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Consulting to the Air Pollution Control Industry

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

-Addendum, Analysis of the Cost of Complying with Lower Hg Emissions Levels

C-22-CAELP_4

to:

Center for Applied Environmental Law and Policy (CAELP)

January 5, 2023

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I. Executive Summary

This is an addendum to a prior August 19, 2021 report that examined PM and Hg control technologies available to coal-fired electric generating units and the ability to control these pollutants to lower levels.

This new effort examined the ability to lower Hg emissions further to below 0.15 lb/TBtu for non low-rank coal and to below 0.50 lb/TBtu for low-rank coal from the levels being achieved to comply with the current MATS standards for these two types of coal.[1] The emissions levels discussed in this report are achievable using available technologies, albeit, while incurring additional cost. This effort utilized the same NRDC database as in the prior effort, and in determining the cost of additional control factored the following into its analysis:

- Reported Hg emissions for existing units (using the same emission rate reported in the NRDC database as the currently-controlled rate).
- Planned retirements of existing units (some units were removed from the NRDC database based upon planned retirement year). However this analysis did not account for any additional retirements that may occur due to the Inflation Reduction Act.
- Equipment installed (using the same equipment configuration as reported in the NRDC database).[2]

Costs estimated and presented in this effort are:

1) Those *incremental* costs over those already being incurred to comply with the current Hg and PM standards.[3] These costs capture the additional capital, operating, maintenance and variable operating costs associated with complying with the lower emission levels examined here.
2) Those *incremental* costs over those already being incurred to comply with the existing Hg standard in the event that coal-fired plants also took measures to comply with a lower PM emission standard of 0.0015 lb/MMBtu.

Incremental Hg compliance costs over current Hg compliance costs with the current PM standard are estimated to be:

- For non low-rank coal (NLRC) units, the estimated annualized capital cost is $435 million, estimated maintenance cost is $79 million, and estimated variable

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[1] The emission levels of 0.15 lb/TBtu and 0.50 lb/TBtu are potential emission limits for NLRC and LRC units, respectively. Actual controlled levels assumed for this effort are 20% below these levels.

[2] Some minor corrections were made comparing EIA Form 860 and Air Markets Program Data (AMPD). In some cases the AMPD reflected the existence of an SO_2 control device that may not have been reflected in the NRDC database (which utilized EIA Form 860 data).

[3] Throughout this addendum, “PM standard,” "PM emission standard,” “PM emission limits,” and “PM emission requirements” refer to a standard for emissions of non-Hg hazardous metals that uses the filterable PM emissions rate as a surrogate for hazardous metals to demonstrate compliance.

operating costs are $181 million, for a total estimated annual cost of $695 million. This is the estimated incremental cost over what is currently being spent to comply with current Hg and PM emissions limits.

- For low-rank coal (LRC) units, the estimated annualized capital cost is $7 million, estimated maintenance cost is $1.3 million, and estimated variable operating costs are $21 million, for a total estimated annual cost of $29.3 million. This is the estimated incremental cost over what is currently being spent to comply with current Hg and PM emissions limits.

In the event that PM emission requirements are made more stringent at 0.0015 lb/MMBtu, the *incremental* Hg compliance costs of achieving a lower Hg level over current Hg compliance costs are estimated to be:

- For NLRC units, the estimated annualized capital cost is $106 million, estimated maintenance cost is $19.2 million, and estimated variable operating costs are $39 million, for a total estimated annual cost of $164 million. This is the estimated incremental cost over what would be spent to comply with the current Hg emission limit and a new PM emission limit of 0.0015 lb/MMBtu.
- For LRC units, the estimated annualized capital cost is $5 million, estimated maintenance cost is $910,000, and estimated variable operating costs are $4.4 million, for a total estimated annual cost of $10.3 million. This is the estimated incremental cost over what would be spent to comply with the current Hg emissions limit and a new PM emission limit of 0.0015 lb/MMBtu.

