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Report to the Chairman, Subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works, U.S. Senate

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CLEAN AIR ACT

Mercury Control Technologies at Coal-Fired Power Plants Have Achieved Substantial Emissions Reductions

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Highlights

Highlights of GAO-10-47, a report to the Chairman, Subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works, U.S. Senate

CLEAN AIR ACT

Mercury Control Technologies at Coal-Fired Power Plants Have Achieved Substantial Emissions Reductions

Why GAO Did This Study

The 491 U.S. coal-fired power plants are the largest unregulated industrial source of mercury emissions nationwide, annually emitting about 48 tons of mercury—a toxic element that poses health threats, including neurological disorders in children. In 2000, the Environmental Protection Agency (EPA) determined that mercury emissions from these sources should be regulated, but the agency has not set a maximum achievable control technology (MACT) standard, as the Clean Air Act requires. Some power plants, however, must reduce mercury emissions to comply with state regulations or consent decrees.

After managing a long-term mercury control research and development program, the Department of Energy (DOE) reported in 2008 that systems that inject sorbents—powdery substances to which mercury binds—into the exhaust from boilers of coal-fired power plants were ready for commercial deployment. Tests of sorbent injection systems, the most mature mercury control technology, were conducted on a variety of coal types and boiler configurations—that is, on boilers using different air pollution control devices. In this context, GAO was asked to examine (1) reductions achieved by mercury control technologies and the extent of their use at power plants, (2) the cost of mercury control technologies, and (3) key issues EPA faces in regulating mercury emissions from power plants. GAO obtained data from power plants operating sorbent injection systems. EPA and DOE provided technical comments, which we incorporated as appropriate.

View GAO-10-47 or key components.
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What GAO Found

Commercial deployments and 50 DOE and industry tests of sorbent injection systems have achieved, on average, 90 percent reductions in mercury emissions. These systems are being used on 25 boilers at 14 coal-fired plants, enabling them to meet state or other mercury emission requirements—generally 80 percent to 90 percent reductions. The effectiveness of sorbent injection is largely affected by coal type and boiler configuration. Importantly, the substantial mercury reductions using these systems commercially and in tests were achieved with all three main types of coal and on boiler configurations that exist at nearly three-fourths of U.S. coal-fired power plants. While sorbent injection has been shown to be widely effective, DOE tests suggest that other strategies, such as blending coals or using other technologies, may be needed to achieve substantial reductions at some plants. Finally, some plants already achieve substantial mercury reductions with existing controls designed for other pollutants.

The cost of the mercury control technologies in use at power plants has varied, depending in large part on decisions regarding compliance with other pollution reduction requirements. The costs of purchasing and installing sorbent injection systems and monitoring equipment have averaged about $3.6 million for the 14 coal-fired boilers operating sorbent systems alone to meet state requirements. This cost is a fraction of the cost of other pollution control devices. When plants also installed a fabric filter device primarily to assist the sorbent injection system in mercury reduction, the average cost of $16 million is still relatively low compared with that of other air pollution control devices. Annual operating costs of sorbent injection systems, which often consist almost entirely of the cost of the sorbent itself, have been, on average, about $675,000. In addition, some plants have incurred other costs, primarily due to lost sales of a coal combustion byproduct—fly ash—that plants have sold for commercial use. The carbon in sorbents can render fly ash unusable for certain purposes. Advances in sorbent technologies that have reduced sorbent costs at some plants offer the potential to preserve the market value of fly ash.

EPA's decisions on key regulatory issues will have implications for the effectiveness of its mercury emissions standard. In particular, the data EPA decides to use will impact (1) the emissions reductions it starts with in developing its regulation, (2) whether it will establish varying standards for the three main coal types, and (3) how the standard will take into account a full range of operating conditions at the plants. These issues can affect the stringency of the MACT standard EPA proposes. For example, if EPA uses data from its 1999 power plant survey as the basis for its mercury standard, the standard could be less stringent than what has been broadly demonstrated in recent commercial deployments and DOE tests of sorbent injection systems at power plants. On July 2, 2009, EPA announced that it would seek approval from the Office of Management and Budget to conduct an information collection request to update existing emissions data, among other things, from power plants.

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Abbreviations

BTU	British thermal units
CEMS	continuous emissions monitoring systems
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
MACT	maximum achievable control technology
OMB	Office of Management and Budget

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Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

October 8, 2009

The Honorable Thomas R. Carper
Chairman
Subcommittee on Clean Air
and Nuclear Safety
Committee on Environment
and Public Works
United States Senate

Dear Mr. Chairman:

Mercury is a toxic element that poses human health threats—including neurological disorders in children that impair their cognitive abilities. Coal-fired power plants, the nation's largest electricity producers, represent the largest unregulated industrial source of mercury emissions in the United States.[1] In 2000, the Environmental Protection Agency (EPA) determined that it was "appropriate and necessary" to regulate mercury emissions from coal-fired power plants under section 112 of the Clean Air Act. Subsequently, in 2005, EPA chose to promulgate a cap-and-trade program,[2] rather than establish a maximum achievable control technology (MACT) standard to control mercury emissions as required under section 112. However, the cap-and-trade program was vacated by the D.C. Circuit Court of Appeals in February 2008 before EPA could implement it.

EPA must now develop a MACT standard to regulate mercury emissions from coal-fired power plants. As prescribed by the Clean Air Act, the MACT standard shall require that mercury emissions from all coal-fired boilers be reduced to the average amount emitted by the best performing

[1]EPA's 1999 data, the agency's most recent available data on mercury emissions, show that the 491 U.S. coal-fired power plants annually emit 48 tons of mercury into the air. These emissions are unregulated at the federal level and largely unregulated at the state level.

[2]EPA's cap-and-trade program, known as the Clean Air Mercury Rule, was established under Clean Air Act section 111 and set a cap on mercury emissions of 38 tons for 2010 and a second phase cap of 15 tons for 2018. The rule included a model cap-and-trade program that states could adopt to achieve and maintain their mercury emissions budgets. States could join the trading program by adopting the model trading rule in state regulations, or by adopting regulations that mirrored the necessary components of the model trading rule. States could also opt out of the trading program entirely as long as they imposed controls on plants sufficient to meet the mercury budget set for the state by the federal rule.

12 percent of coal-fired boilers.[3] While developing MACT standards for hazardous air pollutants can take up to 3 years, EPA may be required to promulgate its standard sooner depending on the outcome of a pending lawsuit. Specifically, EPA has been sued by several environmental groups requesting that the EPA Administrator promulgate a MACT standard to regulate mercury emissions for coal-fired power plants by a date no later than December 2010.

The Department of Energy's (DOE) National Energy Technology Laboratory has worked with EPA and the Electric Power Research Institute (EPRI),[4] among others, during the past 10 years on a comprehensive mercury control technology test program. Mercury is emitted in such low concentrations that its removal and measurement are particularly difficult, and it is emitted in several forms, some of which are harder to capture than others.[5] The DOE program has focused largely on testing sorbent injection systems[6] on all coal types and at a variety of boiler configurations at operating power plants.[7] This regimen of testing was important because the type of coal burned and the variety of air pollution control devices for other pollutants already installed at power plants can impact the effectiveness of sorbent injection systems. For example, some power plants already achieve mercury reductions as a "co-benefit" of using devices designed to reduce other pollutants, such as sulfur dioxide, nitrogen oxides, and particulate matter.

According to a 2008 report in which DOE described its mercury technology testing program, "DOE successfully brought mercury control technologies to the point of commercial-deployment readiness." Nonetheless, the report stated that while the results achieved during

[3]According to EPA, its MACT is to also cover the other hazardous air pollutants listed in the Clean Air Act as well as emissions from oil-fired power plants. For categories with fewer than 30 sources, the MACT standard must be set, at least, at the average level achieved by the top five performing units.

[4]EPRI is an independent non-profit company funded by electricity producers that conducts research and development in the electricity sector.

[5]Mercury can be emitted in oxidized, elemental, or particulate-bound form.

[6]Sorbent injection systems inject sorbents—powdery substances, typically activated carbon, to which mercury binds—into the exhaust from boilers before it is emitted from the stack.

[7]In this report, the term "boiler configuration" refers to a coal-fired boiler's suite of air pollution control devices.

DOE's field tests met or exceeded program goals, the only way to truly know the effectiveness—and associated costs—of mercury control technologies is through their continuous operation in commercial applications at a variety of configurations. At least 18 states have laws or regulations requiring mercury emissions reductions at coal-fired power plants.[8] The compliance time frames for the state requirements vary. As of August 2009, five states—Connecticut, Delaware, Illinois, Massachusetts, and New Jersey—require compliance with mercury emission limits. In this context, you asked us to examine (1) what mercury reductions have been achieved by existing mercury control technologies and the extent to which they are being used at coal-fired power plants; (2) the costs associated with mercury control technologies currently in use; and (3) key issues EPA faces in developing a new regulation for mercury emissions from coal-fired power plants.

To respond to these objectives, we identified power plants with coal-fired boilers that are currently operating sorbent injection systems—the most mature, mercury-specific control technology—to reduce mercury emissions. Using a structured interview tool, we interviewed plant managers and engineers at the 14 coal-fired power plants operating sorbent injection systems to reduce mercury emissions. These individuals provided data on the effectiveness of sorbent injection systems at reducing mercury emissions and the costs of doing so.[9] We also obtained information on the engineering challenges plant officials have encountered in installing and operating sorbent injection systems and actions taken to mitigate those challenges.[10] In addition, we examined DOE National

[8]Two of the states expect mercury emissions reductions from required installations of multipollutant control technologies; the other sixteen have specific mercury emissions reduction targets. These 18 states are those that had mercury emissions reduction requirements in place before the Clean Air Mercury Rule was promulgated or which promulgated state-specific provisions in addition to the provisions required by the rule and have not specifically repealed those provisions as of August 2009. GAO did not confirm whether each state is actively enforcing or planning to enforce these rules. Provisions of some state rules may rely on provisions of the Clean Air Mercury Rule, which have been vacated.

[9]We interviewed managers at plants with 24 of the 25 boilers using sorbent injection systems. As of August 2009, data for one boiler were not provided. Mercury emissions data for one boiler were being reviewed by the state clean air agency and were not provided in time for inclusion in this report.

[10]We visited six plants using sorbent injection systems, and we interviewed plant managers at six other plants that reported meeting state mercury emissions requirements with existing pollution control devices for other pollutants.

