the combination of controls for other pollutants. For example, available data show that the extent of mercury reduction achieved by sorbent injection at facilities using electrostatic precipitators depends largely on the location of these devices at the plant. The location of an electrostatic precipitator in turn affects the temperatures of the flue gas entering the device, with more mercury captured at cooler temperatures. Thus, the results achieved at a particular plant may not serve as a reliable indicator of the performance of that control at all plants.

DOE's research and development program has funded tests of mercury controls on each coal type in light of its and EPA's conclusions that the form of mercury emitted—which varies by coal type—and other chemical variations among coal types, such as chlorine content, can have an impact on a control's removal effectiveness. For example, lower removal rates in activated carbon injection tests have occurred primarily at plants burning low rank coal or at plants with existing controls that are less conducive to mercury removal. One university-based researcher attributes the challenge of mercury reductions on lignite—a low rank coal—to its chemical composition, but believes that chemically enhanced sorbents and special additives can improve the ability of the sorbent to bind to this form of mercury, thereby addressing this problem. The more recent mercury removal results we reviewed tended to support this view as monthlong tests using chemically enhanced carbon-based sorbents achieved average reductions of 70 percent or greater on low-rank coals, including lignites, suggesting that this technology may achieve high-level mercury reductions from low-rank coals (See app. III for more information on these results).

Since most of the field tests have focused on sorbent injection, fewer data are available on the performance of non-sorbent mercury controls, such as multipollutant controls, enhancements to existing controls, and mercury oxidation technologies. Results from 11 of the 19 tests of such controls were not yet available (9 of the tests were not planned to begin until after February 2005). The few available results show that average mercury removal achieved by multipollutant controls and enhancements has ranged from about 50 percent to 90 percent. The field tests of mercury oxidation technologies, multipollutant controls, enhancements and other non-sorbent technologies, lasting several days to several months, have included all coal types, but most (7 of 10) to date have focused on bituminous coal. In addition, a future DOE project will fund a test of a multipollutant control on a plant burning subbituminous coal and three tests of mercury controls, including mercury oxidation and enhancements, on plants burning lignite coal.[20]

Stakeholders Generally Agree That Sorbent Injection Is the Most Promising Control and That Some Additional Tests Are Needed

As noted above, EPA determined as part of its March 2005 mercury rule that it could not reasonably impose requirements that would force the use of mercury-specific controls before 2010. Specifically, EPA believes that chemically enhanced carbon-based sorbents could reduce mercury emissions at a broad spectrum of plants but regards long-term testing as necessary in order to evaluate (1) the mercury removal performance of technologies when operated continuously for more than several months at a time; and (2) the impact that these controls have on a plant's overall efficiency and operations. Furthermore, DOE officials have said that while sorbent injection holds much promise, it is unwise to depend solely on one approach for mercury control in part because the site-specific variables at each power plant affects the performance of mercury controls. DOE has concluded that it will be necessary to build a broad portfolio of mercury control options.

Likewise, technical papers and presentations about the field tests by research and development participants express a high degree of confidence in the capability of sorbents, particularly chemically enhanced carbon-based sorbents, but also suggest the need for additional evaluation of the impact of these controls, if any, on the efficiency and reliability of power plants. For example, a paper written by a sorbent vendor conducting DOE-

[20]DOE has required most projects in this round of testing to last at least for 1 month. The exact duration of these tests has not yet been determined.

funded tests concluded that recent monthlong tests of chemically enhanced carbon-based sorbent injection have shown high mercury removal at plants that burn subbituminous coals, but also discussed concerns about the long-term use of this control on a power plant's operations. This vendor concluded that although these tests did not show any adverse effects resulting from the chemically enhanced carbon-based sorbent, concerns and issues surrounding the contamination of fly ash that can render it unsuitable for sale for certain applications have not yet been resolved. With regard to potential adverse impacts at plants, no serious adverse effects have been associated with sorbent injection tests lasting up to 1 month in duration, according to EPA.

To provide additional perspective on the expected long-term performance of mercury controls, we asked survey respondents to indicate whether they believed power plants could use mercury controls to achieve industrywide mercury reductions of 50, 70, or 90 percent by 2008.[21] We also asked the respondents whether their perceptions would differ if the reductions were averaged across the industry (as in an emissions trading program) or if they were required at each plant. We found that many survey respondents (22 of the 38 answering this question) were confident in the ability of power plants to achieve a 50 percent reduction by 2008 regardless of whether the reductions were achieved at each plant or averaged across the industry.[22] EPA set the mercury emissions cap for 2010 based on a 50 percent reduction from the 75 tons in coal.

The stakeholders were progressively less confident in the ability of plants to achieve 70 and 90 percent reductions by 2008. For the 70 percent reduction scenario, stakeholders were more confident in the ability of plants to achieve this reduction averaged across the industry rather than at each plant; 16 stakeholders described themselves as confident or very confident in the ability of plants to achieve this level of reduction nationwide, while 21 described themselves as less confident or not at all confident. For the 90 percent scenario, the vast majority of the survey respondents (33 of 38 that answered this question) described themselves as not at all confident or less confident in the ability of plants to achieve this

[21]We asked respondents to consider the amount of mercury in coal—75 tons—as the baseline when considering each mercury reduction.

[22]This would result in nationwide emissions of 37.5 tons per year, given the baseline of 75 tons of mercury in coal.

level of reduction nationwide by 2008. Appendix V summarizes the survey responses for each of the three scenarios.

Furthermore, we asked the 40 survey respondents to identify additional testing needed to assess the ability of mercury control technologies to effectively and reliably reduce mercury emissions by 70 percent. Most of the survey responses (40 of 45)[23] showed that stakeholders believe that some additional testing is needed for at least one technology. For example, the 14 power industry respondents said that additional testing is needed for sorbent injection. In addition, 3 of the 4 carbon-based sorbent vendors answering this question as well as 9 of the 12 researchers and government officials believed that some additional testing is needed to show that carbon-based sorbent injection would reliably and effectively achieve mercury reductions of 70 percent.

Three policy stakeholders representing the power industry believed that more tests are needed to evaluate factors such as the performance of controls on low-rank coals, the impact on small power plants, and the ability of plants to use mercury controls without compromising electricity generation. Several of the power industry respondents expressed concern about the potential for mercury controls to interfere with a plant's overall efficiency or cause malfunctions, and a power industry representative pointed out that such disruptions are a concern because power plants cannot store electricity for use as a backup when they experience technical problems. Information from ongoing and planned long-term tests will provide important information on both the long-term performance of mercury controls and the effect, if any, that these controls have on the efficiency or reliability of power plants.

In addition, several plants have recently announced plans to install mercury controls to comply with either state permit requirements or the terms of legal settlements. For example, a power plant in New Mexico announced in March 2005 that it would install sorbent injection within the next 2 years to reduce mercury emissions as part of a settlement agreement with two environmental groups. A plant representative stated that while he believes sorbent technology "is not that advanced … it is advanced enough to use it to reduce mercury emissions" at the power plant. Another power

[23]The number of survey responses exceeds the number of survey participants because technology vendors were given the option of submitting a survey for each technology they produce. Five of the 14 technology vendors submitted two surveys.

plant currently under construction in Iowa has a state air pollution permit requiring the company to control mercury emissions and is installing sorbent injection technology. The company expects to reduce mercury emissions from subbituminous coal by 83 percent. Finally, under an agreement with the state of Wisconsin, a Michigan power plant owned by a Wisconsin-based company has begun to install a multipollutant control that will use sorbent injection to reduce mercury and other pollutants.

Mercury Control Costs Depend on a Variety of Factors, and Current Estimates Vary Widely

The estimated costs to install and operate mercury controls vary greatly and depend on a number of site-specific factors, including the amount of sorbent used (if any), the ability of existing air pollution controls to remove mercury, and the type of coal burned. EPA and DOE have developed the most comprehensive estimates available for mercury controls based on modeling and data from a limited number of field tests, making them both preliminary and uncertain.[24] These estimates, as well as other available estimates, focus on sorbent injection, the most developed mercury control technology. Estimated costs for sorbent injection vary greatly depending on whether facilities achieve mercury reduction targets by using this technology in combination with their existing air pollution control devices or instead add fabric filters to collect the spent sorbent. Regardless of the exact costs of the controls, most of the stakeholders we contacted generally expect the costs to decrease over time.

Cost Estimates Depend on Several Site-Specific Factors

The available cost estimates are projections based on a limited number of tests, primarily of activated carbon injection. The cost estimates we reviewed show that the total costs of installing and operating mercury controls vary depending on factors such as sorbent consumption, the ability of existing air pollution controls to remove mercury, and the type of coal burned. We discuss each of these factors in more detail below:

[24]Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, *Performance and Cost of Mercury and Multipollutant Emission Control Technology Applications on Electric Utility Boilers* (Research Triangle Park, N.C., 2003).

Jeff Hoffmann and Jay Ratafia-Brown, Science Applications International Corporation, *Preliminary Cost Estimate of Activated Carbon Injection for Controlling Mercury Emissions from an Un-Scrubbed 500 MW Coal-Fired Power Plant*, a report prepared for the Department of Energy, National Energy Technology Laboratory, November 2003.

- **Sorbent consumption:** The amount of sorbent that a facility needs to use greatly influences control cost estimates. According to DOE, sorbent consumption levels for activated carbon injection technology directly relate to the desired level of mercury control. Further, while increasing the amount of carbon injected increases mercury removal, the performance of the carbon eventually levels off, requiring increasingly greater amounts of carbon to achieve an incremental mercury reduction. For example, test data from a plant burning subbituminous coal show that more than twice as much sorbent would be needed to remove 60 percent of the mercury from the plant's flue gas than to remove 50 percent. Therefore, the cost of the activated carbon can increase dramatically, depending on the desired level of mercury removal and the type of coal burned.