II. Analysis Results

In this effort, the NRDC database that was utilized in the prior analysis was adjusted to remove any units whose owners have announced plans to retire them by end of 2027 or earlier using June 2022 EIA Form 860 data.[4] It is unlikely that these units would be impacted by a change in the emission limit, as most or all would likely be retired prior to a revision taking effect.

A. Non Low-Rank Coal (NLRC) Units with Hg Emissions Under 0.15 lb/TBtu

There are 35 NLRC units (of those that have not announced plans to retire by end of 2027) that had emissions under 0.15 lb/TBtu, compared to the current limit of 1.2 lb/TBtu. As shown in Figure 1, the PM controls were broken down between units with ESPs only (29%), baghouses only (26%), and ESPs followed by baghouses (43%) and there was one unit with a venturi scrubber (VS). The unit with a VS for PM control was equipped with ACI.

Figure 1. PM control for NLRC units with Hg emissions at or below 0.15 lb/TBtu

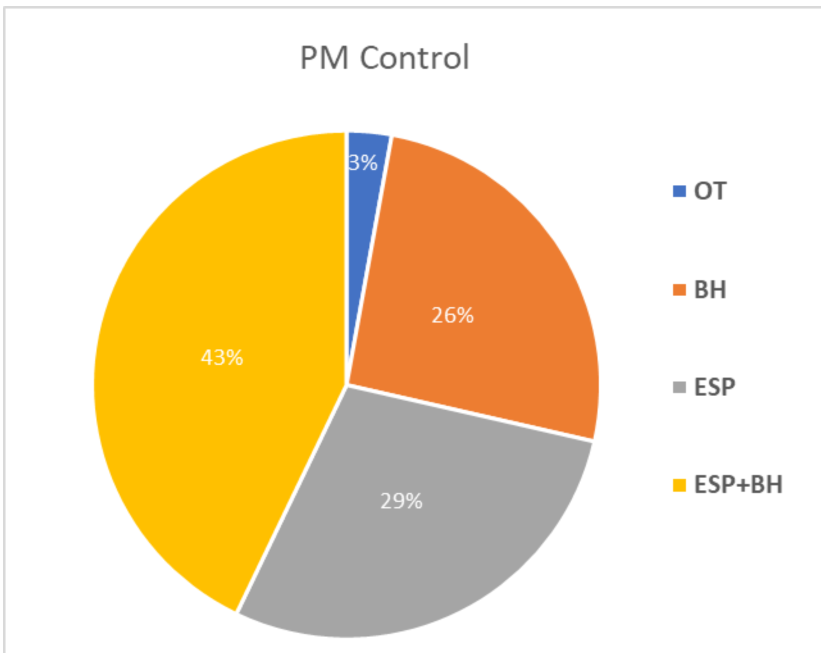


Table 1 shows the breakdown of SO_2 capture methods for each method of PM capture for the 35 NLRC units with Hg emissions at or below 0.15 lb/TBtu. As shown, 4 units are equipped with an ESP but no SO_2 control methods.