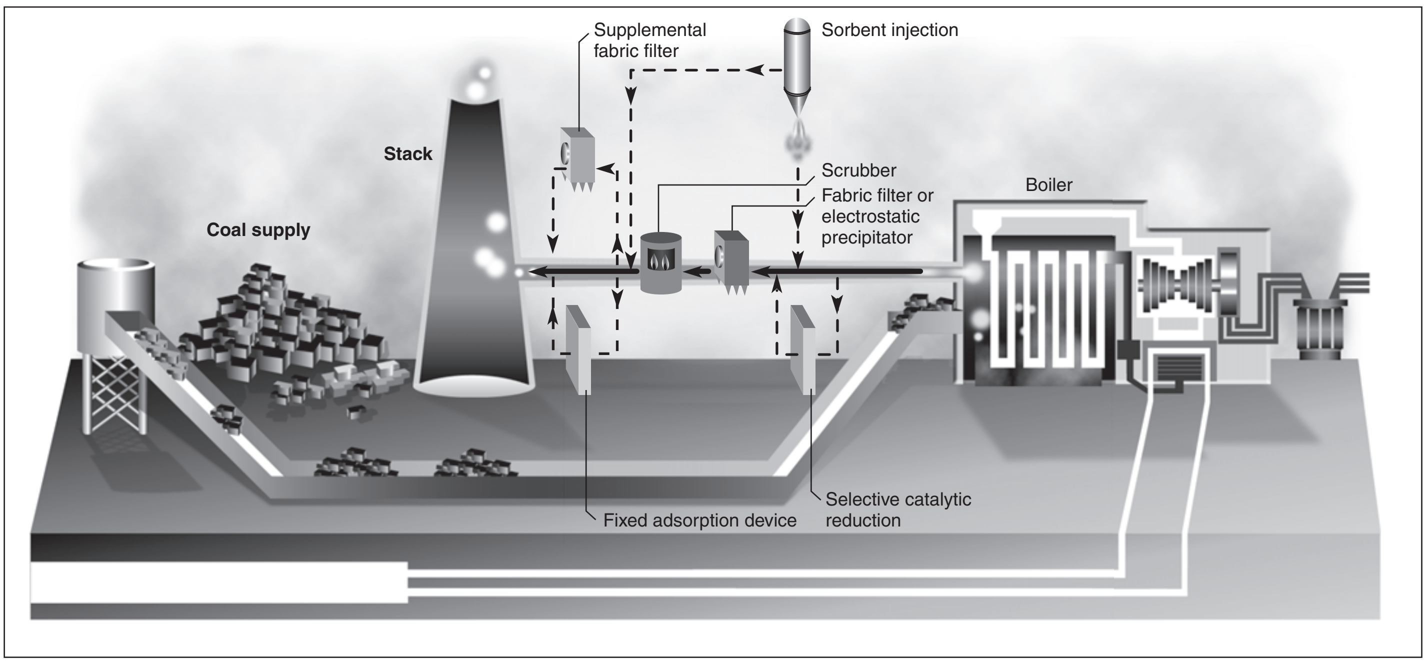
Energy Technology Lab, EPRI, and academic reports on the effectiveness and costs of sorbent injection systems over time and reviewed literature from recent technical conferences that addressed strategies to overcome challenges that some plants have experienced with sorbent injection systems. We also reviewed EPA's requirements for establishing MACT standards under the Clean Air Act and recent court cases with implications for how EPA establishes such standards. Finally, we met with EPA officials in the Office of Air and Radiation regarding the agency's plans for regulating mercury at power plants. Appendix I provides a more detailed description of our scope and methodology. We conducted this performance audit from November 2008 through September 2009 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Mercury enters the environment in various ways, such as through volcanic activity, coal combustion, and chemical manufacturing. As a toxic element, mercury 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. Fish contaminated with methylmercury may pose health threats to people who rely on fish as part of their diet. Mercury can harm fetuses and cause neurological disorders in children, resulting in, among other things, impaired cognitive abilities. The Food and Drug Administration 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. In recent years, most states have issued advisories informing the public that concentrations of mercury have been found in local fish at levels of public health concern.

Coal-fired power plants burn at least one of three primary coal types—bituminous, subbituminous, and lignite—and some plants burn a blend of these coals. 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 the chemical variation within and among coal types.[11] In addition to mercury, coal combustion releases other harmful air pollutants, including sulfur dioxide and nitrogen oxides. EPA regulates these pollutants under its program intended to control acid rain and its new source performance standards program. Figure 1 shows various pollution controls that may be used at coal-fired power plants: selective catalytic reduction to control nitrogen oxides, wet or dry scrubbers to reduce sulfur dioxide, fabric filters and hot-side or cold-side electrostatic precipitators to control particulate matter, and sorbent injection to reduce mercury emissions.

Figure 1: Sample Layout of Air Pollution Controls, Including Sorbent Injection to Control Mercury, at a Coal-Fired Power Plant



Source: GAO analysis of Electric Power Research Institute data.

[11]Coal combustion releases mercury in oxidized, elemental, or particulate-bound form. Oxidized mercury is more prevalent in the flue gas from bituminous coal combustion, and it is relatively easy to capture using some sulfur dioxide controls, such as wet scrubbers. Elemental mercury, more prevalent in the flue gas from combustion of lignite and subbituminous coal, is more difficult to capture with existing pollution controls. Particulate-bound mercury is relatively easy to capture in particulate matter control devices.

From 2000 to 2009, DOE's National Energy Technology Lab conducted field tests at operating power plants with different boiler configurations to develop mercury-specific control technologies capable of achieving high mercury emission reductions at the diverse fleet of U.S. coal-fired power plants.[12] As a result, DOE now has comprehensive information on the effectiveness of sorbent injection systems using all coal types at a wide variety of boiler configurations. Most of these tests were designed to achieve mercury reductions of 50 to 70 percent while decreasing costs—which consist primarily of the cost of the sorbent. Thus, the results from the DOE test program may understate the mercury reductions that can be achieved by sorbent injection systems to some extent. For example, while a number of short-term tests achieved mercury reductions in excess of 90 percent, the amount of sorbent injection that achieved the reductions was often decreased during long-term tests to determine the minimum cost of achieving, on average, 70 percent mercury emissions reductions.

Beginning in 2007—near the end of the research program—DOE field tests aimed to achieve reductions of 90 percent or greater mercury at low costs. However, DOE reported that federal funding for the DOE tests was eliminated before the final phase of planned tests was completed. Under its mercury testing program, DOE initially tested the effectiveness of untreated carbon sorbents, and then DOE tested the effectiveness of chemically treated sorbents. In addition, DOE assessed solutions to impacts on plant devices, structures, or operations that may result from operating these systems—called "balance-of-plant impacts." We note that DOE, EPRI, and others have also helped develop and test other technologies, including oxidation catalysts and precombustion mercury removal, to reduce mercury emissions that may become commercially available in the future. We provide information on some of these emerging technologies in appendix II.

[12]DOE's research program also tested different types of boilers (such as T-fired, wall-fired and cyclone); DOE officials said the pollution control devices were the more important parameter in mercury emissions reductions.

Substantial Mercury Reductions Have Been Achieved Using Sorbent Injection Technology at 14 Plants and in Many DOE Tests

Power plants using sorbent injection systems—either commercially deployed or tested by DOE and industry—have achieved substantial mercury reductions with the three main types of coal and on boiler configurations that exist at nearly three-fourths of U.S. coal-fired power plants. Some plants, however, may require alternative strategies to achieve significant mercury emissions reductions. Nonetheless, some plants already achieve substantial mercury emissions reductions with existing control devices for other pollutants.

Sorbent Injection Systems Have Achieved Substantial Mercury Emissions Reductions at Power Plants

The managers of 14 coal-fired power plants reported to us they currently operate sorbent injection systems on 25 boilers to meet the mercury emissions reduction requirements of five states and several consent decrees and construction permits. Data from power plants show that these boilers have achieved, on average, reductions in mercury emissions of about 90 percent.[13] Of note, all 25 boilers currently operating sorbent injection systems nationwide have met or surpassed their relevant regulatory mercury requirements, according to plant managers.[14] Following are a few examples:

- A 164 megawatt[15] bituminous-fired boiler, built in the 1960s and operating a cold-side electrostatic precipitator and wet scrubber, was reported as exceeding its 90 percent reduction requirement—achieving more than a 95 percent mercury emission reduction using chemically treated carbon sorbent.

[13]This number reflects data reported by officials with 9 boilers that were required to achieve 90 percent mercury emission reduction—which 7 surpassed—and 10 boilers that were required to achieve reductions between 80 percent and 89 percent. We do not have mercury emissions reduction data for 5 of the 24 sorbent injection systems because the power company running these systems is not required to measure emissions under its regulatory framework. Data for another boiler are being reviewed by the state clean air agency.

[14]Data from commercial applications of sorbent injection systems show that mercury reductions have been achieved over periods ranging from 3 months to more than a year. Most data we examined reflected mercury emissions as of the fourth quarter of 2008. Since that time, the power plants have continued to use sorbent injection systems—in some cases, these systems have been in continuous use for nearly 2 years.

[15]A megawatt is a unit for measuring the electric generation capacity of a power plant. One megawatt of capacity operating for one full day produces 24 megawatt-hours—or 24,000 kilowatt-hours—of electricity.

- A 400 megawatt subbituminous-fired boiler, built in the 1960s and operating a cold-side electrostatic precipitator and a fabric filter, was reported as achieving a 99 percent mercury reduction using untreated carbon sorbent, exceeding its 90 percent reduction regulatory requirement.

- A recently constructed 600 megawatt subbituminous-fired boiler operating a fabric filter, dry scrubber, and selective catalytic reduction system was reported as achieving an 85 percent mercury emission reduction using chemically treated carbon sorbent, exceeding its 83 percent reduction regulatory requirement.

While mercury emissions reductions achieved with sorbent injection on a particular boiler configuration do not guarantee similar results at other boilers with the same configuration,[16] the reductions achieved in deployments and tests provide important information for plant managers who must make decisions about pollution controls to reduce mercury emissions as more states' mercury regulations become effective and as EPA develops a national mercury regulation.[17] Further, in 2008, DOE reported that the high performance observed during many of its field tests at power plants with a variety of boiler configurations has given coal-fired power plant operators the confidence to begin deploying these technologies. The sorbent injection systems currently used at power plants to reduce mercury emissions are operating on boiler configurations that are used at 57 percent of U.S. coal-fired power boilers.[18] Further, when the results of 50 tests of sorbent injection systems at power plants conducted primarily as part of DOE's or EPRI's mercury control research and

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[16]As we reported in 2005, the results achieved at a particular power plant may not necessarily serve as a reliable indicator of the performance of the same control devices at all plants. For example, some 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 affects the temperatures of the flue gas entering the device, allowing more mercury to be captured at cooler temperatures.

[17]For example, see EPRI's 2006 *Mercury Control Technology Selection Guide*, which summarized tests by DOE and other organizations to provide the coal-fired power industry with a process to select the most promising mercury control technologies. EPRI assessed the applicability of technologies to various coal types and power plant configurations and developed decision trees to facilitate decision making.

[18]We used EPA's 2006 National Electric Energy Data System database for calculating the percentage of coal-fired boilers with particular configuration types. We excluded coal-fired boilers under 25 megawatts from our analysis because the Clean Air Act does not apply to smaller units such as these.

development programs are factored in, mercury reductions of at least 90 percent have been achieved at boiler configurations used at nearly three-fourths of coal-fired power boilers nationally.[19] Some boiler configurations tested in the DOE program that are not yet included in commercial deployments follow:

- A 360 megawatt subbituminous-fired boiler with a fabric filter and a dry scrubber using a chemically treated carbon sorbent achieved a 93 percent mercury reduction.

