IPM Model – Updates to Cost and Performance for APC Technologies

Mercury Control Cost Development Methodology

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Purpose of Cost Algorithms for the IPM Model

The primary purpose of the cost algorithms is to provide generic order-of-magnitude costs for various air quality control technologies that can be applied to the electric power generating industry on a system-wide basis, not on an individual unit basis. Cost algorithms developed for the IPM model are based primarily on a statistical evaluation of cost data available from various industry publications as well as Sargent & Lundy's proprietary database and do not take into consideration site-specific cost issues. By necessity, the cost algorithms were designed to require minimal site-specific information and were based only on a limited number of inputs such as unit size, gross heat rate, baseline emissions, removal efficiency, fuel type, and a subjective retrofit factor.

The outputs from these equations represent the "average" costs associated with the "average" project scope for the subset of data utilized in preparing the equations. The IPM cost equations do not account for site-specific factors that can significantly affect costs, such as flue gas volume and temperature, and do not address regional labor productivity, local workforce characteristics, local unemployment and labor availability, project complexity, local climate, and working conditions. In addition, the indirect capital costs included in the IPM cost equations do not account for all project-related indirect costs, such as project contingency, that a facility would incur to install a retrofit control.

Mercury Speciation

Mercury is contained in varying concentrations in different coal supplies. During combustion, mercury is released in the form of elemental mercury. As the combustion gases cool, a portion of the mercury transforms to ionic mercury. Ultimately, there are three possible forms of mercury:

- Elemental (Hg^0),
- Ionic or Oxidized (Hg^{++}), or
- Particulate-bound.

The proportion of the various mercury forms is called its speciation. The conversion of elemental mercury to the other forms depends on several factors: cooling rate of the gas, presence of halogens or sulfur trioxide (SO_3) in the flue gas, amount and composition of fly ash, presence of unburned carbon, and the installed air pollution control equipment. Particulate-bound mercury typically is bound to fly ash or unburned carbon.

Given the interaction of the various parameters, ionic mercury can vary between 10% and 90% of the total mercury in the flue gas. Particulate mercury generally ranges from about 5-15% of the total mercury. The remainder is elemental mercury that typically makes up 10-90% of the total mercury.

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Air Pollution Control Equipment Co-Benefits

SCR catalysts promote the oxidation of elemental mercury to the ionic form. However, the extent of oxidation through the SCR catalyst can be limited by other factors, such as low flue gas halogen concentrations. SCR systems will convert some elemental mercury to ionic mercury depending on the halide content in the coal. The catalyst used in SCR systems is designed to facilitate the conversion of NO_x to N_2 and H_2O. One active ingredient used in SCR catalyst is vanadium pentoxide, which oxidizes sulfur dioxide (SO_2) to SO_3 as well as elemental mercury to ionic mercury. Mercury oxidation is inhibited by ammonia injection. Typically, most of the mercury oxidation occurs in the last layer of catalyst where the concentration of ammonia is the lowest.

Another mechanism of mercury oxidation occurs across fabric filter elements in a baghouse. Unburned carbon in the fly ash accumulates in the filter cake on the filter elements. The unburned carbon oxidizes elemental mercury to ionic mercury in the presence of halide in the flue gas. The degree of oxidation depends on the quantity of unburned carbon present in the filter cake as well as the halide content in the coal.

Because the flue gas is in intimate contact with the filter cake on the fabric filters, mercury can be adsorbed on the carbon particles present in the fly ash. The mercury is bound to the particulates in the filter cake, and the particulate mercury is removed at the same efficiency as the solids. For this reason, fabric filters can result in extremely high mercury capture, depending on the unburned carbon concentration, or can improve the capture with the use of any mercury sorbent. Fabric filters can achieve higher mercury removal efficiency compared to electrostatic precipitators (ESPs) due to the filter cake. ESPs rely on in-flight capture and do not achieve the same flue gas contact time observed with baghouse filter cake.

Ionic mercury is highly water soluble, unlike elemental mercury, and is readily captured in both wet and dry FGD systems. The formation of oxidized mercury upstream of an FGD system, either from combustion due to the presence of SCR catalyst or from conversion in a baghouse, could be captured by an FGD system downstream.

Mercury Control Technology

Activated carbon injection (ACI) involves the adsorption of mercury on activated carbon by injection of carbon in the flue gas. Commercial experience has shown that ACI can achieve a 90% reduction in total mercury in some cases. The speciation of the mercury plays a significant role in the ease of its capture. ACI can remove both oxidized and elemental mercury; however, the choice of carbon sorbent is highly dependent on the speciation. In addition, some flue gas constituents, especially SO_3, reduce the effectiveness of ACI.

