IPM Model – Updates to Cost and Performance for APC Technologies

Dry Sorbent Injection for SO2/HCl Control Cost Development Methodology

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Eastern Research Group, Inc.

Prepared by

Sargent & Lundy

55 East Monroe Street • Chicago, IL 60603 USA • 312-269-2000

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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 proprietary data available from various industry equipment and sorbent suppliers (including Lhoist and Solvay) as well as Sargent & Lundy's proprietary database (which includes multiple test campaigns and permanent installations) 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.

In the past five years the industry trend has moved towards installing DSI systems at smaller facilities. This update includes reviews of more recent installation costs and has updated the cost algorithm to capture the more recent trends for installations with lower feed rates. Additionally, since the application of DSI for SO_2 removal in electric power generation, the industry has continued to improve on system performance improvements. These improvements have included (1) the application of Computation Fluid Dynamics (CFD) analysis of injection location ductwork to evaluate the uniformity of the gas flow where the sorbent is injected, (2) improved lance design or injection system design to more widely distribute the sorbent within the duct, and (3) use of enhanced hydrated lime products for improved performance with hydrated lime injection. The model algorithm has been updated based on current availability of higher performing injection system and design methodology.

Technology Description

Dry sorbent injection (DSI) is a viable technology for moderate SO_2/HCl reduction on coal-fired boilers. Short term demonstrations and utility testing have shown SO_2/HCl removals greater than 80% for systems using trona-based sorbents and up to 98% for sodium bicarbonate sorbent. It should be noted that greater than 80% shouldn't be selected as a base design without testing being performed. The lowest achievable outlet emission recommended to be used for sodium based DSI is 0.10 lb/MMBtu, especially when being applied on a system-wide basis. Outlet emission rates below 0.10 lb/MMBtu may be achievable for specific facilities, but the lower rate should be demonstrated through unit-specific engineering analysis, design, and testing at the specific facility.

The most commonly used sodium-based sorbent is Trona, but sodium bicarbonate is also used. However, if the goal is only HCl removal, the amount of sorbent injection will be significantly lower. In this case, Trona may still be the most commonly used reagent, but hydrated lime also has been employed in some situations. Because of Trona's high reactivity with SO_2, when this sorbent is used, significant SO_2 removal must occur before high levels of HCl removal can be achieved. Studies show, however, that hydrated lime is quite effective for HCl removal because the need for simultaneous SO_2 removal is much reduced. In either case, actual testing must be carried out before the permanent DSI system for SO_2 or HCl removal is designed.

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The level of SO_2 removal for sodium-based sorbents can vary from 0 to 98% depending on the Normalized Stoichiometric Ratio (NSR), type and quality of sorbent, and particulate capture device. NSR is defined as follows:

$$\frac{(moles\ of\ Na\ Injected)}{(moles\ of\ SO_2\ in\ Flue\ Gas)} \Big/ (theoretical\ moles\ of\ Na\ required)$$

The level of SO_2 removal for calcium-based sorbents can vary from 0 to 50% depending on the Stoichiometric Ratio (SR), quality of sorbent and particulate capture device. SR is defined as follows:

$$\frac{(moles\ of\ Ca\ Injected)}{(moles\ of\ SO_2\ in\ Flue\ Gas)}$$

The required injection rate for alkali sorbents can vary depending on the required removal efficiency, NSR (or SR), and particulate capture device. The costs for an SO_2 mitigation system are primarily dependent on sorbent feed rate. This rate is a function of NSR or SR and the required SO_2 removal (the latter is set by the utility and is not a function of unit size). Therefore, the required SO_2 removal is determined by the user-specified SO_2 emission limit, and the cost estimation is based on sorbent feed rate and not unit size. Because HCl concentrations are low compared with SO_2 concentrations, any unused reagent for SO_2 removal is assumed to be used for HCl removal, resulting in a very small change in the NSR used for SO_2 removal when HCl removal is also a goal.

The sorbent solids can be collected in either an ESP or a baghouse. Baghouses generally achieve greater SO_2 removal efficiencies than ESPs because the presence of filter cake on the bags allows for a longer reaction time between the sorbent solids and the flue gas. Thus, for a given removal efficiency, the NSR is reduced when a baghouse is used for particulate capture.