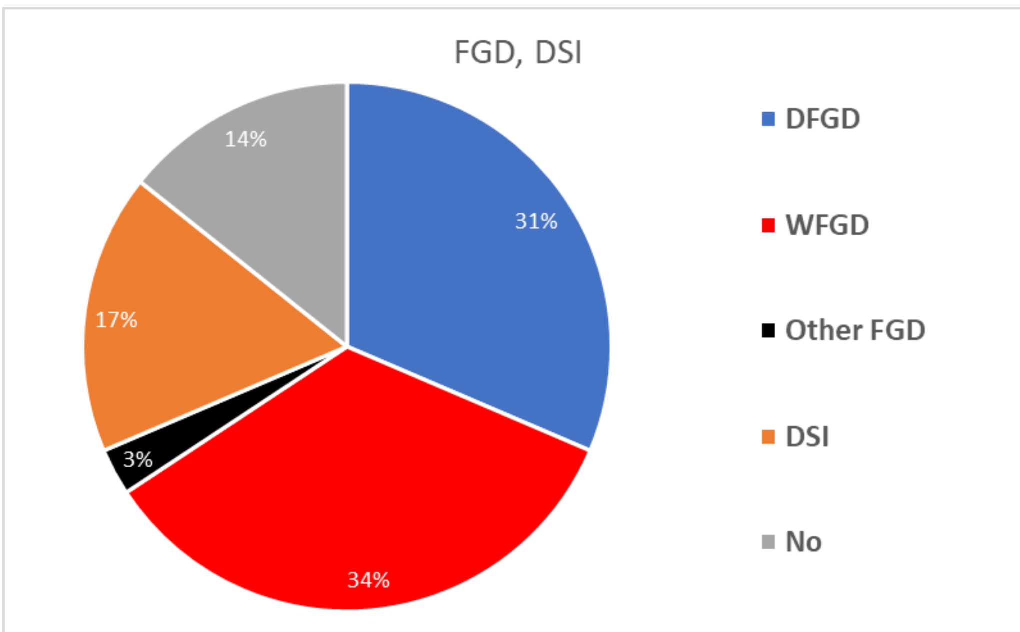
[4] In addition, because the Rockport plant in Indiana is committed to be shutdown no later than 2028, that is also unlikely to install the controls needed to comply.

Table 1. PM and SO_2 control technology and ACI for NLRC units with Hg emissions at or below 0.15 lb/TBtu

	DFGD	WFGD	Other FGD	DSI	No SO_2	ACI
BH only	3	0	1	4	1	0
ESP only	0	6	0	0	4	1
ESP+BH	8	5	0	2	0	10
VS	0	1	0	0	0	1
Grand Total	11	12	1	6	5	12

NLRC units with Hg emissions at or below 0.15 lb/TBtu were mostly scrubbed, as shown in Figure 2. The "other FGD" is REACT process, a process that uses activated coke to capture NOx, SO_2, and Hg.

Figure 2. SO_2/Acid gas controls for NLRC units with Hg emissions at or below 0.15 lb/TBtu



ACI was reported as installed on only 12 of the 35 units. It is possible that there are more ACI equipped units than reported. Of these, all but one was reported to be installed in combination with a scrubber, as shown in Figure 3. This figure demonstrates that ACI can be used in combination with other technologies to achieve low Hg emissions.

Table 2 shows the configuration of those NLRC units with emissions below 0.15 lb/TBtu that were indicated in the NRDC database as *not* having ACI. Some of these, especially those lacking either a baghouse or scrubber (3 units in total), likely have ACI, although ACI was not reported in the EIA Form 860 data which was utilized to develop the NRDC database. Scrubbed units, units with a baghouse, or units with REACT technology may be capable of 0.15 lb/TBtu without ACI. In some cases the intrinsic Hg capture of these other control technologies will be adequate. In other cases the operator may utilize fuel additives or scrubber chemical additives rather than ACI in order to reduce Hg emissions to lower levels than what is achieved with the scrubber, REACT or baghouse alone.

Figure 3. ACI in combination with other technologies for NLRC units with Hg emissions at or below 0.15 lb/TBtu