Non-carbon-based sorbents have also been used sparingly in the utility industry for mercury capture. One type of non-carbon sorbent, amended silicates, has been demonstrated and applied to a small number of units. The capital and O&M costs are competitive in those applications, hence, the cost generated for ACI with a high sorbent injection rate can also be used as a proxy for the cost of using amended silicates.

Note that with the addition of an ACI system and capture of the carbon in the same particulate collector as fly ash, beneficial use of the fly ash may be limited: the carbon may prevent sale of the fly ash to the cement markets. Even the “concrete friendly” activated carbons are not well accepted in the cement industry without prior testing by the fly ash purchaser. The sorbent developer claims, however, that amended silicates are completely compatible with fly ash beneficial use in the cement industry.

Mercury Capture

As discussed previously, elemental mercury is insoluble in water and, therefore, cannot be collected in FGD systems. Elemental mercury can be removed with injected sorbents or must be converted to another form to be captured in downstream FGD systems.

In contrast to elemental mercury, ionic mercury is highly water soluble. In dry FGD systems, the ionic mercury is captured in the injected lime slurry. Dry FGD systems evaporate the liquid phase, allowing the ionic mercury to be removed with the solid by-product in the baghouse. In wet FGD systems, ionic mercury is soluble in the liquid. The captured mercury leaves the FGD system bound with the solid by-product and/or as a constituent in the purge water.

Flue gas SO_3 concentrations greater than 5 to 7 ppmv may result in the required carbon feed rate to be increased significantly to meet a high mercury removal target, and 90% or greater mercury removal may not be feasible in some cases. Based on commercial testing, the capacity of activated carbon can be cut by as much as one half with an increase in SO_3 from just 5 ppmv to 10 ppmv. In some cases, alkali reagent injection (typically Trona) before the mercury sorbent injection system can reduce the SO_3 concentration and facilitate easier mercury capture. For the purposes of the evaluation, no alkali injection was included.

Recent commercial data indicate that in some operating scenarios, the capability of the wet FGD to capture and remove ionic mercury can be reduced; this phenomenon is sometimes called “re-emission.” Extensive testing is on-going to determine the mechanism for re-emission and to develop additives to mitigate the problem. For the purposes of the cost estimation, a wet FGD additive that eliminates re-emission is modeled as an additional variable operating cost.

Particulate-bound mercury is removed very efficiently from the flue gas by the particulate control device. Therefore, it is desirable to convert as much mercury as possible to particulate-bound mercury. As discussed above, high SO_3 levels have been shown to inhibit the binding of ionic mercury to fly ash or mercury sorbents. Activated carbon, non-carbon based sorbents, and/or the addition of halogens increase the conversion of elemental and ionic mercury to particulate-bound mercury.

Establishment of Cost Basis

Commercial experience indicates that wet or dry FGD systems can capture greater than 90% of the ionic mercury. SCR catalysts can convert much of the elemental mercury to ionic mercury in the presence of halogens. When an SCR exists and there are relatively high halogen concentrations in the flue gas, it is possible that greater than 90% of the mercury could be ionic mercury. Therefore, if there is no re-emission, the capture of total mercury by an FGD following an SCR would be in the range of 80 to 90%.

Bituminous coals are associated with relatively high halogen concentrations in the flue gas. Thus, flue gas mercury from bituminous coals that is treated by an SCR could be approximately 90% ionic mercury. Sorbent injection is not required when an FGD system is in place downstream of an SCR for bituminous fuels and the required total mercury removal is less than 80%. To ensure full wet FGD co-benefit capture, costs are included to provide slurry additives to address re-emission. Both capital and variable O&M costs are included for the slurry additive injection system. If a total mercury removal of greater than 80% is required, a sorbent injection system (either with activated carbon or a non-carbon sorbent) would likely be installed and no slurry additives would be required. However, alkali injection may be required for SO_3 control to meet the removal requirements with ACI or the non-carbon sorbents. No costs are included for alkali injection.

PRB and lignite coals have relatively low halogen concentrations. For those fuels, coal additives can promote ionic mercury speciation. With an SCR followed by an FGD and coal additives included, a maximum of 80% total mercury removal could be achieved without a sorbent injection system. Coal additives, for PRB and lignite fuels, are included in the cost estimate when an SCR and an FGD system are in place and the total mercury removal is less than 80%. The coal additive costs include capital, variable O&M, and a one-time royalty fee associated with the injection process. The variable operating cost is based on a 100-ppm_w addition of bromine to the coal. In the future, additional costs might be associated with water treatment systems based on effluent limits on bromine in the wastewater. This evaluation does not address potential future water treatment requirements.

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If greater than 80% removal of the total mercury is required for PRB or lignite coals, mercury sorbent injection system would need to be installed. The sorbent injection system could include coal additives to promote ionic mercury speciation or halogenated carbon or non-carbon sorbents could be used. The user of the cost algorithms will need to pick the type of sorbent to be injected. If the user chooses “standard” activated carbon, which does not contain added halogens, then the costs of a coal additive system are automatically included in the cost algorithm.

