IPM Model – Updates to Cost and Performance for APC Technologies

SDA FGD Cost Development Methodology

Final

March 2024

Project 13527-002

Eastern Research Group, Inc.

Prepared by

Sargent & Lundy

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

LEGAL NOTICE

This analysis ("Deliverable") was prepared by Sargent & Lundy, L.L.C. ("S&L"), expressly for the sole use of Eastern Research Group, Inc. ("Client") in accordance with the agreement between S&L and Client. This Deliverable was prepared using the degree of skill and care ordinarily exercised by engineers practicing under similar circumstances. Client acknowledges: (1) S&L prepared this Deliverable subject to the particular scope limitations, budgetary and time constraints, and business objectives of the Client; (2) information and data provided by others may not have been independently verified by S&L; and (3) the information and data contained in this Deliverable are time sensitive and changes in the data, applicable codes, standards, and acceptable engineering practices may invalidate the findings of this Deliverable. Any use or reliance upon this Deliverable by third parties shall be at their sole risk.

This work was funded by U.S. Environmental Protection Agency (EPA) through Eastern Research Group, Inc. (ERG) as a contractor and reviewed by ERG and EPA personnel.

SDA FGD Cost Development Methodology

Purpose of IPM Model

Cost algorithms in the IPM model are based primarily on a statistical evaluation of cost data available from various industry publications, and do not take into consideration site-specific cost issues. The primary purpose of the IPM cost modules 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. By necessity, the cost algorithms were designed to require minimal site-specific information. The IPM cost equations can provide order-of-magnitude capital costs for various air quality control systems based only on a limited number of inputs such as unit size, gross heat rate, inlet SO_2 level, fuel sulfur level, % 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 impact costs, such as flue gas volume, temperature and do not address regional labor productivity, local workforce characteristics, local unemployment and labor availability, project complexity, local climate, and working conditions. Finally, the indirect capital costs included in the IPM cost equations do not account for all project-related indirect costs a facility would incur to install a retrofit control such as project contingency.

Establishment of Cost Basis

Cost data for the SDA FGD systems based on actual installations were more limited than those for the wet FGD systems until 2012. However, since 2012 the market trend has shifted toward the installation of dry FGD/CDS technology. Even with the new data, a similar trend of capital cost with generating capacity (MW size) is generally seen between the wet and SDA system. The same least-square curve fit power relationship for capital costs as a function of generating capacity, up to 600 MW, was used for the wet and SDA cost estimation with the constant multiplier adjusted to ensure that the curve represented the data available.

The curve fit was set to represent proprietary in-house cost data of a "typical" SDA FGD retrofit for removal of 95% of the inlet sulfur. It should be noted that the lowest available SO_2 emission guarantees, from the original equipment manufactures of SDA FGD systems, are 0.06 lb/MMBtu. The typical SDA FGD retrofit was based on:

- Retrofit Difficulty = 1 (Average retrofit difficulty);
- Gross Heat Rate = 9800 Btu/kWh;
- SO_2 Rate = 2.0 lb/MMBtu;
- Type of Coal = PRB;
- Project Execution = Multiple lump-sum contracts; and
- Recommended SO_2 emission floor = 0.08 lb/MMBtu.

A dry FGD system designed to treat 100% of the flue gas is capable of meeting Mercury Air Toxics Standards (MATS) limits for HCl of 0.002 lb/MBtu. Dry FGDs can remove up to 99% HCl in the flue gas.

Based on the recently acquired data and recently completed projects along with relevant cost indices, it appears the overall capital cost has increased by 48% over the costs published in 2016. The majority of the escalation between 2016 and 2024 can be attributed to the 29% escalation experienced between January 2021 and January 2022, according to the Chemical Engineering

SDA FGD Cost Development Methodology

Plant Cost Index (CEPCI). While escalation from 2016 to 2024 outside of 2021 averaged a more typical 2%, the effect of pandemic and supply-chain related escalation has resulted in major cost increases over this period.

Units below 50 MW will typically not install an SDA FGD system. Sulfur reductions for small units would be accomplished by treating smaller units at a single site with one SDA FGD system, switching to a lower sulfur coal, repowering or converting to natural gas firing, using dry sorbent injection, and/or reducing operating hours. Capital costs of approximately $1,500/kW may be used for units below 50 MW under the premise that these units will be combined.

Based on the typical SDA FGD performance, the technology should not be applied to fuels with more than 3 lb SO_2/MMBtu, and the cost estimator should be limited to fuels with less than 3 lb SO_2/MMBtu. Typically, both SDA and circulating dry scrubber (CDS) technologies have been applied to low sulfur fuel (lower than 2 lb/MMBtu).