- **Other air pollution controls already installed**: The air pollution controls already installed at a facility—especially fabric filters and electrostatic precipitators used for controlling particulate matter—can have a major effect on the cost of controlling mercury because some of these devices already remove varying amounts of mercury. For example, DOE's tests have shown that fabric filters generally remove more mercury than electrostatic precipitators. Thus, facilities with fabric filters may already remove enough mercury to achieve a desired or required level of reduction. However, plants that do not have an existing fabric filter and choose to install one may incur significant costs due to their high capital expense. Additionally, EPA believes that controls for other pollutants some plants will install to comply with the interstate rule—such as selective catalytic reduction to control nitrogen oxides and wet scrubbers to control sulfur dioxide—will result in further mercury capture. Therefore, the combination of other air pollution controls may reduce or in some cases eliminate the need for a plant to install mercury-specific controls to reduce its mercury emissions. As noted above, EPA based its mercury reduction goals for 2010 to 2018 on the level of control it expects plants will achieve with controls for these other pollutants.

- **Type of coal burned**: According to EPA, the amount of mercury captured by a given control technology is generally higher for plants burning bituminous coals than for those burning subbituminous coals. This difference arises because the flue gas from bituminous coal contains higher levels of substances that facilitate mercury capture. Along these lines, DOE's cost estimates assume that an electrostatic precipitator will capture 36 percent of mercury from plants that burn bituminous coal, but none of the mercury from plants that burn subbituminous coal. Thus, DOE estimated that mercury removal costs are higher for subbituminous-fired plants than bituminous-fired plants.

Available Mercury Control Cost Estimates Are Preliminary and Vary Greatly

Most of the available cost estimates for mercury control focus on sorbent injection, the most developed technology. DOE and EPA have developed comprehensive cost estimates; however, they are preliminary and, in EPA's case, based on model plants rather than actual power plants. Further, while DOE developed its estimates from tests in power plants, the agency indicated that its mercury control costs may be off by as much as 30 percent in either direction because (1) the estimates were developed from a limited data set of relatively short-term tests and thus are highly uncertain, and (2) they are based on a number of assumptions that, if changed, would result in significantly different estimates. According to DOE, further testing of sorbent injection for a variety of coals is needed to accurately assess the costs of implementing the technology throughout the United States. In addition, EPA's and DOE's cost estimates were published in October and November 2003, respectively, and do not reflect the more recent test data. For example, more recent field tests with chemically enhanced sorbents have shown that these sorbents may be more efficient at removing mercury than the sorbents used in earlier tests. Thus, chemically enhanced sorbents may achieve a high level of mercury removal using less sorbent and without the high capital cost of installing a fabric filter. DOE expects to issue revised cost estimates which will reflect lower costs based on recent testing. As a result, the available cost estimates may not accurately reflect the costs that power plants would incur if they chose to install mercury controls.

In addition, the two agencies' cost estimates relied on different assumptions and are not directly comparable. Most notably, the two agencies based their cost estimates on plants of different size and made varying assumptions about the percentage of time that an average plant operates (called capacity factor). For example, EPA conducted its modeling for 100- and 975-megawatt plants, while DOE based its estimates on a 500-megawatt plant.[25] As a result, EPA provided a wider range of cost estimates. Furthermore, EPA assumed a plant capacity factor of 65 percent, while DOE assumed an 80 percent capacity factor, which resulted in higher operating costs in the DOE estimates.[26] Additionally, based on available data for plants with an existing electrostatic precipitator that burn bituminous coal, EPA's modeling predicted the existing control equipment would achieve a 50 percent mercury removal without sorbent injection, while DOE assumed that this configuration would remove no more than 36 percent of mercury and that sorbent injection was needed even for achieving 50 percent mercury removal.[27]

Although the DOE and EPA estimates reflect different assumptions as discussed above, we are providing the two agencies' cost estimates for achieving a 70 percent mercury reduction at a bituminous-fired coal power plant under two scenarios (using an existing electrostatic precipitator and installing a supplemental fabric filter) to provide a perspective on the costs power plants could incur to install sorbent injection technologies.

- For a 100-megawatt plant using an existing electrostatic precipitator, EPA estimated that capital costs would total $527,100 ($5.27 per kilowatt, 2003 dollars), and the operating and maintenance costs would total $531,820 annually for a plant operating at 65 percent capacity ($0.93 per megawatt-hour).[28] Alternatively, if this plant were to install a supplemental fabric filter, the capital costs would increase to about $5.8 million ($57.73 per kilowatt) and the operating and maintenance costs would decrease to $171,959 annually ($0.30 per megawatt-hour).

- For a 500-megawatt plant using an existing electrostatic precipitator, DOE estimated the capital costs would total $984,000 ($1.97 per kilowatt), and the annual operating and maintenance costs would total

[25]A megawatt is a unit of power equal to one million watts, or enough electricity to power about 750 homes at any given time.

[26]According to a DOE official, the varying assumptions regarding the plant capacity factor reflect different assumptions about which coal-fired power plants will use sorbent technologies.

[27]According to EPA, while 36 percent is an average removal rate for bituminous coals, the 50 percent rate they used in this case was based on specific assumptions about a particular type of bituminous coal in the scenario they analyzed.

[28]Costs expressed in dollars per megawatt-hour and mills per kilowatt-hour are numerically equal.

about $3.4 million ($0.97 per megawatt-hour) for a plant operating at 80 percent capacity (2003 dollars). Alternatively, if this plant were to install a supplemental fabric filter, the capital costs would increase to about $28.3 million ($56.53 per kilowatt), and the operating and maintenance costs would decrease to about $2.6 million annually ($0.74 per megawatt-hour).

- For a 975-megawatt plant using an electrostatic precipitator, EPA estimated that capital costs would total about $2.4 million ($2.47 per kilowatt), and the operating and maintenance costs would be about $5.1 million annually for a plant operating at 65 percent capacity ($0.92 per megawatt-hour). Alternatively, if this plant were to install a supplemental fabric filter, the capital costs would increase to about $35.4 million ($36.32 per kilowatt), and the operating and maintenance costs would decrease to about $1.6 million annually ($0.30 per megawatt-hour).

These data show that DOE estimated lower capital costs per unit of power generating capacity than EPA, while EPA estimated slightly lower operating and maintenance costs than DOE. This may result from the fact that EPA assumed higher rates of mercury removal with existing controls than DOE, as well as DOE's use of a higher plant capacity factor than EPA. Appendix VI provides additional information on EPA's and DOE's cost estimates for sorbent injection control technologies.

According to EPA, the costs of sorbent injection technologies to control mercury emissions are very small compared to other air pollution control equipment when other retrofits, such as the addition of fabric filters, are not required. EPA also reports that the fixed operating costs for these systems are also relatively low, stemming from the simplicity of the equipment. In EPA's rulemaking documents, the agency said that in light of the more recent tests of chemically enhanced sorbents, their earlier estimates likely overstated the actual costs power plants would incur. DOE officials said they shared this view.

EPA also estimated costs for multipollutant controls, including advanced dry scrubbers. Although these controls cost substantially more than sorbent injection, they would provide additional benefits by controlling other types of pollutants such as nitrogen oxides and sulfur dioxide.[29] EPA regarded cost information for multipollutant controls as preliminary, because there had been limited commercial experience with these technologies in the United States. In part because the agency estimated a range of capital and operating costs for each scenario, EPA's estimates of the cost of these technologies varied widely.[30] For example, for advanced dry scrubbers, EPA estimated the capital costs as $115.46 to $243.08 per kilowatt, with costs per kilowatt generally higher for smaller plants.[31] For 100-megawatt and 975-megwatt plants, capital costs could be as low as $16.2 million and as high as $168.7 million respectively. EPA estimated operating and maintenance costs for a 100-megawatt plant to be between $1.1 million and $1.3 million per year, assuming a plant capacity factor of 65 percent (or between $1.93 and $2.35 per megawatt-hour). For a 975-megawatt plant, operating and maintenance costs were estimated to be between $9.3 million and $37.5 million per year, assuming a plant capacity factor of 65 percent (or between $1.68 to $6.76 per megawatt-hour).

In addition to the cost estimates from EPA and DOE, we surveyed technology vendors, representatives of coal-fired power plants, and researchers about the cost of these technologies. Seventeen of these stakeholders provided sorbent injection cost information, but these estimates were incomplete and not always comparable due to site-specific variations and differing assumptions. The vendors generally provided lower cost estimates than those provided by the power industry, while estimates provided by researchers had the broadest range.

EPA and DOE officials and other stakeholders identified relevant cost estimates compiled by other nongovernmental entities:

[29]When combined with existing equipment, advanced dry scrubbers were estimated to achieve mercury removal rates between 96 and 99 percent in EPA's models.

[30]In calculating these estimates, EPA assumed that the unit capital cost could vary by as much as 20 percent, while operating and maintenance costs were calculated assuming a range of reagent costs that varied by as much as plus or minus $20 per ton. Due to these variations, cost ranges presented in unit costs, such as dollars per kilowatt, do not always match the calculated cost ranges in total dollars for a plant of a given size.

[31]In estimating costs for advanced dry scrubbers, EPA only presented costs for plants burning bituminous coal.

- Charles River Associates, an economics and business consulting firm, provided cost estimates for activated carbon sorbent injection in combination with an existing or supplemental fabric filter.[32] Rather than presenting estimates of costs for particular plant sizes and mercury removal percentages, Charles River Associates provided formulas with variables for mercury removal and plant size.[33] Using these formulas and a plant size of 500 megawatts, Charles River Associates' analysis would generate estimates of total capital costs of about $749,278 for using sorbent injection with an existing fabric filter and about $20.6 million for sorbent injection and a supplemental fabric filter (1999 dollars). Operating and maintenance costs comprise a fixed cost based on plant size and a variable component that could be calculated for a range of mercury removal percentages. For example, a 90 percent mercury reduction using sorbent injection with an existing fabric filter for a bituminous coal-fired 500-megawatt plant operating at 80 percent capacity over the course of a year (7,008 hours) would cost $999,473 per year, or about $0.29 per megawatt-hour. A 90 percent reduction at the same size plant burning subbituminous coal would cost $1.3 million per year or about $0.38 per megawatt-hour. Annual operating and maintenance costs were about $75,000 higher for the configuration where a supplemental fabric filter was installed.