When a sorbent injection system is required, the design feed rate will dictate the size of the equipment and the resulting capital costs. Feed rate is a function of required removal and type of the particulate collection device as baghouse offers higher residence time compared to ESP.

The activated carbon rate was based on the use of brominated carbon. Current industry experience indicates that 3-5 pounds of carbon injected for every 1,000,000 acfm of flue gas will ensure adequate mercury capture and is a common design target for systems with an ESP. When a baghouse is used to capture the carbon, a reduced feed rate of 1-2 pounds of carbon injected for every 1,000,000 acfm is generally acceptable. No co-benefit removal is considered in the carbon feed rate calculation, and no additional alkali injection to remove SO_3 or other inhibitors is included.

In summary, the factors and assumptions used are as follows:

- 2 lb per 1,000,000 acfm carbon feed rate with a baghouse,
- 5 lb per 1,000,000 acfm carbon feed rate with an ESP,
- Flue gas rate established after the air preheater,
- No co-benefit or other unit operations considered, and
- No alkali injection considered.

To account for all of the variables, the capital cost was established based on the actual anticipated sorbent feed rate, not the plant power rating. Cost data for several ACI systems were reviewed and a relationship was developed for the capital costs of the system on a feed rate basis. The developer of the amended silicates claims the sorbent will use the same equipment as an ACI system. Therefore, no changes to the capital costs were included based on the use of a non-carbon sorbent.

Another capital cost impact from a sorbent injection system is often the addition of a baghouse to capture the sorbent. A baghouse can be required for several reasons:

- If the existing ESP cannot remove the additional particulate load associated with the sorbent injection, a baghouse may be needed.

- If flue gas conditioning (SO_3 injection) is required for the existing ESP, a new baghouse should be installed. Use of flue gas conditioning indicates that the existing ESP is marginally acceptable for the current solids load and the additional sorbent load would result in excessive particulate emissions.
- If the system uses PRB coal, which tends to be low in chloride (leading to flue gas mercury composed of mostly elemental mercury), a baghouse may be needed. Installation of a baghouse can result in varying degrees of oxidation of the elemental mercury through contact with the unburned carbon in the fly ash. The oxidized mercury may be captured in downstream wet FGD systems. Mercury oxidation does not proceed at the same rate through an ESP compared to a baghouse.

A polishing baghouse with an air-to-cloth (A/C) ratio of 6.0 or lower should be considered when the baghouse is installed after an existing particulate-capture device that will remain in service to capture the majority of the fly ash. The sorbent system could be installed downstream of the existing particulate-capture device and upstream of the new baghouse. The design has two benefits. First, a smaller capital investment is required for a polishing baghouse compared to that for a full-sized baghouse. Second, any beneficial use of the fly ash can be maintained.

A full sized baghouse, with an A/C ratio of 4.0 or lower, should be specified when the baghouse will be the primary particulate collection device for the fly ash and mercury sorbent. The lower A/C ratio will provide better bag life with a high inlet particulate loading expected for the single particulate-capture device in the process.

The benchmarking of the capital costs from the projects performed by Sargent & Lundy since 2012 showed that the capital costs were relatively constant over the period from 2012 to 2015.

Capital costs were developed for the baghouse addition. The option to include a 4.0 A/C or a 6.0 A/C baghouse or not to include a baghouse is left to the user of the cost algorithm. Cost data from the S&L current database of projects, for several different baghouse installations, was reviewed and a relationship was developed for the capital costs of the system on a flue gas rate basis. The capital costs include the following:

- Duct work modifications and reinforcement,
- Foundations,
- Structural steel,
- ID fan modifications or new booster fans, and
- Electrical modifications.

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Methodology

Inputs

Several input variables are required in order to predict the total future retrofit costs:

- Type of coal,
- Unit size,
- Unit heat rate,
- Baghouse addition option and required size, and
- Type of sorbent.

A retrofit factor that equates to difficulty of system construction must be defined.

The cost methodology is based on a unit located within 500 feet of sea level. The actual elevation of the site should be considered separately and factored into the flue gas rate because the rate is directly affected by the site elevation. The flue gas rate should be increased based on the ratio of the atmospheric pressure at sea level and at the unit location. As an example, a unit located 1 mile above sea level would have an approximate atmospheric pressure of 12.2 psia. Therefore, the flue gas rate should be increased by the following multiplier:

14.7 psia/12.2 psia = 1.2 multiplier to the flue gas rate

Outputs

Total Project Costs (TPC)

First, the installed costs are calculated for a sorbent injection system as required (BMC). Then, an installed cost for the baghouse (as applicable) is calculated (BMB). However, if a sorbent system is not needed because of the existing equipment co-benefit capture, some form of fuel or FGD additive may be required. If a wet FGD is used to remove 90% of the ionic mercury, slurry additives may be required. A base module price for the slurry additives would be included in the capital estimate (BMF). If PRB or lignite is fired, and the total mercury removal is less than 80%, then additional halogens can be added to the coal. The installed capital cost for the coal additive system is included as applicable (BMA).