- A 220 megawatt boiler burning lignite, equipped with a cold-side electrostatic precipitator, increased mercury reduction from 58 percent to 90 percent by changing from a combination of untreated carbon sorbent and a boiler additive to a chemically treated carbon sorbent.

- A 565 megawatt subbituminous-fired boiler with a fabric filter achieved mercury reductions ranging from 95 percent to 98 percent by varying the amount of chemically treated carbon sorbent injected into the system.[20]

As these examples of commercially deployed and tested injection systems show, power plants are using chemically treated sorbents and sorbent enhancement additives, as well as untreated sorbents. Chemically treated sorbents and additives can help convert the more difficult-to-capture mercury common in lignite and subbituminous coals to a more easily captured form, which helped DOE and industry achieve high mercury reduction across all coal types.[21] The DOE test program initially used untreated sorbents. On the basis of these initial tests, we reported in 2005 that sorbent injection systems showed promising results but that they were not effective when used at boilers burning lignite and subbituminous

[19]We identified 56 field tests conducted by DOE during its mercury control technology testing program. Of these tests, we analyzed mercury reduction data of 41 tests conducted at power plants. The majority of these tests were long-term tests (30 days or more). Our analysis does not include mercury reduction data associated with the other 15 tests either because they reflected mercury reduction associated with mercury oxidation catalysts—an emerging mercury control technology—or because test result data were not reported. We also analyzed results of 9 tests conducted by industry, primarily by EPRI.

[20]The rate of sorbent injection varied between 1.0 pounds per million actual cubic feet and 3.0 pounds per million actual cubic feet.

[21]DOE injected sorbents that were treated with halogens such as chlorine or bromine, which help convert mercury from an elemental form into an oxidized form.

coals.[22] Since then, DOE's shift to testing chemically treated sorbents and enhancement additives showed that using chemically treated sorbents and enhancement additives could achieve substantial mercury reductions for coal types that had not achieved these results in earlier tests with untreated sorbents. For example, injecting untreated sorbents reduced mercury emissions by an average of 55 percent during a 2003 DOE test at a subbituminous-fired boiler. Recent DOE tests using chemically treated sorbents and enhancement additives, however, have resulted in average mercury reductions of 90 percent for boilers using subbituminous coals.[23] Similarly, recent tests on boilers using lignite reduced mercury emissions by about 80 percent, on average.

The examples of substantial mercury reductions highlighted above also show that sorbent injection can be successful with both types of air pollution control devices that power plants use to reduce emissions of particulate matter—electrostatic precipitators and fabric filters. In some commercial deployments, fabric filters were installed to assist with mercury control. Plant officials told us, for example, that they chose to install fabric filters to assist with mercury control for 10 of the sorbent injection systems currently deployed—but that some of the devices were installed primarily to comply with other air pollution control requirements. One plant manager, for example, said that the fabric filter installed at his plant has helped the sorbent injection system achieve higher levels of mercury emission reductions but that the driving force behind the fabric filter installation was compliance with particulate matter emission limits. Further, as another plant manager noted, fabric filters may provide additional benefits by limiting emissions of acid gases and trace metals, as well as by preserving fly ash—fine powder resulting from coal combustion—for sale for reuse.[24] Fabric filters, which are more effective at mercury emission reduction than electrostatic precipitators, are increasingly being installed to reduce emissions of particulate matter and other pollutants, but currently less than 20 percent of boilers have them.

[22]GAO, *Clean Air Act: Emerging Mercury Control Technologies Have Shown Promising Results, but Data on Long-Term Performance Are Limited*, GAO-05-612 (Washington, D.C.: May 31, 2005).

[23]On subbituminous coal units, eight long-term tests were conducted using chemically treated sorbents. The average mercury emission reduction was 90 percent, with mercury reductions ranging from 81 percent to 93 percent.

[24]Properties of fly ash vary significantly with coal composition and plant-operating conditions. Some power plants sell fly ash for use in Portland cement and to meet other construction needs.

The successful deployments of sorbent injection technologies at power plants occurred around the time DOE concluded, on the basis of its tests, that these technologies were ready for commercial deployment. As a result, funding for the DOE testing program has been eliminated.[25] As many states' compliance dates for mercury emission reduction near,[26] the Institute of Clean Air Companies reported that power plants had 121 sorbent injection systems on order as of February 2009.[27] (App. III provides data on state regulations requiring mercury emission reductions.)

Some Plants May Require Alternative Strategies to Achieve Significant Mercury Reductions

While sorbent injection technology has been shown to be effective with all coal types and on boiler configurations that currently exist at more than three-fourths of U.S. coal-fired power plants, DOE tests show that some plants may not be able to achieve mercury reductions of 90 percent or more with sorbent injection systems alone. Following are a few reasons why:

- Sulfur trioxide—which can form under certain operating conditions or from using high sulfur bituminous coal—may limit mercury reduction because it interferes with the process of mercury binding to carbon sorbents.
- Hot-side electrostatic precipitators reduce the effectiveness of sorbent injection systems. Installed on 6 percent of boilers nationwide, these particulate matter control devices operate at very high temperatures, which reduces the ability of mercury to bind to sorbents and be collected in the devices.
- Lignite, used by roughly 3 percent of boilers nationwide,[28] has relatively high levels of elemental mercury—the most difficult form to capture.

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[25]The DOE mercury testing program has not received new funding since fiscal year 2008.

[26]Illinois, Maryland, Minnesota, Montana, New Mexico, New York, and Wisconsin require compliance by the end of 2010. Arizona, Colorado, New Hampshire, Oregon, and Utah require compliance in 2012 or later. Georgia and North Carolina require installation between 2008 and 2018 of other pollution control devices that capture sulfur dioxide, nitrogen oxides, and mercury as a side benefit. North Carolina requires the submission of specific mercury reduction plans for certain plants by 2013.

[27]The Institute of Clean Air Companies is the trade association of companies that supply air pollution control and monitoring technology.

[28]As noted earlier, the lignite burned by all coal-fired power plants represents 8 percent of all coal burned in the United States.

Lignite is found primarily in North Dakota and the Gulf Coast (the latter is called Texas lignite). Mercury reduction using chemically treated sorbents and sorbent enhancement additives on North Dakota lignite has averaged about 75 percent—less than reductions using bituminous and subbituminous coals. Less is known about Texas lignite because few tests have been performed using it. However, a recent test at a plant burning Texas lignite achieved an 82 percent mercury reduction.

Boilers that may not be able to achieve 90 percent emissions reductions with sorbent injection alone, and some promising solutions to the challenges they pose, are discussed in appendix IV. Further, EPRI is continuing research on mercury controls at power plants that should help to address these challenges. In some cases, however, plants may need to pursue a strategy other than sorbent injection to achieve high mercury reductions. For example, officials at one plant decided to install a sulfur dioxide scrubber—designed to reduce both mercury and sulfur dioxide—after sorbent injection was found to be ineffective. This approach may become more typical as power plants comply with the Clean Air Interstate Rule and court-ordered revisions to it,[29] which EPA is currently developing, and as some plants add air pollution control technologies required under consent decrees.

Along these lines, EPA air strategies group officials told us that many power plants will be installing devices—fabric filters, scrubbers, and selective catalytic reduction systems—that are typically associated with high levels of mercury reduction, which will likely reduce the number of plants requiring alternative strategies for mercury control. Finally, mercury controls have been tested on about 90 percent of the boiler configurations at coal-fired power plants. The remaining 10 percent include several with devices that are often associated with high levels of mercury emission reductions, such as selective catalytic reduction devices for nitrogen oxides control and wet scrubbers for sulfur dioxide control.

[29]The Clean Air Interstate Rule is a regional air pollution reduction program covering 28 eastern states and the District of Columbia. Developed by EPA and promulgated in May 2005, the rule controls emissions from power plants through caps on sulfur dioxide and nitrogen oxides pollution. A D.C. Circuit Court of Appeals December 23, 2008, ruling leaves this rule and its trading programs in place until EPA issues a new rule to replace it. EPA informed the Court that development and finalization of a replacement rule could take about 2 years.

A Number of Plants Already Achieve Substantial Mercury Reductions with Existing Controls for Other Pollutants

Importantly, mercury control technologies will not have to be installed on a number of coal-fired boilers to meet mercury emission reduction requirements because these boilers already achieve high mercury reductions from their existing pollution control devices.[30] EPA 1999 data, the most recent available, indicated that about one-fourth of the industry achieved mercury reductions of 90 percent or more as a co-benefit of other pollution control devices.[31] We found that of the 36 boilers currently subject to mercury regulation, 11 are relying on existing pollution controls to meet their mercury reduction requirements.[32] One plant manager told us his plant achieves 95 percent mercury reduction as a result of existing devices, specifically with a fabric filter for particulate matter control, a scrubber for sulfur dioxide control, and a selective catalytic reduction system for nitrogen oxides control. Other plants may also be able to achieve high mercury reduction with their existing pollution control devices. For example, according to EPA data, a bituminous-fired boiler with a fabric filter may reduce mercury emissions by more than 90 percent. As discussed above, it is likely that many power plants will be installing devices that are typically associated with high levels of mercury reduction; thus the number of plants that may not require sorbent injection systems to meet regulatory requirements is likely to increase.

[30]Nationwide, mercury reductions achieved as a co-benefit of other pollution control devices reduced mercury emissions from about 75 tons (inlet coal) to approximately 48 tons. Mercury reductions achieved as a co-benefit range from zero to nearly 100 percent, depending on control device configuration and coal type. For example, a boiler using bituminous coal and having a fabric filter can achieve mercury reductions in excess of 90 percent. In contrast, a boiler using subbituminous coal and having only a cold-side electrostatic precipitator might achieve little, if any, co-benefit mercury reduction.

[31]This estimate is based on data from EPA's 1999 information collection request, which EPA air toxics program officials believe to be representative of the current coal-fired power industry.

[32]Two plants with four boilers will face increasingly stringent limits in the next 3 to 4 years. One plant manager, facing a mercury reduction requirement that will increase from 80 percent to 90 percent, told us that the plant is currently installing a sorbent injection system in anticipation of the more stringent standard. The other plant manager, facing a mercury reduction requirement that will increase from 85 percent to 95 percent, told us that his plant will likely need to install a sorbent injection system in the future to supplement the co-benefit mercury capture the plant currently achieves with existing pollution controls.

Mercury Control Technologies Are Often Relatively Inexpensive, but Costs Depend Largely on How Plants Comply with Requirements for Reducing Other Pollutants

The cost to meet current regulatory requirements for mercury reductions has varied depending in large part on decisions regarding compliance with other pollution reduction requirements. For example, while sorbent injection systems alone have been installed on most boilers that must meet mercury reduction requirements—at a fraction of the cost of other pollution control devices—fabric filters have also been installed on some boilers to assist in mercury capture or to comply with particulate matter requirements, according to plant officials we interviewed.

