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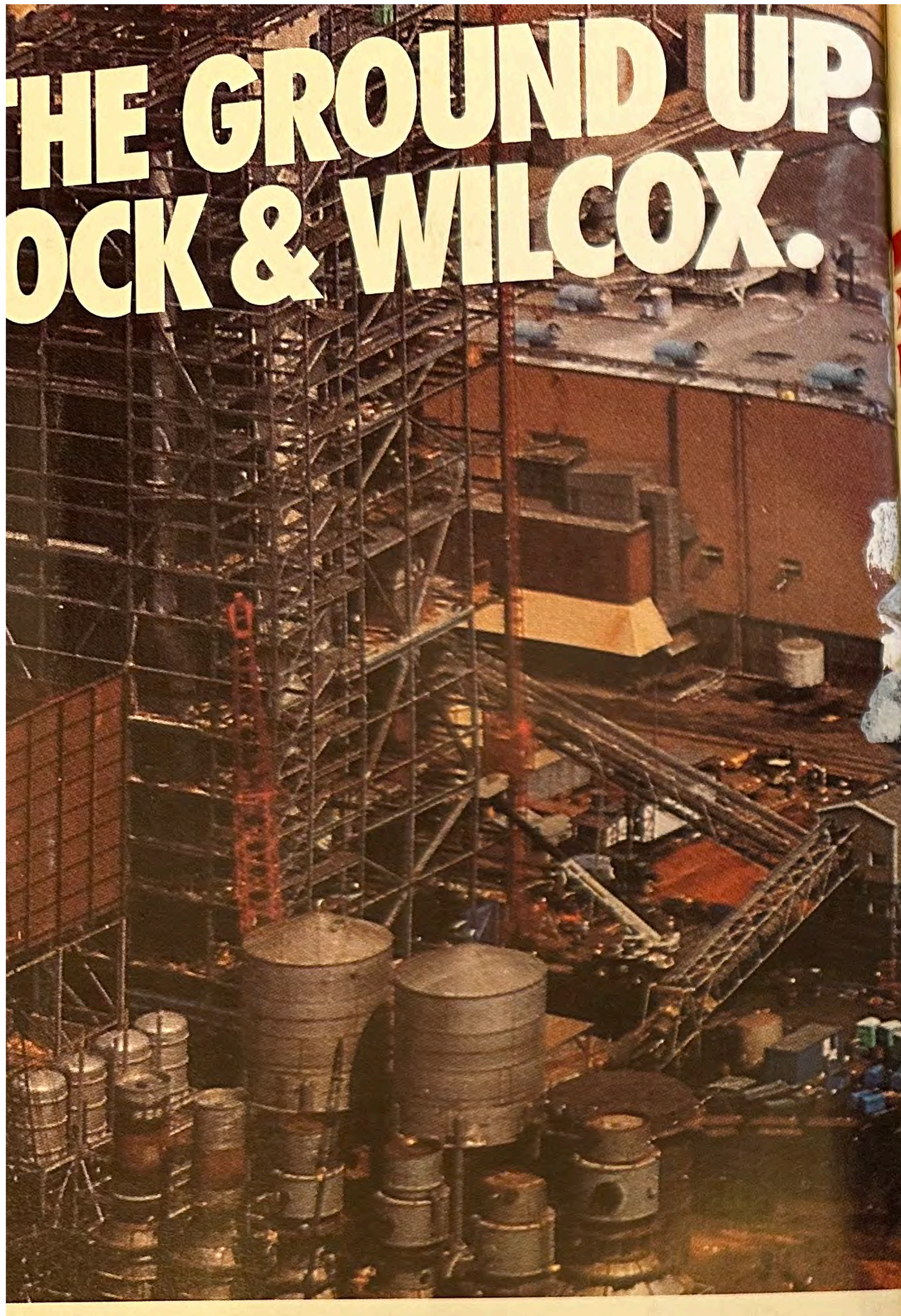

