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Consulting to the Air Pollution Control Industry

Analysis of PM and Hg Emissions and Controls from Coal-Fired Power Plants

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to:

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I. Executive Summary

The Mercury and Air Toxic Standards (MATS) established emission standards for mercury (Hg), non-Hg metal hazardous air pollutants (HAPs)[1], and acid gases from coal- and oil-fired power plants. It also established detailed rules and procedures to demonstrate compliance with those standards, including monitoring and reporting requirements. While EPA regulated non-Hg metal HAPs, it permitted compliance with the non-Hg metal HAPs standards by complying with a particulate matter (PM) emissions limitation as an alternative surrogate pollutant.[2] This is the most common way that power plants chose to comply with the non-Hg metal HAPs requirements of the MATS rule. This report provides the results of an analysis of PM and Hg emissions data from coal-fired power plants and a discussion of the primary technological methods to control those emissions. The objective of this effort was to assess the emissions performance currently being achieved by coal-fired power plants with different control configurations and potential for additional reductions. The industry has made significant technological advances since the MATS rule was finalized in 2011. This analysis evaluated:

- New technology developments, including changes in costs, that may have occurred since 2011.
- More widespread implementation of technologies that may have been available in 2011 but were not widely deployed, and the resulting improvements in emissions performance.
- Developments in best practices that may have occurred since 2011.

In addition, with the understanding of the above, the analysis also considered whether the emissions standards established by MATS could potentially be made more stringent, to what degree, and at what cost, consistent with the requirements of the Clean Air Act. Section 112 of the Clean Air Act states: "[t]he Administrator shall review, and revise as necessary (taking into account developments in practices, processes, and control technologies), emission standards promulgated under this section no less often than every 8 years."

This analysis utilized a comprehensive dataset published by the Natural Resources Defense Council (NRDC)[3] that includes company-reported data on Hg, SO_2, HCl, and PM emissions, as well as facility characteristics, pollution control equipment installed, equipment age, and other factors. The data were compiled from publicly available data sources: WebFire, Air Markets Program Data, and EIA 860.

A. Conclusions regarding PM emissions

MATS set a limit on emissions of non-mercury metals, which present in the form of PM and can be controlled by technologies that reduce PM generally. MATS allows coal units to demonstrate compliance with the non-mercury metals limit by remaining under a filterable PM limit of 0.03 lb/MMBTu, which serves as a surrogate for measuring emissions of non-mercury metals. Coal units have overwhelmingly chosen to comply with the non-mercury metals limit by adhering to the surrogate limit on filterable PM.

[1] This report is focused on non-mercury metal HAP particulate matter but uses PM emissions as an alternative surrogate pollutant for the non-mercury metals which are regulated under MATS.

[2] PM from coal plants is comprised of non-Hg metal HAPs as well as other particulates. MATS established a filterable PM emissions limit of 0.03 lb/MMBtu as a surrogate for non-Hg metal HAPs.

[3] https://www.nrdc.org/resources/coal-fired-power-plant-hazardous-air-pollution-emissions-and-pollution-control-data

The PM control technologies discussed in this report help enable coal units to meet requirements for non-mercury metal emissions. The assessment of emissions data and analysis of methodologies for PM emissions control found that significant improvements in PM emissions rates since 2011 are largely the result of:

- Wider deployment today of technologies that may have existed in 2011, but were not widely deployed in 2011 (e.g., new filter bags, high frequency transformer rectifiers, continuous monitoring devices) and associated performance improvements based on greater experience.
- Improved practices. More attention paid by operators to keeping their PM emissions control equipment running well due to more regular and more robust monitoring.
- Technology improvements, including monitoring technology, filter bag technology, and electrostatic precipitator (ESP) technology.

Faced with a requirement to control PM emissions, industry found low-cost ways to achieve lower PM emissions that were not anticipated in 2011 or considered in EPA's 2011 assessment. Improvements in technology and operations since 2011, by technology type, include:

ESPs

- Correction of operational issues (e.g., leak repair, faulty electrodes, insulators, and plates); increases in treatment time (typically, $20/kW or less).
- High frequency transformer rectifiers (by far most common improvement approach (about $10/kW).
- Replacing or rebuilding internals (costs vary widely, likely in the range of $20-$50/kW).
- Adding fields or other approaches to increase treatment time (costs most likely over $50/kW).
- Fabric filter installed downstream of an ESP ($150-$200/kW to add FF, could be as much as $400/kW in the most challenging situations).