The SO_2 capture ability of the dry-sorbent is also a function of particle surface area. To increase the particle surface area, the trona may be injected into a relatively hot flue gas. Heating the trona produces micropores on the particle surface, which greatly improve the sulfur capture ability. For Trona, the sorbent should be injected into flue gas at temperatures above 275°F to maximize the micropore structure. However, if the flue gas is too hot (greater than 800°F), the solids may sinter, reducing their surface area and thus lowering the SO_2 removal efficiency of the sorbent.

Another way to increase surface area is to mechanically reduce the particle size by grinding the sorbent. Typically, Trona is delivered unmilled. The ore is ground such that the unmilled product has an average particle diameter of approximately 30 μm. Commercial testing has shown that the reactivity of the Trona can be increased when the sorbent is ground to produce particles smaller than 30 μm. Sodium Bicarbonate when used as the sorbent gains reactivity with in-line mills. In the cost estimation methodology, the Trona and sodium bicarbonate is assumed to be delivered in the unmilled state only. To mill the sorbent, in-line mills are continuously used during the injection process. Therefore, the delivered cost of sorbent will not change; only the reactivity of the sorbent and amount used change when milled. Estimated capital costs associated with in-line milling are included when a milled reagent is selected.

Ultimately, the NSR required for a given removal is a function of particle size and particulate capture equipment. In the cost program, the user can choose either as-delivered Trona (approximately 30 μm average size) or in-line milled Trona (approximately 15 μm average size) for injection. When selecting sodium bicarbonate as the sorbent the cost model is based on in-line milling. The average Trona particle size and the type of particulate removal equipment both contribute to the predicted sorbent feed rate.

The SO_2 capture ability of hydrated lime is also a function of particle surface area and temperature. An enhanced lime is available in the market for improved surface area per pound of sorbent. Additionally, the type of particulate control device also influences the SO_2 removal efficiency. The cost program estimate for SR is based on the use of an enhanced lime product.

When targeting the removal of SO_2 with sorbent injection HCl in the flue gas stream will also react with the sorbent. Typical concentrations of HCl in the coal fired flue gas streams will be much lower than the SO_2 concentrations. The SO_2 and HCl gas will compete for reaction with the injected sorbent. However, due to lower concentrations of HCl in the flue gas stream an emission limit will be achieved for the HCl prior to the projected removal efficiency of the SO_2 in most cases. The lower emission limit for HCl is established in the present work to be 0.002 lb/mmBtu based on test data and to meet the Mercury Air Toxics (MATS) regulation. The purpose of the present cost model is based on the SO_2 injection rates; HCl removal rates are provided for information purposes only and are not used as an input into the cost model.

Establishment of the Cost Basis

For wet or dry FGD systems, sulfur removal is generally specified at the maximum achievable level. With those systems, costs are primarily a function of unit size and target sulfur removal rate. However, DSI systems are quite different. The major cost for the DSI system is the sorbent itself. The sorbent feed rate is a function of sulfur generation rate, particulate collection device, and removal efficiency. To account for all of the variables, the capital cost was established based on a sorbent feed rate, which is calculated from user input variables. Cost data for several DSI systems were reviewed and a relationship was developed for the capital costs of the system on a sorbent feed-rate basis. The data was converted to 2021 dollars based on an escalation factor of 2.5% based on the industry trends over the last ten years (2010-2020) excluding the current market conditions[1].

Methodology

Inputs

Several input variables are required in order to predict future retrofit costs. The sulfur feed rate and NSR are the major variables for the cost estimate. The NSR is a function of the following:

- Removal efficiency,
- Sorbent particle size, and
- Particulate capture device.

A retrofit factor that equates to difficulty in construction of the system must be defined. The gross unit size and gross heat rate will factor into the amount of sulfur generated.