  In its modeling, Charles River Associates considered only sorbent injection technology with an existing or retrofitted fabric filter because the firm expects that this combination would have a lower cost per pound of mercury removed than sorbent injection alone. Charles River Associates' operating and maintenance cost estimates for activated carbon injection alone are lower than the EPA and DOE estimates; however, the Charles River estimates reflect the assumption that plants already had a fabric filter, while EPA and DOE assumed plants already had an electrostatic precipitator.

[32]Anne Smith et al., Charles River Associates , and John H. Wile, E&MC Group, *Projected Mercury Emissions and Costs of EPA's Proposed Rules for Controlling Utility Sector Mercury Emissions* (Washington, D.C., 2004).

[33]These formulas allow capital and fixed operating and maintenance costs to vary by the size of the plant and allow variable operating and maintenance costs to vary depending on the desired level of mercury reduction.

- MJ Bradley & Associates, an engineering and environmental consulting firm, summarized costs for other multipollutant controls that have undergone full-scale testing.[34] One technology, which uses ozone to oxidize nitrogen oxide and mercury, has been estimated to remove over 90 percent of nitrogen oxide and mercury from a plant's flue gas; it also controls sulfur dioxide.[35] This technology is estimated to cost between $90 and $120 per kilowatt in capital costs and $1.7 to $2.37 per megawatt-hour in annual operating and maintenance costs. For a 500-megawatt plant operating at 80 percent capacity, this would equate to $45 million to $60 million in capital costs and $6.0 million to $8.3 million in annual operating and maintenance costs.[36] MJ Bradley also estimated the costs of a system that removes sulfur dioxide and mercury and decomposes nitrogen oxide through a multi-stage oxidation, chemical, and filter process. The target mercury removal rate for this process is 85 to 98 percent, which MJ Bradley reports the manufacturer guarantees. The estimated capital cost of this process is between $110 and $140 per kilowatt, or $55 million to $70 million for a 500-megawatt plant. A downstream fabric filter is associated with this process to remove particulate matter, which could add an additional cost.

In considering the cost estimates, it is important to note that plants may identify and choose the most cost-effective option for complying with EPA's mercury rule. The cost-effectiveness of a given mercury control will vary by facility, depending on site-specific factors, including the type and configuration of controls already installed. Furthermore, the desired level of mercury control at a plant will affect its control costs and some plants may meet their mercury reduction goals by modifying existing air pollution control equipment, thereby negating the need for additional mercury controls. In cases where plants decide to install mercury controls, the desired control level will affect the cost-effectiveness of the various technologies. For example, sorbent injection with a downstream fabric filter may prove cost effective for facilities seeking a high level of reduction, but less cost effective for plants seeking lower level reductions

[34]MJ Bradley also presented cost estimates for sorbent injection, but presented the same cost information reported by DOE.

[35]M.J. Bradley & Associates, *Status of Development of Mercury Control Technologies* (Concord, Mass., Aug. 5, 2004).

[36]Calculated annual operating and maintenance costs assume a 500-megawatt plant operating at 80 percent capacity, i.e. 7008 hours per year.

because of the relatively high capital costs. In the example given above for a 70 percent mercury reduction at plants burning bituminous coal, based on annualized costs, EPA's estimates suggest it is more cost-effective for both the 100- and 975-megawatt plants to achieve that reduction without installing a supplemental fabric filter; however, DOE's estimates suggest it is more cost-effective for the 500-megawatt plant to install the supplemental filter when accounting for the loss of revenue and increased disposal costs plants could incur from not being able to sell their fly ash.[37]

Fly ash disposal plays a role in determining the most cost effective compliance option because the plants that sell their fly ash and choose to use carbon-based sorbents may lose revenue and face increased disposal costs if they can no longer sell their fly ash.[38] According to EPA, power plants sell about 35 percent of their fly ash for use in other applications, with 15 percent going to uses, such as cement manufacturing, where carbon contamination could pose a problem. The presence of carbon-based sorbent in fly ash may render it unusable for such purposes, particularly as a cement substitute in making concrete. Therefore, in some cases, plants using carbon-based sorbent may not be able to sell their fly ash and instead have to pay for its disposal. Plants may mitigate this problem by installing sorbent injection downstream of the electrostatic precipitator. This would, however, require the plants to install a fabric filter to collect the spent sorbent. DOE estimated that this configuration may be a cost-effective method to achieve mercury reductions for plants that wish to continue selling their fly ash, but the high capital costs of installing a fabric filter may

[37]EPA's estimates suggest that the installation of the fabric filter is more cost-effective than carbon injection alone to achieve an 80 percent mercury reduction at a 975-megawatt plant and a 90 percent mercury reduction at both the 100- and 975-megawatt plants.

[38]DOE's estimates indicate that for a plant that sells its fly ash, loss of fly ash sales and related disposal costs could increase the cost of mercury removal by between $31,232 and $213,133 per pound of mercury removed for a plant using activated carbon injection with an existing electrostatic precipitator. Costs vary depending on the type of coal burned and the desired level of mercury reduction. For example, the cost per pound of mercury removed for a 50 percent mercury reduction at a bituminous coal-fired plant increases from $32,598 to $245,731 when accounting for the potential impact in lost fly ash sales. EPA estimated that using current technology, the marginal cost of mercury control will be $23,200; $30,100; and $39,000 per pound of mercury removed in 2010, 2015, and 2020 respectively (in 1999 dollars). EPA also conducted a sensitivity analysis—assuming that mercury controls will improve over time and therefore cost less—that showed this marginal cost falling to $11,800; $15,300; and $19,900 respectively in 2010, 2015, and 2020. These mercury removal analyses were conducted by EPA using the Integrated Planning Model, and are therefore based on different assumptions and modeling efforts than those that went into the 2003 mercury control cost report.

render this choice uneconomic for some facilities. However, based on more recent tests, EPA believes that chemically enhanced sorbents can be more efficient at achieving a high level of mercury removal and may not render fly ash unusable for other purposes. Therefore, the use of these sorbents might prevent a plant from having to install a fabric filter and allow them to continue selling fly ash.

Most Stakeholders Expect the Costs to Decrease over Time

Regardless of the exact magnitude of costs, 22 of the 40 survey respondents, all of the 14 policy stakeholders we interviewed, EPA, and DOE expect mercury control costs to decrease over time. Stakeholders cited a number of reasons for this belief, including the presence of a mercury rule, the expected development of a market that would lead to competition and increased demand for technologies, and anticipated improvements in technology performance as a result of innovation and experience. According to EPA and DOE officials, the most recent test results of injected sorbent technologies suggest that the cost of using these technologies will be less than these agencies estimated in 2003, stemming from advances in the sorbents. Likewise, EPA's economic impact analysis of the mercury rule reports that the actual cost of mercury control may be lower than currently projected, since the rule may lead to further development and innovation of these technologies, which would likely lower their cost over time.

In addition to the views of these stakeholders, experience with pollution control requirements under other air quality regulations also suggests that costs may decrease over time. While factors affecting the cost of mercury control technology may or may not be analogous to that of technologies to control other regulated pollutants, an examination of the cost trends for other air pollution controls shows that costs have declined over time. For example, according to EPA, the acid rain sulfur dioxide trading program was shown in recent estimates to cost as much as 83 percent less than originally projected.[39] Furthermore, studies conducted by other researchers demonstrate that costs of air pollution control technologies have declined. For example, research conducted by Carnegie Mellon University found that the capital cost of sulfur dioxide control technology

[39]Part of the fall in acid rain costs is due to lower costs of transportation, since the deregulation of rail made it cheaper to ship low-sulfur coal greater distances.

for a coal-fired power plant decreased from approximately $250 to $130 per kilowatt of electricity generating capacity between 1976 and 1995 (1997 dollars). Similarly, case studies analyzed by the Northeast States for Coordinated Air Use Management (NESCAUM) found the total operating and maintenance costs of sulfur dioxide controls decreased about 80 percent between 1982 and 1997.[40] NESCAUM also found a reduction in the capital cost of nitrogen oxide controls, which it attributed to improvements in operational efficiency.

Concluding Observations

Because data on the performance of mercury controls stem from a limited number of tests rather than permanent installations at power plants, data on the long-term performance of these technologies are limited. Furthermore, while the available data show promising results, forecasting when power plants could rely on these technologies to achieve significant mercury reductions—such as by 2008 or later—involves professional judgment. The judgment of the stakeholders we contacted varied substantially, with control vendors and some researchers expressing optimism about the potential for sorbent technologies to achieve substantial mercury reductions in the near term, while power industry stakeholders, DOE, and EPA highlighted the need for more long-term tests. Current and future DOE tests will enhance knowledge about these controls, especially on their effectiveness in removing mercury and the potential impacts they may have on plant operations. In addition, information from the power plants that plan to install mercury controls as part of settlement agreements or to meet state-level requirements could shed additional light on these issues.

A number of factors complicate efforts to estimate the costs of installing mercury controls. For example, available data suggest that site-specific variables will dictate the level of expense that power plant owners and operators will incur should they install one of the available mercury control technologies. While even the current cost estimates for the most advanced of the technologies—sorbent injection—are highly uncertain for individual plants, many of the stakeholders we contacted expect these costs to decline. Further, past experience with other air pollution control regulations suggests that the costs of pollution controls decline over time

[40]Based on studies by the Electric Power Research Institute and the Massachusetts Institute of Technology that showed operating and maintenance costs decline from $17.3 per megawatt-hour to $3.34 per megawatt-hour in 1999 dollars.

due to technological improvements, the development of a market, and increased experience using the controls.

Recent data already show a similar trend with respect to mercury controls. For example, EPA and DOE have stated that advanced sorbent technologies have the potential to achieve greater mercury removal at lower cost than previously estimated. Also, the emissions trading program established under EPA's mercury rule gives industry flexibility in determining how it will comply with the control targets, enabling plants to choose the most cost-effective compliance option, such as installing controls, switching fuels, or purchasing emissions allowances. Finally, because the power industry must also further reduce its emissions of nitrogen oxide and sulfur dioxide to comply with the interstate rule, the power industry has the opportunity to cost-effectively address emissions of all three pollutants simultaneously.

