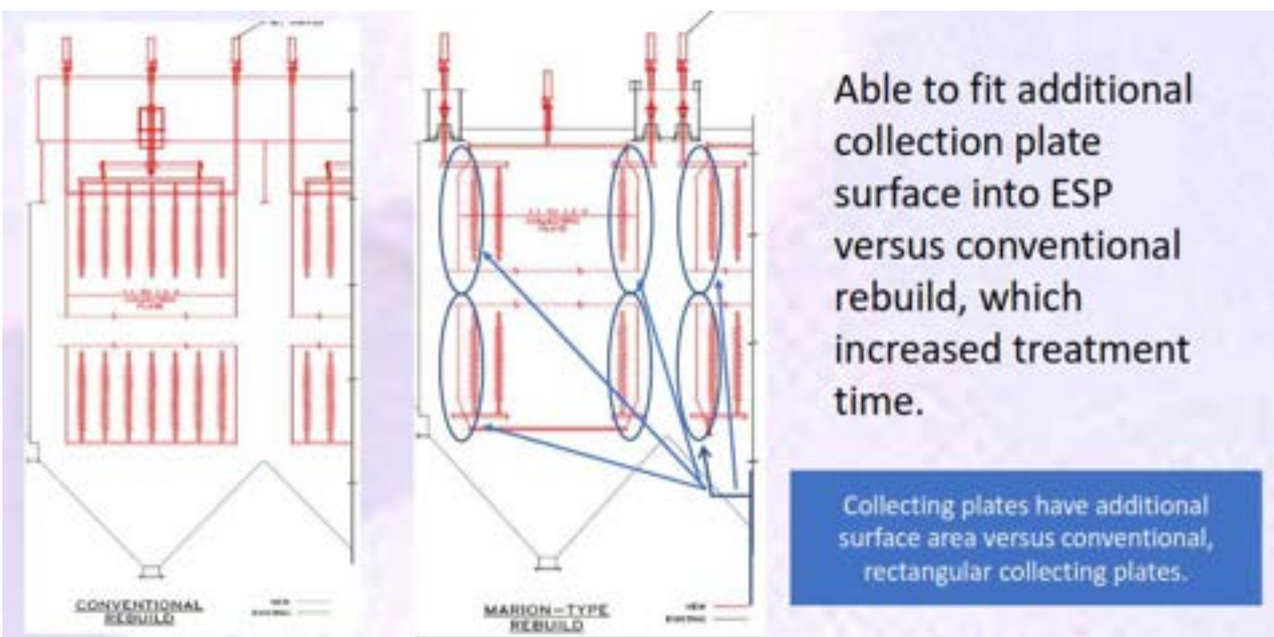
generally does not require significant changes to the ESP casing or support structure or ductwork because it works within the existing casing and ductwork. This rebuilds the ESP to original performance, or perhaps better since components and controls have improved. This would typically include HFTR upgrade since the cost of including it is relatively small and electrical controls are normally being replaced in any event.

- This is less of a major upgrade as much as a restoration of the ESP to "like-new" condition, or better. It should be done periodically because of routine wear and tear and associated deterioration of performance – perhaps every 25 years or so - simply to restore the performance of the ESP. The level of wear and tear will be determined by the specific application, with some more challenging than others. Although this sort of upgrade is recommended, these are not universally performed on old or degraded ESPs if emissions are within the limit. If performed more frequently, this type of upgrade would make PM emissions lower and more consistent than what is experienced with historical practice.
- Benefits include higher power input and greater reliability, and typically can improve treatment time as well by optimizing the treatment volume within the existing ESP casing. An example is the rebuild at Southern Illinois Power Company's Marion unit #4, as shown in Figure 4. 2011 EIA Form 923 shows typical PM emissions of 0.04 lb/MMBtu for this unit, while the reported PM emissions in 2019 for it averaged 0.00343 lb/MMBtu,[15] or a roughly 91% reduction in PM emissions, achieving an emission rate roughly one ninth the MATS PM emissions limit.
- Cost would be about \$50/kW – and will vary depending upon the specifics of the ESP.

Figure 4. Rebuild at Southern Illinois Power Company's Marion unit #4. [16]



[15] See NRDC database
[16] R. Mastropietro, "Electrostatic Precipitator Rebuild Strategies For Improved Particulate Emissions"

Increasing the casing volume to increase treatment time (Equivalent to Option 3 of EPA's three options from IPM v4.10, where EPA estimated the capital cost at $100/kW)

- This entails rebuilding the ESP in a manner that increases treatment time beyond what is possible within the existing ESP casing – raising height, adding fields, or other work outside of the existing ESP casing, along with improvement of existing equipment.
- This can be done by adding fields, adding a parallel chamber, or increasing height of the ESP, as shown in examples in Figure 5, Figure 6, and Figure 7, respectively.
- This is the most expensive option relative to other measures detailed above and therefore this is a fairly rare retrofit. The cost is normally between $50/kW and $80/kW, perhaps higher in some cases. Additional fields for an ESP have been estimated to be in the range of $65/kW for some projects. It will often include HFTR upgrade.
- This also requires having adequate space, which is a major limitation on this type of improvement.

According to data presented by Mastropietro,[17] a roughly one-third increase in treatment time will reduce emissions by about 50% and a roughly two-thirds increase in treatment time will reduce PM emissions by about 70%. There is a threshold where further PM emission reductions will not be possible. This is because of the effect of re-entrainment emissions from the final field of the ESP. The impact of re-entrainment on outlet emissions will be determined by the particulars of the ESP, especially, the number of fields, but also inlet loading, condition and treatment time of upstream fields, and resistivity of the fly ash. As a result, some ESPs may not be able to achieve an adequate reduction in emission rate without addition of fields in a major ESP upgrade or addition of a fabric filter.

Because major ESP upgrades that add fields or expand the ESP casing become costly and may be limited by space, such upgrades are rare, and a utility will seriously consider the alternative of a BH. A BH retrofit will cost significantly more than a major ESP retrofit, but it offers several advantages for control of mercury and acid gases as well as PM, as will be discussed later.

[17] Mastropietro, "Electrostatic Precipitator Rebuild Strategies For Improved Particulate Emissions"

Figure 5. ESP rebuild that adds an additional field[18]