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The base modules are as follows:

BMC =	Base sorbent injection system
BMB =	Base baghouse
BMF =	Base wet FGD re-emission additive system
BMA =	Base coal halogen additive system
BM =	BMC + BMB + BMF + BMA

The base module installed costs include the following:

- All equipment,
- Installation,
- Buildings,
- Foundations,
- Electrical, and
- Average retrofit difficulty.

The total base module installed cost (BM) is then increased by these cost components:

- Engineering and construction management costs are included at 10% of the BM cost for a sorbent only system or 10% of the BM cost when a new baghouse is added.
- Labor adjustment for 6 x 10-hour shift premium, per diem, etc. are included at 5% of the BM cost for a sorbent-only system or 10% of the BM cost when a new baghouse is added.
- Contractor profit and fees are included at 5% of the BM cost for a sorbent only system or 10% of the BM cost when a new baghouse is added.

A capital, engineering, and construction cost subtotal (CECC) is established as the sum of the BM and the additional engineering and construction fees.

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Additional costs and financing expenditures for the project are computed based on the CECC. Financing and additional project costs include the following:

- Owner's home office costs (owner's engineering, management, and procurement) is added at 5% of the CECC.
- Allowance for Funds Used During Construction (AFUDC) is added at 0% of the CECC and owner's costs because mercury sorbent injection projects are expected to be completed in less than a year.
- With the addition of a baghouse, 6% of the CECC is added to account for AFUDC based on a complete project duration of 2 years.
- If coal additives are required, based on the type of fuel, existing equipment, total mercury removal, and sorbent type, then a one-time royalty fee may have be added to the total project cost (C2) depending on the technology supplier. The royalty fee is added to the bottom-line project cost with no burden allowances.

The total project cost is based on a multiple lump sum contract approach. Should a turnkey engineering procurement construction (EPC) contract be executed, the total project cost would be 10 to 15% higher than what is currently estimated.

Escalation is not included in the estimate. The total project cost (TPC) is the sum of the CECC and the additional costs and financing expenditures.

Fixed O&M (FOM)

The fixed operating and maintenance (O&M) cost is a function of the additional operations staff (FOMO), maintenance labor and materials (FOMM), and administrative labor (FOMA) associated with the sorbent installation. The FOM is the sum of the FOMO, FOMM, and FOMA.

The following factors and assumptions underlie calculations of the FOM:

- All of the FOM costs were tabulated on a per kilowatt-year (kW-yr) basis.
- In general, no additional operators are required for a sorbent or additive system or a baghouse. Therefore, the operations staff fixed cost (FOMO) is zero.
- The fixed maintenance materials and labor is a direct function of the process capital cost at 1.0% of the BM for a sorbent system only and 0.5% of the BM when a baghouse is added.
- The administrative labor is a function of the FOMO and FOMM at 3% of the sum of (FOMO + 0.4FOMM).

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Variable O&M (VOM)

Variable O&M is a function of the following:

- Sorbent use and unit costs,
- Waste production and unit disposal costs,
- Additional power required and unit power cost, and
- Bag and cage replacement as applicable.

The following factors and assumptions underlie calculations of the VOM:

- All of the VOM costs are tabulated on a per megawatt-hour (MWh) basis.
- The sorbent usage is calculated from the unit size and heat rate.
- The sorbent waste generation rate is equal to the sorbent feed rate.
- When the activated carbon is captured in the same particulate collector as the fly ash, any fly ash produced may have to be landfilled. As a worst-case cost estimate, the entire fly ash amount is included in the waste rate. Typical ash contents for each fuel are used to calculate a total fly ash production rate.
- The fly ash production is added to the sorbent waste only when a new baghouse is not included. With the addition of a new baghouse, the existing particulate collector should remain in operation to capture the fly ash and maintain any beneficial uses.
- The use of non-carbon-based amended silicates should continue to allow for the beneficial reuse of the fly ash. Therefore, if a non-carbon sorbent is used, only the additional sorbent waste rate is included in the cost estimate.
- Bag and cage replacement is assumed every 3 and 9 years, respectively, for unit operations with 6.0 A/C.
- Bag and cage replacement is assumed every 5 and 10 years, respectively, for unit operations with 4.0 A/C.
- The additional power required includes air blowers for the injection system and power for the baghouse compressors, as applicable.
- The additional power is reported as a percentage of the total unit gross production. In addition, a cost associated with the additional power requirements can be included in the total variable costs.
- An allowance for wet FGD additives, to reduce re-emission of the mercury, is included for wet FGD systems with SCRs only.
- An additional allowance is included for PRB or lignite coals. The allowance is based on halogen coal additives to enhance ionic mercury formation with units that have both an FGD (wet and dry) and an SCR or for units injecting standard carbon.