Fabric filters or baghouses[4]

- Correction of operational issues (e.g., casing and ductwork leak repair, typically, $20/kW or less).
- Improved maintenance and better management of bag cleaning processes.
- Bag and/or compartment leakage detectors to identify maintenance issues.
- Improved fabrics that are less prone to failure and clean more easily.
- Bag replacement (about $2-3/kW, roughly $1.15 million for 500 MW unit).

The impact of PM CEMS and "real-time" monitoring

- PM CEMS were considered a "new" or "emerging" technology in 2011, with limited application. Thus, many facilities did not install them. The technology is common today.
- More frequent monitoring allows facility operators to quickly identify and address potential problems.
- This is supported by the fact that PM CEMS are far more widely used among the best-performing versus worst-performing units.
- PM CEMS cost roughly $250,000 to install.

[4] The terms "fabric filter" (FF) and "baghouse" (BH) are interchangeable for the purpose of this document, and both refer to the same device or control technology.

Evaluation of PM Data

The PM emissions rate data from EPA Clean Air Markets Division and Energy Information Administration's boiler-level database, as reflected in the NRDC spreadsheet,[5] was evaluated by ATP, to include division of units into deciles by PM emissions rate. Decile 1 includes the units with the lowest PM emission rate, and decile 10 the units with highest PM emission rate. The assessment of top and bottom performing units (PM emissions rate) shows:

- There is room for significant improvement:
  - There are technological improvements that have been deployed and, in some cases, could still be deployed.
  - The difference in PM emission rate between top and bottom deciles is very significant – roughly a factor of ten.
  - It appears that at some of the bottom performing units, are doing "just enough" to satisfy the MATS limits.
- Type of installed control has some impact on overall performance, but is not the sole factor in a unit's performance:
  - A significant portion of decile 1 had both ESP and BH.
  - A significant portion of the top deciles are unscrubbed with only an ESP for PM controls, indicating that this configuration – the most challenging configuration - is capable of low emissions.
  - Top deciles consistently had newer equipment.
  - Top performing deciles are likely employing best maintenance and management of existing controls, contributing to low PM emissions.
  - Scrubbers make a difference, but scrubbers are not the deciding factor:
    - Scrubbers were more common among top performing units, but removal by scrubbers cannot alone explain the large difference between top and bottom deciles.
    - Scrubbers are likely an indication of the overall investment in and importance of the unit. Because of their high cost, scrubbers are typically installed on facilities that are regarded as vital units.
- Top deciles are far more likely to be using PM CEMS.
  - PM CEMS were relatively novel when MATS was developed, used at a fairly limited number of facilities.
  - PM CEMS provide feedback that can be used to identify problems right away.

Impact of a reduced emissions rate standard

Based on analysis of the compliance data from NRDC's spreadsheet, the coal fleet is, for the most part, controlling to well below the MATS PM emission standard; only a small number of units reported emissions close to the level of the emission standard. Therefore, a reduction in the emission standard

[5] https://www.nrdc.org/resources/coal-fired-power-plant-hazardous-air-pollution-emissions-and-pollution-control-data

would be possible without a large impact on the coal fleet. Analysis suggests that very little cost impact would result from a reduction in the PM emissions standard to 0.007 lb/MMBtu. Most units with ESPs could comply with this standard with only modest improvements or maintenance costs and some units with older ESPs would require relatively modest upgrades. At 0.003 lbs/MMBtu, some units with ESPs would need to install baghouses but roughly half of units with ESPs would be able to meet this standard with modest upgrades or no additional costs. Reduction of a PM standard to 0.0015 lb/MMBtu would likely require baghouses on all coal units and fabric upgrades for those existing baghouses that are not operating well enough to meet such a revised standard. Table 1 provides a preliminary estimate of the impact of reduction of the PM standard to different levels. This is believed to be a conservative estimate.

Table 1. Estimated impact of reduction in PM emission rate standard[6]