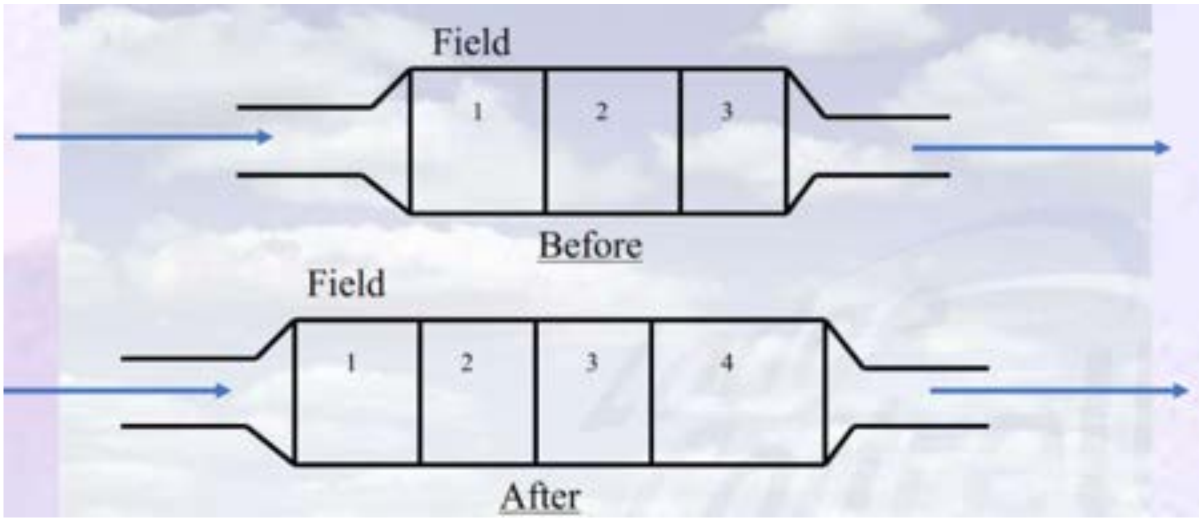
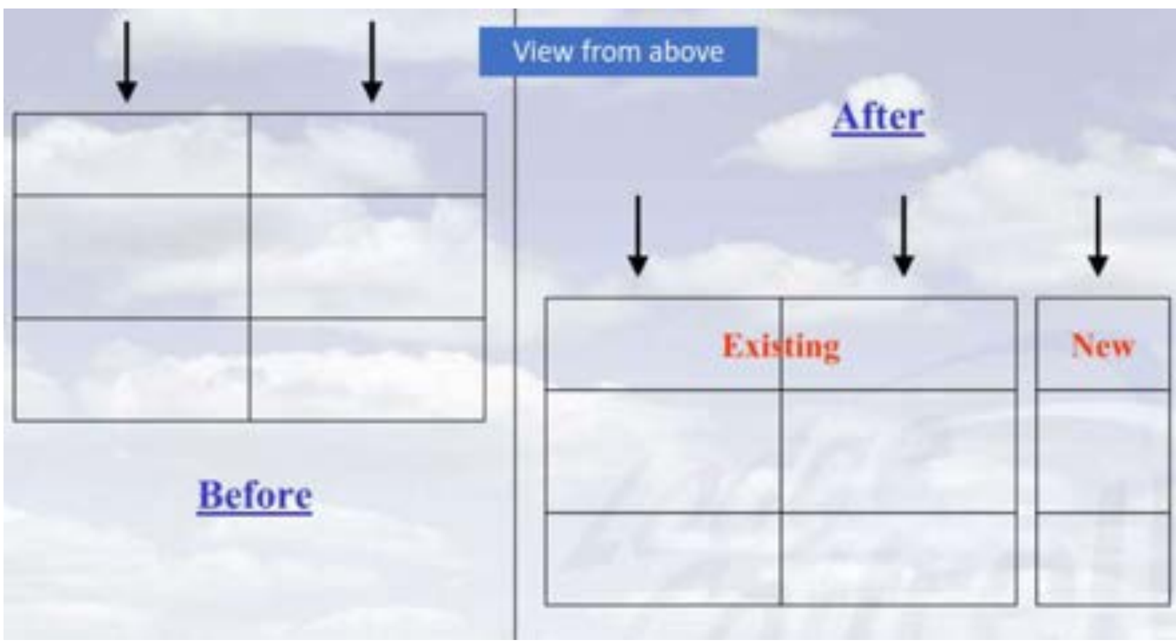
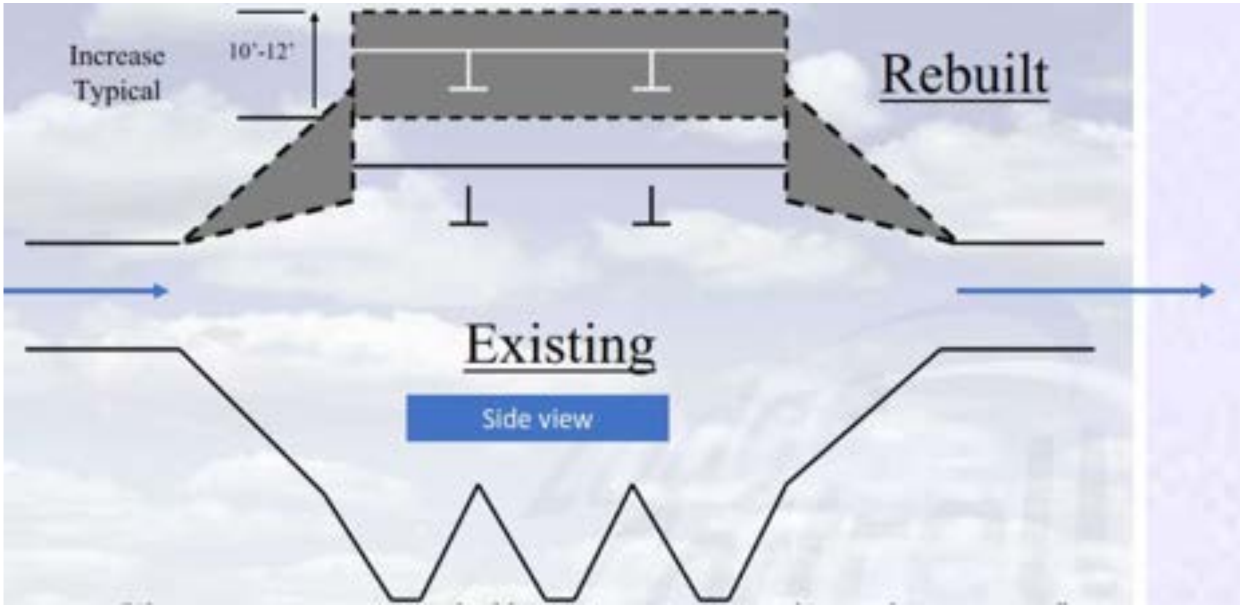


Figure 6. ESP rebuild that adds a parallel chamber[19]



[18] Ibid.
[19] Ibid.

Figure 7. ESP rebuild that increases the height of the ESP [20]



Data on cost of ESP upgrades

ATP has assembled data collected from utility capital budgets that it has reviewed in the normal course of its business. The data, that is presented in Table 3, has been normalized to a $/kW (2012 $) basis and any information that could be used to identify the plant or unit is not provided. In some cases, the details of what was included in the budget was not available. The costs range from a low of $4/kW for HFTR upgrades on one unit to over $80/kW for ESP changes that included increased volume. Additional fields for an ESP were in the range of $65/kW. Duct repairs cost in the range of about $6-$18/kW. In some cases, this includes repair of expansion joints that are used to connect ductwork and allow for thermal expansion. The expansion joints are frequently the locations of leaks. The large number of HFTR project budgets is an indication of the attractiveness of this approach. Every project is unique. For any other situation, these costs should be regarded as indicative of rough cost estimates, recognizing that there might be some significant differences. Some applications that included HFTR sets also included other ESP improvements, including repair or replacement of some ESP components, such as electrodes, insulators, and plates. Some of these projects did not proceed because the unit was ultimately retired, but that is not believed to impact the validity of these utility estimates. The data on installation of a wet ESP is shown, and this data will be discussed later.

[20] Ibid.

Table 3. Costs for ESP upgrades or modifications.[21]

Row Labels	Average of $/kW	Max of $/kW	Min of $/kW	Count of projects
Add Field to ESP	$65	$65	$64	2
Additional ESP	$52	$52	$52	1
Duct Repairs/expansion joint	$14	$18	$6	4
ESP (HFTR)	$8	$25	$3	32
ESP Changes (incl enlargement)*	$22	$82	$3	22
ESP Tune-Up	$4	$6	$2	2
WESP	$175	$180	$160	7

* The wide range of costs and large number of projects is indicative of a wide range of project types – from minor ESP changes to far more major ones. For these projects, the project description either did not have adequate detail to clearly put it into another project category, or it included several project characteristics.

Impact of activated carbon on ESPs

As described by Mastropietro,[22] activated carbon will slightly reduce the resistivity of the fly ash. This small positive impact on PM capture generally offsets the small increase in inlet PM loading. So, for well-designed and functioning ESPs, ACI generally does not increase outlet PM emissions. As Staudt has described, experience has shown that ACI has had no measurable adverse impact on outlet emissions of the ESP.[23]

Effect of cofiring natural gas on ESP operation

The cofiring of natural gas with coal will reduce exhaust gas SO_3 concentration somewhat, increasing fly ash resistivity and adversely impacting PM capture. Cofiring natural gas will also reduce PM inlet loading. The impact of resistivity on reduced capture will usually be greater than the impact of reduced inlet PM loading on outlet PM emissions. However, reducing fly ash resistivity is easily performed at a very low cost with flue gas conditioning, which is widely used for ESPs on boilers that have changed fuels to lower sulfur coal.

B. Fabric filters (aka baghouses)

The terms fabric filter and baghouse will be used interchangeably in this report. They refer to the same device and these terms are commonly used interchangeably in industry.

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[21] These are reported in 2012 $ and can be escalated to 2020 $ using the CEPCI. The 2012 CEPCI was 584.6 and the 2020 CEPCI was 596.2, or roughly 2% increase in cost. Additional data is in the appendices.

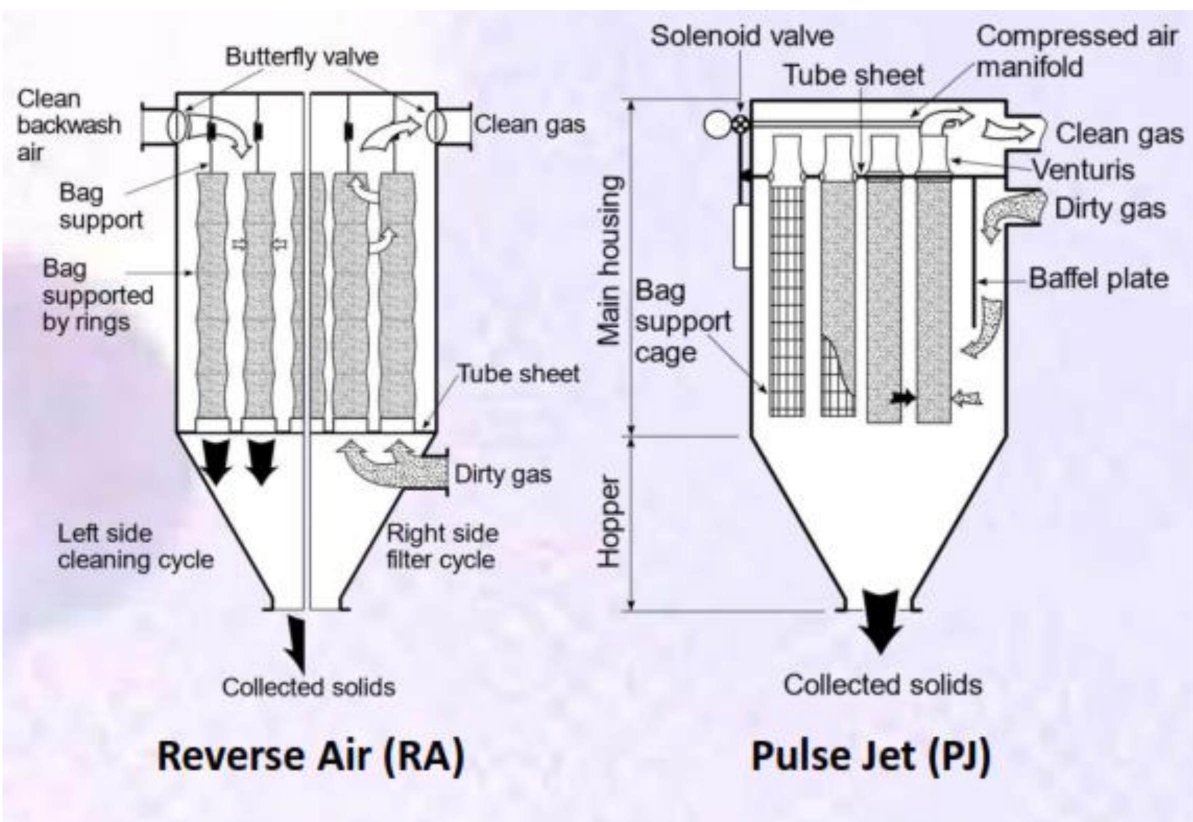
[22] Mastropietro, R., "Fly Ash Resistivity with Injected Reagents and Predicted Impacts on Electrostatic Precipitators," http://www.carmeusena.com/sites/default/files/brochures/flue-gas-treatment/tp-LCI-NOL-TEC-Systems-inj-reagents-fly-ash-resistivity-ESP-perf.pdf