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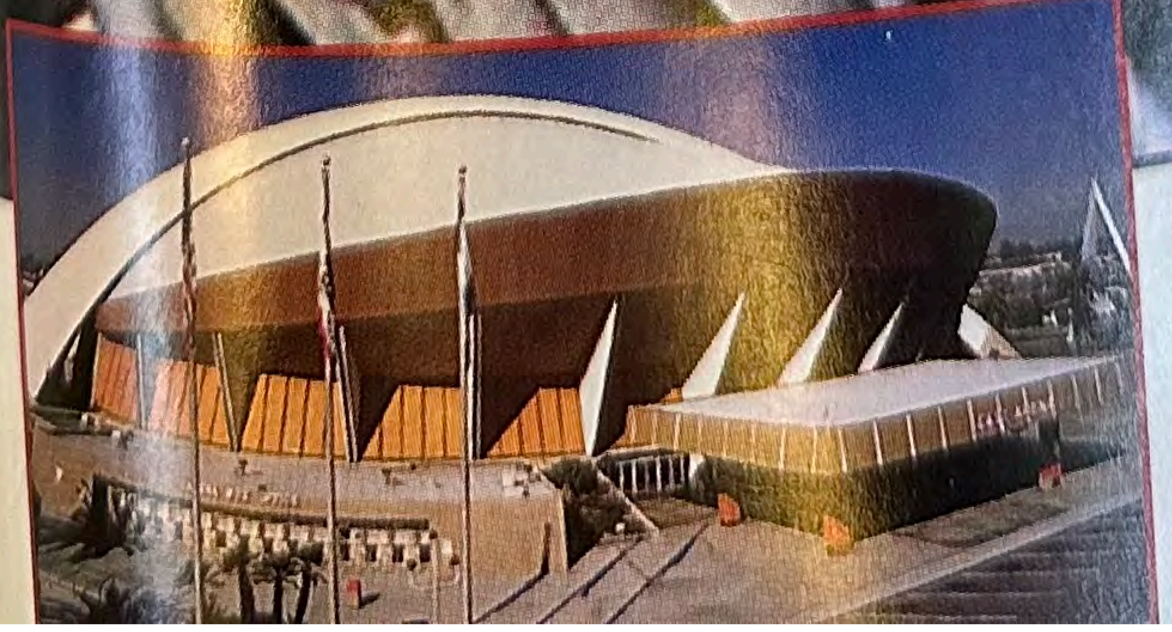

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By Ramsay Change, George R. Offen and the Electric Power Research Institute

Mercury emission control technologies: An EPRI synopsis

The air toxics provisions under Title III of the 1990 Clean Air Act Amendments (CAAA) require the U.S. Environmental Protection Agency (EPA) to conduct a study that focuses on electric utility emissions. Due to be completed by the end of 1995, this study is being conducted to determine whether the release of toxic materials, including mercury, present an unacceptable risk to public health.

CONTROLLING 50 PERCENT OF THE MERCURY EMITTED BY U.S. UTILITY POWER PLANTS COULD RANGE FROM $1 BILLION TO $10 BILLION PER YEAR

Of the 189 substances designated "hazardous air pollutants" (commonly called "air toxics"), mercury was also singled out for a separate report because of concerns that humans could be harmed by the consumption of fish that have accumulated methylmercury from their food sources.

The Electric Power Research Institute (EPRI), the research and development arm of its member electric utilities, is conducting research on mercury in four areas: 1) determining the extent of mercury emissions from electric utility power plants, 2) understanding health effects, 3) modeling mercury dispersion, transport, deposition and bioaccumulation, and 4) assessing mercury control strategies. While the focus of this paper is on the last area, a precis of the results obtained to date in the other three areas is presented first.