The costs of purchasing and installing sorbent injection systems and monitoring equipment have averaged about $3.6 million for the 14 coal-fired boilers that use sorbent injection systems alone to reduce mercury emissions.[33] For these boilers, the cost ranged from $1.2 million to $6.2 million.[34] By comparison, on the basis of EPA estimates, the average cost to purchase and install a wet scrubber for sulfur dioxide control, absent monitoring system costs, is $86.4 million per boiler, ranging from $32.6 million to $137.1 million.[35] EPA's estimate of the cost to purchase and install a selective catalytic reduction device to control nitrogen oxides ranges from $12.7 million to $127.1 million, or an average of $66.1 million.

Capital costs can increase significantly if fabric filters are also purchased to assist in mercury emission reductions or as part of broader emission reduction requirements. For example, plants installed fabric filters at another 10 boilers for these purposes. On the five boilers where plant officials reported also installing a fabric filter specifically designed to assist the sorbent injection system in mercury emission reductions, the average reported capital cost for both the sorbent injection system and fabric filter was $15.8 million per boiler—the costs ranged from $12.7 million to $24.5 million. Importantly, some of these boilers have uncommon configurations[36]—ones that, as discussed earlier, DOE tests

[33]Cost data are reported in 2008 dollars.

[34]The total cost to purchase and install a sorbent injection system reflects the costs of (1) sorbent injection equipment, (2) an associated mercury emissions monitoring system, and (3) associated engineering and consulting services.

[35]EPA's 2006 cost estimates are reported in 2008 dollars.

[36]Three of the five boilers with fabric filters designed specifically to assist in mercury reduction, for instance, have hot-side electrostatic precipitators—a relatively rare particulate matter control device that inhibits high mercury removal when sorbent injection systems are used without fabric filters.

showed would need additional control devices to achieve high mercury reductions.[37]

For the five boilers where plant officials reported installing fabric filters along with sorbent injection systems largely to comply with requirements to control other forms of air pollution, the average reported capital cost for the two technologies was $105.9 million per boiler, ranging from $38.2 million to $156.2 million per boiler.[38] For these boilers, the capital costs result from requirements to control other pollutants, and we did not determine what portion of these costs would appropriately be allocated to the cost of reducing mercury emissions. Decisions to purchase such fabric filters will likely be driven by the broader regulatory landscape affecting plants in the near future, such as requirements for particulate matter and sulfur dioxide reductions, as well as EPA's upcoming MACT standard to regulate mercury emissions from coal-fired power plants. Information on detailed average costs to purchase and install sorbent injection systems and monitoring equipment, with and without fabric filters, is provided in appendix V.

Regarding operating costs, plant managers said that annual operating costs associated with sorbent injection systems consist almost entirely of the cost of the sorbent itself. In operating sorbent injection systems, sorbent is injected continuously into the boiler exhaust gas to bind to mercury passing through the gas. The rate of injection is related to, among other things, the level of mercury emissions reduction required to meet regulatory requirements and the amount of mercury in the coal used. For the 18 boilers with sorbent injection systems for which power plants provided sorbent cost data, the average annualized cost of sorbent was $674,000—ranging from $76,500 to $2.4 million.

Plant engineers often adjust the injection rate of the sorbent to capture more or less mercury—the more sorbent in the exhaust gas, the higher the likelihood that more mercury will bind to it. Some plant managers told us that they have recently been able to decrease their sorbent injection rates,

[37]The costs reported by officials of coal-fired power plants that installed sorbent injection systems and, in some cases, fabric filters may not necessarily serve as reliable indicators of the costs of the same control devices at all plants.

[38]The average cost of the sorbent injection system for these boilers was $2.9 million and for the monitoring systems, $500,000. The average cost for the fabric filters was $84 million and for the engineering studies, $11 million.

thereby reducing costs, while still complying with relevant requirements. Specifically, a recently constructed plant burning subbituminous coal successfully used sorbent enhancement additives to considerably reduce its rate of sorbent injection—resulting in significant savings in operating costs when compared with its original expectations. Plant managers at other plants reported that they have injected sorbent at relatively higher rates because of regulatory requirements that mandate a specific injection rate. In one state, for example, plants are required to operate their sorbent injection systems at an injection rate of 5 pounds per million actual cubic feet.[39] Among the 19 boilers for which plant managers provided operating cost data, the average injection rate was 4 pounds per million actual cubic feet; rates ranged from 0.5 to 11.0 pounds per million actual cubic feet.

For those plants that installed a sorbent injection system alone to meet mercury emissions requirements—at an average cost of $3.6 million—the cost to purchase, install, and operate sorbent injection and monitoring systems represents 0.12 cents per kilowatt hour, or a potential 97 cent increase in the average residential consumer's monthly electricity bill. How, when, and to what extent consumers' electric bills will reflect the capital and operating costs power companies incur for mercury controls depends in large measure on market conditions and the regulatory framework in which the plants operate. Power companies in the United States are generally divided into two broad categories: (1) those that operate in traditionally regulated jurisdictions where cost-based rate setting still applies (rate-regulated) and (2) those that operate in jurisdictions where companies compete to sell electricity at prices that are largely determined by supply and demand (deregulated). Rate-regulated power companies are generally allowed by regulators to set rates that will recover allowable costs, including a return on invested capital.[40] Minnesota, for example, passed a law in 2006 allowing power companies to seek regulatory approval for recovering the costs of state-required reductions in mercury emissions in advance of the regulatory schedule for rate increase requests. One power company in the state submitted a plan for the installation of sorbent injection systems to reduce mercury

[39]Pounds per million actual cubic feet is the standard metric for measuring the rate at which sorbent is injected into a boiler's exhaust gas.

[40]Under traditional cost-based rate regulations, utility companies submit to regulators the costs they seek to cover through the rates they charge their customers. Regulators examine the power companies' requests and decide what costs are allowable under the relevant rules.

emissions at two of its plants at a cost of $4.4 million and $4.5 million, respectively, estimating a rate increase of 6 to 10 cents per month for customers of both plants.[41]

For power companies operating in competitive markets where wholesale electricity prices are not regulated, prices are largely determined by supply and demand. Generally speaking, market pricing does not guarantee full cost recovery to suppliers, especially in the short run. Of the 25 boilers using sorbent injection systems to comply with a requirement to control mercury emissions, 21 are in jurisdictions where full cost recovery is not guaranteed through regulated rates.

In addition to the costs discussed above, some plant managers told us they have incurred costs associated with balance-of-plant impacts. The issue of particular concern relates to fly ash—fine particulate ash resulting from coal combustion that some power plants sell for commercial uses, including concrete production, or donate for such uses as backfill. According to DOE, about 30 percent of the fly ash generated by coal-fired power plants was sold in 2005; 216 plants sold some portion of their fly ash. Most sorbents increase the carbon content of fly ash, which may render it unsuitable for some commercial uses.[42] Specifically, some plant managers told us that they have lost income because of lost fly ash sales due to its carbon content and incurred additional costs to store fly ash that was previously either sold or donated for re-use. For the eight boilers with installed sorbent injection systems to meet mercury emissions requirements for which plants reported actual or estimated fly-ash-related costs, the average net cost reported by plants was $1.1 million per year.[43]

[41]The rate increase request will be submitted in conjunction with requests for rate increases for the utility's other plants.

[42]Technologies to mitigate balance-of-plant costs associated with fly ash are available. For example, one plant installed a polishing fabric filter using TOXECON™ system, which preserves the plant's ability to sell its fly ash. Another plant had previously installed an ash reduction device that removes excess carbon in fly ash and enables the plant to sell the vast majority of its fly ash when operating its sorbent injection system.

[43]DOE's research program also examined the potential costs plants may incur to dispose of fly ash if the carbon and mercury content renders it unsuitable for commercial uses. See Andrew P. Jones et al., *DOE/NETL's Phase II Mercury Control Technology Field Testing Program: Updated Economic Analysis of Activated Carbon Injection*, prepared at the request of DOE, May 2007.

Advances in sorbent technologies that have reduced costs at some plants also offer the potential to preserve the market value of fly ash. For example, at least one manufacturer offers a concrete-friendly sorbent to help preserve fly ash sales—thus reducing potential fly ash storage and disposal costs. Additionally, a recently constructed plant burning subbituminous coal reported that it had successfully used sorbent enhancement additives to reduce its rate of sorbent injection from 2 pounds to less than one-half pound per million actual cubic feet—resulting in significant savings in operating costs and enabling it to preserve the quality of its fly ash for reuse. Other potential advances include refining sorbents through milling and changing the sorbent injection sites. Specifically, in testing, milling sorbents has, for some configurations, improved their efficiency in reducing mercury emissions—that is, reduced the amount of sorbent needed—and also helped minimize negative impact on fly ash re-use. Also, in testing, some vendors have found that injecting sorbents on the hot side of air preheaters can decrease the amount of sorbent needed to achieve desired levels of mercury control.[44]

In addition, some plant managers reported balance-of-plant impacts associated with sorbent injection systems, such as ductwork corrosion and small fires in the particulate matter control devices. The managers told us these issues were generally minor and have been resolved. For example, two plants experienced corrosion in the ductwork following the installation of their sorbent injection systems. One plant manager resolved the problem by purchasing replacement parts at a cost of $4,500. The other plant manager told us that the corrosion problem remains unresolved but that it is primarily a minor engineering challenge that does not impact plant operations. Four plant managers reported fires in the particulate matter control devices; plant engineers have generally solved this problem by emptying the ash from the collection devices more frequently. Overall, despite minor balance-of-plant impacts, most plant managers said that the sorbent injection systems at their plants are more effective than they had originally expected.

[44]An air preheater is a device designed to preheat the combustion air used in a fuel-burning furnace for the purpose of increasing the thermal efficiency of the furnace.

Decisions EPA Faces on Key Regulatory Issues Will Have Implications for the Effectiveness of Its Mercury Emission Standard for Coal-Fired Power Plants and the Availability of Monitoring Data

EPA's decisions on key regulatory issues will impact the overall stringency of its MACT standard regulating mercury emissions. Specifically, the data EPA decides to use will affect (1) the mercury emission reductions calculated for "best performers," from which a proposed emission limit is derived; (2) whether EPA will establish varying standards for the three coal types; and (3) how EPA's standard will take into account varying operating conditions. Each of these issues will affect the stringency of the MACT standard the agency proposes. In addition, the format of the standard—whether it limits the mercury emissions as a function of the amount of mercury per trillion British thermal units (BTU) of heat input (an input standard) or on the basis of the amount of mercury per megawatt hour of electricity produced (an output standard)—may affect the stringency of the MACT standard the agency proposes. Finally, the court's decision to vacate the Clean Air Mercury Rule, which required most coal-fired power plants to conduct continuous emissions monitoring for mercury beginning in 2009, has delayed for a number of years the continuous emissions monitoring that would have started in 2009 at most coal-fired power plants.