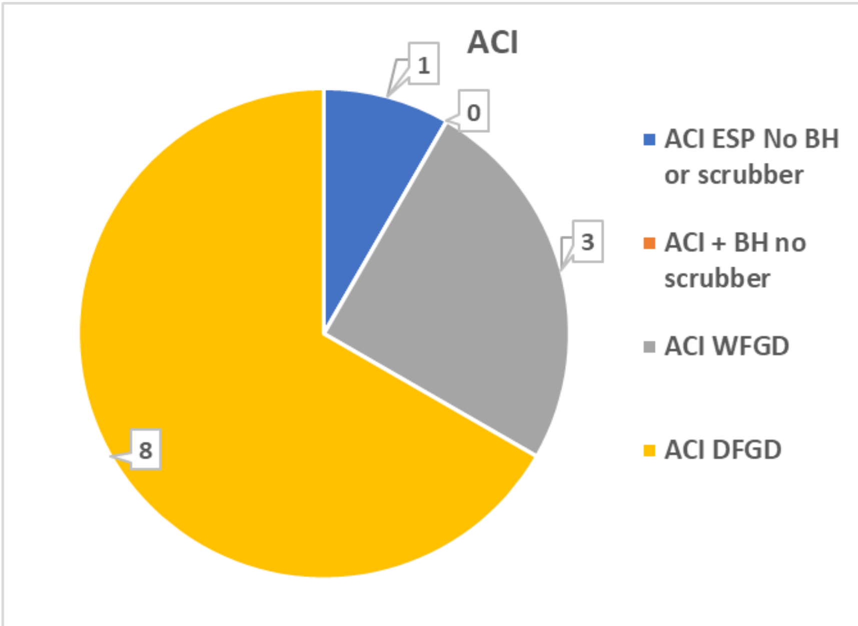


Table 2. Configuration of NLRC units with Hg emissions below 0.15 lb/TBtu indicated as not having ACI

	DFGD	WFGD	Other FGD	DSI	NO SO2
BH only	3	0	1	4	1
ESP only	0	6	0	0	3
ESP+BH	0	3	0	2	0
Grand Total	3	9	1	6	4

B. Low-Rank Coal (LRC) units

There are 20 LRC units listed that currently do not have announced retirement dates at or before 2027. All 12 ESP-equipped units are in combination with a WFGD. Of the eight units with baghouses, two are unscrubbed and six have FGD (four DFGD and two WFGD). None of them currently have emissions below 0.50 lb/TBtu. Therefore, all of the facilities will require incremental expenses to achieve an emission rate at or below 0.50 lb/TBtu. However, ACI has been shown to be very effective in reducing emissions to well below this emission rate on NLRC units, and because every LRC unit has at least a baghouse or a scrubber, very high capture efficiencies are expected to be achievable with either ACI or chemical additives.

C. Methodology for estimating cost

Hg compliance cost assumptions

Companies typically target controlling to an emission rate that is lower than the emission limit, and this is often referred to as "compliance margin". The amount of compliance margin used by a company will depend upon a range of factors such as the configuration of the plant, the method of control, and the company's confidence level with a given control method. For the purpose of this analysis, it is assumed that units would target achieving a Hg rate that is 20% below 0.15 lb/TBtu for NLRC and 0.5 lb/TBtu for LRC to provide a degree of compliance margin. This means that a target emission rate of 0.12 lb/TBtu is used for NLRC units to maintain them below 0.15 lb/TBtu and 0.40 lb/TBtu for LRC units to maintain them below 0.50 lb/TBtu. Percent additional reduction is calculated based upon these values and the prior measured Hg emission rate.

For NLRC facilities that are only equipped with ESPs, do not have adequately low Hg emissions to meet the lower Hg standard, and do not have baghouses or scrubbers, it is assumed that they would need to install baghouses if additional reduction is needed to meet the standard.[5] For NLRC units, there are 33 of these units, with a total capacity of about 19,000 MW. This is conservative because some units with only ESPs may be able to comply with a lower Hg rate through incremental carbon injection. Further, the assumption that units will use a fabric filter when an ESP is installed without a downstream baghouse or scrubber is conservative because there are already some NLRC units without a fabric filter or scrubber that achieve at or below 0.15 lb/TBtu. In the case of LRC units, all of them are equipped with a fabric filter and/or a scrubber. So, no baghouse retrofits are assumed for LRC units to meet a lower Hg standard.

The cost of a fabric filter is assumed to be approximately $150/kW.

ACI is assumed to be installed at a cost of $15/kW if additional reduction is needed and ACI is not currently installed.