[23] Staudt, J., "Does ESP Size Really Matter", at https://www.andovertechnology.com/wp-content/uploads/2021/06/Does-ESP-size-really-matter.pdf.

How they work

Fabric filters used in coal fired power plant applications are predominantly of two types: reverse air (RA) or pulse jet (PJ), pictured in Figure 8. In both cases, untreated flue gas enters the baghouse and passes through a fabric filter that is in the shape of a long cylinder (which for PJ baghouses is closed at the bottom and for RA baghouses is often closed at the top – thus, the term filter "bag" or "baghouse"). The fabric filter separates the particulate matter from the gas, and the treated flue gas then leaves the baghouse. In the case of RA baghouses, the gas typically passes from the inside of the cloth cylinder to the outside of the cylinder. For PJ baghouses the gas passes from the outside of the fabric cylinder to the inside of the cylinder (the cylinder is closed at the bottom and sealed to a tube sheet at the top). An internal wire cage prevents collapse of the filter bag during operation. The treated flue gas leaves the fabric filter through the top. The filters must be periodically cleaned. For RA baghouses, a portion of the baghouse called a compartment is shut off from the untreated gas flow, and treated air is passed through in a reverse direction that causes the collected PM to fall to the bottom of the baghouse. Rings prevent collapse of the filter bag during cleaning. For PJ baghouses the filter bags are periodically cleaned by a jet of pulsed air introduced to the open top of the bag, flexing the bag fabric outward, and causing collected PM to drop to the bottom of the baghouse. For both baghouse types, the solids collect in the bottom hopper of the baghouse and are discharged to the ash collection system.

Figure 8. Reverse Air and Pulse Jet baghouses

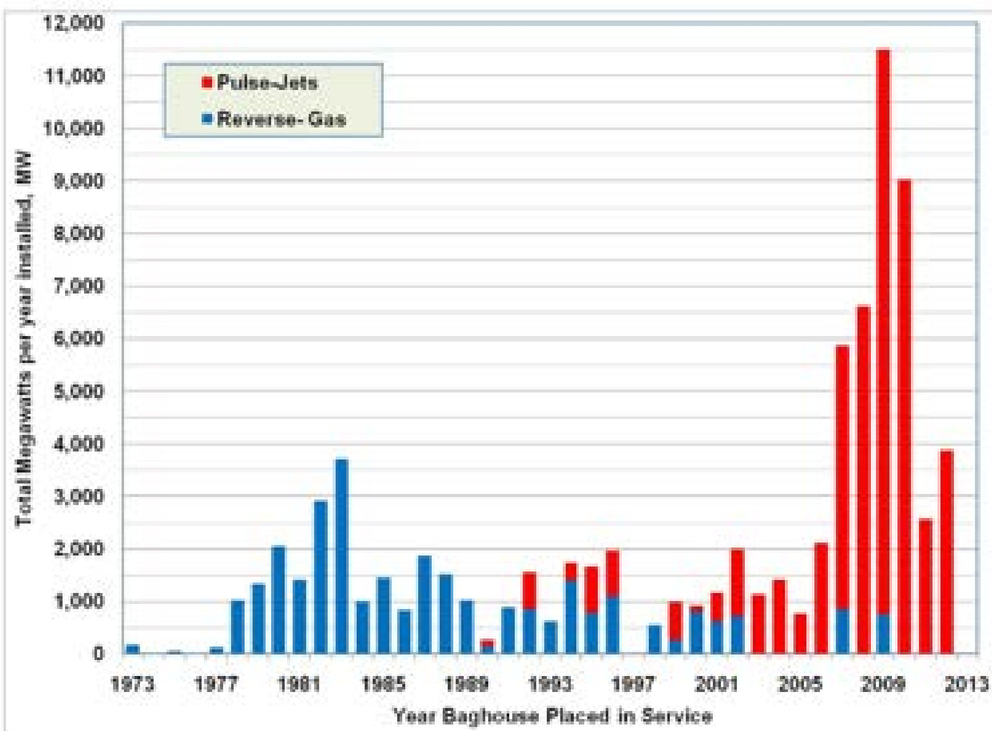


Newer baghouses tend to be PJ type since they are frequently less expensive to build[24] and more compact in size because they can handle a higher gas flowrate for a given square footage of filter fabric (see Figure 9). A PJ baghouse does not have to shut down a compartment in order to clean but they require more durable fabrics because the cleaning is more energetic. More reliable and durable fabrics have made PJ baghouses more attractive today.

The cost of a fabric filter retrofit will be dependent upon the size of the unit and the complexity of the site. Sites that require long duct runs to accommodate locating the baghouse will be much more expensive than others. Figure 10 shows reported costs of fabric filter retrofits. As shown, most retrofits are in the range of about $100/kW to $250/kW. However, some may be more expensive due to site space limitations that would make it necessary to have long duct runs.

An important design parameter for baghouses is air-to-cloth ratio, or AC. AC is equal to the actual cubic feet per minute of gas flowrate through the baghouse divided by the square footage of filter material in the baghouse. There is an advantage to operating at a lower AC because fabrics last longer; however, that requires a more expensive baghouse that must be larger to accommodate more filter fabric for a given, treated gas flowrate. PJ baghouses have a somewhat higher AC than RA baghouses designed for the same gas volume flow rate.

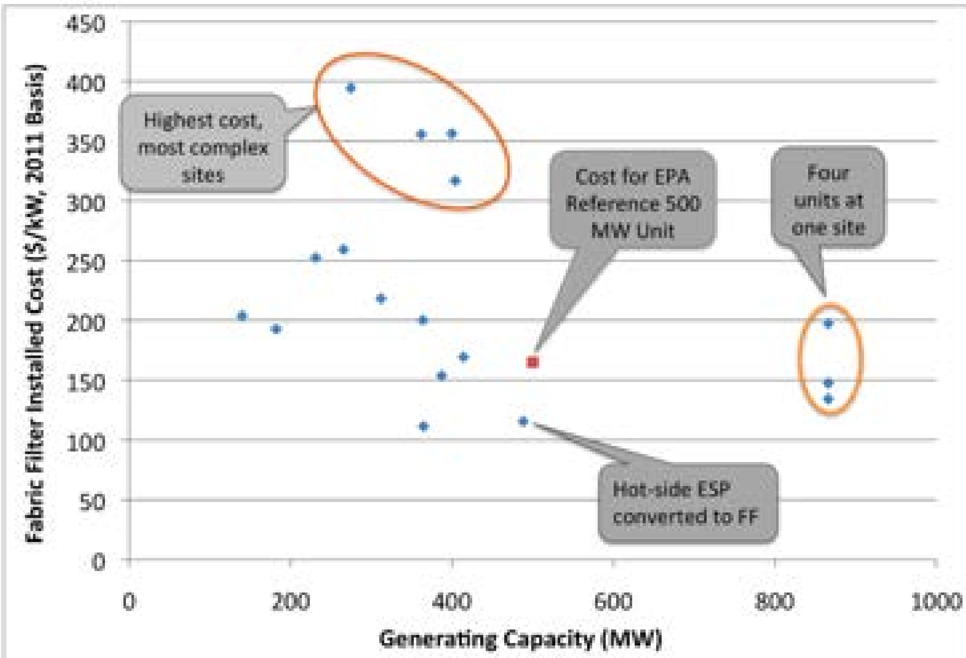
Figure 9. Installation history of RA and PJ baghouses by US Power Plants[25]



[24] How much less expensive will depend upon a number of factors, to include coal type, the selection of fabric, and other factors.