EPRI has found that mercury is present in very small quantities in coal (0.02 to 0.25 ppm, an average of 0.09 ppm). Concentrations in fuel oil are approximately one to two orders of magnitude less than in coal, and virtually nonexistent in natural gas.[1] Consequently, the amount of mercury emitted from utility power plants is small. Uncontrolled emissions from a typical 500-MW coal-fired plant would be less than 250 pounds per year, or less than 1 pound per day.[1] Actual emissions are lower, since environmental control technologies that utilities use to control the emission of several air pollutants, such as particulate matter and sulfur dioxide (SO_2), remove some mercury. The annual contribution of U.S. fossil-fuel-fired electric utility boilers (plants fueled by coal, oil or natural gas) with existing criteria pollutant control equipment in place has been estimated to be less than 16 percent of all U.S. man-made sources and less than 1 percent of worldwide man-made sources.[2]

The second area of EPRI mercury research is human health risk assessment. While such assessments remain incomplete, initial studies show the risk to be quite small to humans. In one assessment, EPRI studied mercury emissions from four representative power plants. At each plant, EPRI found the mercury health risks by all exposure pathways to be insignificant.[3] Work in the third area is in progress to resolve some of the uncertainties associated with understanding mercury transport and deposition, bioaccumulation factors and threshold levels.

The fourth area of EPRI mercury research is assessment of mercury control strategies. Any decision to regulate mercury emissions from utility power plants must consider the effectiveness and cost of available mercury control options. The purpose of this paper is to provide an overview of research completed to date on mercury control technologies for utility power plants. The paper covers control technology effectiveness, projected cost and impact on power plant operation. Prepared by EPRI, this overview is intended for all parties interested in learning more about mercury control at utility power plants, including utility customers and shareholders, regulators, the media and the general public.

Control technology issues

Determining the effectiveness and cost of mercury control technologies for utility power plants is complicated by several factors. First of all, mercury is present mainly in the vapor phase in utility power plant flue gas, making capture difficult in existing emissions control devices, such as electrostatic precipitators (ESPs), baghouses, and SO_2 and particulate scrubbers. Therefore, methods are needed for converting the mercury to the solid phase, capturing the mercury on solid sorbent, or converting the mercury to a soluble form for those units that are already equipped with a scrubber.

Second, existing methods of mercury capture have been developed mainly for municipal waste combustors (MWCs). These techniques include the direct injection of activated carbon or sodium sulfide, wet or dry scrubbing, and the use of activated carbon beds. Some observers have suggested that these control technologies could be applied to utility boilers. However, the technologies probably will not remove mercury from utility flue gas as effectively or at comparable cost as in MWCs. The reasons for this involve several important differences between municipal waste combustion and utility power plant combustion.

Both the fuel burned and the combustion conditions in the two types of plants are quite different. Hence, the flue gas composition for the two plant types is distinctly different (see Table). Compared to municipal solid waste or refuse-derived fuel, fossil fuels are much lower in mercury concentrations. Mercury concentrations in flue gas from coal-fired utility boilers are approximately one to three orders of magnitude lower than those from MWCs. Mercury concentrations from oil- and gas-fired utility power plants are even lower.[2] There is evidence that mercury removal effectiveness decreases dramatically with lower mercury concentrations.[4]

Research to date has shown that mercury removal effectiveness depends on the species or compound forms of the mercury in the flue gas. This mercury speciation is highly dependent on other flue gas components, such as chlorides, sulfur oxides (SO_x) and oxygen.[5] The Table shows that utility boilers operate with much lower excess air levels (air above and beyond).

In addition, utility power plant flue gas is typically lower in chloride and higher in SO_2 than MWC exhaust gas. Thus, mercury tends to be present primarily as soluble mercuric chloride in municipal waste combustion flue gas, while utility power plant flue gas contains varying proportions of elemental mercury (nonsoluble) and oxidized mercury (soluble and nonsoluble species).

In summary, based on information compiled by EPA, EPRI and others, differences between utility combustion and municipal waste combustion concentrations and species of mercury, flue gas composition and process conditions cause mercury control technologies to function quite differently on the two types of plants. Instead of extrapolating mercury removal data from MWCs to utility flue gas, specific test data should be obtained from utility power plants to determine the actual effectiveness and potential costs of mercury control technologies.