PM Limit (lbs/MMBTU) *(Current standard is 0.03 lbs/MMBTU)*	**Implications for facilities with ESPs**	**Implications for facilities with baghouses**	**Implications for fleet as a whole** *(Preliminary estimates)*
0.007	• Most units can meet with modest improvements • Units with ESP built in last 20 years should be able to achieve with modest maintenance costs (~$20/kW or less) • A few units with significantly older ESPs may need to undergo ESP upgrades/rebuilds (~$50/kW)	• Virtually all units can easily meet this limit with no additional costs • A few units may require some maintenance or bag replacement ($2-5/kW)	• More than half of all units can achieve with little to no additional costs, 42% of fleet is above 0.007 lb/MMBtu • $268M annualized cost with >7,200 tons PM reduction (preliminary estimate)
0.003	• Many units may need to make upgrades but should be technically feasible for all units • Roughly half of units with ESPs would need to install baghouses, especially those with ESPs older than 30 years ($150-200/kW) • Remaining units could achieve with modest upgrades ($20-50/kW • Units with ESPs and wet scrubbers may not be able to fit baghouse before scrubber, but could install wet ESP after scrubber ($100-150/kW)	• Many units can still meet this with little to no costs • Some units may need modest upgrades. For instance, units may need to replace bag ($2-5/kW) and replace every 3 years rather than 5 years.	• About 25% of fleet can achieve with little to no additional costs • $1.29B annualized cost with >16,800 tons PM reduction (preliminary estimate)
0.0015-0.002	• Most units with ESPs would need to install baghouses, especially those with ESPs older than 30 years ($150-200/kW) • Remaining units could achieve with modest upgrades ($20-50/kW) • Some ESPs would still not require additional investments	• Many units can still meet this with little to no costs • Some units would need modest upgrades ($5/kW)	• 12-20% of the fleet can achieve with little to no additional costs • $2.4B annualized cost with >22,900 tons PM reduction (preliminary estimate)
Less than 0.0015	• Nearly all units with ESPs would need to make substantial upgrades, including installing baghouses	• Most units would need to make modest upgrades	• Most units would require modest to substantial improvements • $2.5B+ annualized cost (preliminary estimate)

[6] Estimated costs and PM reductions are approximate, and based upon an assumed BH upgrade cost of $5/kW for upgraded bags, $20/kW for a minor ESP upgrade, $50/kW for major upgrade, and $150/kW for installation of BH.

B. Conclusions regarding Hg emissions control

Methods for controlling mercury include scrubbers, baghouses, and ESPs – all of which are primarily used to control other pollutants – as well as Hg-specific control technologies, especially activated carbon injection (ACI).

All methods of Hg controls experienced large advances as MATS focused the attention of power plant owners and technology suppliers on the goal of capturing Hg efficiently and at the lowest possible cost.

ACI, which is the most commonly used Hg-specific control technology, is a “dial up” technology that is used to increase Hg capture beyond the inherent Hg capture of PM or SO_2 control devices. Lower emissions can be achieved with increased carbon injection rates.

Hg technology developments

There has been a large reduction in Hg emissions compared to 2011 ICR collected data. Improvements in Hg emissions since 2011 were the result of:

- Wider deployment of mercury control technologies that existed when the MATS regulations were finalized in 2011.
    - Broader use of ACI that had been deployed in states with Hg rules.
    - Use of PM and SO_2 controls to reduce Hg emissions.
- Advances in Hg control technologies that were motivated by the need to control Hg on all coal fired power plants in order to comply with MATS. These included:
    - More advanced activated carbons that required lower treatment rates or were much more effective in situations that had previously been very difficult (for example, the presence of high levels of SO_3 or NO_2). These carbons also had less adverse impact on fly ash marketability, particularly for cement applications, further reducing cost.
    - Chemicals and other technological advances developed since 2011 to improve Hg oxidation and capture in PM or SO_2 control equipment.
    - Improvements in continuous Hg monitoring that facilitated improved monitoring and use of controls, including the ability to quickly identify and correct for potential problems.
- Development of “best practices” that did not exist prior to the adoption of MATS and its requirement to control Hg.
    - Limited experience in 2011 meant that “best practices” had not yet been developed.

Evaluation of Hg emissions data

The database from NRDC’s website shows that most of the coal fleet is operating well below the applicable standards. Hg capture was estimated from information in the IPM documentation, Chapter 9. For not low-rank coals, the data demonstrated that:

- There is substantial room for improvement, the top decile had an emissions rate nearly one tenth of the limit.
- The top six deciles are all controlling to over 90% removal, and the top two deciles well over 95% Hg capture.

- The top deciles are more likely to burn bituminous coal and more likely to be located in the East. The bottom deciles are more likely to burn subbituminous coal and more likely to be located in the West.
- The difference between top and bottom units was determined to be more a function of control equipment than coal type.
  - Top units are more likely to be scrubbed and also more likely to have a fabric filter.
  - Bottom decile units are more likely to have ACI controls installed; the data do not indicate the extent to which ACI controls are actually operating or the treatment rates being used.
  - Top decile units did include unscrubbed units with an ESP+ACI, demonstrating that high removal was possible for that configuration.