[25] EPRI Power Plant Baghouse Survey, 1019729. 2010

Figure 10. Reported costs of baghouse retrofits (2011 $)[26]



Factors that affect fabric filter performance

PM emissions from a baghouse will increase as filter material fails through one of three means: (1) mechanical failure, such as abrasion or excessive flexing; (2) thermal degradation, or overheating of material; and (3) chemical degradation from acids or other harsh chemicals in the exhaust gas. The other ways that PM emissions from a baghouse can increase include leakage that bypasses the bag filter from tubesheet seal leakage or corrosion of the tubesheet or other parts. Coal operators can reduce abrasion and wear and tear through lower bag cleaning frequency because each bag cleaning event stresses the filter bags. Blinding of bags can occur when the flow of flue gas through portions of the filter bag is reduced or cut off due to deposits on the bags that are not readily cleaned off by regular cleaning events. Blinding can be due to moisture or other effects, and it will adversely impact filter bag life because more air must be forced through the unblinded portions of the bags, which stresses the bags. To extend bag life and reduce PM emissions over time, operators should optimize bag-cleaning frequency to reduce blinding but avoid stress from overcleaning.

Baghouse operation prior to MATS and advancements since 2011

Prior to MATS, most baghouses did not receive attention until there was a significant problem. PM was not monitored or reported with the same 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. For most operating coal plants, the only continuous monitoring

[26] Cichanowicz, J.E., "Current Capital Cost and Cost-Effectiveness of Power Plant Emission Control Technologies", prepared for Utility Air Regulatory Group, July 2013; Costs are in 2011 $. They can be approximately escalated to 2020 $ using the Chemical Engineering Plant Cost Index (CEPCI). The 2011 CEPCI was 585.7 and the 2020 CEPCI was 596.2, or roughly a 1.8% increase

device intended for PM was an opacity monitor, which is a far less reliable indicator for PM performance than a CEMS device. Stack tests were performed on perhaps a yearly basis as determined by the state requirements. As a result, problems could go unnoticed for a significant period of time or would not be noticed until they were significant enough to get attention.

MATS emission rate requirements and monitoring requirements (continuous PM monitor or, alternatively, quarterly stack tests) made operators of coal-fired power plants much more attentive to the operations and performance of their PM control devices.

Because a baghouse can achieve very low PM emissions, to comply with MATS, units that already had baghouses in place frequently improved their performance by simply addressing pre-existing problems. These problems that often did not get addressed in a timely manner included ductwork and casing leaks that resulted in more than design gas flow. This leakage increased bag cleaning frequency and fabric filter pressure drop, contributing to greater stress on fabrics. Other problems included failure of filter bags, blinding of bags, and leakage of plenum seals, which all contributed to increased PM emissions.

Apart from improvements in fabric technology, discussed in the following section, most of the underlying engineering associated with baghouse technology has only experienced minor changes over the past decade. However, MATS forced companies to deploy improved fabric materials and improved operating practices described above. For example, there is more widespread use of membrane and P84 felted bags than before MATS. Efforts to reduce leakage and take measures to minimize risk of bag failure have been deployed. All fabric filters are capable of very low filterable PM emission rates; the substantial variation in emissions among fabric filter-equipped units is the result of the degree to which improved fabrics and operating practices have been deployed.

Because fabric filter failure creates risks of high PM emissions, more durable materials have been developed over the years, and this development has continued since 2011. Table 4 shows a list of some fabrics that are used. For example, fiberglass, once the most widely used material (and one that heavily relied upon filter cake for high filtration), has largely been replaced by other materials, such as NOMEX and PPS (Ryton), P84 and Teflon-coated bags that are more durable and clean more easily. The newer fabrics are more expensive, but also more reliable. PPS felt was found in a 2010 EPRI survey to be the most common fabric for pulse-jet fabric filters.[27] As these bag materials have evolved, durability against flexing, abrasion, high temperatures and harsh chemistry have improved reliability, having a positive impact on emissions performance. Felted and coated fabrics are also less reliant on a base particulate layer for filtration. This is helpful for performance because when a cleaning event removes a base layer of PM from a fabric that relies upon that base layer for filtration of the finer fractions of PM, some finer PM fractions may pass through the fabric filter. Coated fabrics, such as Teflon or Goretex or P84 felt, also clean more easily than other fabrics, which means that less energetic and less frequent cleaning may be possible. The benefit of less frequent cleaning is that this reduces the wear and tear that could damage filter bags and lessen the effectiveness of the baghouse in capturing PM. Some fabrics, such as P84, are intrinsically more effective as filters but are also more expensive. Therefore, they may be used in a

[27] EPRI Power Plant Baghouse Survey, 1019729. 2010

composite form in combination with a less expensive material. P84 fabric, for example, which is often used as a needle felt on a less expensive substrate (such as fiberglass), has irregularly, multi-lobe shaped fabric (not cylindrical) that has interlocking fibers that offer finer filtration in a manner similar to a membrane.

Table 4. Fabrics used in utility coal-fired applications [28]

Standard Fabrics Used in Utility Coal-Fired Boiler Applications 1

	Acrylic	PPS	Aramid	Fiberglass	P84	Pleated elements
Max Operating Temp	265 F	375 F	400 F	500 F	500 F	Dependent on base fabric
	130 C	190 C	204 C	260 C	260 C	
Concerns in coal fired boiler applications	Lowest maximum operating temperature.	Susceptible to degradation at elevated temperatures coupled with oxygen levels over 12%.	Not as capable as PPS in chemically active gas stream environment.	Woven style fabric that is more fragile than other options. Requires tight tolerance to be maintained on bag-to-cage fit in pulse jet applications.	Dimensional stability at higher temps over 400 F. Requires oversizing of filter to maintain proper bag-to-cage fit.	Air to cloth ratio must be below 3.5 to 1. Applicable only when additional cloth area is needed to lower air to cloth ratio and eliminate inlet abrasion.
Relative Cost	$	$$$	$$$	$$	$$$$	$$$$$
Fabric treatments to improve performance	**ePTFE Membrane:** Laminated to collection surface-most efficient option, enables fabric to handle system upsets reviewed in paper at more consistent airflow/less cleaning frequency.					
	Micro-denier fibers/Tri-lobal fibers: Creates improved efficiency over standard fibers by increasing total fiber surface area. Limited improvement over ability to handle upset conditions reviewed.					
	PTFE Coating: Non-membrane surface coating used to improve dust cake release-sacrifices ability to maintain consistent airflow leading to increased cleaning frequency/high differential pressure.					
	Singe: Removes some of the fabric surface area, creating an improved ability of the fabric to release dust cake. Limited improvement over ability to handle upset conditions reviewed.					

According to Sargent & Lundy, the cost of filter bags has increased between 2012 and 2017, largely a result of improvement in filter bag materials. For this reason, they incorporated an escalation factor for bags in their cost estimating algorithm, but they did not provide guidance on the factors to use.[29]

Methods to improve baghouse performance

There are several ways to improve fabric filter performance, including the following:

- **Reducing boiler casing and ductwork leakage will reduce the amount of gas that must be pulled through a fabric filter, which effectively reduces air to cloth ratio**
    - Lower pressure drop means less frequent cleaning and longer bag life, which makes filter bags less prone to failure and high PM emissions.

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[28] https://www.power-eng.com/emissions/air-pollution-control-equipment-services/real-world-performance-results/#gref

[29] https://www.epa.gov/sites/production/files/2018-05/documents/attachment_5-7_pm_control_cost_development_methodology.pdf, page 9

  - Less dilution from leakage means higher temperatures, less condensation and blinding, lower pressure drop, less frequent cleaning, and longer bag life, which means that filter bags are less prone to failure and high PM emissions.
  - Lower gas flow means less risk of leakage around bag seals.
  - This also offers the benefit of lower induced draft fan load, which has the benefit of lowering cost because of lower parasitic load.
- **Installation of bag leak detectors and greater attention to baghouse maintenance**
  - Leak detectors are PM measuring devices installed on a baghouse that can identify leakage in a baghouse compartment to help make an early diagnosis of a bag failure. They are different from CEMS, which are used for compliance measurements and are installed farther downstream. Having a leak detector on a compartment will help identify the offending bags and can potentially be more sensitive in identifying a failure than a PM CEMS that senses the total gas flow rather than just one compartment. PM CEMS are independently useful in detecting problems with baghouses, such as damaged bags.
- **Regular inspection to detect damaged bags, corrosion of fabric filter plenum and bypass of filter bags**
- **Optimizing bag cleaning frequency**
  - This is something that should always be pursued to minimize risk of filter bag failure.
  - Frequent cleaning can prematurely wear out bags and can cause higher PM emission rates.
  - Bag cleaning schedules should be based on the differential pressure across the baghouse. Ignoring differential pressure can result in cleaning that is either too frequent or too infrequent.
- **Use of more reliable and better filtering fabrics**
  - A wide variety of fabrics are available, as previously addressed.
  - Improved fabrics are less likely to fail due to chemical, thermal or abrasion failure (longer life in harsher environments).
  - Improved fabrics offer more effective cleaning (especially, for membrane-coated bags), which reduces cleaning frequency and extends bag life.
  - PTFE membrane-coated bags and felt bags are less reliant upon establishing a filter cake for achieving high filtration effectiveness.
  - More durable materials, such as NOMEX and PPS (Ryton), P84 and Teflon-coated bags; also less reliant upon filter cake
  - To realize the benefits of more expensive fabrics (like P84) at a more modest cost, they are often used in combination with less expensive fabrics in composite filter media.