Uncontrolled flue gas composition for coal-fired utility boilers and municiple waste combustors

Uncontrolled flue gas parameter or composition	Coal-fired utility boilers	Municipal waste combustors
Temperature (°F)	250-350[6,7]	350-570[8,9]
Mercury content (micrograms/dscm)	1-10[1]	100-1,000[10]
Sulfur dioxide (SO_2) content (ppm)	100-3,000[5,11]	100-300[5,11]
Hydrogen chloride (HCl) content (ppm)	5-100[5,11]	100-1,000[5,11]
Excess air (%)	15-25[12]	50-110[13]

A third factor that complicates determination of the effectiveness and cost of mercury control technologies for utility power plants involves sampling and analysis. The low mercury concentrations in flue gas, typically on the order of 1-10 micrograms per normal cubic meter (micrograms/Nm_3), present sampling and analytical challenges. Obtaining good repeatable samples is challenging because, at these low concentrations, any sample contamination (e.g., contact with human hands, sampling equipment or laboratory apparatus not kept scrupulously clean) can be as large as the flue gas concentration of mercury itself.

Determining the effectiveness and cost of mercury control technologies for utility power plants is complicated by several factors.

Adding to the measurement challenge is the fact that mercury exists in the flue gas in a variety of forms, primarily metallic or elemental mercury [Hg(0)] and oxidized mercury [Hg(II)], such as mercuric chloride or mercuric oxide. Significant mercury is sometimes measured in the particulate phase (on fly ash) as well. Sampling and analysis techniques to capture and measure these species individually have not yet been fully developed and verified. Thus, much uncertainty remains as to the exact forms of mercury present in flue gas. These species must be quantified because they not only exhibit different responses to potential control technologies, but also different atmospheric deposition properties. EPRI is conducting several research and testing projects to compare and enhance methods of sampling and analyzing mercury from utility power plant flue gas, as well as to determine the dominant form of mercury emitted in combustion flue gas.

Control technology options

The science of controlling mercury emissions from utility power plants is poorly understood. Uncertainty about the effectiveness of mercury control methods compounds uncertainty about the costs of such control. Estimating a range of potential costs for mercury control at utility power plants is possible if assumptions are made on mercury control effectiveness. However, it is uncertain whether the resulting range encompasses the actual costs that would be realized. Further information on control technology effectiveness, as well as plant operating and maintenance cost impacts, is needed to reduce this uncertainty.

To learn more about mercury control technologies for utility power plants, EPRI and the U.S. Department of Energy (DOE) are sponsoring a variety of research and testing projects. To date, EPRI research and testing has focused on two potential methods of reducing mercury emissions from utility power plants—sorbent injection and wet scrubbing. Sorbent injection appears to be the most promising and cost-effective approach for units without a scrubber (approximately two-thirds of existing coal-fired capacity). A better understanding of the mercury control mechanisms could show where and how to use scrubbers installed for SO_2 control for mercury removal at low additional cost.

Sorbent injection

Sorbent injection involves directly injecting a sorbent material, such as activated carbon, into the plant's flue gas stream. This sorbent binds the vapor-phase mercury through physical adsorption and/or chemical reaction and is collected in downstream particulate control equipment, such as a fabric filter or ESP.

Activated carbon injection at various test facilities varied in the effectiveness of removing trace mercury levels in flue gas and depended on flue gas composition and temperature, coal type, mercury species present, activated carbon properties and injection rate and other plant operating conditions.[14,15]

While researchers observed high mercury removal efficiencies in some tests, low to moderate removal was measured at other typical operating conditions. Some preliminary guidelines to improve mercury capture with activated carbon injection can be established, but confidently predicting the level of flue gas mercury control achievable for specific utility power plant sites is not yet possible.

For these preliminary tests, Figure 1 illustrates the variation in total vapor-phase mercury removal from utility flue gas.[14,15] Activated carbon was injected upstream of a pulse-jet baghouse (particulate control equipment). By lowering the flue gas temperature from 345 F to 250 F, the total vapor phase mercury removal efficiency was improved from 0 percent to 37 percent (tests 1 and 2).