Current Data from Commercial Deployments and DOE Tests Could Be Used in Determining Whether to Support a More Stringent Standard for Mercury Emissions from Power Plants Than Was Last Proposed by EPA

Obtaining data on mercury emissions and identifying the "best performers"—defined as the 12 percent of coal-fired power plant boilers with the lowest mercury emissions[45]—is a critical initial step in the development of a MACT standard regulating mercury emissions. EPA may set one standard for all power plants, or it may establish subcategories to distinguish among classes, types, and sizes of plants. For example, in its 2004 proposed mercury MACT standard,[46] EPA established subcategories for the types of coal most commonly used by power plants. Once the average mercury emissions of the best performers are established for power plants—or for subcategories of power plants—EPA accounts for variability in the emissions of the best performers in its MACT standards. EPA's method for accounting for variability has generally resulted in MACT standards that are less stringent than the average emission reductions achieved by the best performers.

[45]This is how section 112 of the Clean Air Act, as amended, defines best performers for the largest categories of sources when establishing MACT standards.

[46]Prior to finalizing the Clean Air Mercury Rule, EPA also proposed a MACT standard regulating mercury emissions from coal-fired power plants. EPA chose not to finalize the MACT rule.

To identify the best performers, EPA typically collects emissions data from a sample of plants representative of the U.S. coal-fired power industry through a process known as an information collection request. Before a federal agency can collect data from 10 or more nongovernmental parties, such as power plants, it must obtain approval from the Office of Management and Budget (OMB) for the information collection request. According to EPA officials, this data collection process typically takes from 8 months to 1 year. Although EPA has discretion in choosing the data it will use to identify best performers,[47] on July 2, 2009, EPA published a draft information collection request in the *Federal Register* providing a 60-day public comment period on the draft questionnaire to industry prior to submitting this information collection request to OMB for review and approval. EPA's schedule for issuing a proposed rule and a final rule has not yet been established; the agency is currently defending a lawsuit that may establish such a schedule.[48]

Our analysis of EPA's 1999 data, as well as more current data from deployments and DOE tests, shows that newer data may have several implications for the stringency of the standard. First, the average emissions reductions of the best performers, from which the standard is derived, may be greater using more current data than the reductions derived from EPA's 1999 data. Our analysis of EPA's 1999 data shows an average mercury emission reduction of nearly 91 percent for the best performers.[49] In contrast, using more current commercial deployment and DOE test data, as well as data on co-benefit mercury reductions collected in 1999, an average mercury emission reduction of nearly 96 percent for best performers is demonstrated. The 1999 data do not reflect the significant and widespread mercury reductions achieved by sorbent injection systems. Further, EPA's 2004 proposed MACT standards for mercury were substantially less stringent than the 1999 average emission

[47]EPA officials told us, for instance, that the agency could decide to use data from its 1999 information collection request or data from commercial deployments and DOE tests.

[48]Under the Clean Air Act Amendments of 1990, EPA had 10 years from the enactment of the amendments, or 2 years from the listing of electric steam-generating units as sources of hazardous air pollutants subject to regulation, whichever was later, to promulgate a MACT standard. Because EPA did not list electric steam-generating units until 2000, it originally had 2 years, or until 2002, to promulgate a MACT standard. Because EPA missed this promulgation date, a mandatory duty lawsuit was filed against the agency that will result in a court-approved schedule.

[49]Our analysis of EPA's data includes the three primary coal types: bituminous, subbituminous, and lignite.

reduction of the best performers because of variability in mercury emissions among the top performers, as discussed later in more detail.

Second, more current information that reflects mercury control deployments and DOE tests may make the rationale EPA used in the past to create MACT standards for different subcategories less compelling to the agency now. In 2004, using 1999 data, EPA proposed separate MACT standards for each type of coal used at power plants. The agency explained that mercury emissions reductions from boilers using lignite and subbituminous coal was substantially less than from those using bituminous coal. Specifically, the 1999 data EPA used for its 2004 proposed MACT standards showed that best performers achieved average emission reductions of 97 percent for bituminous, 71 percent for subbituminous, and 45 percent for lignite. In contrast, more current data show that sorbent injection systems have achieved average mercury emissions reductions of more than 90 percent with bituminous and subbituminous coal types and nearly this amount with lignite.

Finally, using more current emissions data in setting the MACT standard for regulating mercury may mean that accounting for variability in emissions will not have as significant an effect as it did in the 2004 proposed MACT—when it led to a less stringent MACT standard—because more current data may already reflect variability. In its 2004 proposed MACT, EPA explained that its 1999 data, obtained from the average of short-term tests (three samples taken over a 1- to 2-day period), did not necessarily reveal the range of emissions that would be found over extended periods of time or under a full range of operating conditions they could reasonably anticipate. EPA thus extrapolated longer-term variability data from the short-term data, and on the basis of these calculations, proposed MACT standards equivalent to a 76 percent reduction in mercury emissions for bituminous coal, a 25 percent reduction for lignite, and a 5 percent reduction for subbituminous coal—20 to 66 percentage points lower than the average of what the best performers achieved for each coal type.

However, current data may eliminate the need for such extrapolation. Data from commercial applications of sorbent injection systems, DOE field tests, and co-benefit mercury reductions show that mercury emissions reductions well in excess of 90 percent have been achieved over periods ranging from more than 30 days in field tests to more than a year in commercial applications. Mercury emissions measured over these periods may more accurately reflect the variability in mercury emissions that plants would encounter over the range of operating conditions.[50] Along these lines, at least 15 states with mercury emission limits require long-term averaging—ranging from 1 month to 1 year—to account for variability. According to the manager of a power plant operating a sorbent injection system, long-term averaging of mercury emissions takes into account the "dramatic swings" in mercury emissions from coal that may occur. He told us that while mercury emissions can vary on a day-to-day basis, this plant has achieved 94 percent mercury reduction, on average, over the last year.[51] Similarly, another manager of a power plant operating a sorbent injection system told us the amount of mercury in the coal used at the plant "varies widely, even from the same mine." Nonetheless, the plant manager reported that this plant achieves its required 85 percent mercury reduction because the state allows averaging mercury emissions on a monthly basis to take into account the natural variability of mercury in the coal.

The Type of Standard EPA Chooses May Also Affect the Stringency of the Regulation

In 2004, EPA's proposed mercury MACT included two types of standards to limit mercury emissions: (1) an output-based standard for new coal-fired power plants and (2) a choice between an input- or output-based standard for existing plants. Input-based standards establish emission limits on the basis of pounds of mercury per trillion BTUs of heat input; output-based standards, on the other hand, often establish emission limits

[50]According to officials with one industry group, many coal-fired power plants use coal from numerous mines, and the mercury content in coal from these different sources can vary dramatically. These officials said that variability in mercury emissions resulting from the use of coal from different sources should be considered when setting a MACT standard. Officials with several coal-fired power plants told us that requiring compliance over long time periods—such as monthly, quarterly, or annually—is one way to ensure that such variability is accounted for.

[51]The requirement for this plant, which the plant manager reported it has met, is for a 90 percent reduction averaged over a 3-month period.

on the basis of pounds of mercury per megawatt hour of electricity produced. These standards are referred to as emission limits.[52]

Input-based limits can have some advantages for coal-fired power plants. For example, input-based limits can provide more flexibility to older, less efficient plants because they allow boilers to burn as much coal as needed to produce a given amount of electricity, as long as the amount of mercury per trillion BTUs does not exceed the level specified by the standard.[53] However, input-based limits may allow some power plants to emit more mercury per megawatt hour than output-based limits. Under an output-based standard, mercury emissions cannot exceed a specific level per megawatt-hour of electricity produced—efficient boilers that use less coal will be able to produce more electricity than inefficient boilers under an output-based standard. Moreover, under an output-based limit, less efficient boilers may have to, for example, increase boiler efficiency or switch to a lower mercury coal. Thus, output-based limits provide a regulatory incentive to enhance both operating efficiency and mercury emission reductions. If all else was held equal, less mercury would be emitted nationwide under an output-based standard.

We found that at least 16 states have established a format for regulating mercury emissions from coal-fired power plants. Eight states allow plants to meet either an emission limit or a percent reduction, three require an emission limit, four require percent reductions, and one state requires plants to achieve whatever mercury emissions reductions—percent

[52]For the purposes of setting a standard, emissions limits can be correlated to percent reductions. For example, EPA's 2004 proposed standards for bituminous, lignite, and subbituminous coal (2, 9.2, and 5.8 pounds per trillion BTUs, respectively) are equivalent with mercury emissions reductions of 76, 25, and 5 percent, respectively, based on nationwide averages of the mercury content in coal. During EPA's 2004 MACT development process, state and local agency stakeholders, as well as environmental stakeholders, generally supported output-based emission limits; industry stakeholders generally supported having a choice between an emission limit and a percent reduction. EPA must now decide in what format it will set its mercury MACT standard(s).

[53]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 coal, which has relatively low heating values.

reduction or emission limit—are greater.[54] On the basis of our review of these varying regulatory formats, we conclude that to be meaningful, a standard specifying a percent reduction should be correlated to an emission limit. When used alone, percent reduction standards may reduce the actual mercury emissions reductions achieved. For example, in one state, mercury reductions are measured against the "historical" amount of mercury in coal, rather than the amount of mercury in coal being currently used by power plants in the state. If plants are required to reduce mercury by, for example, 90 percent compared to historical coal data, but coal used in the past had higher levels of mercury than the plants have been using more recently, then actual mercury emission reductions would be less than 90 percent. In addition, percent reduction requirements do not provide an incentive for plants burning high mercury coal to switch coals or pursue more effective mercury control strategies because it is easier to achieve a percent reduction requirement with higher mercury coal than with lower mercury coals.

Similarly, a combination standard that gives regulated entities the option to choose either a specified emission limit or a percent reduction might reduce the actual mercury emission reductions achieved. For example, a plant burning coal with a mercury content of 15 pounds per trillion BTUs that may choose between meeting an emission limit of 0.7 pounds of mercury per trillion BTUs or a 90 percent reduction could achieve the percent reduction while emitting twice the mercury that would be allowed under the specified emission limit. As discussed earlier, for the purposes of setting a standard, a required emission limit that provides a consistent benchmark for plants to meet can be correlated to a percent reduction. For example, according to EPA's Utility Air Toxic MACT working group, a 90 percent mercury reduction based on national averages of mercury in coal generally equates to a national average emission limit of approximately 0.7 pounds per trillion BTUs.[55] For bituminous coal, a 90

[54]Colorado, Connecticut, Delaware, Illinois, Massachusetts, New Jersey, Oregon, and Utah allow either an emission limit or a percent reduction; Montana, New Mexico, and New York require an emission limit; Maryland, Minnesota, New Hampshire, and Wisconsin require percent reductions (Wisconsin mercury emission standard changes to require meeting either a limit or a percent reduction in 2015); and Arizona requires the more stringent option—whichever is more stringent, a percent reduction or emission limit.