- **More frequent bag replacement, costs are estimated as follows:**
    - Operating costs associated with bag replacement are roughly $0.069/MWh of operation for air-to-cloth ratio of 4, and about $0.073/MWh of operation for air-to-cloth ratio of 6 based upon Sargent & Lundy study for EPA.[30]
    - For example, a 500 MW coal plant that operates at a 75% capacity factor, would spend about $230,000 per year or $1.15 million over five years. Five years would be a typical bag life.[31]
    - This translates to $2.3/kW for a complete bag replacement. Conservatively accounting for the potential for higher cost fabrics means that a cost in the range of $2/kW to $5/kW may result every 3-5 years. Better bag materials will increase the cost of the replacement but will also generally result in better filtration and longer bag life. So, more frequent bag replacement combined with better materials will have the best result for PM emissions but may be more than necessary for a particular PM emission level.
    - How much of an improvement in PM emissions will result from bag replacement depends heavily upon the condition of the bags that are being replaced – but new bags in a well-functioning baghouse are capable of providing PM emissions under 0.0015 lbs/MMBTU based on current performance data discussed in a later section.
- **Reduce air-to-cloth ratio though addition of bag compartments.**
    - Adding additional compartments can lower cleaning and lower pressure drop – resulting in longer bag life.
    - This is more expensive than other approaches, but less expensive than a new baghouse. This is generally only done if other approaches prove to be inadequate, and it is determined that current air-to-cloth ratio is too high.

Impact of activated carbon on baghouse operation

In a normal, full-burden baghouse (no upstream ESP), ACI will increase the inlet PM burden to a baghouse, but this is typically much less than one percent of the normal fly ash loading – essentially, less than normal fly ash variability. For example, fly ash into a PM control device typically averages between about 5 and 10 lbs/million Btu of heat input. If ACI is used at a treatment rate of under 1 lb/million ACF and a boiler has about 4000 ACFM per MW and a heat rate of 10,500 Btu/kWhr,[32] the result is about 0.02 lb of activated carbon/MMBtu, or only about 0.3% of the fly ash input to the fabric filter – well below the typical variability of ash loading. In fact, ACI treatment rates for fabric filters are typically well below 1 lb/million ACF and would therefore have much less impact than 0.3% of fly ash loading. So, the impact of ACI on downstream fabric filter operation is negligible.

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[30] https://www.epa.gov/sites/production/files/2018-05/documents/attachment_5-7_pm_control_cost_development_methodology.pdf. This is calculated using the equation for VOMB on pages 10-13 and using a gross heat rate of 10,500 Btu/kWh and assuming subbituminous coal.
[31] Ibid.
[32] These are common estimates of gas flowrate and heat rate

Impact of natural gas cofiring on baghouse operation

Natural gas cofiring will reduce the PM burden to the baghouse in proportion to the percentage of coal that is replaced. Reduced PM loading will reduce bag cleaning frequency, which will improve filter bag life and improve emissions. It will also increase moisture while reducing SO_3 content of the flue gas. SO_3 increases the acid dew point and moisture reduces it. Therefore, these two effects offset one another. MATS also resulted in reduced SO_3 emissions in many cases, which is beneficial with this regard. Moisture can contribute to blinding of filter bags and sulfuric acid can chemically harm some filter bag materials. Because the effects offset one another, cofiring of natural gas should not have a significant impact on blinding and it may reduce chemical attack on filter bag material. By reducing acids in the flue gas and reducing bag cleaning frequency, cofiring will have a beneficial impact on filter bag reliability. Therefore, the overall impact of natural gas cofiring will generally be positive.

C. TOXECON, OR COHPAC

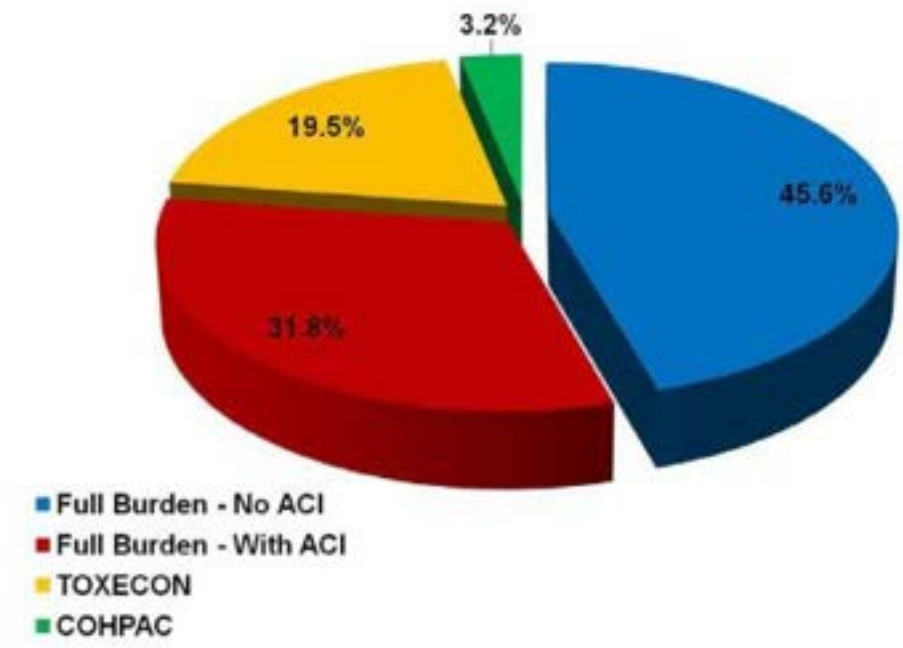
TOXECON is an acronym for TOXic Emissions CONtrol device. COHPAC is an acronym for COmpact Hybrid PArticle Collector. A COHPAC system is a PM collection system that combines an ESP followed by a downstream baghouse. A TOXECON system differs from a COHPAC system only in that between the ESP and the downstream baghouse is a device that injects a reagent or sorbent to capture an air toxic, such as injection of activated carbon after the ESP but before the baghouse. For the purpose of PM emissions control, COHPAC and TOXECON can be considered equivalent. A baghouse that does not have an upstream ESP may be regarded as a full-burden baghouse because PM is not removed upstream of the baghouse, as occurs for a COHPAC or TOXECON. Some coal power plants equipped with ESPs were incapable of meeting one or more of the MATS emissions control requirements with only the ESP and therefore had to add controls. In some of these cases, owners/operators added a baghouse downstream of the ESP. For example, coal power plants equipped with only a hot-side ESP[33] for air pollution control (no scrubber or fabric filter) were incapable of achieving adequate Hg capture with ACI to meet the MATS requirement without addition of a fabric filter. Therefore, coal units with hot-side ESPs either converted the hot-side ESP to a cold-side ESP or added a baghouse.

As shown in Figure 10, the cost of a fabric filter retrofit will vary, but is generally in the range of about \$150/kW. A TOXECON baghouse is, in principle, slightly less expensive than a full-burden baghouse due to slightly higher air-to-cloth ratio possible in a TOXECON arrangement, but the actual cost will be very dependent upon the difficulty of the retrofit.

In 2010, the Electric Power Research Institute (EPRI) conducted a survey of baghouses and found that slightly over 20% of the PJ baghouses installed were in a TOXECON or COHPAC arrangement. As shown in Figure 11, the largest fraction of baghouses were full burden baghouses that did not include ACI. This, of course, was prior to MATS. In many states there was no requirement to control mercury.

[33] A hot-side ESP is installed upstream of the air preheater at a point where the exhaust gas temperature is in the range of about 600ºF, while cold-side ESPs are installed downstream of the air at a point where the exhaust gas temperature is in the range of about 300ºF.

Figure 11. Configurations of Pulse-Jet baghouses in the Power Generation Industry [34]