Further tests at 200 F showed that greater than 90-percent removal is possible in some cases. However, lowering the temperature requires injection of large amounts of water, a costly process that can cause significant corrosion and deposition of fly ash on duct walls, on ESP surfaces and in the baghouse. Alternatives to spray cooling that avoid these problems, such as heat exchangers, are also costly. Injecting more carbon (as measured by the weight ratio of injected carbon to flue gas mercury, tests 2 and 3) increased removal effectiveness.

Unknown differences in low sulfur subbituminous coals (tests 4 and 5) may have caused variations from site to site, even though both sites were operated at similar carbon injection rates and temperatures.

Figure 1

Preliminary test results using activated carbon injection

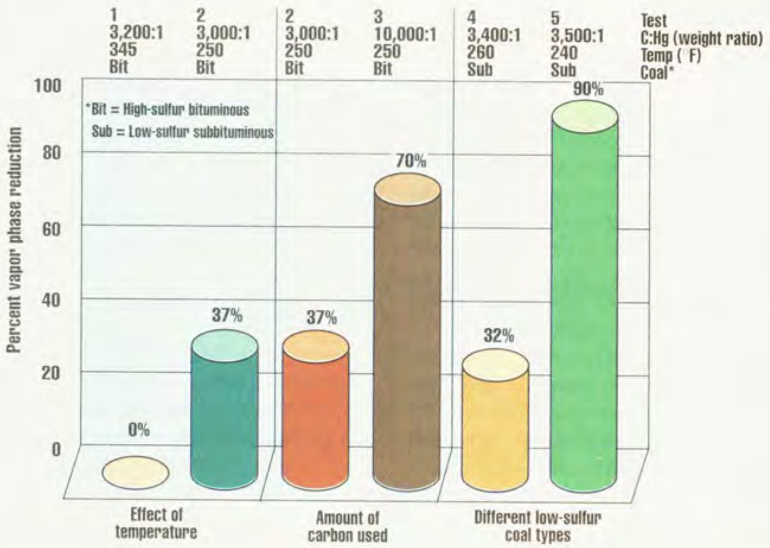
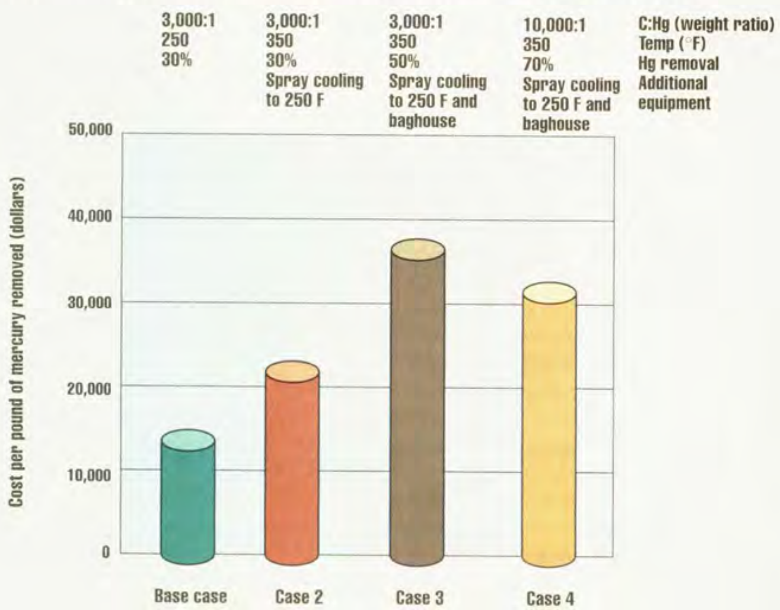


Figure 2

Preliminary cost estimates (levelized capital and operating cost)



To determine if activated carbon injection can be effective under the various operating conditions encountered in utility power plants, a better understanding of the factors affecting mercury removal is needed. Use of other sorbents (such as lower cost diatomaceous earth or zeolites, and various high-surface-area and chemically active materials) must be evaluated. The impact on the plant (e.g., degraded ESP performance and reduced ash salability due to excess carbon) must be determined. In addition, waste disposal options must be evaluated to ensure that mercury collected does not volatilize from landfills or present other solid or liquid waste problems. EPRI is conducting or planning projects to address these issues.