For low-rank coals it was demonstrated that:

- All units are complying with emissions below the 4 lb/TBtu standard.
- Only two of the units are unscrubbed, and these have BHs. These are also the lowest emitting units.
- Estimated Hg capture rates are generally well below 90% -- much lower than the capture rates that ACI is capable of. This is likely because the higher emission rate limit for these units does not require greater capture rates.
- The large majority of units utilize ACI; the four that don't are scrubbed and may use oxidizing agents or other chemicals to enhance Hg capture in the PM or SO_2 control device.

Impact of reduced emissions rate standards

The coal fleet is currently complying with the Hg emissions standard and in most cases is achieving emission rates that are well below the standard.

- For not low-rank coals, a lower Hg standard of 0.7 lb/TBtu could be complied with at a modest cost to some units, and no cost for most units.
- For not low-rank coals, a lower Hg standard of 0.3 lb/TBtu could be complied with at a modest cost to most units, and no cost for some units. The cost would not exceed 1 mill/kWh and would likely be much less. Units with fabric filters would have very little cost increase, if any.
- For low-rank coals, a lower standard could be complied with, as it appears that the estimated capture rate of these facilities is well below what is possible for available technologies. The highest estimated coal Hg content is 14.9 lbs/TBtu. These seven units are all units burning Texas Lignite, and they are equipped with scrubbers. Two have baghouses, and five have ESPs. Therefore, as scrubbed units, they are all capable of achieving higher capture rates (current capture rates are estimated at 80%-85% based upon 2019 data). About a third of all low rank coal units are already controlling to below 2 lbs/TBtu. A standard of 2 lbs/TBtu would necessitate modest increased cost that would likely be well below 1 mill/kWh, as this is consistent with under 90% removal in all cases. A control level of 1 lb/TBtu might also be justified, as this would require less than 95% capture in every case, and in most cases much less. Units with fabric filters would experience very little cost increase, if any. Wet-scrubbed units could enhance capture using scrubber chemicals at a modest cost, likely well below 1 mill/kWh.
- Table 2 summarizes the estimated impact of reducing the Hg emission limits.

Table 2. Estimated impact of reduction in Hg emission rate standard

Hg limit for not-low rank coal units (current standard 1.2 lb/TBtu)	**Units with Electrostatic Precipitators**	**Units with Baghouses**	**Overall**
0.7 lb/TBtu (equivalent to 90% Hg removal)	• Majority of units would have little to no additional cost • Roughly 25% of units would need to increase ACI treatment at additional cost of 1 mill/kWh or less	• Virtually all units can control to this level with little to no incremental cost	• Less than 50% of units are above 0.7 lb/TBtu
0.3 lb/TBtu (equivalent to 95% Hg removal)	• 75% of units with ESPs would need to increase ACI treatment at cost of 1 mill/kWh or less • If a unit installs a baghouse to meet the PM standard, it would not need any additional ACI	• Most units can control to this level with little or no incremental cost • Few units would incur 0.25 mill/kWh cost or less	• Roughly 50% of units are above 0.3 lb/Tbtu

Hg limit for low rank units (current standard is 4 lb/TBtu)	**Scrubbed units**	**Unscrubbed units**
2 lbs/TBtu (< 90% Hg removal)	• Low-Modest cost for most units, no cost for about a third of units	• No cost for one unit; modest cost well under 1 mill/kWh for other two
1 lbs/TBtu (< 95% Hg removal)	• Low-Modest cost of up to 1 mill/kWh for most units	• No cost for one unit; cost of up to 1 mill/kWh for other two

II. Methods of PM Control

Various methods of PM control were examined to identify how they work, how the technologies have been improved since 2011, and what may be possible going forward. This section of the report includes:

- A brief explanation of how these control devices work, to illustrate potential means to improve the performance of the devices and potential limitations on any performance improvements.
- A discussion of the type of improvements that can be performed for an existing control technology, the degree of performance improvement available, and what those improvements might cost.
- A discussion of the impacts of activated carbon injection and gas cofiring on PM control, as these are deployed on a fairly wide level in the industry.
- A comparison of operation of the technology pre-MATS and post-MATS.
- Conclusions regarding possibilities for more stringent emission limitations, and what their cost impact would be.