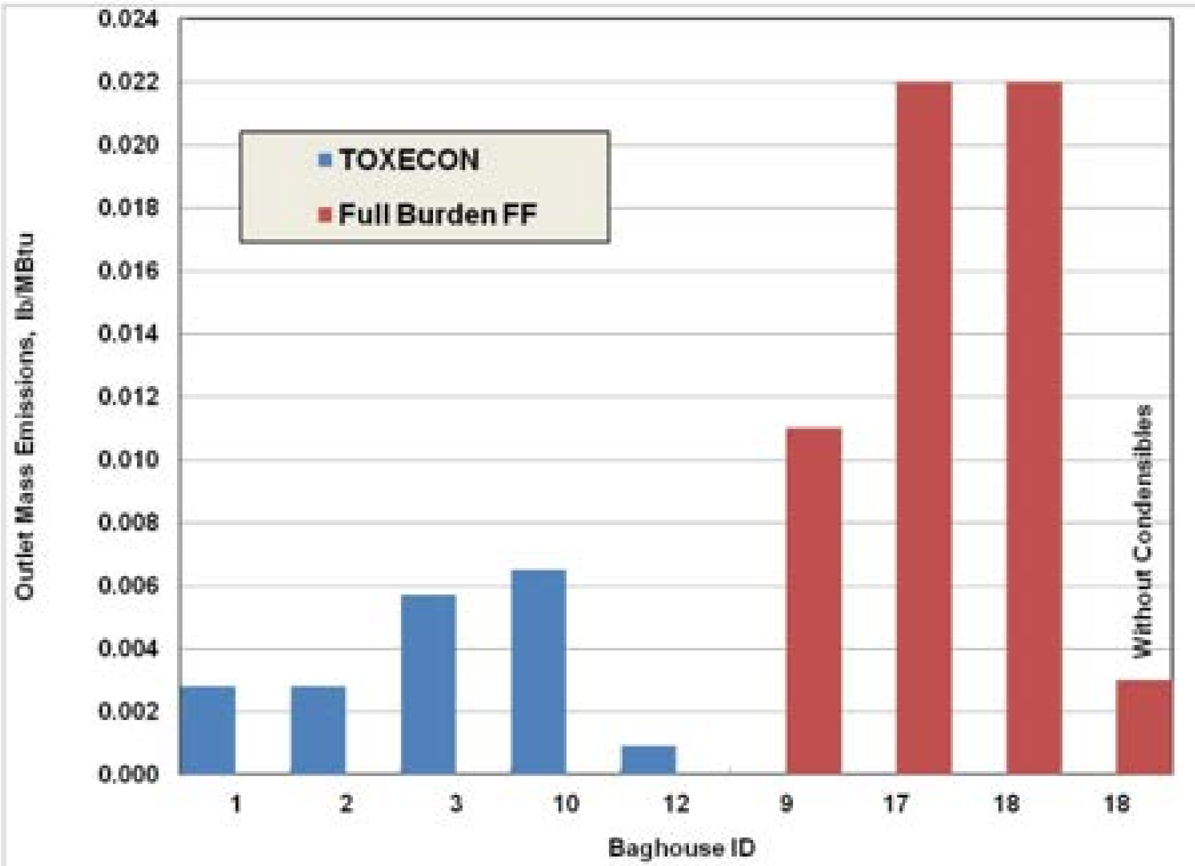
The impact of TOXECON on PM and other emissions

The addition of a fabric filter to meet one requirement, such as PM, will be beneficial to meeting other MATS requirements, such as mercury. In the case of a hot-side ESP, the addition of a baghouse to help with meeting the Hg limit with ACI also helps to reduce PM emissions. The addition of a baghouse for PM control will also improve the cost of Hg emissions control because the activated carbon is used much more effectively, reducing the activated carbon that is required for any given removal rate. A fabric filter will also make collection of acid gases with dry sorbent injection (DSI) more effective. Thus, there are substantial synergies possible through the addition of a fabric filter.

An EPRI baghouse survey found that a TOXECON system most often had lower outlet PM mass emissions than a full-burden baghouse. These results are shown in Figure 12. It was later determined that several of the full-burden baghouses were experiencing bag leaks. This illustrates some important points. First, bag leakage is the principal reason for high emissions for any BH. Second, the combination of an upstream ESP with a downstream baghouse reduces the risk of high emissions when a filter bag leaks, or another leak occurs, because the inlet loading to the baghouse is much less in the TOXECON arrangement. So, it is possible that the TOXECON baghouses in the EPRI study also had bag leaks, but the impact of the leaks would be much less than for a full-burden baghouse. That is why a TOXECON configuration reduces the risk of high PM emissions in the event of a filter bag failure.

[34] EPRI Power Plant Baghouse Survey, 2010, 1019729, fig 1-4

Figure 12. Comparison of full-burden baghouse emissions to TOXECON emissions[35]



D. Wet ESPs

Wet ESPs are not widely used on coal power plants because most coal plants utilize either a dry ESP or a baghouse. Wet ESPs differ from dry ESPs in that the collection plates are cleaned with a stream of water. This offers two benefits: 1) re-entrainment of fly ash does not occur to a significant extent, which improves PM capture, and: 2) higher power levels are possible. Wet ESPs can be installed downstream of a wet FGD system and used to capture mist. It is not possible to install a fabric filter downstream of a wet scrubber due to the presence of moisture that would plug the baghouse. A wet ESP might be an option for a scrubbed unit that needed to increase ESP treatment time but did not have adequate space to make ESP modifications. Utility budgetary data provided in Table 3 suggest that a wet ESP costs in the range of about $150-200/kW.[36]

[35] Ibid.

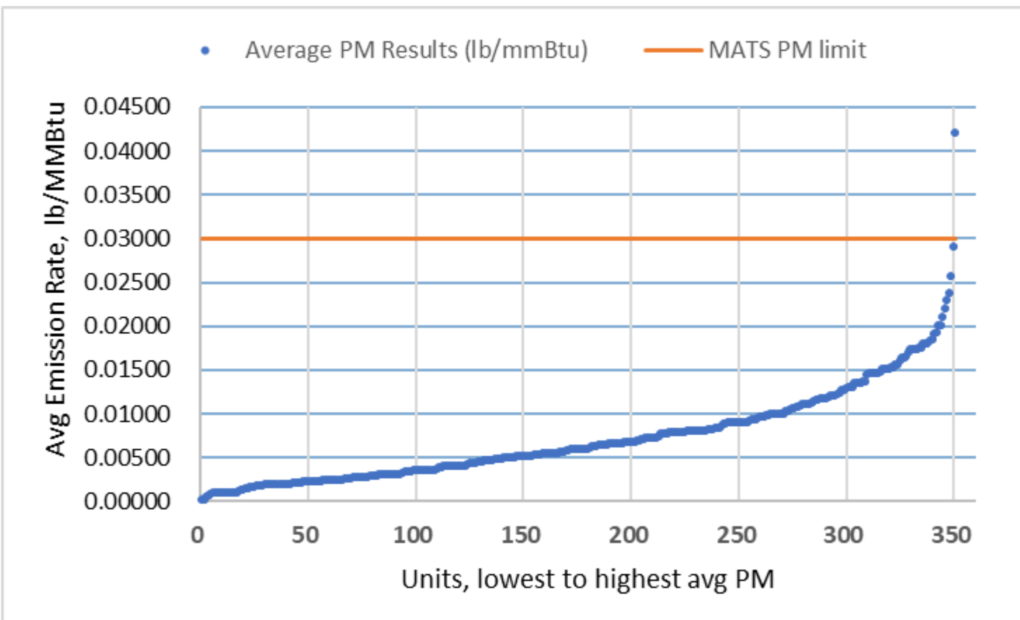
[36] See Table 3

E. Assessment of PM Emissions Data

The database published by NRDC includes the average, minimum and maximum reported PM emissions from EPA's 2019 Air Markets Program Data as well as facility characteristics from EIA Form 860 data. ATP further examined this data to look for relationships that could be used to explain performance.[37]

Figure 13 shows that over 99% of all the units in the database were under the PM emissions limit of 0.03 lb/mmBtu, based on the average emission rates calculated for each unit (i.e., average of 2019 PM CEMS data or 2019 PM stack test data). Those units that had emission rates above 0.03 lb/mmBtu may have still complied with the rule based on a facility-wide averaging plan.[38] The average emission rate was 0.0072 lb/mmBtu and median emission rate was 0.0060 lb/mmBtu. The best performing 25% of units had an average emission rate of 0.002 lb/mmBtu and a maximum average emission rate of 0.003 lb/mmBtu.

Figure 13. Overview of PM emissions data.



Given the range of data, ATP examined the full population of units by breaking the population into deciles to examine if there were any trends. Decile 1 was the decile with those units that had the lowest PM emissions, and so on. Figure 14 shows the average PM emissions for each decile. As shown, the PM

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[37] ATP analyzed the data for 351 sources in the Unit Level PM Analysis worksheet of the NRDC database where an average unit PM emissions rate was provided for the unit in the Webfire data. The Unit Level PM Analysis was calculated from the Webfire data where that data showed an emission level for a specific unit. For a small number of common-stack units the Webfire data did not provide a unit-level PM emission rate. Those units are are included in the analysis as reported in Webfire. In the "Master Data all combined" worksheet of the NRDC database, each common stack is broken out to a unit level estimate, even if it was reported at the common stack level from the Webfire report. For example, Marion 916-123 is in the Unit Level Analysis spreadsheet once (as a common stack represting units 1, 2, and 3), while Marion 976-123 is listed 3 separate times to represent data on a unit level in the Master Database all combined worksheet. Due to the small number of affected units, this is not expected to make a large difference in the results of the decile analysis.

[38] It is acknowledged that the limit is a 30-day average, which is somewhat more stringent than an annual average.

emissions rate for the top deciles were on the order of one fifteenth those of the bottom decile. The impact of coal was examined in Figure 15. As shown, there was no apparent trend in PM performance with respect to the type of coal being used at the facility.