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Input options are provided for the user to adjust the variable O&M costs per unit. Average default values are included in the base estimate. The variable O&M costs per unit options are as follows:

- Sorbent cost in $/ton; the cost for activated carbon did not change significantly since 2013 due to market competition.
- Waste disposal costs in $/ton.
- Auxiliary power cost in $/kWh; no noticeable escalation has been observed for auxiliary power cost since 2013.
- Bag and cage costs in $/item; the cost of bags have increased from approximately $80/bag to $100/bag.
- Operating labor rate (including all benefits) in $/hr.

The variables that contribute to the overall VOM are as follows:

VOMR =	Variable O&M costs for sorbent
VOMW =	Variable O&M costs for waste disposal
VOMP =	Variable O&M costs for additional auxiliary power
VOMB =	Variable O&M costs for bags and cage replacement
VOMF =	Variable O&M costs for a wet FGD additive; only applies when there is an SCR, wet FGD system, and less than 80% total mercury capture. In that case, no mercury sorbent injection system is required.
VOMA =	Variable O&M costs for a coal additive; only applies to units burning PRB or lignite coal and when there is an SCR, FGD system, and less than 80% total mercury capture or to units burning PRB or lignite coal that inject standard carbon.

The total VOM is the sum of VOMR, VOMW, VOMP, VOMB, and VOMF and/or VOMA as applicable. The additional auxiliary power requirement is also reported as a percentage of the total gross power of the unit.

Table 1 contains an example of the complete capital and O&M cost estimate worksheet when using an existing ESP for the activated carbon and fly ash capture. Table 2 contains an example of the complete capital and O&M cost estimate worksheet when using an existing baghouse for activated carbon and fly ash capture. Table 3 shows a complete cost methodology for PRB coal burning using injection of activated carbon and adding a baghouse. Table 4 contains details of an existing SCR and wet FGD system burning PRB coal and requiring less than 80% total mercury removal.

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Table 1. Example of a Complete Cost Estimate for an ACI System with an Existing ESP

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		ESP	<--- User Input
Baghouse Addition	J		Not Added	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	516	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	516	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	21.0	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BMC ($) =	1,600,000*B*(M^0.15)	$	4,083,000	Base sorbent injection module includes all equipment from unloading to injection
BMB ($) =	if (J = Not Added then 0, J = 6.0 Air-to-Cloth then 530, J = 4.0 Air-to-Cloth then 600) *B*L^0.81	$	-	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BMF ($) =	if there is a wet FGD, SCR, and capture is less than 80% then $500,000 else 0	$	-	Base module for wet FGD additive addition (as applicable)
BMA ($) =	if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then $1,000,000 else 0	$	-	Base module for coal additive addition (as applicable)
BM ($) =	BMC + BMB + BMF + BMA	$	4,083,000	Total Base module cost including retrofit factor
BM ($/KW) =			8	Base module cost per kW
Total Project Cost				
A1 = 10% of BM		$	408,000	Engineering and Construction Management costs
A2 = if baghouse addition then 10% else 5% of BM		$	204,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = if baghouse addition then 10% else 5% of BM		$	204,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$**	**4,899,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =			**10**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	245,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = if baghouse addition then 6% else 0% of CECC + B1		$	-	AFUDC For ACI system only: 0% for less than 1 year engineering and construction cycle For additional baghouse: 6% for a 2 year engineering and construction cycle
C1 = 15% of CECC + B1		$	-	EPC fees of 15%
C2 = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent in standard PAC then 2500*A else 0		$	-	One time coal additive royalty fee (as applicable)
TPC ($) = CECC + B1 + B2 + C2		**$**	**5,144,000**	Total project cost
TPC ($/kW) =			**10**	Total project cost per kW

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Table 1 Continued

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		ESP	<--- User Input
Baghouse Addition	J		Not Added	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	516	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	516	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	21.0	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*X/(A*1000)	$	-	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM/(B*A*1000)*(0.01 for a sorbent system only or 0.005 when a baghouse is added)	$	0.08	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.00	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.08**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*S/(2000*A)	$	0.88	Variable O&M costs for sorbent
VOMW ($/MWh) = Q*T/A	$	1.26	Variable O&M costs for waste disposal that includes the sorbent and the fly ash waste as applicable
VOMP ($/MWh) =U*R*10	$	0.01	Variable O&M costs for additional auxiliary power required.
VOMB ($/MWh) = if a baghouse is added then L/(J*A*341640)* if(J = 6.0 Air-to-Cloth then (V/3+W/9) else J = 4.0 Air-to-Cloth then (V/5+W/10))	$	-	Variable O&M costs for bags and cages.
VOMF ($/MWh) = if there is a wet FGD, SCR, and capture is less than 80% then 230/A else 0	$	-	Variable O&M costs for wet FGD additive addition
VOMA ($/MWh) = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then 0.0298*C/1000 else 0	$	-	Variable O&M costs for coal additive addition
VOM ($/MWh) = VOMR + VOMW + VOMB + VOMF + VOMC	**$**	**2.15**	