Due to the variability in mercury removal effectiveness in these tests, estimating activated carbon injection costs is difficult and somewhat speculative. Cost can be estimated using the limited data available and assuming specific mercury removal efficiencies (even though achieving these removal levels may not be possible).

Figure 2 shows four scenarios for activated carbon injection. At the hypothetical 250-MW, ESP-equipped, pulverized-coal plant used for this assessment, flue gas temperature was 250 F (cooled with spray gas cooling from 350 F in cases 2 through 4), and mercury flue gas concentration was assumed to average 10 micrograms/m_3.

Estimated removal costs (levelized annual capital and operating costs) range from $14,400 to $38,200 per pound of mercury removed, depending on the percent mercury removal and carbon/mercury weight ratio that are assumed, whether spray cooling is needed to achieve the 250 F temperature, and whether a baghouse is used to supplement existing particulate control equipment.

For example, case 4 has lower costs than case 3 even though more activated carbon is used, because of the higher mercury removal efficiency that was assumed. By contrast, costs to remove mercury from MWCs have been estimated at $200-$900 per pound of mercury removed.[16]

The pulverized coal plant analysis does not address uncertain factors such as spray cooling impacts (e.g., corrosion and ash deposition), water costs and the effect of high carbon injection levels on ESP and baghouse performance, as well as ash salability and waste disposal costs. All of these factors could dramatically increase the cost of mercury control, and further research is needed in these areas to assess some of the resulting problems and cost impacts.[2]

The science of controlling mercury emissions from utility power plants is poorly understood.

Wet scrubbing

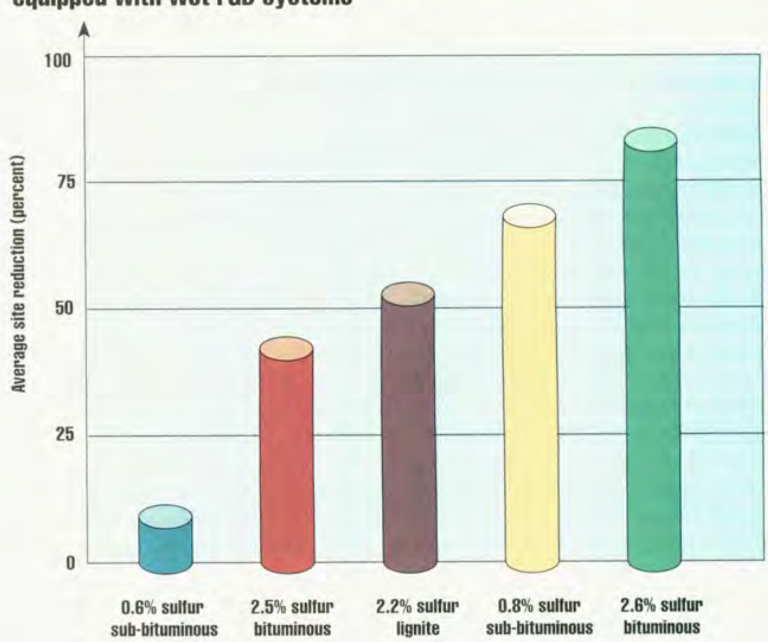
Fossil utility boilers equipped with wet FGD systems to reduce emissions of SO_x currently amount to approximately one-third of utility capacity nationwide. If these devices could also effectively remove mercury from flue gas, utilities might derive a double benefit from such equipment.

Figure 3, presenting information collected by EPRI and DOE, summarizes the mercury reduction observed at various full-scale sites equipped with wet FGD systems.[2] The data are based on the differences between the mercury concentration in the fuel and in the flue gas exiting the FGD system; they show that mercury removal across wet FGD systems using limestone ranged from 10 percent to 84 percent.