Agency Comments

We provided a draft of this report to DOE and EPA for review and comment. DOE reviewed the report and said that it generally agreed with our findings. EPA's Office of Air and Radiation and Office of Research and Development provided technical comments, which we incorporated as appropriate.

As agreed with your offices, unless you publicly announce the contents of this letter earlier, we plan no further distribution until 15 days from the report date. At that time, we will send copies of the report to the EPA Administrator, DOE Secretary, and other interested parties. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you have any questions about this report, please contact me at (202) 512-3841 or stephensonj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix VII.

John B. Stephenson
Director, Natural Resources and Environment

List of Requesters

The Honorable Olympia J. Snowe
Chair, Committee on Small Business and Entrepreneurship
United States Senate

The Honorable James M. Jeffords
Ranking Minority Member
Committee on Environment and Public Works
United States Senate

The Honorable Joseph I. Lieberman
Ranking Minority Member
Committee on Homeland Security and Governmental Affairs
United States Senate

The Honorable Patrick J. Leahy
Ranking Minority Member
Committee on the Judiciary
United States Senate

The Honorable Thomas R. Carper
Ranking Minority Member
Subcommittee on Clean Air, Climate Change, and Nuclear Safety
Committee on Environment and Public Works
United States Senate

The Honorable Barbara Boxer
Ranking Minority Member
Subcommittee on Superfund and Waste Management
Committee on Environment and Public Works
United States Senate

The Honorable Hillary Rodham Clinton
United States Senate

The Honorable Mark Dayton
United States Senate

The Honorable Frank Lautenberg
United States Senate

Objectives, Scope, and Methodology

Congressional requesters asked us to (1) describe the use, availability, and effectiveness of technologies to reduce mercury emissions at power plants; and (2) identify the factors that influence the cost of these technologies and report on available cost estimates. To respond to these objectives, we surveyed a nonprobability sample of 59 key stakeholders in three groups, including 22 mercury control technology vendors, 21 representatives of the coal-fired power industry, and 16 individual researchers and/or government officials.[1] We supplemented and corroborated, to the extent possible, the survey information through structured interviews with 14 stakeholders who view the reduction of mercury emissions from a policy perspective, including senior staff at EPA's Office of Policy Analysis and Review and DOE's Office of Fossil Energy. Finally, we interviewed vendors and researchers of mercury emissions monitoring technology to obtain and analyze information on the availability and reliability of mercury monitoring devices.

Our work dealt with (1) technologies or measures that are specifically intended to control mercury emissions and (2) modifications to existing controls for other pollutants (e.g., nitrogen oxides, particulate matter, or sulfur dioxide) that are specifically intended to enhance mercury removal. We did not assess the availability, use, cost, or effectiveness of controls for other pollutants that capture mercury as a side-benefit because EPA had already conducted an extensive analysis of that topic as part of the rule development process. As a result, our work addressed only technologies specifically intended to control mercury. We did not independently test these technologies. Lastly, we focused on technologies that had advanced to the field-test stage rather than on technologies in earlier stages of testing. Most of the test data we reviewed were from full-scale tests, but the field tests of less developed controls, such as some multipollutant controls, were not full-scale. In these cases, the data were obtained from slipstream tests at power plants, where segments, rather than the entire stream, of the flue gas were diverted for testing.

We relied primarily on surveys to obtain current data and professional judgment on the status of mercury controls. We developed three different surveys, one for each stakeholder group, which requested information about the availability, use, effectiveness, and cost of mercury control

[1]Results from nonprobability samples cannot be used to make inferences about a population because in a nonprobability sample some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

technologies. The scope and nature of some questions varied between the three surveys in order to reflect the varying expertise of each stakeholder group. To the extent possible, we structured the questions to facilitate comparisons between the responses of each stakeholder group. We used this format because we expected researchers, government officials, and power industry respondents to possess broad knowledge about a portfolio of mercury controls while technology vendors would have extensive information about a limited number of controls, or those that they produce, develop or sell. The most significant difference between the three surveys was that we asked technology vendors to answer questions only about the control produced, developed, or sold by each vendor, whereas the questions for researchers, government officials, and power industry respondents were not limited to one mercury control.

We developed the three surveys with survey specialists between July 2004 and October 2004. We took steps in the design, data collection, and analysis phases of the work to minimize nonsampling and data processing errors. We conducted pretests of the surveys, and staff involved in the evaluation and development of mercury control technologies within EPA's Office of Research and Development and DOE's Office of Fossil Energy also reviewed and commented on the three surveys. We made changes to the content and format of the final surveys based on the pretests, comments of EPA and DOE officials, and comments of our internal reviewer. We followed up with those that did not respond promptly to our surveys. We also independently verified the entry of all survey responses entered into an analysis database as well as all formulas used in the analyses.

We mailed paper copies of the surveys to 59 stakeholders and received 45 surveys from 40 stakeholders (68 percent response rate), which included 14 representatives of coal-fired power plants, 12 researchers and government officials, and 14 technology vendors. Because we asked technology vendors to complete one survey for each mercury control technology that they develop, produce, or sell, the number of surveys exceeded the number of respondents—five of the 14 vendors responding to our survey submitted more than one survey. Upon receiving the surveys and reviewing the questions, four stakeholders (1 power industry representative, 1 vendor, and 2 researchers/government officials) informed us that they were unable to participate. Finally, we contacted each stakeholder who did not return a survey by the deadline several times, either via email, phone, or both.

We developed separate nonprobability samples for each of the three groups we surveyed, identifying stakeholders based on the extent of their expertise and involvement with the research, development, and demonstration of mercury control technologies.

- To compile a list of mercury control technology vendors, we spoke with DOE staff overseeing the mercury technology demonstration program to identify companies that either manufacture a mercury control technology for coal-fired power plants or research these technologies to develop them commercially. Although we excluded from the technology vendors group any company or organization that conducts research solely for evaluative or academic reasons and lacks a significant financial interest in the performance of the technology, we did include these stakeholders in the researcher and government official group. Next, we spoke with DOE and mercury technology vendors and reviewed available documents to identify the stage of testing of each company's product(s), and we included on our list the companies whose product(s) have undergone commercial demonstrations, full-scale field tests, pilot-scale tests, or slipstream tests. We then corroborated the list of mercury control technology vendors with the Institute of Clean Air Companies, the national trade organization for air pollution control vendors, to ensure the completeness of the list of mercury control vendors. Our survey of mercury control technology vendors included a representative from each of the 22 companies we identified as meeting these criteria.

- We identified an initial list of 21 representatives from the coal-fired power industry to participate in our survey based primarily on a list generated from Platts' POWERdat database of the power generators who burned the most coal in calendar year 2002, which is the most recent year of available data. We determined that this database was sufficiently reliable for this purpose. We based our selection of stakeholders on the quantity of coal burned because it correlated more closely with mercury emissions than any other available variable. We included a representative from each of the 20 generators that burned the most coal in calendar year 2002, accounting for 60 percent of the coal burned for power generation in that year in the United States. One company from this list declined to participate in our survey. Therefore, we added the next-largest company on the list. This final group of 20 generators accounted for 59 percent of the coal burned for power generation in that year. Additionally, we added one company to our group of generators—resulting in a total of 21 generators surveyed—

because it had begun a commercial demonstration of a mercury control technology. Next, we corroborated our list of generators by asking representatives of the following organizations to identify contacts within the coal-fired power industry who would be knowledgeable of mercury control technologies: (1) three power companies that have actively participated in mercury control technology demonstrations; (2) the Edison Electric Institute, the trade association for electric utilities; and (3) the National Rural Electric Cooperative Association, which represents utilities serving rural communities. The power industry stakeholders identified by these three organizations all corresponded with those we had placed in the group of 21 generators.

- For the survey targeting researchers and government officials, we included senior agency staff involved in the evaluation and development of mercury control technologies within EPA's Office of Research and Development and DOE's National Energy Technology Laboratory, state government officials in states that initiated action to limit mercury emissions from power plants, and experts from companies and non-profit organizations that do research on mercury control technologies. We coordinated with the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials, the national association of state and local air pollution control agencies, to identify nine states that had initiated actions to reduce mercury emissions from power plants and the state officials that had been involved with research and development of mercury control technologies. After speaking with representatives from these states, we eliminated one of the states because the legislation did not specifically target mercury emissions. We spoke to representatives of the following eight states: Connecticut, Illinois, Iowa, Massachusetts, New Hampshire, New Jersey, North Carolina, and Wisconsin.

We recognized that the technology vendors and power industry respondents might have had concerns about disclosing sensitive or proprietary information. Therefore, although we have included a list of the survey respondents below, this report does not link individual survey responses to any particular technology vendor or representative of the coal-fired power industry. We mailed the survey to stakeholders on October

22, 2004, and asked to receive responses by November 8, 2004. Of the 59 stakeholders we contacted, the following 41 responded to our survey:[2]

- ADA Environmental Solutions
- ADA Technologies Incorporated
- AES Corporation
- Alstom Power
- American Electric Power Company, Incorporated
- Andover Technologies
- Apogee Scientific, Incorporated
- Babcock Power Incorporated
- Basin Electric Power Cooperative
- CarboChem
- Cormetech, Incorporated
- Dominion Resources, Incorporated
- Electric Power Research Institute
- Enerfab Clean Air Technologies (CR Clean Air Technologies)
- FirstEnergy Corporation
- EnviroScrub Technologies Corporation
- Hamon Research Cottrell

[2]We received responses from 41 stakeholders, but 2 of these respondents completed one survey together in order to describe a product produced by both companies. Because the 2 stakeholders completed one survey for one mercury control, we counted this as one response as part of our survey analysis.