Mercury Control Cost Development Methodology

Table 2. Example of a Complete Cost Estimate for an ACI System with an Existing Baghouse

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		Baghouse	<--- User Input
Baghouse Addition	J		Not Added	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	206	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	206	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	20.8	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Capital Cost Calculation		**Example**	**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BMC ($) =	1,600,000*B*(M^0.15)	$ 3,559,000	Base sorbent injection module includes all equipment from unloading to injection
BMB ($) =	if (J = Not Added then 0, J = 6.0 Air-to-Cloth then 530, J = 4.0 Air-to-Cloth then 600) *B*L^0.81	$ -	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BMF ($) =	if there is a wet FGD, SCR, and capture is less than 80% then $500,000 else 0	$ -	Base module for wet FGD additive addition (as applicable)
BMA ($) =	if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then $1,000,000 else 0	$ -	Base module for coal additive addition (as applicable)
BM ($) =	BMC + BMB + BMF + BMA	$ 3,559,000	Total Base module cost including retrofit factor
BM ($/KW) =		7	Base module cost per kW
Total Project Cost			
A1 = 10% of BM		$ 356,000	Engineering and Construction Management costs
A2 = if baghouse addition then 10% else 5% of BM		$ 178,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = if baghouse addition then 10% else 5% of BM		$ 178,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$ 4,271,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =		**9**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$ 214,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = if baghouse addition then 6% else 0% of CECC + B1		$ -	AFUDC For ACI system only: 0% for less than 1 year engineering and construction cycle For additional baghouse: 6% for a 2 year engineering and construction cycle
C1 = 15% of CECC + B1		$ -	EPC fees of 15%
C2 = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent in standard PAC then 2500*A else 0		$ -	One time coal additive royalty fee (as applicable)
TPC ($) = CECC + B1 + B2 + C2		**$ 4,485,000**	Total project cost
TPC ($/kW) =		**9**	Total project cost per kW

Mercury Control Cost Development Methodology

Table 2 Continued

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		Baghouse	<--- User Input
Baghouse Addition	J		Not Added	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	206	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	206	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	20.8	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?** ☑	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*X/(A*1000)	$	-	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM/(B*A*1000)*(0.01 for a sorbent system only or 0.005 when a baghouse is added)	$	0.07	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.00	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.07**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*S/(2000*A)	$	0.35	Variable O&M costs for sorbent
VOMW ($/MWh) = Q*T/A	$	1.25	Variable O&M costs for waste disposal that includes the sorbent and the fly ash waste as applicable
VOMP ($/MWh) =U*R*10	$	0.01	Variable O&M costs for additional auxiliary power required.
VOMB ($/MWh) = if a baghouse is added then L/(J*A*341640)* if(J = 6.0 Air-to-Cloth then (V/3+W/9) else J = 4.0 Air-to-Cloth then (V/5+W/10))	$	-	Variable O&M costs for bags and cages.
VOMF ($/MWh) = if there is a wet FGD, SCR, and capture is less than 80% then 230/A else 0	$	-	Variable O&M costs for wet FGD additive addition
VOMA ($/MWh) = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then 0.0298*C/1000 else 0	$	-	Variable O&M costs for coal additive addition
VOM ($/MWh) = VOMR + VOMW + VOMB + VOMF + VOMC	**$**	**1.61**	

Mercury Control Cost Development Methodology

Table 3. Example of a Complete Cost Estimate for an ACI System in a Separate Particulate Collection Device (Baghouse)