[55]Presentation on "Recommendations on the Utility Air Toxics MACT, Final Working Group Report, October 2002." The Working Group on the Utility MACT was formed under the Clean Air Act Advisory Committee, Subcommittee for Permits/New Source Reviews/Toxics.

percent reduction equates to a limit of 0.8 pounds per trillion BTUs; for subbituminous coal, a 90 percent reduction equates to a limit of 0.6 pounds per trillion BTUs; and for lignite, a 90 percent reduction equates to a limit of 1.2 pounds per trillion BTUs.

Continuous Monitoring of Mercury Emissions at Most Power Plants Has Been Delayed

EPA's now-vacated Clean Air Mercury Rule required most coal-fired power plants to conduct continuous emissions monitoring for mercury—and a small percentage of plants with low mercury emissions to conduct periodic testing—beginning in 2009. State and federal government and nongovernmental organization stakeholders told us they support reinstating the monitoring requirements of the Clean Air Mercury Rule. In fact, in a June 2, 2008, letter to EPA, the National Association of Clean Air Agencies requested that EPA reinstate the mercury monitoring provisions that were vacated in February 2008 because, among other things, they are important to state agencies with mercury reduction requirements and power plants complying with them.[56] This association also said the need for federal continuous emissions monitoring requirements is especially important in states that cannot adopt air quality regulations more stringent than those of the federal government. However, EPA officials told us the agency has not determined how to reinstate continuous emissions monitoring requirements for mercury at coal-fired power plants outside of the MACT rulemaking process.

Under the Clean Air Mercury Rule, the selected monitoring methodology for each power plant was to be approved by EPA through a certification process. For its part, EPA was to develop performance specifications—protocols for quality control and assurance—for continuous emissions monitoring systems (CEMS). However, when the Clean Air Mercury Rule was vacated in February 2008, EPA delayed development of these performance specifications. EPA has taken steps recently to develop performance specifications for mercury CEMS under a May 6, 2009, proposed rule limiting mercury emissions from facilities that produce Portland cement.[57] As part of this proposed rule, EPA also proposed performance specifications that describe performance evaluations that must be conducted to ensure the continued accuracy of the CEMS

[56]The National Association of Clean Air Agencies represents air pollution control agencies in 53 states and territories and over 165 major metropolitan areas across the United States.

[57]Portland cement is the most common type of cement in general use around the world. It is a basic ingredient of concrete, mortar, stucco and most non-specialty grout.

emissions data. In the proposed rule, EPA stated that the performance specifications for mercury CEMS used to monitor emissions from Portland cement facilities could also apply to other sources. Further, an EPA Sector Policies and Programs Division official told us that if EPA chooses—as it did in its 2004 proposed MACT—to require continuous monitoring for mercury emissions in its final rule regulating hazardous air pollutants from coal-fired power plants, the performance specifications will already be in place for continuous emissions monitoring systems' use when the Portland cement MACT is finalized.

Effective continuous emissions monitoring can assist facilities and regulators ensure compliance with regulations and can also help facilities identify ways to better understand the efficiency of their processes and operations. For example, using CEMS, plant managers told us they can routinely make adjustments in the amount of sorbent needed to meet regulatory requirements, potentially reducing costs. Nevertheless, monitoring mercury emissions is more complex than monitoring other pollutants, such as nitrogen oxides and sulfur dioxide, which are measured in parts per million—mercury is emitted at lower levels of concentration than other pollutants and is measured in parts per billion. Consequently, mercury CEMS may require more time to install than CEMS for other pollutants, and according to plant engineers using them, getting these relatively complex monitoring systems up and running properly involves a steeper learning curve.

In our work, we found that mercury CEMS were installed on 16 boilers at power plants and used for monitoring operations and compliance reporting.[58] Plant managers reported that their mercury CEMS were online from 62 percent to 99 percent of the time. The system that was online 62 percent of the time was not used for compliance purposes but rather to monitor the effectiveness of different sorbent injection rates on mercury emissions. Excluding this case, CEMS were online about 90 percent of the time, on average. When these systems were offline, it was mainly because of failed system integrity checks or for routine parts replacement. Some plant engineers told us that they believed CEMS were several years away from commercial readiness to accurately measure mercury emissions but that they had purchased and installed the CEMS in anticipation of the requirement that was part of the now-vacated Clean Air Mercury Rule.

[58]At least 15 states have enacted mercury emission standards that include a continuous emission or other long-term monitoring requirement

Others using CEMS said that these systems are accurate at measuring mercury emissions and can be used to determine compliance with a stringent regulation.

EPA, EPRI, the National Institute of Standards and Technology, and others are working collaboratively to approve protocols for quality assurance and control for mercury CEMS that will ensure the continued accuracy of the emissions data at the precise levels of many state rules. These organizations are in the final phase of their collaborative effort, and in July 2009 they provided interim procedures to states that require use of mercury CEMS and other groups that use these systems.

Concluding Observations

Data from commercially deployed sorbent injection systems show that substantial mercury emissions reductions have been achieved at a relatively low cost. Importantly, these results, along with test results from DOE's comprehensive research and development program, suggest that similar reductions can likely be achieved at most coal-fired power plants in the United States. Other strategies, including blending coal and using other technologies, exist for the small number of plants with configuration types that were not able to achieve significant mercury emissions reductions with sorbent injection alone.

Whether power plants will install sorbent injection systems or pursue multipollutant control strategies will likely be driven by the broader regulatory context in which they operate, such as requirements for sulfur dioxide and nitrogen oxides reductions in addition to mercury, and the associated costs to comply with all pollution reduction requirements. Nonetheless, for many plants, sorbent injection systems appear to be a cost-effective technology for reducing mercury emissions. For other plants, sorbent injection may represent a relatively inexpensive bridging technology—that is, one that is available for immediate use to reduce only mercury emissions but that may be phased out—over time—with the addition of multipollutant controls, which are more costly. Moreover, some plants achieve substantial mercury emissions reductions without mercury-specific controls because their existing controls for other air pollutants also effectively reduce mercury emissions. In fact, while many power plants currently subject to mercury regulation have installed sorbent injection systems to achieve required reductions, about one-third of them are relying on existing pollution control devices to meet the requirements.

As EPA proceeds with its rulemaking process to regulate hazardous air pollutants from coal-fired power plants, including mercury, it may find that current data from commercially deployed sorbent injection systems and plants that achieve high co-benefit mercury reductions would support a more stringent mercury emission standard than was last proposed in 2004. More significant mercury emissions reductions are actually being achieved by the current best performers than was the case in 1999 when such information was last collected—and similar results can likely be achieved by most plants across the country at relatively low cost.

Agency Comments and Our Evaluation

We provided a draft of this report to the Administrator, EPA, and the Secretary, DOE, for review and comment. EPA and DOE provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to interested congressional committees; the Administrator, the Environmental Protection Agency; the Secretary, Department of Energy; and other interested parties. The report is also available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff 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 VI.

Sincerely yours,

John B. Stephenson
Director, Natural Resources
and Environment

Appendix I: Objectives, Scope, and Methodology

This appendix details the methods we used to examine (1) the mercury reductions that have been achieved by existing mercury control technologies and the extent to which they are being used at coal-fired power plants, (2) the costs associated with mercury control technologies currently in use, and (3) key issues the Environmental Protection Agency (EPA) faces in developing a new regulation for mercury emissions from coal-fired power plants.

For the first two objectives, we identified coal-fired power plants subject to regulatory requirements to reduce mercury emissions by contacting clean air agencies in all 50 states. In so doing, we identified those states that had established laws or regulations—or had coal-fired power plants subject to consent decrees or construction permits—requiring reductions in mercury emissions. In states where laws or regulations are in effect, we asked clean air agency officials to identify which coal-fired power plants are meeting the requirements—either through "co-benefit" mercury removal achieved by plants' existing air pollution control equipment or by operating sorbent injection systems. State clean air agency officials identified 14 coal-fired power plants that are currently operating sorbent injection systems to meet regulatory requirements to reduce mercury emissions.[1] For these plants, we developed a structured interview instrument to obtain information on the effectiveness of sorbent injection systems in reducing mercury emissions and the associated costs of the systems and the monitoring equipment.[2] We designed the instrument to also obtain information on the engineering challenges, if any, that plant officials experienced when operating the systems and the steps taken to mitigate such challenges. Staff involved in the evaluation and development of mercury control technologies within EPA's Office of Research and

[1]Representatives of one plant that is operating a sorbent injection system to meet its state's mercury reduction requirements did not participate in the structured interview, stating they could not participate until a compliance report had been completed and submitted to the state clean air agency.

[2]We obtained data on the capital and operating costs incurred to purchase, install, and operate sorbent injection systems and determined their potential impact on utility rates. To account for differences in timing, we adjusted these costs for inflation to represent 2008 dollars. We then used, by boiler, the reported operating costs, total electrical output, and capital costs to determine a levelized cost per kilowatt hour. The levelized cost is an assessment of the anticipated costs of a sorbent injection system over its lifetime, including capital costs and operations and maintenance costs. We assumed a 20-year lifetime and a return on capital of 10 percent. We then compared these costs with DOE data on 2008 average utility rates by state to determine the potential impact on utility rates, should the plants we interviewed pass on 100 percent of the costs to consumers.

Development and DOE's Office of Fossil Energy reviewed and commented on the instrument. We conducted the structured interview with representatives of 13 of the 14 coal-fired power plants and conducted site visits at 6 of them. We conducted structured interviews with officials at the following plants:

- B.L. England, New Jersey
- Brayton Point, Massachusetts
- Bridgeport Harbor, Connecticut
- Crawford, Illinois
- Fisk, Illinois
- Indian River Generating Station, Delaware
- Mercer Generating Station, New Jersey
- Presque Isle, Michigan
- TS Power Plant, Nevada
- Vermillion Power Station, Illinois
- Walter Scott Jr. Energy Center, Iowa
- Waukegan, Illinois
- Weston, Wisconsin

Furthermore, state clean air agency officials identified six coal-fired power plants that are aiming to meet mercury emission reduction requirements through operation of existing air pollution control equipment. From officials with these six plants, we obtained information on the effectiveness of the existing controls in reducing mercury emissions, as well as the reliability and costs of mercury emissions monitoring equipment. We spoke with officials at the following plants:

- AES Thames, Connecticut
- Carney's Point, New Jersey
- Deepwater, New Jersey

- EdgeMoor, Delaware
- Logan, New Jersey
- Salem Harbor, Massachusetts

In addition to examining the effectiveness of commercially deployed sorbent injection systems, we examined field test results of sorbent injection systems—installed at operating power plants—conducted by DOE and the Electric Power Research Institute (EPRI) over the past 10 years as part of DOE's comprehensive mercury control technology test program. We relied primarily on data from the second and third phases of the DOE field testing program. The second phase of the DOE program focused heavily on chemically treated sorbents, which helped many boiler configurations achieve much higher mercury emission reductions than the same boiler configurations achieved under phase one tests, when untreated sorbents were used. The third phase of the DOE program focused on finding solutions to "balance-of-plant" impacts. To determine the percentage of coal-fired boilers nationwide that have air pollution control device configurations that are the same as those at power plants with commercially deployed sorbent injection systems or where field tests occurred, we used a draft version of EPA's National Electricity and Energy Data System database that contains boiler level data, as of 2006, on coal type used, pollution control devices installed, and generating capacity.[3]

We conducted a reliability review of the data we received from coal-fired power plants, EPA, and DOE. Through our review, we determined that the data were sufficiently reliable for our purposes. Our assessment consisted of interviews with officials about the data systems and elements of data. We also corroborated the data with other sources, where possible. For example, we verified the information in structured interviews by obtaining compliance reports from state clean air agencies, where possible. Finally, we reviewed literature presented at the 2008 MEGA Symposium and the 2009 Energy and Environment Conference on (1) strategies to overcome challenges that some plants have experienced with sorbent injection systems, such as sulfur trioxide interference, and (2) on emerging mercury control technologies, such as oxidation catalysts.