- Illinois Environmental Protection Agency, Bureau of Air
- KFx
- Mobotec USA
- NORIT-Americas, Incorporated
- New Hampshire Department of Environmental Sciences
- New Jersey Department of Environmental Protection
- North Carolina Division of Air Quality
- Powerspan
- PPL Corporation
- Progress Energy, Incorporated
- Reaction Engineering
- Reliant Energy Incorporated
- Scottish Power Plc (Known as Pacificorps in the U.S.)
- Sorbent Technologies Corporation
- Southern Company
- Southern Research Institute
- TXU Corporation
- Tennessee Valley Authority
- United Technologies
- U.S. Department of Energy, National Energy Technology Laboratory
- U.S. EPA, Office of Research and Development, Air Pollution Prevention and Control Division

- We Energies
- Wisconsin Department of Natural Resources, Bureau of Air Management
- Xcel Energy, Incorporated

We supplemented and corroborated, to the extent possible, the survey information with testimonial evidence. This included structured interviews with 14 policy stakeholders familiar with the policy implications of mercury control technology research, including senior staff at EPA's Office of Policy Analysis and Review and DOE's Office of Fossil Energy, state and local regulatory organizations, electric utility associations, and environmental organizations.[3] We developed a nonprobability sample for the group of policy stakeholders. We worked with a survey expert to develop a set of structured interview questions about the availability, use, effectiveness, and cost of mercury control technologies. In order to minimize nonsampling error, we took steps to ensure that the questions were unambiguous, balanced, and clearly understandable. The interview questions were similar to the survey questions, but tailored to reflect the policy expertise of the interview participants. For example, rather than asking interview participants to provide data on mercury technology demonstrations, we sought their views on the implications of mercury technology demonstrations for mercury policies. We conducted pretests of the structured interview, including one with an EPA official in the Office of Policy Analysis and Review. We made changes to the content and format of the final interview questions based on the pretests.

We conducted the 14 structured interviews between November 2004 and December 2004 with stakeholders from the following 13 organizations:[4]

- American Public Power Association
- Clean Air Task Force

[3]The policy stakeholders we interviewed did not participate in the three surveys we conducted.

[4]We conducted 14 interviews with stakeholders representing these 13 organizations. In order to include the perspective of several senior air policy staff at EPA, we conducted two interviews with the agency.

- Edison Electric Institute
- Institute of Clean Air Companies
- MJ Bradley
- National Rural Electric Cooperative Association
- National Wildlife Federation
- Northeast States for Coordinated Air Use Management
- Regional Air Pollution Control Agency
- State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officers
- U.S. Department of Energy, Office of Fossil Energy
- U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy Analysis and Review
- U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards

Finally, because of the important role monitoring data play in the regulation of air pollutants, we gathered and analyzed information on the availability and reliability of two kinds of mercury monitoring devices—sorbent traps and continuous emissions monitors—by conducting seven structured interviews with the technology vendors and researchers in the government and private sectors. We developed the list by consulting with EPA's lead expert on mercury monitoring technology and then comparing it to the list of presenters at DOE's Mercury Measurements Workshop, which was conducted in July 2004. Because this list of monitoring technology vendors primarily represented one of the two advanced mercury monitors, we included an organization regarded as a major developer of the other mercury monitoring device. Finally, we also included researchers and government stakeholders with broad knowledge of the mercury monitoring industry.

We could not interview all 18 stakeholders we identified for the sorbent trap and continuous emissions monitors because of time constraints.

Therefore, we decided to (1) interview four researchers and government officials, (2) interview the major producer of sorbent traps, and (3) interview a random sample of the multiple vendors involved with the eight kinds of continuous emissions monitors. Within this last group, we compiled a list of 13 mercury monitoring vendors, which was then randomized by a senior GAO methodologist. We interviewed the first 3 stakeholders on the randomized list of 13 mercury monitoring vendors in order to include their knowledge and perspectives on the industry. We were not able to reach the sorbent trap producer for an interview.

We based the questions for the monitoring interviews on those posed in the mercury control technology surveys, including the same concepts and emphasizing the availability and level of demonstration of monitoring technologies, and again took steps to minimize nonsampling errors. We conducted two pretests of the monitoring interviews. Finally, we corroborated the numerical values used in questions about the accuracy and reliability of mercury monitors with EPA's mercury monitoring expert in the Office of Research and Development. We made changes to the content and format of the final interview questions based on the pretests and the EPA official's comments.

Lastly, we identified and reviewed governmental and nongovernmental reports estimating the cost of mercury control technologies. We identified two government cost reports—one from EPA and one from DOE—and four nongovernmental cost reports. We excluded two of the nongovernmental reports from our analysis because these reports addressed cost issues that were either too limited in scope or were not germane to our research objectives. We then reviewed the results of both government reports and two remaining nongovernmental reports as part of our technology cost analysis. We took several steps to assess the validity and reliability of computer data underlying the cost estimates in the EPA, DOE, and nongovernmental reports which were discussed in our findings, including reviewing the documentation and assumptions underlying EPA's economic model and assessing the agency's process for ensuring that the model data are sufficient, competent, and relevant. We determined that these four reports are sufficiently reliable for the purposes of this report.

As part of our effort to consider data on mercury control demonstrations and costs, we assessed compliance with internal controls related to the availability of timely, relevant, and reliable information. We also obtained data on mercury emissions. Because the emissions data are used for background purposes only, we did not assess their reliability.

We performed our work between May 2004 and May 2005 in accordance with generally accepted government auditing standards.

Availability and Costs of Mercury Monitoring Technology

This appendix provides information on technologies that facilities may use to monitor mercury emissions, including background information on monitoring technologies and requirements under EPA's mercury rule, as well as on the availability and cost of different monitoring technologies.

Background

In addition to technologies that control emissions, those that monitor the amount of a pollutant emitted can play an equally important role in the success of an air quality rule's implementation. For example, effective emissions monitoring assists facilities and regulators in assuring compliance with regulations. In some cases, monitoring data can also help facilities better understand the efficiency of their processes and identify ways to optimize their operations.

Accurate emissions monitoring is particularly important for trading programs, such as that established by the mercury rule. According to EPA, the most widespread existing requirements for using advanced monitoring technologies stem from EPA's Acid Rain program. Under the program, power plants have been allowed to buy and sell emissions allowances, but each facility must hold an allowance for each ton of sulfur dioxide it emitted in a given year; furthermore, facilities must continuously monitor their emissions.[1] According to EPA, monitoring ensures that each allowance actually represents the appropriate amount of emissions, and that allowances generated by various sources are equivalent, instilling confidence in the program. Conversely, a study by the National Academy of Public Administration found that the lack of monitoring in other trading programs led to difficulty in ensuring the certainty of emissions reductions.

EPA's mercury rule requires mercury emissions monitoring and quarterly reporting of mercury emissions data. For plants that emit at least 29 pounds of mercury annually, EPA requires continuous emissions monitoring, while sources that emit less than this amount may instead conduct periodic testing—testing their emissions once or twice a year depending on their emissions level. According to EPA, the mercury emissions from sources exempt from continuous monitoring comprise approximately 5 percent of nationwide emissions. EPA estimates that the

[1]The Clean Air Interstate Rule revised these provisions of the Acid Rain Program to require additional allowances beginning in the year 2010.

annual impact in monitoring costs for the entire industry will total $76.4 million.[2]

EPA Expects That Monitoring Technologies Will Be Available Prior to the Compliance Deadlines

EPA expects that two technologies will be available to monitor mercury emissions continuously prior to the rule's deadline and requires continuous emissions monitoring for most facilities either by a Continuous Emissions Monitoring System (CEMS) or a sorbent trap monitoring system, while facilities that emit low levels of mercury can conduct periodic monitoring using a testing protocol known as the Ontario-Hydro Method:

- **CEMS** continuously measures pollutants released by a source, such as a coal-fired power plant. Some CEMSs extract a gas sample from a facility's exhaust and transport it to a separate analyzer while others allow effluent gas to enter a measurement cell inserted into a stack or duct. This allows for continuous, real-time emissions monitoring. EPA estimates that a unit's annual CEMS operating, testing, and maintenance cost would be about $87,000, while a unit's capital cost would be about $70,000.
- **Sorbent trap monitoring** systems collect a mercury sample by passing flue gas through a mercury trapping medium, such as an activated carbon tube. This sample is periodically removed and sent to a lab for analysis. The rule requires that the average measurement of two separate sorbent trap readings be reported. Sorbent trap monitoring allows for continuous monitoring, but is not considered a real-time method. EPA estimates that a unit's annual sorbent trap operating and testing costs would be about $113,000 per year, while a unit's capital cost would be about $20,000.
- The **Ontario-Hydro Method**, a periodic testing method, involves manually extracting a sample of flue gas from a coal-fired plant's stack or duct, usually over a period of a few hours, which is then analyzed in a laboratory. EPA estimates this method would cost about $12,500 a year for two tests and about $7,000 for one test.

[2]Based on the annualized capital and operating costs of the technologies units are expected to use and the number of units expected to use each technology.

Stakeholders Believe That Mercury Monitoring Technology Is Available, Reliable, and Will be Able to Meet Quality Control and Assurance Standards by 2008

All of the stakeholders we asked about the availability of CEMS or sorbent trap systems said that the technologies were available for purchase. Furthermore, an EPA monitoring technology expert and the vendors we interviewed agreed that there were no technical or manufacturing challenges that would prevent vendors from supplying monitors to coal-fired power plants by 2008. However, some researchers identified factors that could affect vendors' ability to supply monitors by that date, including whether vendors had sufficient production capacity to meet the industry's demand for the equipment. All three vendors we interviewed were aware of power plants in other countries that had installed mercury monitoring equipment (including Germany, Japan, and the United Kingdom). Two respondents were aware of power plants in the United States that had permanently installed mercury monitoring equipment.

Most researchers considered CEMS and sorbent trap technologies to be accurate and reliable, and the CEMS vendors also characterized their technologies as accurate and reliable. Researchers cited the need for additional testing of certain subcomponents of the continuous monitoring systems. Stakeholders were generally confident that these technologies would be able to meet proposed quality control and assurance standards by 2008, although two researchers expressed concerns that EPA's proposed standards might be too strict for CEMS to meet.