Figure 14. Average PM emissions rate per decile

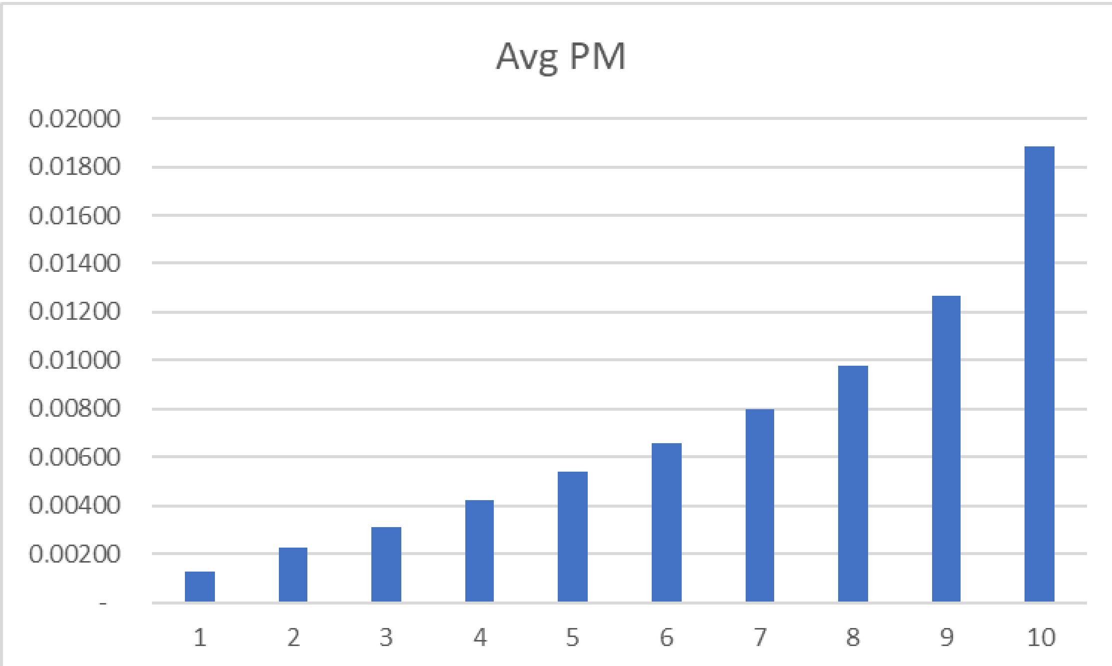
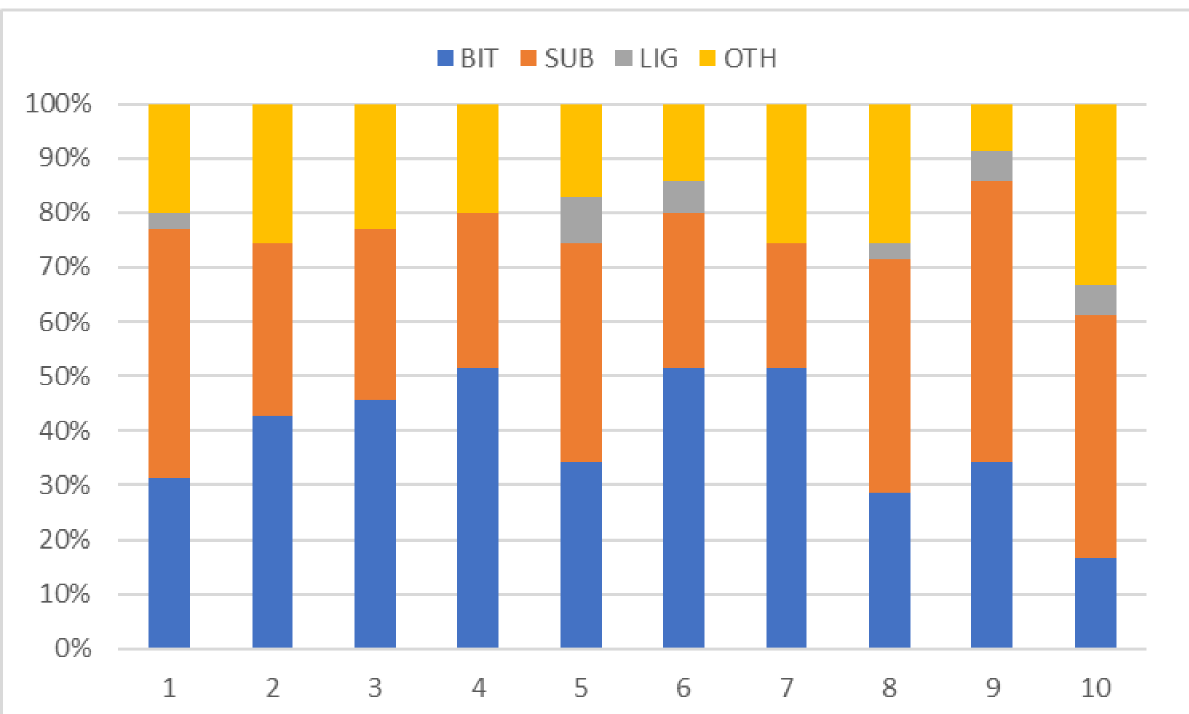
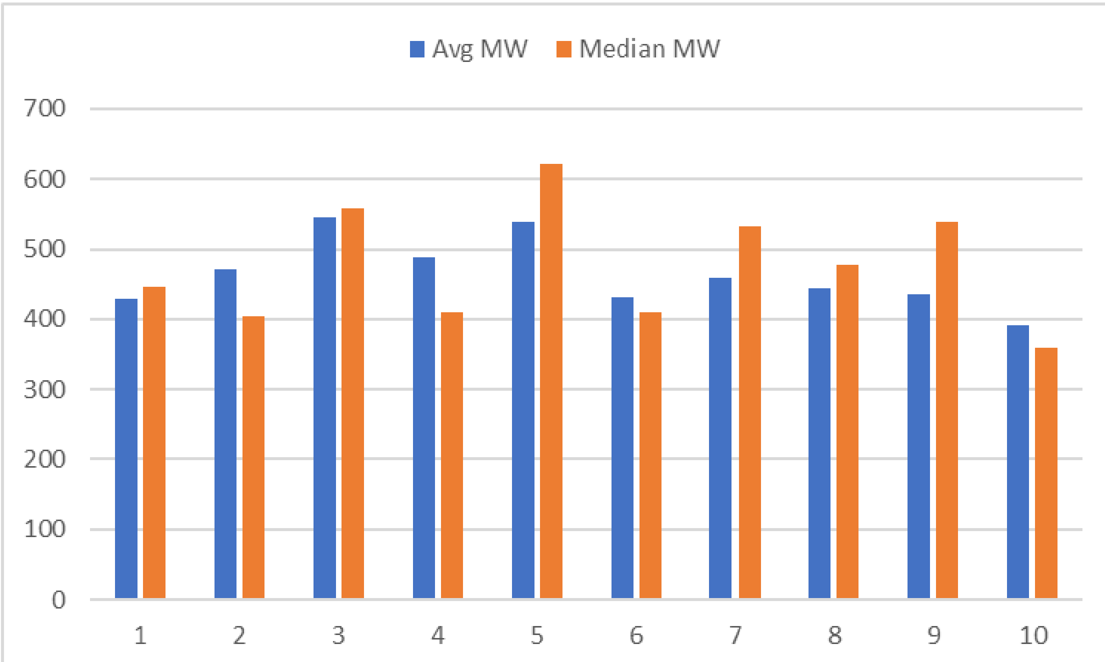


Figure 15. Coal type by decile



The unit size (in MW) was also examined. Figure 16 demonstrates that there is no apparent trend based upon unit size.

Figure 16. Average and Median MW size by decile



Trends were observed in the deciles when equipment was examined. As shown in Figure 17, perhaps as expected, the highest percentage of baghouses and dry FGD are in decile number 1.

Figure 18 shows the same data, but with both forms of scrubber combined. As shown, the top deciles are far more likely to be scrubbed than the bottom deciles. This likely has much less to do with the PM removal performed by the scrubbers than the fact that scrubbers, due to their high cost, are normally installed on the most important units which are therefore the best maintained and equipped. Scrubbers do improve PM capture, but they alone cannot account for the large difference in PM emissions between the top and bottom deciles. Wet scrubbers remove some PM, but not enough to explain the difference between top and bottom deciles. A large percentage of the top decile is equipped with dry scrubbers, which is reasonable because dry scrubbers are equipped with BHs. A well-functioning BH is the most effective filterable PM capture device. About two thirds of the top decile is equipped with BHs, well above the fraction of any other decile equipped with BHs.

It is also apparent by the ESP and BH percentages that a substantial number of the top decile units are TOXECON or COHPAC. Decile 6 is most likely to just have an ESP for PM control (but may also be scrubbed). It is also apparent from these figures that the top deciles are about as likely to have ACI as other deciles, confirming that ACI does not adversely impact PM emissions. Significantly, the top decile included three unscrubbed units with an ESP, ACI and no BH, demonstrating that this configuration is capable of having very low PM emissions.

Figure 19 shows the expected result that unscrubbed units with an ESP and no BH tend to be lowest in decile 1 and higher in lower deciles, as this is generally regarded as the most difficult situation to control PM. But, the presence of seven units with this configuration in the top two deciles shows that it is possible for PM to be very effectively controlled in this configuration.