[3]We excluded boilers with generating capacity of less than 25 megawatts from our analysis because they would not be subject to a MACT regulation under the Clean Air Act.

For the third objective, we examined EPA's requirements for establishing MACT standards under the Clean Air Act and recent court cases with implications for how EPA establishes such standards.[4] We interviewed EPA officials in the Clean Air Markets Division and Sector Policies and Programs Division regarding the agency's plans for regulating mercury at power plants. To examine EPA's process for identifying best performers, we obtained and analyzed EPA data on mercury emissions reductions from the agency's 1999 information collection request. Using these data, we followed the steps EPA described in its proposed 2004 MACT rulemaking to calculate the average mercury emissions reductions achieved by the best performing 12 percent of boilers—the threshold for calculating a minimum MACT emissions standard under the Clean Air Act. We then used newer data—the data we obtained from commercially deployed sorbent injection systems and DOE and industry tests—and followed the same steps to calculate the average mercury emissions reductions achieved by the best performing 12 percent of these boilers.

In addition, we examined EPA's steps to resolve technical monitoring challenges, including how the agency develops quality control and assurance procedures for continuous emissions monitoring systems. We also obtained data from coal-fired power plants—operating 16 continuous emissions monitoring systems—on the reliability of the systems, including data on the number of times the systems were offline, the outcome of periodic system integrity checks, and the extent to which plant engineers believed the systems to accurately measure mercury emissions. We interviewed EPA's technical experts in the Clean Air Markets Division.

We conducted this performance audit from November 2008 through September 2009 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[4]We examined the following cases: *National Lime Association v. EPA*, 233 F.3d 625 (D.C. Cir. 2000); *Cement Kiln Recycling Coal. v. EPA*, 255 F.3d 855 (D.C. Cir. 2001); *Sierra Club v. EPA*, 479 F.3d 875 (D.C. Cir. 2007); *Natural Resources Defense Council v. EPA*, 489 F.3d 1250 (D.C. Cir. 2007); *Natural Resources Defense Council v. EPA*, 489 F.3d 1364 (D.C. Cir. 2007).

Appendix II: Emerging Technologies That May Reduce Mercury Emissions from Coal-Fired Power Plants

In addition to sorbent injection systems, DOE, EPRI, and others have developed and tested other technologies to reduce mercury emissions that show promise and may become commercially available in the future. These technologies are being developed to potentially lower the cost of mercury removal for some plants and enable others—those for which sorbent injection may be ineffective—to achieve significant mercury emission reductions. Such technologies include oxidation catalysts, which help convert elemental mercury into oxidized mercury that can be captured in particulate control devices; the MerCAP™ process, which involves installing metal plates with sorbents on them in the exhaust gas (instead of injecting sorbents); and low-temperature mercury capture, which involves lowering the temperature of the exhaust gas to enable mercury to bind more effectively to the unburned carbon in fly ash. Finally, novel technologies are being developed by entities such as the Western Research Institute.[1] The technologies the Western Research Institute is working on include those designed to remove mercury directly from coal before it is burned. Innovative techniques for mercury control could eventually replace or augment the more mature technologies discussed in this report, according to DOE.

Oxidation catalysts. Oxidation catalysts are powdered chemicals injected into either the boiler or the boiler's exhaust gas to help change elemental mercury into oxidized mercury—a form that is easier to capture in pollution control devices for sulfur dioxide and particulate matter. According to recent research, oxidation of elemental mercury, which is then collected in particulate matter control devices or absorbed across a wet scrubber system, has the potential to be a reliable and cost-effective mercury control strategy for some coal-fired power plants, especially those that must comply with sulfur dioxide emission requirements. According to DOE, examples of oxidation catalysts tested at operating power plants include the following:

- URS Corporation tested oxidation catalysts at a plant that fires a blend of Texas lignite and subbituminous coals. Tests completed in April 2005 showed that oxidation catalysts enabled the wet scrubber to achieve mercury reductions ranging from 76 percent to 87 percent, compared with only 36 percent reduction under baseline conditions.

[1]The Western Research Institute is a not-for-profit research organization involved in advanced energy systems, environmental technologies, and highway materials research.

- URS has also begun testing oxidation catalysts at a boiler firing low-sulfur eastern bituminous coal that is equipped with a cold-side electrostatic precipitator. According to DOE, the project represents the next logical advancement of the catalytic oxidation technology, and it will answer technical questions such how much catalyst is required to achieve high mercury oxidation percentages, what is the catalyst life, and what is the efficiency of mercury capture in wet scrubber systems using oxidation catalysts.

MerCAP™: Developed by EPRI, MerCAP is a process in which metal plates laced with carbon sorbents are positioned in a boiler's exhaust gas stream to adsorb mercury. During two 6-month tests, MerCAP was used at a boiler equipped with a dry scrubber and a fabric filter and at another boiler equipped with a wet scrubber. After more than 250 days of continuous operation at one plant, mercury reduction averaged 30 percent to 35 percent across acid-treated MerCAP plates and 10 to 30 percent across the untreated plates. At the other plant, MerCAP achieved 15 percent mercury reduction when a water wash system for the plates was installed, which helped prevent limestone slurry from the wet scrubber system from inhibiting mercury reduction. MerCAP™ is still in the research and development phase, and although these mercury reduction amounts appear relatively low, when engineers altered the spacing between the metal plates, mercury emission reductions increased to about 60 percent in some cases.

Low-temperature mercury capture process: The low temperature mercury capture process helps reduce mercury emissions by cooling the exhaust gas temperature to about 220° Fahrenheit, which promotes mercury adsorption to the unburned carbon inherent in fly ash. This process may have the ability to reduce mercury emissions by over 90 percent, as was recently shown by one company performing a limited scale test.

Pilot testing of novel mercury control technology: The Western Research Institute is developing and evaluating the removal of mercury from coal prior to combustion. The institute developed a two-step process that involves first evaporating moisture in the coal and then heating the coal with inert gas. Pre-combustion mercury removal technology has been successful in removing 75 percent of mercury from subbituminous coal and 60 percent of mercury from lignite coal, but the technology has encountered difficulty when used with bituminous coal. By removing up to 75 percent of mercury before combustion, less mercury remains in the exhaust gas for removal by pollution control devices. In addition, pre-combustion technology has other benefits: (1) removing the moisture from the coal increases the heat content of the coal for combustion purposes, which may reduce the amount of coal burned by the plant and increase efficiency by about 3 percent; (2) this process also helps to remove other trace metals; (3) the water that is removed from the coal during pre-combustion treatment can be recovered and re-used in plant operations. According to DOE, Western Research Institute testing has also shown that, for some coals, the amount of time the coal is exposed to heat affects the amount of mercury removed. For example, an increase of 8 minutes of "residence time" resulted in the removal of nearly 80 percent of mercury before combustion.[2]

DOE in-house development of novel control technologies: DOE recently patented three techniques that are now licensed and in commercial demonstration. First, the thief carbon process—which involves extracting carbon from the boiler and using it as sorbent to inject into the exhaust gas for mercury capture—may be a cost-effective alternative to sorbent injection systems for mercury removal from boilers' exhaust gas. Thief carbon sorbents, for instance, range from $90 to $200 per ton according to DOE—less than 10 percent of the typical cost of sorbents used in sorbent injection systems. According to the Western Research Institute, which tested the thief carbon process at an operating power plant, mercury emission reductions were comparable to those achieved by commercially available sorbents. Second, DOE patented the photochemical oxidation process. This process introduces an ultraviolet light into the exhaust gas to help convert mercury to an oxidized form for collection in other pollution control devices.[3] Finally, DOE researchers have invented a new sorbent that works at elevated temperatures. The new sorbent, which is palladium-based, removes mercury at temperatures above 500° Fahrenheit and, according to DOE, may improve the overall energy efficiency of the combustion process.[4]

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[2]During testing, the percentage of mercury removed from coal varied from 50 percent to almost 90 percent, depending on the amount of time the coal was exposed to heat and inert gas, according to DOE.

[3]Researchers at DOE's National Energy Technology Laboratory received the 2005 Award for Excellence in Technology Transfer from the Federal Laboratory Consortium for the photochemical oxidation method.

[4]Researchers at DOE's National Energy Technology Laboratory received the 2008 Award for Excellence in Technology Transfer for developing the palladium-based sorbent.

Appendix III: Summary of State Regulations Requiring Reductions in Mercury Emissions from Coal-Fired Power Plants

Table 1 summarizes data about state regulations that require reductions in mercury emissions from coal-fired power plants, including compliance date, percent reduction required, and emission limit. This table represents the best available data on state regulations, which appear to be independent of rules that were adopted in accordance with the vacated Clean Air Mercury Rule as of August 2009. For states with percent reduction and emission limit provisions, plants generally may choose the format with which they will comply.