The wide range in mercury removal effectiveness with wet scrubbers appears to depend on the mercury species present and the scrubber design (mass transfer characteristics, or how effectively the scrubber liquid contacts the vapor). Differences in wet scrubber design and scrubbing effectiveness may explain why seemingly similar coals have very different scrubber mercury removal efficiencies.

Figure 3

Mercury removal at full-scale utility power plant sites equipped with wet FGD systems



However, the data available to date are insufficient to determine all factors that may affect mercury removal. Even for an MWC, where most of the mercury is assumed to be present as readily soluble mercuric chloride, wet scrubber testing at Fort Dix, N.J., demonstrated a range of 17 percent to 75 percent for mercury capture efficiencies.[17]

As in the activated carbon injection tests, accurately determining the mercury species present is difficult, especially when mercury speciation apparently changes along the flue gas pathway. Recent EPRI pilot tests showed that soluble oxidized mercury species such as mercuric chloride were readily captured, while insoluble elemental mercury was not captured with a wet scrubber.

A better understanding of mercury species present and their removal across the wet scrubber will direct the development of methods to influence the formation of those mercury species upstream that may be captured more effectively by FGD systems. EPRI is continuing to sponsor several projects on mercury control with wet FGD scrubbing to address these research needs.

For boilers with existing wet scrubbers, the cost of any mercury removal achieved with the wet FGD would be zero, assuming that equipment modifications or reagents are not needed and that mercury removed in the scrubber does not require additional treatment or special disposal. For boilers without wet FGD, the cost can be estimated by projecting the cost of constructing and operating an FGD system to remove mercury and assuming SO_2 removal as a side benefit.

Because utilities can trade "emission allowances" of SO_2 under CAAA provisions, SO_2 reductions have an actual market value. This value can be used to offset a portion of the costs of mercury removal. In this case, a credit of $160 per ton of SO_2 removed is assumed.

In a low-sulfur (0.48 percent) coal scenario that assumes 75 percent of the inlet mercury is in a soluble oxidized form such as mercuric chloride, and that 90 percent of the oxidized mercury can be removed by wet scrubbing (68 percent total mercury removal), estimated costs are $116,000 per pound of mercury removed (annual levelized capital and operating costs). In a more likely scenario, if 50 percent of the inlet mercury is in the oxidized form, and this species is removed with a 90-percent efficiency (45 percent of total mercury removal), estimated costs would be $174,000 per pound of mercury removed.[2]

In a high-sulfur (4 percent) coal case, the costs for mercury control are $76,000 and $114,000 per pound of mercury, for the cases in which 75 percent and 50 percent of the inlet mercury is in the soluble oxidized form, respectively. The actual cost of controlling mercury with wet scrubbing would increase significantly if SO_2 allowance values are lower or if scrubber sludge treatment comparable to that of hazardous waste is required.[2]

Other options

In Germany and Japan, activated carbon beds are used at some MWCs as final-stage polishing units for removal of dioxins, SO_x, NO_x, volatile organics and trace metals. These carbon beds are located downstream of primary FGD units and particulate collectors. Due to the large amounts of activated carbon used in these beds, mercury removal has been very effective in some applications. Activated carbon beds have also been used in isolated cases at utility power plants as primary SO_2 and NO_x control systems, typically in cases where unusual, site-specific economics favor these more expensive systems.[2]

For boilers with existing wet scrubbers, the cost of any mercury removal achieved with the wet FGD would be zero.

Direct adaptation of existing carbon bed technology to mercury removal from utility power plant flue gas is extremely costly because of the large flue gas volumes and low mercury concentrations involved. One researcher estimated the cost at $130,000 per pound of mercury removed.[18] A thorough engineering and economic analysis would be necessary to determine the feasibility of modifications that reduce bed size and the amount of carbon in the bed. Further, the effectiveness of the modified beds for mercury removal under various flue gas conditions needs to be determined.