Based on commercial testing, removal efficiencies with DSI are limited by the particulate capture device employed and particulate emission limits. Trona, when captured in an ESP, typically removes 40 to 50% of SO_2 without an increase in particulate emissions, whereas hydrated lime may remove an even lower

[1] To escalate prices from Jan 2021 to July 2022 costs, an escalation factor of 19.5% should be used, based on the Handy Whitman steam production plant index.

percentage of SO_2 before the ESP performance is impacted.[2] This is related to the electrical resistivity of each of the sorbents. A baghouse used with sorbents generally achieve a higher SO_2 removal efficiency (50 to 98%) than that of an ESP. DSI technology, however, should not be applied to fuels with sulfur content greater than 2 lb SO_2/MMBtu.

Units with a baghouse and limited NO_X control that target a high SO_2 removal efficiency with sodium sorbents may experience a brown plume resulting from the conversion of NO to NO_2. The formation of NO_2 would then have to be addressed by adding an adsorbent, such as activated carbon, into the flue gas. However, many coal-fired units control NO_X to a sufficiently low level that a brown plume should not be an issue with sodium-based DSI. This algorithm does not incorporate any additional costs to control NO_2.

The equations[3] provided in the cost methodology spreadsheet allow the user to input the required removal efficiency, within the limits of the technology. In the examples below, SO_2 removal for a unit with an ESP is set at 50% and 70% for a unit with a baghouse. The sorbent NSR would then be calculated as follows:

For an ESP at 50% removal

Unmilled Trona NSR = 1.68

Milled Trona NSR = 1.26

Sodium Bicarbonate NSR: = 0.93

For a baghouse at 70% removal

Unmilled Trona NSR = 1.61

Milled Trona NSR = 1.31

Sodium Bicarbonate = 0.90

The algorithm identifies the maximum expected HCl removal based on SO_2 removal. The HCl removal should be limited to achieve 0.002 lb HCl/MBtu to meet the Mercury Air Toxics (MATS) regulation. The hydrated lime algorithm should be used only for the HCl removal requirement. For hydrated lime injection systems, the SO_2 removal should be limited to 20% to achieve maximum HCl removal. The algorithm for the HCl removal is based on the removal rate of SO_2 determined from the sorbent injection rate. The algorithm takes into account a range of HCl inlet concentrations, but the algorithm averages this variability of HCl concentration at the inlet for the estimated HCl removal.

The current trend in the industry is to use in-line milling of the Trona to improve its utilization. For a minor increase in capital, milling can greatly reduce the variable operating expenses, thus it is recommended that only milled Trona be considered in the simplified algorithm.

[2] These control efficiencies represent average fleet level control efficiencies that can generally be achieved without increasing PM emissions. Individual units may be able to achieve higher efficiencies, depending on the configuration of the existing boiler and control devices. However, there is uncertainty with applying an assumed performance to any specific unit without doing site specific testing.

[3] The cost equations represent the average of the fleet and are intended to be used to develop fleet costs on an average basis. There is uncertainty with applying these equations or assumed performance to any specific unit without doing site specific testing.

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Outputs

Total Project Costs (TPC)

First, the base installed cost for the complete DSI system is calculated (BM). The base installed cost includes the following:

- All equipment[4],
- Installation.
- Buildings,
- Foundations,
- Electrical, and
- Average retrofit difficulty.

The base module cost is adjusted by the selection of in-line milling equipment, if milled reagent is selected. The base installed cost is then increased by the following:

- Engineering and construction management costs at 10% of the BM cost;
- Labor adjustment for 6 x 10-hour shift premium, per diem, etc., at 5% of the BM cost; and
- Contractor profit and fees at 5% of the BM cost.

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

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) are added at 5% of the CECC.
- Allowance for Funds Used During Construction (AFUDC) is not added to the CECC and owner's costs because these projects are expected to be completed in less than a year.

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 could 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.

[4] The cost equations assume that the current PM control equipment can handle any additional waste from the sorbent feed and do not factor in upgrades or additional PM control equipment. If additional PM control equipment or upgrades are necessary to meet a particular control efficiency, cost information can be found in the 2016 S&L "Particulate Control Cost Development Methodology" Report.