A. Electrostatic Precipitators (ESPs)

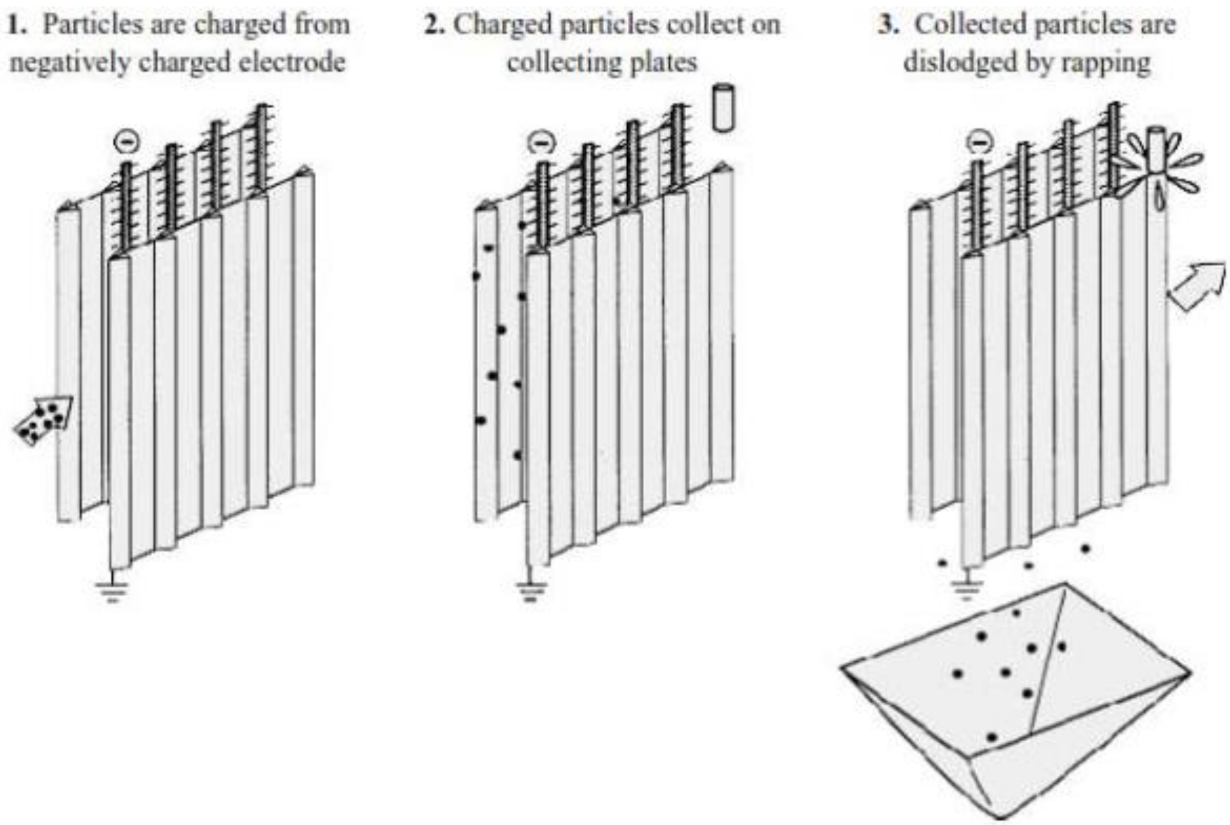
A large majority of coal power plants utilize ESPs for PM emissions control. The following section discusses the major factors that impact ESP performance, how ESPs were generally operated prior to MATS and what has changed since MATS.

How ESPs work

ESPs capture PM emissions by charging the PM electrically so that it is attracted to a collection plate. The untreated flue gas passes through parallel collection plates, between which are placed electrodes that charge the PM. The PM is knocked off of the collection plate by a "rapper," sonic horn, or other device that mechanically knocks off the collected PM (see Figure 1).