Other researchers have shown that sodium sulfide injection can remove mercury from MWC flue gas streams, presumably by reactions to form mercuric sulfide, which is then removed by a particulate control device.[19] Because of limited testing and problems with mercury sampling and analysis, these results have been questioned.

Sodium sulfide injection has not been tested at full scale on utility flue gas. Potential problems also exist with corrosion, hydrogen sulfide formation, and chemical storage and handling.[2]

Future research

EPRI, in conjunction with its member utilities, is actively seeking solutions to many of the questions identified in this paper. The goal of this research and development is to enable utilities to act responsibly and cost effectively to any air toxics regulations. Results of EPRI efforts on methods to speciate mercury are expected by late 1996, and pilot-scale demonstrations of mercury control technologies are planned for 1997. Full-scale demonstration of the most effective technologies will be conducted thereafter, if warranted by risk analyses and resulting regulatory decisions.

Many other novel mercury control concepts, such as the use of gold film coated sorbents, carbon filter bags and pulsed corona discharge plasma are being proposed. However, each of these approaches are unproven, and much work remains to demonstrate their effectiveness.

Conclusions

Trace amounts of mercury are present in fossil fuels burned in utility power plants. However, mercury emissions from the combustion of these fuels are very low. The annual contribution of U.S. fossil-fuel-fired electric utility boilers has been estimated to be less than 1 percent of total global man-made mercury emissions. The risk to human health from utility power plant mercury emissions also appears to be low.

While mercury risk assessments conducted to date generally embody conservative assumptions, sufficient uncertainty in the science exists to warrant continued research. In addition, EPRI is assessing potential mercury control strategies, since any decision to regulate plant mercury emissions will need to consider the cost and effectiveness of available mercury control options against the benefits achievable.

The lack of reliable methods to measure and speciate low mercury concentrations has complicated development of suitable mercury control approaches for utility power plants. Much uncertainty remains as to the exact forms of mercury present in flue gas. These specifics must be quantified because the various mercury species not only exhibit different responses to potential control technologies, but also different atmospheric deposition properties.

Current technologies for controlling mercury emissions have been applied to MWCs. These plants differ from utility power plants in that they have one to three orders of magnitude higher flue gas mercury concentrations, lower gas flow rates, different flue gas compositions and different mercury species present than utility power plants. Thus, methods used in MWCs may not be applicable to utility power plant flue gas or comparable in cost.

Utility power plant tests of two methods used for MWC mercury control, direct carbon injection and wet scrubbing show the mercury removal efficiencies to be highly variable and dependent on flue gas conditions, coal type, fly ash and gas composition, mercury speciation, and sorbent and scrubber properties. While high mercury removal efficiencies were observed in some tests, low to moderate removal was measured at other typical plant conditions.

The level of mercury control achievable under different utility power plant conditions cannot be predicted confidently until more research is conducted. Therefore, a reliable and cost-effective mercury control method for utility boilers has not yet been determined.

Preliminary cost estimates to control 50 percent of the estimated 40 metric tons per year of total mercury emitted from U.S. utility power plants range from $1 billion to $10 billion per year. (These estimates assume that technologies such as activated carbon injection and wet scrubbing effectively remove mercury.)

Other issues that could add significantly to this estimated cost, such as the impact of mercury control technologies on existing plant equipment and the proper disposal of collected waste, must also be addressed.

Authors:

Ramsay Change is manager, Particulate and Air Toxics Control, in the Generation Group at the Electric Power Research Institute. He is responsible for assessing and developing particulate and air toxics control technologies for power plant emissions. He received his masters of science and doctorate in chemical engineering from Stanford University.

George Offen is team manager, Criteria Air Pollutants and Air Toxics Emissions, in the Generation Group at the Electric Power Research Institute. He is responsible for managing an R&D program for cost-effectively reducing NO_x, SO_2, particulate and air toxic emissions from utility boilers. He received his masters of science and doctorate in mechanical engineering from MIT and Stanford, respectively. ■

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