According to EPA, recent field tests have demonstrated that sorbent trap systems can be as accurate as CEMS. The rule requires the implementation of quality assurance procedures for sorbent trap monitoring systems, which EPA says are based on field research and input from parties that commented on the agency's mercury rule during the public comment period. EPA acknowledges that there may be problems with the technology, such as the possibility of the traps becoming compromised, lost, or broken during transit or analysis, which could result in missing data; however, EPA also believes steps can be taken to minimize these possibilities.

Summary of Field-Scale Tests of Mercury Controls

The table below summarizes data about mercury control tests, including the power plant location, duration of continuous testing, coal type, and average mercury removal. We obtained data from DOE's National Energy Technology Laboratory and from the 40 survey respondents about field tests. The tests that have been partially funded by DOE's National Energy Technology Laboratory are identified in the table below by an asterisk symbol.

Table 1: Summary of Mercury Control Field Test Data

Mercury control category	Technology	Location	Duration	Test year	Coal type	Average mercury reduction[a]
Sorbent	Activated carbon*	Wilsonville, AL	9 days	2001	Bituminous	Various test results reported to GAO: 78-90 percent
	Activated carbon*	Pleasant Prairie, WI	Three 5-day tests	2001	Subbituminous	46-73 percent
	Activated carbon*	Somerset, MA	10 days	2002	Bituminous	Various test results reported to GAO: 85 to 90 percent.
	Activated carbon*	Salem, MA	4 days	2002	Bituminous	85-95 percent[b]
	Activated carbon	Underwood, ND	5 days	2003	Lignite	70 percent
	Activated carbon	Denver, CO	6 days[c]	2004	Subbituminous	64 percent
	Activated carbon	Denver, CO	3 hours	2004	Subbituminous	86 percent
	Activated carbon	Undisclosed	1 day	2004	Subbituminous	30 percent
	Activated carbon	Undisclosed	2 days	2004	Subbituminous	55 percent
	Activated carbon and sorbent enhancement*	Stanton, ND	1 month	2004	Lignite	63 percent

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	Activated carbon*	Newnan, GA	1 month	2004	Bituminous	According to preliminary analysis, removal varied by measurement point within the process: ESP[d]+ACI, removal ranged from a minimum of 50 to a maximum of 91 percent (majority data 60-85 percent); ESP+ACI+scrubber, removal ranged from a minimum of 50 to a maximum of 97 percent (majority data 70-94 percent)
	Activated carbon*	Newnan, GA	Not available: testing ongoing[e]	2004-2005	Bituminous	Not available: testing ongoing[e]
	Activated carbon and sorbent enhancement*	Beulah, ND	2 months	2005	Lignite	Not available: testing ongoing[e]
	Activated carbon*[f]	Monroe, MI	Not yet tested[e]	2005	Blend: Subbituminous/ Bituminous	Not yet tested[e]
	Activated carbon*[f]	Conesville, OH	Not yet tested[e]	2005	Bituminous	Not yet tested[e]
	Chemically enhanced carbon	Cliffside, NC	Several multi-hour tests over 1-week period	2003	Bituminous	Average varied; mercury removal ranged from a minimum of 20 percent to a maximum of 90 percent
	Chemically enhanced carbon	Athens, OH	Several multi-hour tests over 2-week period	2003	Bituminous	70 percent
	Chemically enhanced carbon*	St. Louis, MO	30 days	2004	Subbituminous	90 percent
	Chemically enhanced carbon*	Near Garden City, KS	30 days	2004	Subbituminous	90 percent
	Chemically enhanced carbon*	East China Township, MI	30 days	2004	Blend: Bituminous /Subbituminous	94 percent
	Chemically enhanced carbon	Undisclosed	Greater than 10 days	2004	Lignite	70 percent
	Chemically enhanced carbon	Undisclosed	1 day	2004	Subbituminous	60 percent

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	Chemically enhanced carbon*	Stanton, ND	24 days	2004	Lignite	70 percent
	Chemically enhanced carbon*	Stanton, ND	1 month	2004	Lignite	Not yet available[e]
	Chemically enhanced carbon*	Spencer, NC	3 months	2005	Bituminous	Not yet available[e]
	Chemically enhanced carbon*	Stanton, ND	TBD[g]	TBD[g]	Lignite	Not yet tested[e]
	Chemically enhanced carbon*	Portland, PA	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]
	Chemically enhanced carbon*	Located near Goldsboro, NC	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]
	Chemically enhanced carbon*	Romeoville, IL (tentative location)	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Chemically enhanced carbon*	Glenrock, WY	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Chemically enhanced carbon*	Chicago, IL	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Chemically enhanced carbon*	Muscatine, IA	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Chemically enhanced carbon*	Council Bluffs, IA	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Non-Carbon	Denver, CO	6 hours	2004	Subbituminous	28 percent
	Non-Carbon	Denver, CO	6-7 days[h]	2004	Subbituminous	Various test results reported to GAO: 51 percent reported for 7-day test; 57-68 percent reported for 6-day test
	Non-Carbon*	North Bend, OH	1 month	2005	Bituminous	Not yet available[e]
Multipollutant	Activated carbon and enhanced particulate collection*[i]	Wilsonville, AL	5 months	2003	Bituminous	86 percent
	Activated carbon and enhanced particulate collection*[i]	Cheshire, OH	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]
	Activated carbon and enhanced particulate collection*[i]	Newark, AR	TBD[g]	TBD[g]	Subbituminous	Not yet tested[e]
	Activated carbon and enhanced particulate collection*[i]	Near Fairfield, TX	TBD[g]	TBD[g]	Lignite or Lignite/Subbituminous blend	Not yet tested[e]

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	Sorbent and high velocity air	Moncure, NC	14 days	2002	Bituminous	80 percent
	Wet ESP	Shippingport, PA	Not specified	2001-2003	Subbituminous	78 percent
	Corona Discharge[j]	Shadyside, OH	6 days	2004	Blend: Bituminous and subbituminous	75 percent
Mercury oxidation	Chlorine-based additives*	Located near Center, ND	2 months expected	2005	Lignite	Not yet tested[e]
	Chlorine-based additives*	Mt. Pleasant, TX	1 month expected[e]	2005	Lignite	Not yet tested[e]
Enhancement	Wet FGD[k] Additive*	Moscow, OH	2 weeks	2001	Bituminous	52 percent
	Wet FGD Additive*	Litchfield, MI	4 months	2001	Bituminous	79 percent
	Wet FGD Additive	Mt. Storm Lake, northeastern WV	3 days	2004	Bituminous	71 percent
	Wet FGD Additive	Mt. Storm Lake, northeastern WV	7 days	2004	Bituminous	Over 90 percent
	Wet FGD Additive*	Newnan, GA	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]
	Wet FGD Additive*	Conesville, OH	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]
	Wet FGD Additive*	Mt. Pleasant, TX	TBD[g]	TBD[g]	Lignite	Not yet tested[e]
Other	Fixed sorbent structure*	Stanton, ND	6 months expected	2004-2005	Lignite, then switched to subbituminous during testing	Not available: testing ongoing[e]
	Fixed sorbent structure*	Newnan, GA	5 months expected	2005	Bituminous	Not yet available[e]
	Combustion modification*	Rogersvile, TN	TBD[g]	TBD[g]	Bituminous	Not yet tested[e]

Source: DOE National Energy Technology Laboratory and GAO analysis of survey responses.

*Field tests partially funded by DOE's National Energy Technology Laboratory.

[a]Average mercury removal reflects the total mercury removal achieved by the entire system of pollution controls, not just the mercury control, installed at the power plant.

[b]Measurements obtained over a four-day test showed overall mercury capture of 85 to 95 percent.

[c]The test was conducted for 3 to 8 hours per day.

[d]ESP is the abbreviation for electrostatic precipitator.

[e]This is based on DOE's information as of February 2005.

[f]The research team has not yet finalized the selection of sorbent for this test. The research team is testing activated carbon, but will also consider using chemically enhanced carbon injection at this site.

[g]TBD means to be determined. DOE's National Energy Technology Laboratory had awarded funding for this project but a specific testing timeframe had not been identified yet as of February 2005.

[h]The test was conducted for 3 to 8 hours per day. Survey respondents reported test durations of 6 days and 7 days.

[i] This combination of pollution controls includes an enhanced, compact fabric filter designed to capture mercury and particulates at plants already using an electrostatic precipitator.

[j] EPA describes corona discharge technology as the “generation of an intense corona discharge (ionization of air by a high voltage electrical discharge)” in the flue gas (page 7-43). The corona discharge triggers a series of chemical reactions that are intended to improve the capture of mercury and particulate matter. US EPA, National Risk Management Research Laboratory, *Control of Mercury Emissions from Coal-Fired Electric Utility Boilers: Interim Report Including Errata Dated March 21, 2002* (Research Triangle Park, NC, 2002).

[k] FGD is the abbreviation for flue gas desulfurization.

Summary of Stakeholder Perceptions about Availability of Mercury Controls

This appendix provides more detailed information on stakeholders' views regarding the availability of the different mercury controls. Please refer back to appendix I for details about our survey methodology.

Of the stakeholders that either responded to our survey (40) or participated in an interview (14), a majority (40) believed that at least one technology was currently available for purchase. As shown in table 2, many of the researchers and government officials said that activated carbon injection (8 of 12) and chemically enhanced carbon (7 of 12) are currently available, while less than half of the power industry officials also believe activated carbon injection technology is available (6 of 14). All of the vendors associated with carbon-based sorbent injection, including activated carbon (4) and chemically enhanced carbon (2), described their technology as available. In addition, 13 of the 14 policy stakeholders we interviewed—those who do not participate in technology research but are involved in the development of mercury control policy, including representatives of EPA, DOE, regional and local air pollution agencies, environmental advocacy groups, and the electric utility industry—believe that sorbent technology is currently available for purchase.