If ACI is already installed and further Hg reduction is needed, it is assumed that there is an increase in carbon usage. If an increase in carbon usage is determined to be necessary for any facility that does not have a baghouse, is not assumed to install a baghouse, and currently has ACI, it is assumed that an increase in capital cost of $5/kW is needed to account for any changes to the ACI system. Because ESP-only-equipped facilities that require additional reductions are assumed to retrofit a baghouse and because facilities with dry FGD already have a baghouse, this impacts

[5] As shown in Table 1, there are four unscrubbed units with only ESPs for PM control that have Hg emissions below 0.15 lb/TBtu. Aside from these units, the next best unscrubbed units with only ESPs would require over 60% additional Hg capture to meet the lower Hg limit. Therefore, it is assumed that the units needing higher capture would require a fabric filter to achieve the lower Hg limit but those already complying with a lower Hg limit, absent a more stringent PM control requirement that would make a fabric filter necessary, would not.

units that are equipped with wet FGD and ESPs and do not have a baghouse as well. This is believed to be conservative because:

1. Existing ACI systems were generally installed at least seven years ago. In the intervening years, activated carbon suppliers have made substantial improvements in their product, dramatically lowering carbon demand for any given level of mercury capture.[6] As a result, it is reasonable to assume that most systems are utilizing significantly less carbon than the system was initially designed for. Most systems can accommodate an increase in carbon usage without any modification.
2. Methods to reduce Hg through other means, such as with scrubbers or fuel additives, have improved as well over the past seven years, providing additional conservatism.[6]
3. As noted above, most of the ACI systems would not require any changes. However, if modifications were needed for the ACI system to increase injection rate, that would likely be limited to the rotary valve/metering system at the exit of the storage silo, some control programming changes, or perhaps other modest changes. Changes in storage capacity are not likely because most facilities are currently operating at lower capacity factors than planned when the original system was installed and because carbons are far more effective than those available when these systems were originally designed. Therefore, a $5/kW capital charge for an ACI-equipped system that requires additional Hg capture should be conservative.

This impacts 49 units and 29,000 MW of NLRC capacity under the situation where the PM standard is not made more stringent and about 10,000 MW of NLRC capacity when the PM standard is made more stringent.[7] It impacts 11 units and 6,700 MW of LRC capacity where the PM standard is not made more stringent and about 2,500 MW of LRC capacity when the PM standard is made more stringent.

In some cases both a baghouse and ACI are assumed to be added. This is when additional Hg capture is needed and there is an ESP without a downstream baghouse or scrubber or an upstream ACI. It is assumed that no baghouses are retrofit on LRC units for Hg control alone because all already have either a scrubber or baghouse, or both.

Capital costs are assumed to be annualized with a capital recovery factor of 11%.

Fixed operating costs, primarily associated with maintenance, are assumed to be approximately 2% of capital cost on an annual basis.

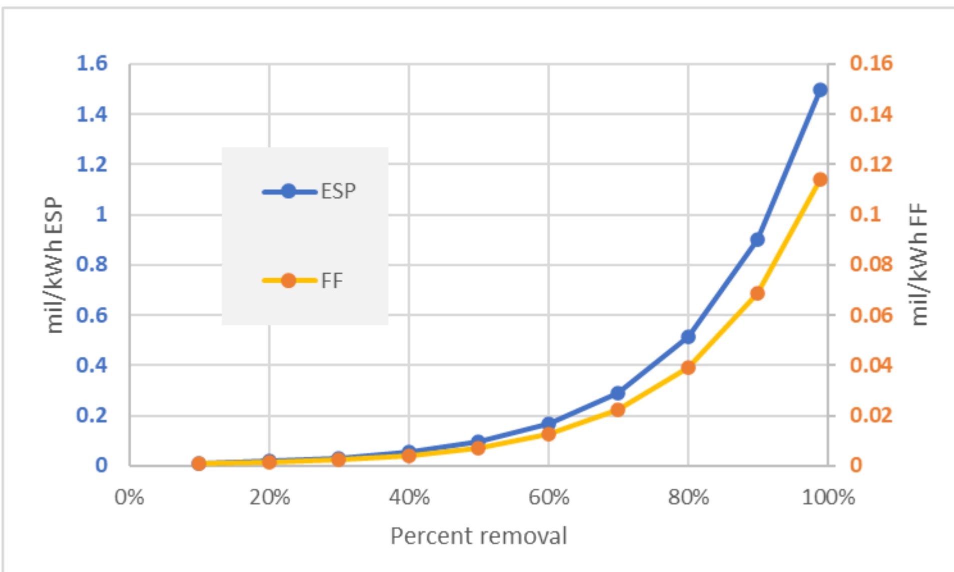
Additional variable operating costs are assumed to be related to estimated ACI treatment rate. There are alternatives to ACI, such as scrubber chemical addition, fuel additives, or other