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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 DSI 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 are tabulated on a per-kilowatt-year (kW-yr) basis.
- In general, 2 additional operators are required for a DSI system. The FOMO is based on the number of additional operations staff required.
- The fixed maintenance materials and labor is a direct function of the process capital cost (BM).
- The administrative labor is a function of the FOMO and FOMM.

Variable O&M (VOM)

Variable O&M is a function of the following:

- Reagent use and unit costs,
- Waste production and unit disposal costs, and
- Additional power required and unit power cost.

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 additional power required includes increased fan power to account for the added DSI system and, as applicable, air blowers and transport-air drying equipment for the SO_2 mitigation system.
- 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.
- The reagent usage is a function of NSR and the required SO_2 removal. The estimated NSR is a function of the removal efficiency required. The basis for total reagent rate purity is 95% for hydrated lime, 100% for sodium bicarbonate, and 98% for Trona.
- The waste-generation rate, which is based on the reaction of Trona, sodium bicarbonate, or hydrated lime with SO_2, is a function of the sorbent feed rate. The waste-generation rate is also adjusted for excess sorbent fed. The reaction products in the waste for hydrated lime and sodium sorbents mainly contain $CaSO_4$ and Na_2SO_4 and unreacted dry sorbent such as $Ca(OH)_2$ and Na_2CO_3, respectively.
- The user can remove fly ash disposal volume from the waste disposal cost to reflect the situation where the unit has separate particulate capture devices for fly ash and dry sorbent.
- If Trona or sodium bicarbonate is the selected sorbent, the fly ash captured with this sodium sorbent in the same particulate control device must be landfilled. Typical ash content for each fuel is used to calculate a total fly ash production rate. The fly ash production is added to the sorbent waste to account for a total waste stream in the O&M analysis.

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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[5]. The variable O&M costs per unit options are as follows:

- Reagent cost in $/ton.
- Waste disposal costs in $/ton that should vary with the type of waste being disposed.
- Auxiliary power cost in $/kWh.
- Operating labor rate (including all benefits) in $/hr.

The variables that contribute to the overall VOM are:

VOMR	=	Variable O&M costs for reagent
VOMW	=	Variable O&M costs for waste disposal
VOMP	=	Variable O&M costs for additional auxiliary power

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

Cost Model Examples

The following cost examples illustrate the possible sorbent and PM control device combinations. Each example was run assuming the maximum SO_2 control efficiency indicated for each sorbent/PM control device combination. The examples are illustrative and as indicated above, there is uncertainty with applying an assumed performance to any specific unit without doing site specific testing.

Table 1 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with milled Trona injection ahead of an ESP.

Table 2 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with milled Trona injection ahead of a baghouse.

Table 3 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with unmilled Trona injection ahead of an ESP.

Table 4 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with unmilled Trona ahead of a baghouse.

Table 5 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with hydrated lime injection ahead of an ESP.

Table 6 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with hydrated lime ahead of a baghouse.

Table 7 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with sodium bicarbonate ahead of an ESP.

Table 8 contains an example of the complete capital and O&M cost estimate worksheet for a DSI installation with sodium bicarbonate ahead of a baghouse.

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[5] Sodium sorbent costs in the examples are provided in 2023 dollars, lime sorbent costs have not been escalated. These values should be updated with the appropriate reagent costs to reflect the analysis being performed.

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Table 1. Example of a Complete Cost Estimate for a Milled Trona DSI System with an ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		ESP	<--- User Input
Sorbent	G		Milled Trona	<--- User Input
Removal Target	H	(%)	85	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		3.08	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	17.54	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	14.11	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM?	P	(ton/hr)	20.73	(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
Aux Power **Include in VOM?**	Q	(%)	0.70	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	270	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 1. Example of a Complete Cost Estimate for a Milled Trona DSI System with an ESP (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BM ($) =	Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	20,583,480	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumidification system
BM ($/KW) =			41	Base module cost per kW
Total Project Cost				
A1 = 10% of BM		$	2,058,000	Engineering and Construction Management costs
A2 = 5% of BM		$	1,029,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM		$	1,029,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3		**$**	**24,699,480**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =			**49**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	1,235,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1		**$**	**25,934,480**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =			**52**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)		$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2		**$**	**25,934,480**	Total project cost
TPC ($/kW) =			**52**	Total project cost per kW
Fixed O&M Cost				
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)		$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)		$	0.41	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)		$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA		**$**	**0.93**	Total Fixed O&M costs
Variable O&M Cost				
VOMR ($/MWh) = M*R/A		$	9.47	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A		$	3.48	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10		$	0.42	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP		**$**	**13.38**	