Table 2: Stakeholder Perceptions on Availability of Sorbent Technologies[a]

Technology	Stakeholder group	Available	Not available	Do not know	Did not answer	Total
Activated carbon injection (ACI)	Coal-fired power industry	6	3	3	2	14
	Researchers and government officials	8	1	1	2	12
	Technology vendors[b]	4	0	0	0	4
	Policy stakeholders	13	1	0	0	14
Total responses		**31**	**5**	**4**	**4**	**44[b]**
Chemically enhanced ACI	Coal-fired power industry	3	5	4	2	14
	Researchers and government officials	7	1	1	3	12
	Technology vendors[b]	2	0	0	0	2
	Policy stakeholders	11	1	2	0	14
Total responses		**23**	**7**	**7**	**5**	**42[b]**
Non-carbon sorbent	Coal-fired power industry	0	8	4	2	14
	Researchers and government officials	1	2	5	4	12
	Technology vendors[b]	1	1	0	0	2
	Policy stakeholders	4	4	6	0	14
Total responses		**6**	**15**	**15**	**6**	**42[b]**

Source: GAO.

[a]Given the uncertainty about federal mercury reduction goals that existed prior to the March 2005 mercury rule and the fact that field testing of mercury controls is ongoing, some of the stakeholders were reluctant to make conclusions about the availability of all mercury controls when we asked them in November and December 2004. Therefore, some participants did not answer this question, and the number of responses for each mercury control reflects in part the extent of field testing.

[b]The number of responses for the question on availability does not correspond to the overall number of survey responses because the availability question differed slightly for technology vendors. We did not seek the technology vendors' perceptions of all mercury controls, an option we gave the other stakeholders, but asked the vendors whether the mercury control they produce, develop, and/or sell is available for purchase without regard to technology effectiveness.

The survey responses regarding the availability of other mercury controls were more limited and less optimistic than those for sorbent injection. While 40 of the 54 stakeholders answered questions about the availability of activated carbon injection, far fewer respondents answered the questions about the availability of other controls.[1] As shown in table 3, the stakeholders who responded to questions about nonsorbent control technologies, such as multipollutant controls, mercury oxidation technologies, and enhancements to existing controls for other pollutants, were more mixed in their views about the availability of these technologies. For example, researchers and government officials expressed a range of views about mercury oxidation technologies—4 believe they are available, 3 do not think they are available, 2 did not know, and 3 chose not to answer this question.

Table 3: Stakeholder Perceptions on Availability of Non-Sorbent Mercury Controls[a]

Technology	Stakeholder group	Available	Not available	Do not know	Did not answer	Total
Mercury oxidation technologies	Coal-fired power industry	0	8	4	2	14
	Researchers and government officials	4	3	2	3	12
	Technology vendors[b]	1	1	0	0	2
	Policy stakeholders	5	6	3	0	14
Total responses		**10**	**18**	**9**	**5**	**42[b]**
Multipollutant controls	Coal-fired power industry[c]	4	3	0	9	16
	Researchers and government officials[c]	6	2	0	6	14
	Technology vendors[b,c]	4	4	0	0	8
	Policy stakeholders[c]	12	4	2	3	21
Total responses		**26**	**13**	**2**	**18**	**59[b,c]**
Enhancements to existing controls	Coal-fired power industry[d]	0	2	1	12	15
	Researchers and government officials[d]	5	4	0	6	15
	Technology vendors[b,d]	1	0	0	0	1
	Policy stakeholders[d]	18	1	0	5	24
Total responses		**24**	**7**	**1**	**23**	**55[b,d]**

Source: GAO.

[a]Given the uncertainty about federal mercury reduction goals that existed prior to the March 2005 mercury rule and the fact that field testing of mercury controls is ongoing, some of the stakeholders

[1]Ten of the 14 vendors were not asked to provide views on the availability of activated carbon because these vendors do not produce, develop, or sell this technology.

were reluctant to make conclusions about the availability of all mercury controls when we asked them in November and December 2004. Therefore, some participants did not answer this question, and the number of responses for each mercury control reflects in part the extent of field testing.

[b]The number of responses for the question on availability does not correspond to the overall number of survey responses because the availability question differed slightly for technology vendors. We did not seek the technology vendors' perceptions of all mercury controls, an option we gave the other stakeholders, but asked the vendors whether the mercury control they produce, develop, and/or sell is available for purchase without regard to technology effectiveness.

[c]The number of responses for the question on availability for multipollutants controls does not correspond to the overall number of survey responses because some stakeholders identified more than one multipollutant control and provided different responses about the availability of those controls.

[d]The number of responses for the question on availability for enhancements to existing controls does not correspond to the overall number of survey responses because some stakeholders identified more than one enhancement and provided different responses about the availability of those enhancements.

Finally, the 14 policy stakeholders we interviewed also expressed mixed views on the availability of mercury controls. Nine described various multipollutant controls as available, 5 viewed mercury oxidation as available, and 8 regarded various enhancements to existing technologies as available.

Stakeholder Confidence in Ability of Technologies to Achieve Mercury Reductions under Three Scenarios

This appendix summarizes the perceptions of survey respondents in the ability of mercury controls to reduce emissions under three scenarios. (Appendix I provides details about our survey methodology.)

We asked survey respondents to assess their confidence in the ability of power plants to achieve mercury reductions of 50, 70, and 90 percent by the year 2008 under two different scenarios. The first scenario resembled the cap-and-trade approach recently finalized by EPA in that it asked stakeholders to consider whether the industry could use available technologies to achieve industrywide reductions of 50, 70 or 90 percent by 2008. The second scenario was similar to an alternative approach considered by EPA that would have required each plant to reduce emissions; for this scenario we asked respondents whether each individual plant could use available technologies to achieve the percentage reductions by 2008.[1]

As shown in tables 4 through 9, the confidence levels depended on the level of reduction required and by stakeholder group. Overall, the technology vendors answering this question expressed the greatest confidence, while the power industry respondents were the least confident. Within each stakeholder group, respondents expressed the greatest confidence overall in achieving a 50 percent reduction by 2008—a reduction that EPA requires under its 2010 cap—and progressively less confidence in the 70 and 90 percent scenarios. For both possible control scenarios—the national limit and facility-specific reductions—a majority of the 38 respondents[2] expressed confidence in achieving the 50 percent reductions (see tables 4 and 5), but many lacked confidence in the feasibility of 90 percent mercury reductions by 2008 (see tables 8 and 9). Respondents expressed mixed opinions about the feasibility of 70 percent reductions by 2008, as shown in tables 6 and 7.

[1]GAO instructed respondents to consider whether such reductions were feasible at most, but not all, power plants. This allowed survey respondents to report confidence in mercury reduction at nearly all power plants without considering highly unusual situations that might arise at certain plants.

[2]This number differs from the number of responses because two of the 40 respondents did not answer these questions.

Table 4: Stakeholder Confidence in Reducing Nationwide Mercury Emissions 50 Percent by 2008

Scale of mercury reduction	Confidence level	Stakeholder group: Power industry respondents	Stakeholder group: Researchers/government officials	Stakeholder group: Vendors	Total
50 percent reduction nationwide[a]	Very confident or confident	2	9	12	**23**
	Less confident	5	1	1	**7**
	Not at all confident	6	0	0	**6**
	Do not know	1	1	0	**2**
Total respondents		**14**	**11**[b]	**13**[b]	**38**

Source: GAO.

[a]The survey asked stakeholders how confident they were that power plants could reduce mercury emissions 50 percent by 2008. In this case, respondents were asked to consider reductions *averaged across* power plants in the United States, which does not mean that each individual plant would achieve the reductions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Table 5: Stakeholder Confidence in Achieving Mercury Reductions of 50 Percent at Nearly Every Plant by 2008

Scale of mercury reduction	Confidence level	Stakeholder group: Power industry respondents	Stakeholder group: Researchers/government officials	Stakeholder group: Vendors	Total
50 percent reduction at nearly each power plant[a]	Very confident or confident	2	9	11	**22**
	Less confident	5	1	2	**8**
	Not at all confident	6	0	0	**6**
	Do not know	1	1	0	**2**
Total respondents		**14**	**11**[b]	**13**[b]	**38**

Source: GAO.

[a]The survey asked stakeholders to consider the likelihood that a single power plant could reduce mercury emissions 50 percent by 2008. In this case, respondents were asked to consider whether most, but not necessarily all, power plants in the United States would each be capable of achieving a 50 percent reduction in mercury emissions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Table 6: Stakeholder Confidence in Reducing Nationwide Mercury Emissions 70 Percent by 2008

		Stakeholder group			
Scale of mercury reduction	**Confidence level**	**Power industry respondents**	**Researchers/government officials**	**Vendors**	**Total**
70 percent reduction nationwidea	Very confident or confident	0	6	10	**16**
	Less confident	1	3	3	**7**
	Not at all confident	13	1	0	**14**
	Do not know	0	1	0	**1**
Total respondents		**14**	**11[b]**	**13[b]**	**38**

Source: GAO.

[a]GAO asked stakeholders how confident they were that power plants could reduce mercury emissions 70 percent by 2008. In this case, respondents were asked to consider reductions *averaged across* power plants in the United States, which does not mean that each individual plant would achieve the reductions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Table 7: Stakeholder Confidence in Achieving Mercury Reductions of 70 Percent at Nearly Every Plant by 2008

		Stakeholder group			
Scale of mercury reduction	**Confidence level**	**Power industry respondents**	**Researchers/government officials**	**Vendors**	**Total**
70 percent reduction at nearly each power plant[a]	Very confident or confident	0	5	7	**12**
	Less confident	1	4	5	**10**
	Not at all confident	13	1	1	**15**
	Do not know	0	1	0	**1**
Total respondents		**14**	**11[b]**	**13[b]**	**38**

Source: GAO.

[a]The survey asked stakeholders to consider the likelihood that a single power plant could reduce mercury emissions 70 percent by 2008. In this case, respondents were asked to consider whether most, but not necessarily all, power plants in the United States would each be capable of achieving a 70 percent reduction in mercury emissions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Table 8: Stakeholder Confidence in Reducing Nationwide Mercury Emissions 90 Percent by 2008

Scale of mercury reduction	Confidence level	Stakeholder group: Power industry respondents	Stakeholder group: Researchers/government officials	Stakeholder group: Vendors	Total
90 percent reduction nationwide[a]	Very confident or confident	0	2	2	**4**
	Less confident	1	2	6	**9**
	Not at all confident	13	6	5	**24**
	Do not know	0	1	0	**1**
Total respondents		**14**	**11[b]**	**13[b]**	**38**

Source: GAO.