[6] This is described in more detail in the prior report.

[7] If a baghouse is added for PM control, that actually reduces carbon usage. So, it is assumed that ACI systems are not upgraded with a baghouse. When a baghouse is added, the ACI injection point may be moved, but that is a very small cost compared to the cost of the baghouse, and this is therefore not included in the cost calculation.

means, that in any situation might be preferred and selected by a unit owner. It is not possible to explore all of these options, and it is therefore assumed that ACI is the method used to increase Hg capture. For incremental variable operating cost (over what may already be experienced with technology used to meet current Hg limits), Figure 4 was developed from the data in Table 9 and Figure 25 of the prior August 19, 2021 report. It shows estimated incremental variable operating cost (in mils/kWh) as a function of incremental Hg removal depending upon whether or not a fabric filter is being used. As shown, higher capture efficiency results in higher treatment rate, but there is no evidence that there is a threshold for the capture rates that are foreseen. Also, for those units that would install a baghouse for a lower PM standard, the carbon usage would likely go down even at a lower required Hg emission rate (higher capture efficiency). This makes this study more conservative because reductions in Hg emissions that result solely from addition of a baghouse (not even factoring in reductions from ACI) are not factored into the calculation of incremental VOM. Total, annual VOM for each unit is calculated assuming a 50% capacity factor.

Figure 4. Estimated incremental variable operating cost



PM Compliance Cost Assumptions

For this effort the incremental cost to reduce Hg was also assessed above the cost of complying with a lower PM emission rate limit of 0.0015 lb/MMBtu. The significance of this is that ESP-equipped facilities would, in many cases, install fabric filters to comply with the lower PM emissions limit, and this would result in lower Hg compliance costs. The following assumptions were made for PM emissions control costs:

In the event a facility is equipped with an ESP and reported 2019 PM emissions are above 0.0015 lb/MMBtu, capital costs are estimated to be:

- $150/kW if emissions are over 0.0030 lb/MMBtu, to retrofit a baghouse

- $50/kW if emissions are between 0.0015 lb/MMBtu and 0.0030 lb/MMBtu to upgrade the ESP
- no cost if emissions are under 0.0015 lb/MMBtu

In the event that a baghouse is already installed and reported 2019 PM emissions are over 0.0015 lb/MMBtu, incremental capital cost is estimated to be $5/kW.

There are some units that do not have a reported PM emissions rate. If these units do not have a baghouse it is assumed that a baghouse would be installed. In this manner, the cost estimates will be conservative.

D. Estimated incremental costs

Incremental costs were examined two ways:

- Incremental costs of controlling to lower Hg standards over the estimated cost of controlling to existing Hg standards without any change in PM standards, and
- Incremental costs of controlling to the lower Hg standards over controlling to the existing Hg standards while controlling to a PM standard of 0.0015 lb/MMBtu.

Incremental costs of Hg reductions without a change to PM emission rate limitations

Table 3 summarizes the estimated incremental costs for NLRC units and LRC units, without a change in the PM emission limit. Costs are presumed to be 2016 dollars.