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		ESP	<--- User Input
Baghouse Addition	J		6.0 Air-to-Cloth	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	206	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	206	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	0.1	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	R	(%)	0.62	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Capital Cost Calculation		**Example**		**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BMC ($) =	1,600,000*B*(M^0.15)	$	3,559,000	Base sorbent injection module includes all equipment from unloading to injection
BMB ($) =	if (J = Not Added then 0, J = 6.0 Air-to-Cloth then 530, J = 4.0 Air-to-Cloth then 600) *B*L^0.81	$	59,560,000	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BMF ($) =	if there is a wet FGD, SCR, and capture is less than 80% then $500,000 else 0	$	-	Base module for wet FGD additive addition (as applicable)
BMA ($) =	if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then $1,000,000 else 0	$	-	Base module for coal additive addition (as applicable)
BM ($) =	BMC + BMB + BMF + BMA	$	63,119,000	Total Base module cost including retrofit factor
BM ($/KW) =			126	Base module cost per kW
Total Project Cost				
A1 = 10% of BM		$	6,312,000	Engineering and Construction Management costs
A2 = if baghouse addition then 10% else 5% of BM		$	6,312,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = if baghouse addition then 10% else 5% of BM		$	6,312,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$**	**82,055,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =			**164**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	4,103,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = if baghouse addition then 6% else 0% of CECC + B1		$	5,169,000	AFUDC For ACI system only: 0% for less than 1 year engineering and construction cycle For additional baghouse: 6% for a 2 year engineering and construction cycle
C1 = 15% of CECC + B1		$	-	EPC fees of 15%
C2 = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent in standard PAC then 2500*A else 0		$	-	One time coal additive royalty fee (as applicable)
TPC ($) = CECC + B1 + B2 + C2		**$**	**91,327,000**	Total project cost
TPC ($/kW) =			**183**	Total project cost per kW

Mercury Control Cost Development Methodology

Table 3 Continued

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		Bituminous	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		FALSE	<--- User Input
Existing PM Control	H		ESP	<--- User Input
Baghouse Addition	J		6.0 Air-to-Cloth	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Standard PAC	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,719,500	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	206	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	206	= M
Fly Ash Waste Rate	P	(ton/hr)	20.7	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	0.1	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	**R**	**(%)**	**0.62**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	1700	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*X/(A*1000)	$	-	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM/(B*A*1000)*(0.01 for a sorbent system only or 0.005 when a baghouse is added)	$	0.63	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.01	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.64**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*S/(2000*A)	$	0.35	Variable O&M costs for sorbent
VOMW ($/MWh) = Q*T/A	$	0.01	Variable O&M costs for waste disposal that includes the sorbent and the fly ash waste as applicable
VOMP ($/MWh) =U*R*10	$	0.37	Variable O&M costs for additional auxiliary power required.
VOMB ($/MWh) = if a baghouse is added then L/(J*A*341640)* if(J = 6.0 Air-to-Cloth then (V/3+W/9) else J = 4.0 Air-to-Cloth then (V/5+W/10))	$	0.06	Variable O&M costs for bags and cages.
VOMF ($/MWh) = if there is a wet FGD, SCR, and capture is less than 80% then 230/A else 0	$	-	Variable O&M costs for wet FGD additive addition
VOMA ($/MWh) = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then 0.0298*C/1000 else 0	$	-	Variable O&M costs for coal additive addition
VOM ($/MWh) = VOMR + VOMW + VOMB + VOMF + VOMC	**$**	**0.79**	

Mercury Control Cost Development Methodology

Table 4. Example of a Complete Cost Estimate for both Additives Systems (Fuel and FGD additives) and without Activated Carbon

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<---- User Input
Retrofit Factor	B		1	<---- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<---- User Input
Type of Coal	D		PRB	<---- User Input
Existing FGD System	E		Wet FGD	<---- User Input
Exisitng SCR	F		TRUE	<---- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		TRUE	<---- User Input (Sorbent injection is not required for caputre less than 80%.)
Existing PM Control	H		ESP	<---- User Input
Baghouse Addition	J		Not Added	<---- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Not Applicable	<---- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,900,000	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	0	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	0	= M
Fly Ash Waste Rate	P	(ton/hr)	13.6	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	0.0	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?**	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	2500	<---- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<---- User Input
Aux Power Cost	U	($/kWh)	0.06	<---- User Input
Bag Cost	V	($/bag)	100	<---- User Input
Cage Cost	W	($/cage)	30	<---- User Input
Operating Labor Rate	X	($/hr)	60	<---- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BMC ($) =	1,600,000*B*(M^0.15)	$	-	Base sorbent injection module includes all equipment from unloading to injection
BMB ($) =	if (J = Not Added then 0, J = 6.0 Air-to-Cloth then 530, J = 4.0 Air-to-Cloth then 600) *B*L^0.81	$	-	Base module for an additional PJFF including: Duct work modifications and reinforcement, foundations, structual steel, ID or booster fans, piping, electrical, etc…
BMF ($) =	if there is a wet FGD, SCR, and capture is less than 80% then $500,000 else 0	$	500,000	Base module for wet FGD additive addition (as applicable)
BMA ($) =	if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then $1,000,000 else 0	$	1,000,000	Base module for coal additive addition (as applicable)
BM ($) =	BMC + BMB + BMF + BMA	$	1,500,000	Total Base module cost including retrofit factor
BM ($/KW) =			3	Base module cost per kW
Total Project Cost				
A1 = 10% of BM		$	150,000	Engineering and Construction Management costs
A2 = if baghouse addition then 10% else 5% of BM		$	75,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = if baghouse addition then 10% else 5% of BM		$	75,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$**	**1,800,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) =			**4**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	90,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
B2 = if baghouse addition then 6% else 0% of CECC + B1		$	-	AFUDC For ACI system only: 0% for less than 1 year engineering and construction cycle For additional baghouse: 6% for a 2 year engineering and construction cycle
C1 = 15% of CECC + B1		$	-	EPC fees of 15%
C2 = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent in standard PAC then 2500*A else 0		$	1,250,000	One time coal additive royalty fee (as applicable)
TPC ($) = CECC + B1 + B2 + C2		**$**	**3,140,000**	Total project cost
TPC ($/kW) =			**6**	Total project cost per kW