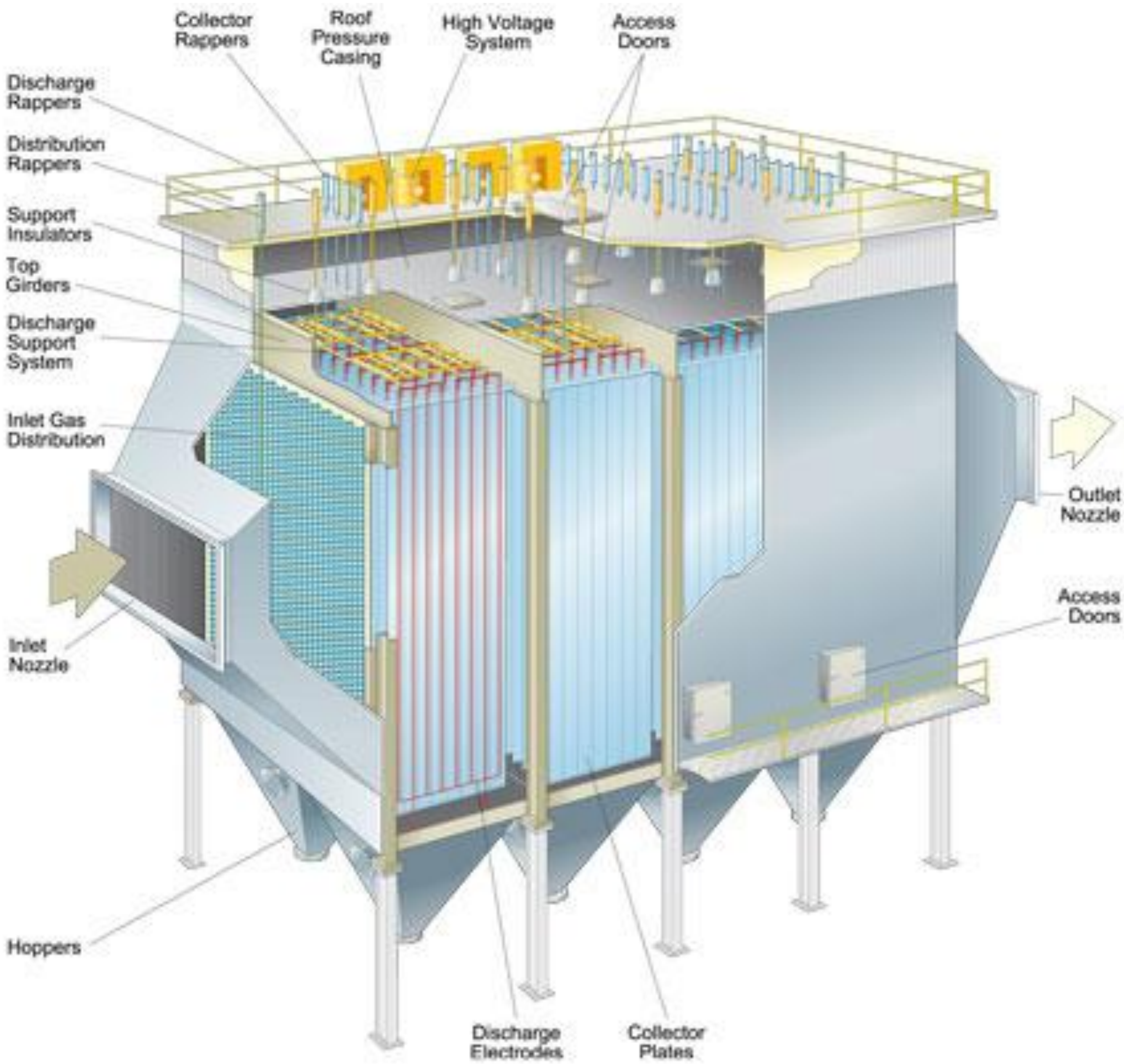
In an ESP, the boiler exhaust gas enters through ductwork, passes through a flow-balancing device in the form of a grid, and then passes through a series of electric fields used to capture the PM. Figure 2 shows an ESP. The gas flow enters from the left in this image. The image also shows the flow passing through several (typically, 3 or more) sequential fields with electrodes and collection plates. Finally, the treated gas exits the ESP to the right.

Figure 1. How an ESP works. [7]



[7] http://www.hamonusa.com/hamonresearchcottrell/products/esp_fundamentals

Figure 2. An electrostatic precipitator, (ESP).[8]



Factors that affect ESP performance

More factors affect ESP performance than FF performance, and the factors that affect ESP performance are often interrelated. Some of these factors and how they are addressed include:

- Treatment time (and flow balancing) – treatment time is the amount of time that the exhaust gas spends between collecting plates as it passes through the ESP. More treatment time improves PM capture. Unbalanced flow means that some parts of the gas have a lower treatment time. Methods to improve (increase) treatment time include:
    - Enlarge ESP, replace internals, improve/balance flow, fix leaks, add fields.
- Re-entrainment – this is re-release of PM when the field is rapped for cleaning, and it will increase outlet PM emissions. It is addressed by:

[8] https://www.babcock.com/resources/learning-center/basic-esp-operation

- Sectionalization – breaking the ESP into multiple, sequential fields so that the final field experiences lower inlet PM loading than the first field. ESPs typically have a minimum of 3 fields and newer ESPs frequently have 5 or more fields.
  - Re-entrainment can establish a threshold of emissions that cannot be lowered below. The degree of re-entrainment will depend upon the design of the ESP, the nature of the fly ash, and especially the number of fields.
- Power level – electrical power into the ESP captures the fly ash, but it may be limited by a number of things that can be addressed by:
  - Repair/replacement of failed electrodes and insulators that limit power input.
  - High frequency transformer rectifiers that improve power that can be input to the ESP.
  - Replacement of internals ("gut and stuff"), weighted wire to rigid discharge electrode (RDE) conversion (improves reliability).
- Resistivity – This relates to the electrical characteristics of the PM being captured. It must be in a proper range – not too high and not too low.
  - Most often a problem of too high rather than too low - often a problem with lower sulfur coals because the presence of SO_3 lowers resistivity to near the ideal level and insufficient SO_3 will increase resistivity to above the ideal level.
  - High resistivity is often addressed through flue gas conditioning – injecting SO_3 or another chemical that improves fly ash resistivity.