For NLRC units, 61,000 MW add ACI, 19,000 MW are estimated to add a baghouse, and 1,100 MW of those add both ACI and a baghouse. ACI is necessary for some LRC units, but it is not necessary to add fabric filters to LRC units because all LRC units have either a fabric filter and/or a scrubber. It is estimated that about 2,200 MW of capacity for LRC units installs ACI. 29,000 MW of NLRC capacity and 6,700 MW of LRC capacity are assumed to upgrade ACI systems to accommodate increased carbon usage. These estimates do not include costs for existing units that have announced retirement by 2027 but do not factor in additional retirements that may occur due to the passage of the Inflation Reduction Act and are therefore conservatively high.

Table 3. Summary of estimated cost of Hg reductions

	NLRC Units	LRC Units
Total capital	$3,951,000,000	$66,000,000
Annualized capital	$435,000,000	$7,000,000
Annual Fixed O&M	$79,000,000	$1,300,000
VOM	$181,000,000	$21,000,000
Total Annualized Cost	$695,000,000	$29,300,000

Incremental costs of Hg reductions if PM emission rate limitation is reduced to 0.0015 lb/MMBtu

If the PM emission limit is reduced to 0.0015 lb/MMBtu, 88,000 MW of NLRC capacity and 7,200 MW of LRC capacity are estimated to retrofit baghouses to meet the more stringent PM standard. This comprises the majority of the cost of complying with the more stringent Hg standard, and this baghouse cost is attributed to PM compliance and not to Hg compliance. This will significantly reduce the *incremental* cost of additional Hg emission reductions because there will not be a need for any additional baghouses to be installed to comply with the Hg standard.

Specifically, where a fabric filter is added for PM emissions control, the cost is attributed to PM emissions and not to Hg emissions control. Where there is additional Hg emissions control needed, increased carbon usage is assumed, but the treatment rate will be less due to the greater effectiveness of ACI when a baghouse is present. This is a conservative assumption because the intrinsic Hg capture with a fabric filter will be greater than that of an ESP and may make additional carbon usage unnecessary.

Where there is an ESP or baghouse improvement (as opposed to addition of a baghouse) for PM emissions control, this is not assumed to impact the cost of ACI, should it be necessary for meeting a lower Hg limit. To meet the PM emission limit, an estimated 13,000 MW of ESPs upgrade (all NLRC). In addition, 43,000 MW of NLRC capacity and 2,800 MW of LRC capacity are estimated to upgrade baghouses.

Estimated total capital expenditures for PM emission control and estimated annualized costs, including costs of baghouses, ESP modifications or modifications to baghouses, are shown in Table 4. As previously described, these estimates are believed to be conservative because any unit that does not have a reported PM emission rate in the NRDC database and is not equipped with a baghouse is assumed to retrofit to install a baghouse. These results are also conservatively high because they do not account for additional retirements that are likely to occur as a result of the passage of the Inflation Reduction Act. This estimate is lower than reported in Table 1 of the prior report because units that have reported that they will be retiring by end of 2027 are removed from this analysis (about 40,000 MW).

Table 4. Estimated cost of complying with PM emissions rate of 0.0015 lb/MMBtu

	NLRC Units	LRC Units
Total capital	$14,120,000,000	$1,100,000,000
Annualized Capital	$1,553,200,000	$121,000,000
Annual Fixed O&M	$282,000,000	$22,000,000
Total annualized Cost	$1,835,200,000	$143,000,000

Table 5 summarizes the estimated incremental costs of Hg reductions for NLRC units and LRC units when there is a change in the PM emission rate. Costs are presumed to be 2016 dollars. These estimates are conservatively high as they do not account for any additional retirements that might occur in the coming years due to the passage of the Inflation Reduction Act.

Table 5. Summary of estimated incremental costs for Hg compliance

	NLRC Units	LRC Units
Total capital	$961,000,000	$45,336,000
Annualized capital	$106,000,000	$5,000,000
Annual Fixed O&M	$19,220,000	$910,000
VOM	$39,000,000	$4,400,000
Total Annualized Cost	$164,220,000	$10,310,000