Table 1: Summary of Key Provisions of State Regulations Requiring Mercury Emission Reductions Applicable to Existing or All Coal-Fired Power Plants

State	Compliance date	Percent reduction	Emission limit	Continuous emission or other long-term monitoring requirement (some state requirements may rely on vacated portions of federal rule)
Arizona[a]	December 31, 2013	90	0.0087 pounds/gigawatt-hour	X
Colorado[a]	July 1, 2014[b]	80	0.0174 pounds/gigawatt-hour	X
	January 1, 2018	90	0.0087 pounds/gigawatt-hour	
Connecticut[a]	July 1, 2008	90	0.60 pounds/trillion BTUs	
Delaware[c]	January 1, 2009	80	1.0 pounds/trillion BTUs	X
	January 1, 2013	90	0.60 pounds/trillion BTUs	
Georgia	Each plant shall install certain types of air pollution control devices, at varying times, according to a legislatively prescribed schedule.			
Illinois[a, d]	July 1, 2009	90	0.0080 pounds/gigawatt-hour	X
Maryland	January 1, 2010	80	No emission limit required	X
	January 1, 2013	90	No emission limit required	
Massachusetts	January 1, 2008	85	0.0075 pounds/gigawatt-hour	X
	October 1, 2012	95	0.0025 pounds/gigawatt-hour	
Minnesota[a]	December 31, 2010[e]	90	No emission limit required	X
	December 31, 2014[f]	90	No emission limit required	
Montana[a]	January 1, 2010	No percent reduction required	0.90 pounds/trillion BTUs[g]	X
New Hampshire[a]	July 1, 2013	80	No emission limit required	X
New Mexico	January 1, 2010/ January 1, 2018	No percent reduction required	Each plant has its own emission limit (in two phases)	X
New Jersey	December 15, 2007	90	3 milligrams/megawatt-hour	

State	Compliance date	Percent reduction	Emission limit	Continuous emission or other long-term monitoring requirement (some state requirements may rely on vacated portions of federal rule)
New York	January 1, 2010[h]	No percent reduction required	0.60 pounds/trillion BTUs	X
North Carolina[i]	December 31, 2013	No percent reduction required	No emission limit required	X
Oregon[a]	July 1, 2012	90	0.60 pounds/trillion BTUs	X
Utah[a]	December 31, 2012	90	0.65 pounds/trillion BTUs	X
Wisconsin	January 1, 2010[j]	40	No emission limit required	X
	January 1, 2015[k]	90	0.0080 pounds/gigawatt-hour	

Source: GAO analysis of state clean air agency data.

[a]Alternate standards may be applied under certain circumstances.

[b]Two plants in Colorado must comply with an 80 percent mercury emission reduction requirement beginning on January 1, 2012.

[c]Requirement applies to large plants. Plants are also subject to mass emission caps beginning in 2009 and becoming more stringent in 2013.

[d]Through 2013, requirement applies to systems of plants and additional minimum requirements apply on a plant-by-plant basis; after 2013, requirement applies to all plants on a plant-by-plant basis.

[e]This compliance date applies to coal-fired boilers equipped with dry scrubbers for air emissions control.

[f]This compliance date applies to coal-fired boilers equipped with wet scrubbers for air emissions conrol.

[g]The Montana regulation established a separate standard for coal-fired boilers using lignite of 1.5 pounds per gigawatt-hour.

[h]Between 2010 and 2015, 13 coal-fired power plants must reach a specific mercury emission limit prescribed by law. If a plant is not on that list, it must achieve an emission limit of 0.60 pounds per trillion BTUs. Beginning in 2015, all plants must achieve an emission limit of 0.60 pounds per trillion BTUs.

[i]North Carolina requires installation of technology that captures sulfur dioxide, nitrogen oxides, and mercury.

[j]Applies to four major utilities.

[k]Applies to large coal-fired power plants. Plants can take an additional six years to achieve 90% reduction if they choose additional nitrogen oxide and sulfur dioxide controls. Small coal-fired power plants must reduce their mercury emissions to that achieved by the Best Available Control Technology by January 1, 2015.

Appendix IV: Potential Solutions for Plants Unable to Achieve High Mercury Emissions Reductions Using Sorbent Injection Systems Alone

DOE tests show that some plants may not be able to achieve mercury emissions reductions of 90 percent or more with sorbent injections alone. Specifically, the tests identified three factors that can impact the effectiveness of sorbent injection systems: sulfur trioxide interference, using hot-side precipitators, and using lignite. These factors are discussed below, along with some promising solutions to the challenges they pose.

Sulfur trioxide interference. High levels of sulfur trioxide gas may limit mercury emission reductions by preventing some mercury from binding to carbon sorbents. Using an alkali injection system in conjunction with sorbent injection can effectively lessen sulfur trioxide interference. Depending on the cause of the sulfur trioxide interference—which can stem from using a flue gas conditioning system, a selective catalytic reduction system, or high-sulfur bituminous coal—additional strategies may be available to ensure high mercury reductions:

- Flue gas conditioning systems, used on 13 percent of boilers nationwide, improve the performance of electrostatic precipitators by injecting a conditioning agent, typically sulfur trioxide, into the flue gas to make the gas more conducive to capture in electrostatic precipitators. Mercury control technology vendors are working to develop alternative conditioning agents to improve the performance of electrostatic precipitators without jeopardizing mercury emission reductions using sorbent injection.

- Selective catalytic reduction systems, common control devices for nitrogen oxides, are used by about 20 percent of boilers nationwide. Although selective catalytic reduction systems often improve mercury capture, in some instances these devices may lead to sulfur trioxide interference when sulfur in the coal is converted to sulfur trioxide gas. Newer selective catalytic reduction systems often have improved catalytic controls, which can minimize the conversion of sulfur to sulfur trioxide gas.

- High-sulfur bituminous coal—defined as having a sulfur content of at least 1.7 percent sulfur by weight—may also lead to sulfur trioxide interference in some cases. As many as 20 percent of boilers nationwide may use high-sulfur coal, according to 2005 DOE data; however, the number of coal boilers using high-sulfur bituminous coal is likely to decline as more stringent sulfur dioxide regulations take effect. Plants can consider using alkali-based sorbents, such as Trona, which adsorb sulfur trioxide gas before it can interfere with the performance of sorbent injection systems. Plants that burn high-sulfur coal can also consider blending their fuel to include some portion of low-sulfur coal. In addition, according to EPA, power companies are likely to install scrubbers for controlling sulfur dioxide at plants burning high-sulfur coal (for those boilers that do not already have them). Scrubbers also reduce mercury emissions as a co-benefit, so many such plants may use them instead of sorbent injection systems to achieve mercury emissions reductions.

Hot-side electrostatic precipitators. Installed on 6 percent of boilers nationwide, these particulate matter control devices operate at very high temperatures, which reduces the amount of mercury binding to sorbents for collection in particulate matter control devices. However, at least two promising techniques for increasing mercury capture have been identified in tests and commercial deployments at configuration types with hot-side electrostatic precipitators. First, during DOE testing 70 percent mercury emission reductions were achieved with specialized heat-resistant sorbents. Moreover, one of the 25 boilers currently using a sorbent injection system has a hot-side electrostatic precipitator and uses a heat-resistant sorbent. Although plant officials are not currently measuring mercury emissions for this boiler, the plant will soon be required to achieve mercury emission reductions equivalent to 90 percent.[1] Second, in another DOE test, three 90 megawatt boilers—each with a hot-side electrostatic precipitator—achieved more than 90 percent mercury emission reductions by installing a shared fabric filter in addition to a sorbent injection system, a system called TOXECON™. According to plant officials, these three units, which are using this system to comply with a consent decree, achieved 94 percent mercury emission reductions during the third quarter of 2008, the most recent compliance reporting period during which the boiler was operating under normal conditions.

Lignite. North Dakota and Texas lignite, the fuel source for roughly 3 percent of boilers nationwide, have relatively high levels of elemental mercury—the most difficult form to capture. Four long-term DOE tests were conducted at coal units burning North Dakota lignite using chemically treated sorbents. Mercury emission reductions averaged 75 percent across the tests. The best result was achieved at a 450 megawatt boiler with a fabric filter and a dry scrubber—mercury reductions of 92 percent were achieved when chemically treated sorbents were used. In addition, two long-term tests were conducted at plants burning Texas lignite with a 30 percent blend of subbituminous coal. With coal blending,

[1]Plant officials did not provide us with mercury emission reduction data for this boiler.

these boilers achieved average mercury emission reductions of 82 percent. Specifically, one boiler, with an electrostatic precipitator and a wet scrubber, achieved mercury reductions in excess of 90 percent when burning the blended fuel. The second boiler achieved 74 percent reductions in long-term testing. However, 90 percent was achieved in short-term tests using a higher sorbent injection rate. Although DOE conducted no tests on plants burning purely Texas lignite, one power company is currently conducting sorbent injection tests at a plant burning 100 percent Texas lignite and is achieving promising results. In the most recent round of testing, this boiler achieved mercury emission reduction of 82 percent using untreated carbon and a boiler additive in conjunction with the existing electrostatic precipitator and wet scrubber.

Appendix V: Average Costs to Purchase and Install Sorbent Injection Systems and Monitoring Equipment, with and without Fabric Filters, per Boiler

Table 2 summarizes information on average costs to purchase and install sorbent injection systems and monitoring equipment, with and without fabric filters. This table includes cost data for boilers with sorbent injection systems and fabric filters installed specifically for mercury emissions control. This table does not include cost data for the 5 boilers with sorbent injection systems and fabric filters that were installed largely to comply with requirements to control other forms of air pollution.[1]

Table 2: Detailed Average Costs to Purchase and Install Sorbent Injection Systems and Monitoring Equipment, with and without Fabric Filters, per Boiler

2008 dollars

Mercury control technology type	Number of boilers using technology type[a]	Cost of sorbent injection system	Cost of mercury emissions monitoring system	Cost of consulting and engineering	Cost of fabric filter	Total
Sorbent injection system alone	14	$2,723,000[b]	$560,000[b]	$382,000[b]	[c]	**$3,594,000[d]**
Sorbent injection system with fabric filter to assist in mercury removal	5	$1,335,000[e]	$120,000[f]	$1,444,000[g]	$19,010,000[h]	**$15,786,000[i]**

Source: GAO analysis of data from power plants operating sorbent injection systems.

[a]We identified 25 boilers using sorbent injection systems to reduce mercury emissions, for which power companies provided cost data on 24. Cost data for 19 of the 24 are provided in the table. We did not report costs in this table for the remaining 5 because much of the cost incurred for fabric filters in these cases is not related to mercury removal. See footnote.

[b]Of the 14 boilers that installed a sorbent injection system alone, cost data for only 12 boilers were provided in this category.

[c]Not applicable.

[d]Numbers do not add to total. Total capital cost data were provided for 14 boilers, but for only 12 in the other cost categories.

[e]Cost data were provided for two boilers in this category. The costs of the sorbent injection systems for the two boilers were $1,071,000 and $1,599,000.

[f]Cost data were provided for two boilers in this category. The costs of the monitoring systems for the two boilers were $107,000 and $160,000.

[g]Cost data were provided for three boilers in this category and were the same for all three boilers.

[h]Cost data were provided for two boilers in this category. The costs of the fabric filters were $15,255,000 and $22,765,000.

[i]Numbers do not add to total. Total capital cost data were provided for five boilers with fabric filters.

[1]For the five boilers where plant officials reported installing fabric filters along with sorbent injection systems largely to comply with requirements to control other forms of air pollution, the average reported capital cost for the two technologies was $105.9 million per boiler, ranging from $38.2 million to $156.2 million per boiler.[1] For these boilers, the capital costs result from requirements to control other pollutants, and we did not determine what portion of these costs would appropriately be allocated to the cost of reducing mercury emissions.

Appendix VI: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

In addition to the contact named above, Christine Fishkin, Assistant Director; Nathan Anderson; Mark Braza; Antoinette Capaccio; Nancy Crothers; Michael Derr; Philip Farah; Mick Ray; and Katy Trenholme made key contributions to this report.

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