As PM emission standards have been reduced over the years, utility ESP treatment times have also become longer, which means that ESPs have become larger for any given coal type and gas flowrate, as shown in Figure 3. Longer treatment times for a given outlet emission rate would generally be associated with lower sulfur coals and shorter treatment times are associated with higher sulfur coals. Lower sulfur coals typically have higher resistivity fly ash that is more difficult to capture and requires longer treatment times or flue gas conditioning by injection of SO_3.

Figure 3. ESP treatment time, required particulate emissions and typical treatment times. [9]

Date	Required Particulate Emissions, LB/MMBTU	Typical Utility ESP Treatment Time, Seconds
1970s	0.10	5-13
1980s	0.03	7-20
1990s	0.03	8-25
2000s	0.015-0.03	10-25

Longer treatment time means a larger ESP

[9] R. Mastropietro, "Electrostatic Precipitator Rebuild Strategies For Improved Particulate Emissions"

ESP operation prior to MATS and improvements since 2011

Prior to MATS, most ESPs did not receive significant attention, unless a significant problem arose. This is because PM was not monitored or reported with the regularity of pollutants such as NOx or SO_2. Continuous PM emissions monitoring was only installed on units that had installed these devices in response to Consent Decrees or other state requirements. Prior to MATS, for most coal units the only continuous monitoring device intended for PM was an opacity monitor, which is a far less reliable indicator for PM because it monitors a surrogate for PM. Stack tests were performed on perhaps a yearly basis as determined by the state requirements. As a result, problems could go unnoticed for a while, or would not be noticed until they were significant enough to get attention, and this inattention resulted in higher PM emission rates over time.

MATS emission rate requirements and monitoring requirements (continuous PM monitor or, alternatively, quarterly stack tests), and especially the need to report the results, made operators of coal-fired power plants much more attentive to the PM control devices, including ESPs.

Prior to MATS, many of the coal units had substantial room for improved PM emissions performance simply because the limited monitoring and reporting requirements had often left problems unidentified or unaddressed. These problems included ductwork and casing leaks that resulted in more than design gas flow through the ESP (lowering treatment time), damaged or out of service fields or electrodes, etc., correction of uneven flow, and other factors.

Fundamental ESP technology has not experienced revolutionary changes since 2011; however, since 2011 various technology improvements have been deployed across the population of ESPs. Furthermore, as will be shown, there are numerous ESP improvement methods that were available in 2011 which may have been deployed since then and in some cases could still be deployed. Not all of these methods were considered in EPA's 2011 assessment and/or the costs of these methods are lower than what EPA assumed in 2011. Moreover, after years of minimizing the attention given to ESPs, industry has learned and started to adopt "best practices" associated with monitoring ESP operation more carefully and maintaining the ESP regardless of whether or not they have made any modifications to the ESP.

There is no universal type of ESP rebuild or other improvement. Across the fleet of ESPs, the improvements, if any, were tailored to the particular situation. As a result, some units have deployed more intensive ESP improvements than others. In many cases, more could be done, often at costs of between \$20-\$50/kW. Furthermore, depending upon the treatment time, coal characteristics and degree of sectionalization of the ESP, there is a limit to the outlet emission rate that is possible due to the phenomenon of re-entrainment in the final ESP field. As a result, some ESPs will reach a practical limit to what is achievable with the existing ESP without adding more fields or adding a baghouse. These types of projects could cost over \$50/kW for adding more fields and on the order of \$150/kW-\$200/kW for addition of a baghouse. The specific costs of these methods are addressed in the following section. The degree to which these retrofits would be necessary would depend on the specific emission limit of a future standard, because there are less expensive means to reduce PM emissions from the ESP at higher emissions limits. This is discussed in more depth below.