Mercury Control Cost Development Methodology

Table 4 Continued

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9500	<--- User Input
Type of Coal	D		PRB	<--- User Input
Existing FGD System	E		Wet FGD	<--- User Input
Exisitng SCR	F		TRUE	<--- User Input (Sorbent injection may not be required. Co-benefit of SCR and FGD system should achieve 80% removal.)
Removal Less Than 80%?	G		TRUE	<--- User Input (Sorbent injection is not required for caputre less than 80%.)
Existing PM Control	H		ESP	<--- User Input
Baghouse Addition	J		Not Added	<--- User Input for retrofit of an additional baghouse after the existing PM control.
Type of Sorbent	Y		Not Applicable	<--- User Input
Heat Input	K	(Btu/hr)	4.75E+09	= A*C*1000
Flue Gas Rate	L	(acfm)	1,900,000	Downstream of an air preheater For Bituminous Coal = A*C*0.362 For PRB Coal = A*C*0.400 For Lignite Coal = A*C*0.435
Sorbent Feed Rate	M	(lb/hr)	0	= If Existing FGD, SCR, and if mercury removal is less than 80% then 0 else L*60/1000000* 2 lb/MMacf for baghouse applications with carbon * 5 lb/MMacf for ESP applications with carbon (Flow determined downstream of an air preheater)
Sorbent Waste Rate	N	(lb/hr)	0	= M
Fly Ash Waste Rate	P	(ton/hr)	13.6	(A*C)* Ash in Coal*(1-Boiler Ash Removal)/(2*HHV) For Bituminous Coal: Ash in Coal = 0.12; Boiler Ash Removal = 0.2; HHV = 11000 For PRB Coal: Ash in Coal = 0.06; Boiler Ash Removal = 0.2; HHV = 8400 For Lignite Coal: Ash in Coal = 0.08; Boiler Ash Removal = 0.2; HHV = 7200
Total Waste Rate	Q	(ton/hr)	0.0	= N/2000+ P or = N/2000 Based on no beneficial uses for fly ash with activated carbon without an additional baghouse or with additional baghouse.
Aux Power **Include in VOM?** ☑	**R**	**(%)**	**0.02**	if J = True then 0.6 + 0.02 else 0 + (0.02)
Sorbent Cost - Delivered	S	($/ton)	2500	<--- User Input (Standard PAC = $1700, Halogenated PAC = $2100,)
Waste Disposal Cost	T	($/ton)	30	<--- User Input
Aux Power Cost	U	($/kWh)	0.06	<--- User Input
Bag Cost	V	($/bag)	100	<--- User Input
Cage Cost	W	($/cage)	30	<--- User Input
Operating Labor Rate	X	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2016 dollars

Fixed O&M Cost			
FOMO ($/kW yr) = (0 additional operators)*2080*X/(A*1000)	$	-	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM/(B*A*1000)*(0.01 for a sorbent system only or 0.005 when a baghouse is added)	$	0.03	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.00	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.03**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*S/(2000*A)	$	-	Variable O&M costs for sorbent
VOMW ($/MWh) = Q*T/A	$	-	Variable O&M costs for waste disposal that includes the sorbent and the fly ash waste as applicable
VOMP ($/MWh) =U*R*10	$	0.01	Variable O&M costs for additional auxiliary power required.
VOMB ($/MWh) = if a baghouse is added then L/(J*A*341640)* if(J = 6.0 Air-to-Cloth then (V/3+W/9) else J = 4.0 Air-to-Cloth then (V/5+W/10))	$	-	Variable O&M costs for bags and cages.
VOMF ($/MWh) = if there is a wet FGD, SCR, and capture is less than 80% then 230/A else 0	$	0.46	Variable O&M costs for wet FGD additive addition
VOMA ($/MWh) = if there is an FGD, SCR, the coal is PRB or Lignite, and capture is less than 80% or the coal is PRB or Lignite and the sorbent is standard PAC then 0.0298*C/1000 else 0	$	0.28	Variable O&M costs for coal additive addition
VOM ($/MWh) = VOMR + VOMW + VOMB + VOMF + VOMC	**$**	**0.76**	