[a]GAO asked stakeholders how confident they were that power plants could reduce mercury emissions 90 percent by 2008. In this case, respondents were asked to consider reductions *averaged across* power plants in the United States, which does not mean that each individual plant would achieve the reductions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Table 9: Stakeholder Confidence in Achieving Mercury Reductions of 90 Percent at Nearly Every Plant by 2008

Scale of mercury reduction	Confidence level	Stakeholder group: Power industry respondents	Stakeholder group: Researchers/government officials	Stakeholder group: Vendors	Total
90 percent reduction at nearly each power plant[a]	Very confident or confident	0	2	2	**4**
	Less confident	1	2	6	**9**
	Not at all confident	13	6	4	**23**
	Do not know	0	1	1	**2**
Total respondents		**14**	**11[b]**	**13[b]**	**38**

Source: GAO.

[a]The survey asked stakeholders to consider the likelihood that a single power plant could reduce mercury emissions 90 percent by 2008. In this case, respondents were asked to consider whether most, but not necessarily all, power plants in the United States would each be capable of achieving a 90 percent reduction in mercury emissions.

[b]One stakeholder in this group that responded to the survey did not answer this question.

Sorbent Injection Cost Estimates from EPA and DOE

This appendix summarizes estimates of the cost of activated carbon injection reported by EPA and DOE in October and November 2003.[1]

Environmental Protection Agency. Using modeling data provided in EPA's cost report, we selected control cost scenarios that are comparable to those DOE presented in its cost study.[2] These estimates include the cost of fly ash disposal for plants that use sorbent injection without a fabric filter, based on the assumption that the presence of sorbent in fly ash makes it unsuitable for sale. EPA provided capital costs in dollars per unit of generating capacity, and operating and maintenance costs in dollars per unit of electricity generated (per hour) for 100- and 975-megawatt plants operating at 65 percent capacity over the course of a year (5,694 hours). Tables 10 and 11 present the range of capital and operating and maintenance costs for the selected EPA plant scenarios; capital costs are in total dollars while operating and maintenance costs are expressed in dollars per year.

[1]Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, *Performance and Cost of Mercury and Multipollutant Emission Control Technology Applications on Electric Utility Boilers* (Research Triangle Park, N.C., 2003).

Jeff Hoffmann and Jay Ratafia-Brown, Science Applications International Corporation, *Preliminary Cost Estimate of Activated Carbon Injection for Controlling Mercury Emissions from an Un-Scrubbed 500 MW Coal-Fired Power Plant*, a report prepared for the Department of Energy, National Energy Technology Laboratory, November 2003.

[2]According to the EPA study, the agency identified a representative range of plant configurations, coal types, and technologies. In developing the range, EPA used 49 model plants. For the estimates presented here, we selected 4 model plants, which were 100-megawatt and 975-megawatt plants with an existing electrostatic precipitator, burning low-sulfur bituminous or subbituminous coals with and without a fabric filter installed, with desired mercury removal levels between 50 and 90 percent, depending on configuration and coal type. These model plants most closely align with the assumptions presented in the DOE cost estimates discussed in this report.

Table 10: Select EPA Cost Estimates of Sorbent Injection for a 100-Megawatt Coal-Fired Power Plant, 2003

Thousands of 2003 dollars

Cost	Low estimate	High estimate	Low-end assumptions	High-end assumptions
Capital	$16.5[b]	$5,947.9	50 percent mercury removal from bituminous-fired unit with existing equipment only; costs include mercury monitoring	90 percent mercury removal from sorbent injection and fabric filter retrofit, as well as mercury monitoring for a subbituminous-fired unit
Annual operating and maintenance[a]	0.6[b]	1,342.6	50 percent mercury removal with existing equipment only; no sorbent injection needed	90 percent mercury removal from sorbent injection without a fabric filter and mercury monitoring for bituminous-fired unit

Source: GAO analysis of EPA data.

[a]Based on a plant capacity factor of 65 percent, includes both variable and fixed operating and maintenance costs.

[b]This reduction is assumed to be met with existing equipment; therefore costs are for mercury monitoring only, no sorbent injection.

Table 11: Select EPA Cost Estimates of Sorbent Injection for a 975-Megawatt Coal-Fired Power Plant, 2003

Thousands of 2003 dollars

Cost	Low estimate	High estimate	Low-end assumptions	High-end assumptions
Capital	$91.7[b]	$36,210.5	50 percent mercury removal from bituminous-fired unit with existing equipment only; costs include mercury monitoring	90 percent mercury removal from sorbent injection and fabric filter retrofit, as well as mercury monitoring for a subbituminous-fired unit
Annual operating and maintenance[a]	5.6[b]	12,868.7	50 percent mercury removal with existing equipment only; no sorbent injection needed	90 percent mercury removal from sorbent injection without a fabric filter and mercury monitoring for bituminous-fired unit

Source: GAO Analysis of EPA data.

[a]Based on a plant capacity factor of 65 percent, includes both variable and fixed operating and maintenance costs.

[b]This reduction is assumed to be met with existing equipment; therefore costs are for mercury monitoring only, no sorbent injection.

EPA estimated that the capital cost of sorbent injection for a 100-megawatt plant would range from $0.17 to $59.5 per kilowatt of capacity, while operating and maintenance costs for the same plant would range from $0.001 to $2.36 per megawatt-hour. For the 975-megawatt plant, EPA estimated that the capital cost would range from $0.09 to $37.1 per kilowatt, while operating and maintenance costs would range from $0.001 to $2.32 per megawatt-hour. EPA also estimated the total annualized cost of these controls in 2003 dollars, which ranged from $0.005 to $2.64 per megawatt-hour or between $2,847 and $1.5 million per year for a 100-megawatt plant.[3] For a 975-megawatt plant, annualized costs ranged from $0.003 to $2.45 per megawatt-hour or between $16,655 and $13.6 million per year.

Capital costs were much higher for scenarios where a fabric filter was installed, while the highest operating and maintenance cost and annualized cost were for achieving a 90 percent mercury reduction for a bituminous coal-fired plant using sorbent injection without installing a fabric filter, due to the amount of sorbent needed to achieve a high mercury removal. At the low end of these costs, EPA assumed that existing equipment is sufficient to achieve a 50 percent reduction in mercury for plants that burn bituminous coal, therefore costs reflect only that of monitoring mercury emissions and do not include actual sorbent injection costs. While total capital and annual costs for the larger plant were higher than for the smaller plant, the annualized cost in dollars per megawatt-hour was actually lower, since costs were spread out over more units of capacity and electricity generated.

Department of Energy. DOE's analysis of the cost of mercury control technologies was based on field testing conducted by DOE's National Energy Technology Laboratory. For its estimates, DOE used a hypothetical power plant of 500 megawatts burning bituminous or subbituminous coal and equipped with an electrostatic precipitator or a layout that consists of sorbent injection and a fabric filter retrofitted downstream of an existing electrostatic precipitator. Cost estimates were developed for mercury removal requirements ranging from 50 to 90 percent as shown below in table 12. DOE estimated capital costs between $1.97 and $57.44 per kilowatt. The high end of the capital cost range represented cases where facilities installed a supplemental fabric filter to achieve higher levels of mercury reduction, while the high end of the operating and maintenance costs represented achieving a 90 percent reduction in mercury emissions

[3]EPA's annualized cost reflects the capital cost annuitized using a levelized carrying charge rate of 13.3 percent assuming a 30-year operating period summed with operating and maintenance costs levelized with a factor of 1.0.

for a plant burning bituminous coal using sorbent injection without a fabric filter.

Table 12: DOE's Cost Estimates for Sorbent Injection Installed on a 500-Megawatt Coal Power Plant, 2003

Thousands of 2003 dollars

Cost	Low estimate	High estimate	Low-end assumptions	High-end assumptions
Capital	$984.0	$28,719.0	50 or 70 percent mercury removal from bituminous-fired unit, 50 or 60 percent mercury removal from subbituminous-fired unit with sorbent injection and existing equipment (no fabric filter)	60 or 90 percent mercury removal with sorbent injection and fabric filter installation for a subbituminous-fired unit
First year operating and maintenance	931.0	15,647.0	50 percent mercury removal with sorbent injection and existing equipment (no fabric filter) from bituminous-fired unit	90 percent mercury removal with sorbent injection and existing equipment (no fabric filter) from bituminous-fired unit

Source: GAO analysis of DOE data.

DOE also provided two sets of annualized cost estimates, one that included a projected impact for the loss of fly ash sales and one that did not. Without a by-product impact, DOE estimated annualized costs to range from $0.37 to $5.72 per megawatt-hour, which equates to about $1.3 million to $20.0 million per year. Estimates with the by-product impact ranged from $1.82 to $8.14 per megawatt-hour, which equates to about $6.4 million to $28.5 million per year. At the high end, these estimates represented the cost of achieving a 90 percent mercury reduction at a bituminous-coal fired plant with sorbent injection, an existing electrostatic precipitator, and no fabric filter. The low-end cost without a by-product impact represented a 50 percent mercury reduction at a bituminous-fired plant using sorbent injection with an electrostatic precipitator, while the low-end cost with a by-product impact was for the same configuration and mercury reduction, but at a subbituminous-fired plant.

In addition, DOE's cost estimates suggest that plants may achieve a high level of mercury control without a fabric filter. While achieving a higher mercury removal rate without a fabric filter would require more sorbent, plants can decide what air pollution control configuration is most cost effective. Furthermore, according to EPA, test results suggest that chemically enhanced sorbent may prove more efficient than activated carbon in achieving high levels of mercury removal at relatively modest injection rates, and thus less expensive to use. According to EPA, tests of these sorbents have achieved mercury removal rates of 40 to 94 percent without a fabric filter, with the highest removal rate achieved during a continuous 30-day test (the longest reported test of these sorbents). Therefore, some facilities seeking to achieve high levels of mercury reduction may not have to incur the substantial cost of adding a fabric filter.

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