DSI Cost Methodology

Table 2. Example of a Complete Cost Estimate for a Milled Trona DSI System with a Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		Baghouse	<--- User Input
Sorbent	G		Milled Trona	<--- User Input
Removal Target	H	(%)	90	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		2.18	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	12.46	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	10.42	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
☑ Fly Ash Waste Rate Include in VOM?	P	(ton/hr)	20.73	(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
Aux Power ☑ Include in VOM?	Q	(%)	0.50	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	270	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 2. Example of a Complete Cost Estimate for a Milled Trona DSI System with a Baghouse (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation	Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime if(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	18,083,999	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumidification system
BM ($/KW) =		36	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,808,000	Engineering and Construction Management costs
A2 = 5% of BM	$	904,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	904,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**21,699,999**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**43**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	1,085,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**22,784,999**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**46**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**22,784,999**	Total project cost
TPC ($/kW) =		**46**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.36	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.88**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	6.73	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	3.12	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.30	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**10.14**	

DSI Cost Methodology

Table 3. Example of a Complete Cost Estimate for an Unmilled Trona DSI System with an ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		ESP	<--- User Input
Sorbent	G		Unmilled Trona	<--- User Input
Removal Target	H	(%)	70	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		3.15	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	17.96	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	14.22	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM? ☑	P	(ton/hr)	20.73	(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
Aux Power **Include in VOM?** ☑	Q	(%)	0.65	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	270	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 3. Example of a Complete Cost Estimate for an Unmilled Trona DSI System with an ESP (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		Example	Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	18,741,170	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumification system
BM ($/KW) =		37	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,874,000	Engineering and Construction Management costs
A2 = 5% of BM	$	937,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	937,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**22,489,170**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**45**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	1,124,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**23,613,170**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**47**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**23,613,170**	Total project cost
TPC ($/kW) =		**47**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.38	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.89**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	9.70	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	3.49	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.39	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**13.58**	

Table 4. Example of a Complete Cost Estimate for an Unmilled Trona DSI System with a Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		Baghouse	<--- User Input
Sorbent	G		Unmilled Trona	<--- User Input
Removal Target	H	(%)	85	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		2.32	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	13.21	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	10.91	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM? ☑	P	(ton/hr)	20.73	(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
Aux Power **Include in VOM?** ☑	Q	(%)	**0.48**	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	270	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 4. Example of a Complete Cost Estimate for an Unmilled Trona DSI System with a Baghouse (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		**Example**	**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	16,686,066	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumification system
BM ($/KW) =		33	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,669,000	Engineering and Construction Management costs
A2 = 5% of BM	$	834,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	834,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**20,023,066**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**40**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	1,001,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**21,024,066**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**42**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**21,024,066**	Total project cost
TPC ($/kW) =		**42**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.33	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.85**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	7.13	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	3.16	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.29	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**10.58**	

DSI Cost Methodology

Table 5. Example of a Complete Cost Estimate for a Hydrated Lime DSI System with an ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		ESP	<--- User Input
Sorbent	G		Hydrated Lime	<--- User Input
Removal Target	H	(%)	40	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		2.83	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	8.08	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	8.97	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
☑ Fly Ash Waste Rate Include in VOM?	P	(ton/hr)	20.73	(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
Aux Power ☑ **Include in VOM?**	Q	(%)	**0.29**	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	150	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

Table 5. Example of a Complete Cost Estimate for a Hydrated Lime DSI System with an ESP (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		Example	Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	14,739,815	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumification system
BM ($/KW) =		29	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,474,000	Engineering and Construction Management costs
A2 = 5% of BM	$	737,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	737,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**17,687,815**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**35**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	884,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**18,571,815**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**37**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**18,571,815**	Total project cost
TPC ($/kW) =		**37**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.30	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.81**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	2.43	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	2.97	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.17	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**5.57**	