Methods for improving ESP performance

There are many ways to improve ESP performance. Cost and performance improvement estimates for each method are approximate and will vary depending on site specific factors. In its IPM v4.10 documentation, US EPA estimated the cost of three methods for improving ESP performance.[10] It is notable that, at the time, EPA was evaluating a proposed PM limit that included condensable PM, which was changed in the final MATS rule. This is partly why the filterable PM trigger points for the three options are all below the filterable PM limit in the final rule. The three methods for upgrading ESP performance included:

- Option 1: High frequency transformer rectifier (HFTR) sets, at an estimated capital cost of $55/kW to be installed for PM emissions up to 0.005 lb/MMBtu.
- Option 2: HFTR and replacement of ESP internals, at an estimated capital cost of $80/kW at PM trigger points over 0.005 up to 0.01 lb/MMBtu.
- Option 3: HFTR, replacement of ESP internals, and addition of an ESP field, at an estimated capital cost of $100/kW at PM trigger points over 0.01 up to 0.02 lb/MMBtu.

In effect, in this methodology every unit with an ESP would incur a cost of at least $55/kW. EPA also included a fourth option of installing a fabric filter in the event filterable PM emissions were over 0.02 lb/MMBtu. Costs of installing a fabric filter will be discussed later. The discussion that follows will demonstrate that there are additional means to improve ESP performance and that the cost and performance improvement estimates in the IPM v4.10 documentation are higher than what has been found in this effort.

The various ways to improve ESP performance, along with the associated approximate costs, include the following: [11]

Repair casing leaks and/or improve flow balancing

- Boiler casing, duct and air preheater leaks increase the flowrate through the ESP, reducing treatment time and adversely impacting performance.
- Imbalanced flow will also result in portions of the gas having low treatment time, which adversely impacts performance.
- Many coal plant operators have learned to live with air preheater leakage of over 20%, which is a large waste of energy.[12] A more reasonable level of leakage is 10% or less.

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[10] Table 5-25 of the 4.10_MATS IPM documentation: https://www.epa.gov/sites/production/files/2015-07/documents/suppdoc410mats.pdf. Three methods of improving ESP performance are shown along with the cost of a fabric filter retrofit.

[11] Costs discussed here are approximate. Data taken from electric utility projects to support these costs will be discussed later.

[12] https://www.power-eng.com/emissions/air-heater-improvement-small-investment-quick-payback/#gref; the vast majority of air preheaters are of the regenerative type, which have an intrinsic amount of air leakage that ideally is minimized.

- Usually, this is a relatively inexpensive improvement. This is not expected to cost much more than about $20/kW.
- A 20% reduction in flow will yield a 25% increase in treatment time – equating to roughly a 40% reduction in PM emission rates.[13]
- A benefit of this is an improvement in boiler heat rate thus reducing the net cost of the improvement because of lower fuel costs. Replacement of air preheater seals (not the entire air preheater) is a relatively inexpensive improvement that provides a good payback.[14]

Repairing the ESP – with in-kind equipment

- Damaged fields can result from wear and tear and leave a portion of the gas untreated – effectively, shortening treatment time.
- Repair or replacement of failed insulators, electrodes or even plates can restore performance – yield perhaps up to 20% - 30% improvement or more, depending upon the defect being corrected.
- Cost depends upon nature of repair, but generally are about $20/kW or less.

Install High Frequency Transformer Rectifier Sets (HFTR) (equivalent to Option 1 of EPA's three options from IPM v4.10, where EPA estimated the capital cost at $55/kW)

- HFTR sets do the following:
  - Change electrical controls to increase the frequency of charging the electrodes.
  - Increases the amount of power put into the ESP and used to charge particles.
- An inexpensive means to achieve moderate improvements in PM emissions.
- Few ESPs had this upgrade prior to MATS
- On the order of 20%-30% improvement or more at a cost of about $10/kW or frequently less.
- This is at a low cost and provides a good benefit. Therefore, HFTR was deployed in response to MATS at many locations.

Improving ESP Reliability – upgrade to newer or more reliable components, even if not damaged

- Replacement of electrodes and insulators.
- Replacement of damaged plates.
- Replacement of weighted wire electrodes with rigid discharge electrodes.
- Cost and performance improvement will vary depending upon what is done.

Complete rebuild within existing casing (aka, "gut and stuff") (equivalent to Option 2 of EPA's three options from IPM v4.10, where EPA estimated the capital cost at $80/kW)

- This entails replacing all of the internals within the existing ESP casing and normally the associated ESP control and power electronics as well. Although there may be casing or ductwork repairs, it

[13] See R. Mastropietro, "Electrostatic Precipitator Rebuild Strategies For Improved Particulate Emissions" for information that shows the relationship between treatment time and emission rate
[14] https://www.power-eng.com/emissions/air-heater-improvement-small-investment-quick-payback/#gref