Figure 17. Percent of decile with equipment

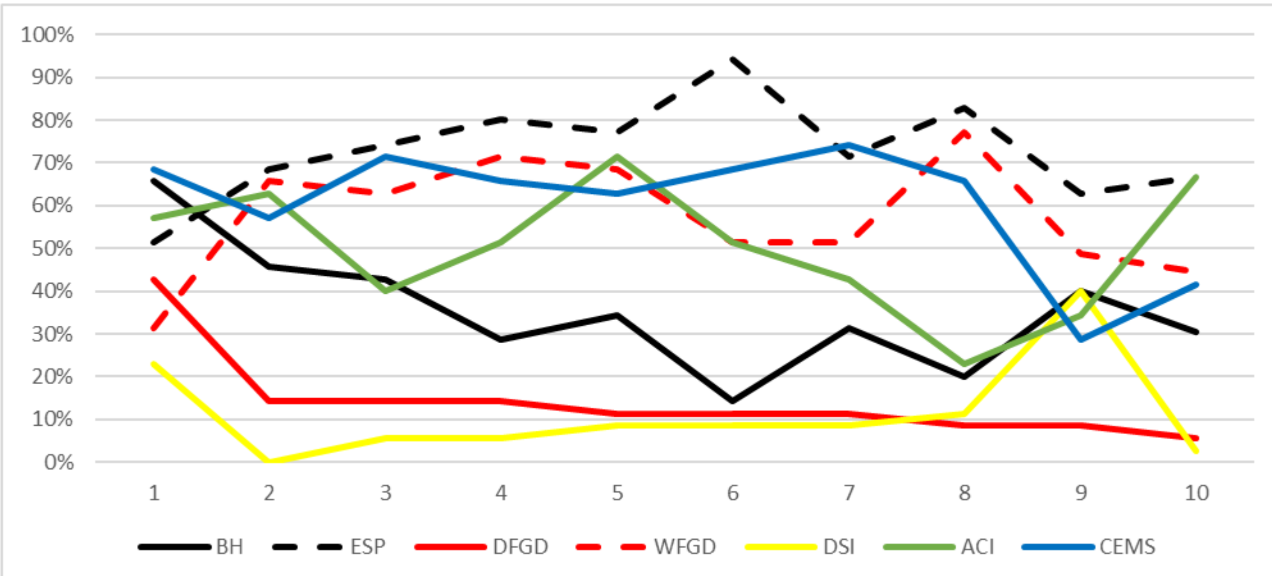


Figure 18. Percent of decile with equipment – scrubbers combined.

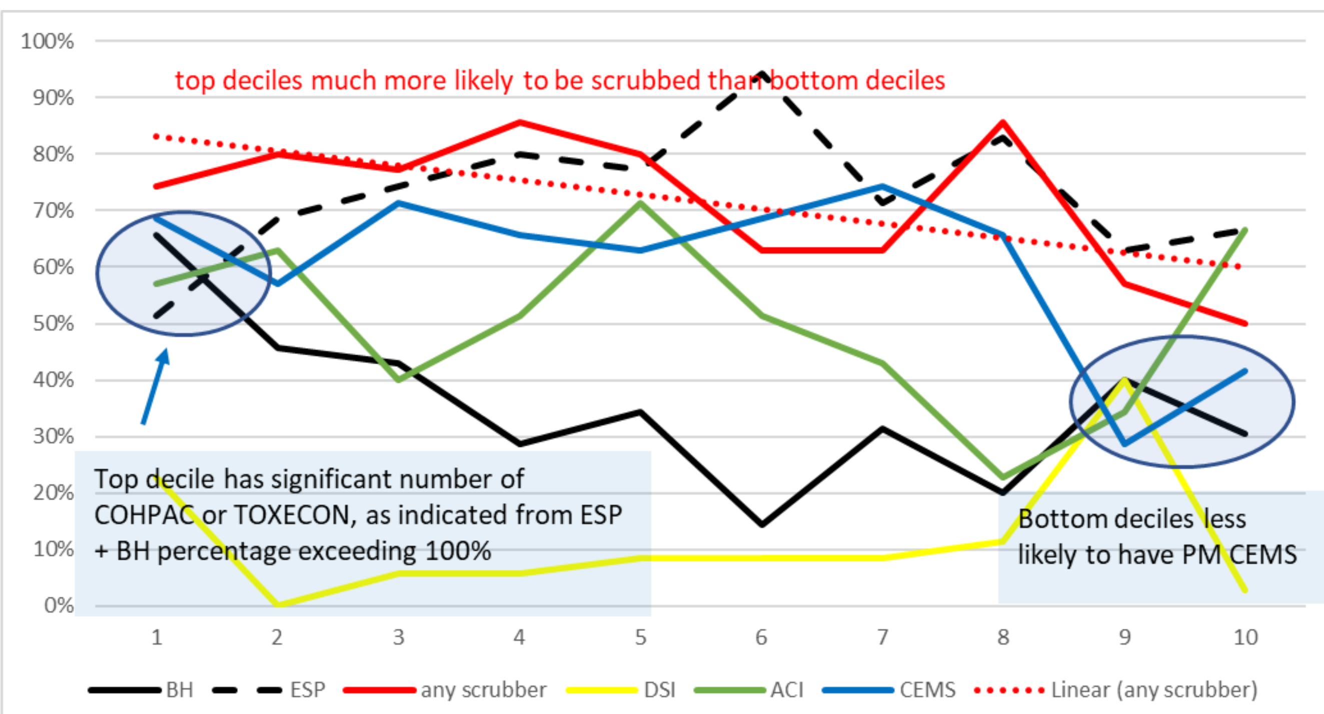
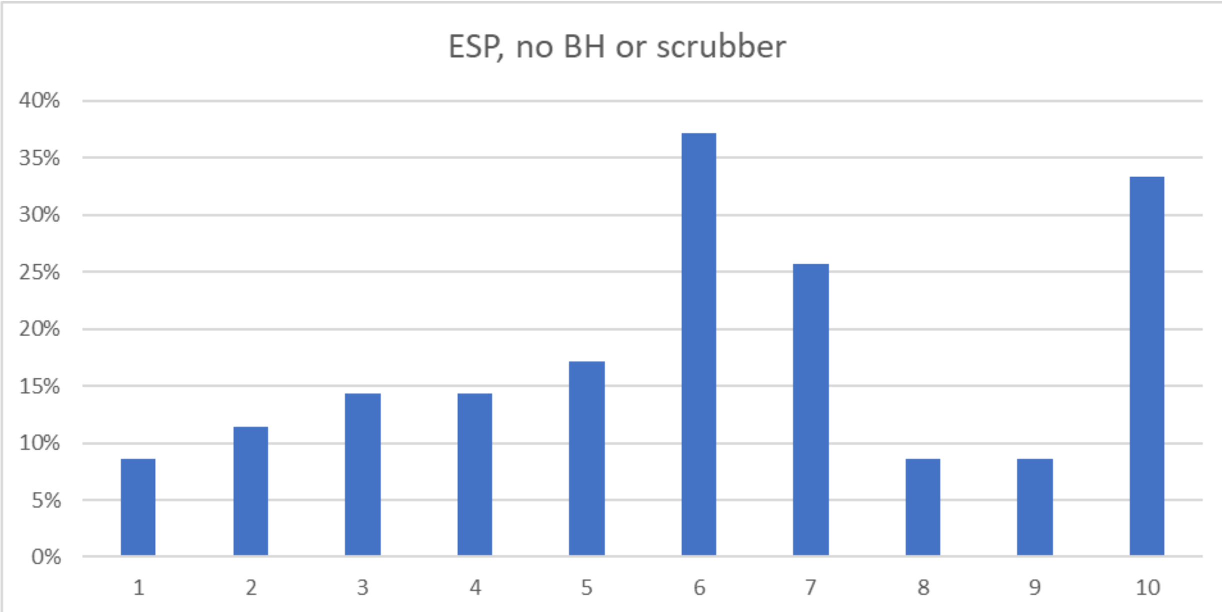


Figure 19. Percent of units in decile that are unscrubbed with ESP and no BH



Except for decile 7, PM CEMS were generally more likely among the top deciles than in the bottom deciles. Decile 7 had the highest percentage of PM CEMS. Deciles 9 and 10 had the lowest percentage of PM CEMS. This suggests that the use of PM CEMS may be associated with better emissions performance. It is worth noting that, prior to MATS, PM CEMS were not in wide use. They were primarily used on units that installed the PM CEMS in response to a Consent Decree or a local requirement. As a result, at the time of MATS, PM CEMS were regarded by many in the industry as early stage and perhaps too risky to use. The utility industry had not yet broadly adopted the technology when MATS was being implemented. PM CEMS provide input that can be used to address problems right away, and the most knowledgeable utilities may have recognized this benefit. To this point about PM CEMS providing indication of a possible need for corrective action, Appendix A provides some examples showing that spikes in daily PM emissions, well above the 30-day average, occurred and there was a subsequent correction to a lower daily rate. In some cases it is unclear if there was a corrective action, or if there was another reason for the reduction in the spike. In some cases the data strongly suggests that a shutdown was taken to address high PM emission rates.

Utilities that were more familiar with this technology - that had not been widely deployed in 2011 - were able to take advantage of the real-time benefit of PM CEMS in reducing PM emissions. This would also be consistent with the fact that top decile units were more likely to be scrubbed (and had newer scrubbers) than bottom decile units. Companies that had recently installed scrubbers were likely to be more technically knowledgeable due to recent experience with sophisticated environmental controls or may have been more committed to investing in environmental controls for their units.