DSI Cost Methodology

Table 6. Example of a Complete Cost Estimate for a Hydrated Lime DSI System with a Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		Baghouse	<--- User Input
Sorbent	G		Hydrated Lime	<--- User Input
Removal Target	H	(%)	50	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		2.16	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	6.17	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	7.28	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM?	P	(ton/hr)	20.73	(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
Aux Power Include in VOM?	Q	(%)	0.22	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	150	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 6. Example of a Complete Cost Estimate for a Hydrated Lime DSI System with a Baghouse (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		Example	Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	13,311,779	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumification system
BM ($/KW) =		27	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,331,000	Engineering and Construction Management costs
A2 = 5% of BM	$	666,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	666,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**15,974,779**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**32**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	799,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**16,773,779**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**34**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**16,773,779**	Total project cost
TPC ($/kW) =		**34**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.27	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.78**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	1.85	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	2.80	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.13	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**4.79**	

DSI Cost Methodology

Table 7. Example of a Complete Cost Estimate for a Sodium Bicarbonate DSI System with an ESP

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		ESP	<--- User Input
Sorbent	G		Sodium Bicarbonate	<--- User Input
Removal Target	H	(%)	95	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		2.69	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	16.77	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	11.85	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM? ☑	P	(ton/hr)	20.73	(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
Aux Power Include in VOM? ☑	Q	(%)	0.67	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	380	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 7. Example of a Complete Cost Estimate for a Sodium Bicarbonate DSI System with an ESP (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation		**Example**		**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BM ($) =	Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	19,538,344	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumidification system
BM ($/KW) =			39	Base module cost per kW
Total Project Cost				
A1 = 10% of BM		$	1,954,000	Engineering and Construction Management costs
A2 = 5% of BM		$	977,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM		$	977,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3		**$**	**23,446,344**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =			**47**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	1,172,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1		**$**	**24,618,344**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =			**49**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)		$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2		**$**	**24,618,344**	Total project cost
TPC ($/kW) =			**49**	Total project cost per kW
Fixed O&M Cost				
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)		$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)		$	0.39	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)		$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA		**$**	**0.91**	Total Fixed O&M costs
Variable O&M Cost				
VOMR ($/MWh) = M*R/A		$	12.75	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A		$	3.26	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10		$	0.40	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP		**$**	**16.41**	

DSI Cost Methodology

Table 8. Example of a Complete Cost Estimate for a Sodium Bicarbonate DSI System with a Baghouse

Fill in the yellow cells with the known data inputs. The resulting costs are tabulated below. Variable names are defined as outlined in the table.

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
SO2 Rate	D	(lb/MMBtu)	1	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Particulate Capture	F		Baghouse	<--- User Input
Sorbent	G		Sodium Bicarbonate	<--- User Input
Removal Target	H	(%)	98	Maximum Removal Targets: Unmilled Trona with an ESP = 70% Milled Trona with an ESP = 85% Unmilled Trona with an BGH = 85% Milled Trona with an BGH = 90% SBC with an ESP = 95% SBC with a BGH = 98% Hydrated Lime with an ESP = 40% Hydrated Lime with a BGH = 50%
Heat Input	J	(Btu/hr)	4.75E+09	A*C*1000
NSR	K		1.79	Unmilled Trona with an ESP = if (H<40,0.0310*H,0.352e^(0.0313*H)) Milled Trona with an ESP = if (H<40,0.0245*H,0.355e^(0.0254*H)) Unmilled Trona with a BGH = if (H<40,0.0196*H,0.296e^(0.0242*H)) Milled Trona with a BGH = if (H<40,0.0150*H,0.220e^(0.0255*H)) SBC with an ESP =if(H<60,0.0185*H,0.255e^(0.0248*H)) SBC with a BGH = if (H<60,0.0120*H,0.165e^(0.0243*H)) Hydrated Lime with an ESP = if(H<10,0.34*H^0.51,0.82*EXP(0.031*H)) Hydrated Lime with a BGH = if(H<10,0.40*H^0.31, 0.62*EXP(0.025*H))
Sorbent Feed Rate	M	(ton/hr)	11.13	Trona = (1.2011 x 10^-06)*K*A*C*D Hydrated Lime = (6.0055 x 10^-07)*K*A*C*D SBC = (1.3125 x 10^-6)*K*A*C*D
Estimated HCl Removal	V	(%)	95	Milled or Unmilled Trona with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu Milled or Unmilled Trona with a BGH =84.598*H^0.0346 or 0.002 lb/MBtu SBC with an ESP = 60.86*H^0.1081, or 0.002 lb/MBtu SBC with a BGH = 84.598*H^0.0346, or 0.002 lb/MBtu Hydrated Lime with an ESP = 54.92*H^0.197 or 0.002 lb/MBtu Hydrated Lime with a BGH = 0.0085*H+99.12 or 0.002 lb/MBtu
Sorbent Waste Rate	N	(ton/hr)	8.33	Trona = (0.7387 + 0.002372*H/K)*M Lime = (1.00 + 0.00777*H/K)*M SBC = (0.6310 + 0.002143 *H/K)*M Waste product adjusted for a maximum inert content of 5% for Hydrated Lime and 2% for Trona and 0% for SBC.
Fly Ash Waste Rate Include in VOM? ☑	P	(ton/hr)	20.73	(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
Aux Power Include in VOM? ☑	Q	(%)	0.45	=if Milled Trona or SBC M*20/A else M*18/A
Sorbent Cost	R	($/ton)	380	<--- User Input (Trona = $270, Hydrated Lime = $150, Sodium Bicarbonate = $380)
Waste Disposal Cost	S	($/ton)	50	<--- User Input (Disposal cost with fly ash = $50. Without fly ash, the sorbent waste alone will be more dificult to dispose = $100)
Aux Power Cost	T	($/kWh)	0.06	<--- User Input
Operating Labor Rate	U	($/hr)	60	<--- User Input (Labor cost including all benefits)

DSI Cost Methodology

Table 8. Example of a Complete Cost Estimate for a Sodium Bicarbonate DSI System with a Baghouse (Continued)

Costs are all based on 2021 dollars

Capital Cost Calculation	Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BM ($) = Unmilled Trona if (M>25 then (860,000*B*M) else 6,290,000*B*(M^0.378) Milled Trona if (M>25 then (950,000*B*M) else 6,970,000*B*(M^0.378)) Hydrated Lime If(M>25 then (910,000*B*M) else 6,690,000*B*(M^0.378)) SBC if(M>25 then (920,000*B*M) else 6,730,000*B*M^0.378)	$	16,733,787	Base module for unmilled sorbent includes all equipment from unloading to injection, including dehumification system
BM ($/KW) =		33	Base module cost per kW
Total Project Cost			
A1 = 10% of BM	$	1,673,000	Engineering and Construction Management costs
A2 = 5% of BM	$	837,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 5% of BM	$	837,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$**	**20,080,787**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**40**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$	1,004,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$**	**21,084,787**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**42**	Total project cost per kW without AFUDC
B2 = 0% of (CECC + B1)	$	-	AFUDC (Zero for less than 1 year engineering and construction cycle)
TPC ($) = CECC + B1 + B2	**$**	**21,084,787**	Total project cost
TPC ($/kW) =		**42**	Total project cost per kW
Fixed O&M Cost			
FOMO ($/kW yr) = (2 additional operator)*2080*U/(A*1000)	$	0.50	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.01/(B*A*1000)	$	0.34	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.02	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**0.85**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = M*R/A	$	8.46	Variable O&M costs for sorbent
VOMW ($/MWh) = (N+P)*S/A	$	2.91	Variable O&M costs for waste disposal that includes both the sorbent and the fly ash waste not removed prior to the sorbent injection
VOMP ($/MWh) =Q*T*10	$	0.27	Variable O&M costs for additional auxiliary power required (Refer to Aux Power % above)
VOM ($/MWh) = VOMR + VOMW + VOMP	**$**	**11.63**	