The alternate dry technology, CDS, can meet removals of 98% or greater over a large range of inlet sulfur concentrations. It should be noted that the lowest SO_2 emission guarantees for a CDS FGD system are 0.04 lb/MMBtu. Recent industry experience has shown that a CDS FGD system has a similar installed cost to a comparable SDA FGD system and has been the technology of choice in last ten years. CDS offers advantages in operational flexibility and can achieve higher SO_2 removal than an SDA system. These advantages, along with the fact that CDS and SDA installed costs are similar, has resulted in CDS becoming the predominant dry FGD system.

Methodology

Inputs

Several input variables are required in order to predict future retrofit costs. The gross unit size in MW (equivalent acfm) and sulfur content of the fuel are the major variables for the capital estimation. A retrofit factor that equates to the difficulty of constructing the system must be defined. The costs herein could increase significantly for congested sites. The unit gross heat rate will factor into the amount of flue gas generated and ultimately the size of the absorber, reagent preparation, waste handling, and balance of plant costs. The SO_2 rate will have the greatest influence on the reagent handling and waste handling facilities. The type of fuel (Bituminous, PRB, or Lignite) will influence the flue gas quantities as a result of the different typical heating values.

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 cost due to the effects on the flue gas volume. The base absorber island and balance of plant costs are directly impacted by the site elevation. These two base cost modules should be increased based on the ratio of the atmospheric pressure at sea level and that 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 base absorber island and balance of plant costs should be increased by:

14.7 psia/12.2 psia = 1.2 multiplier to the base absorber island and balance of plant costs

SDA FGD Cost Development Methodology

Outputs

Total Project Costs (TPC)

First, the installed costs are calculated for each required base module. The base module installed costs include:

- All equipment;
- Installation;
- Buildings;
- Foundations;
- Electrical; and
- Retrofit difficulty.

The base modules are:

BMR	=	Base absorber island cost that includes an absorber and a baghouse
BMF	=	Base reagent preparation cost and waste recycle/handling cost
BMB	=	Base balance of plant costs including: ID or booster fans, piping, ductwork and reinforcement, electrical, etc.
BM	=	BMR + BMF + BMB

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

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

- Owner's home office costs (owner's engineering, management, and procurement) at 5% of the CECC; and
- Allowance for Funds Used During Construction (AFUDC) at 10% of the CECC and owner's costs. The AFUDC is based on a three-year engineering and construction cycle.

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.

SDA FGD Cost Development Methodology

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 SDA FGD 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, 8 additional operators are required for an SDA FGD system. The FOMO was based on the number of additional operations staff required.
- The fixed maintenance materials and labor are a direct function of the process capital cost at 1.5% of the BM. Cost of bags and cages are included in the fixed O&M cost with the assumption that bag replacement is carried out once every 3 years and cage replacement is carried out once every 9 years.
- The administrative labor is a function of the FOMO and FOMM at 3% of the sum of (FOMO + 0.4 FOMM).

Variable O&M (VOM)

Variable O&M is a function of:

- Reagent use and unit costs;
- Waste production and unit disposal costs;
- Additional power required and unit power cost; and
- Makeup water required and unit water cost.

The following factors and assumptions underlie calculations of the VOM:

- All of the VOM costs were tabulated on a per megawatt-hour (MWh) basis.
- The reagent usage is a function of gross unit size, SO_2 feed rate, and removal efficiency. While the capital costs are based on a 95% sulfur removal design, the operating sulfur removal percentage can be adjusted to reflect actual variable operating costs.
- In addition to sulfur removal efficiency, the estimated reagent usage was based on a flue gas temperature into the SDA FGD of 300°F and an adiabatic approach to saturation of 30°F.
- The calcium-to-sulfur stoichiometric ratio varies based on inlet sulfur. The variation in stoichiometric ratio was accounted for in the estimation. The economic estimation is only valid up to 3 lb SO_2/MMBtu inlet.
- The basis for the lime purity was 90% CaO with the balance being inert material.
- The waste generation rate is a function of inlet sulfur and calcium to sulfur stoichiometry. Both variables are accounted for in the waste generation estimation. The waste disposal rate is based on 10% moisture in the by-product.
- The additional power required includes increased fan power to account for the added SDA FGD pressure drop. This requirement is a function of gross unit size (actual gas flow rate) and sulfur rate.

SDA FGD Cost Development Methodology

- 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 makeup water rate is a function of gross unit size (actual gas flow rate) and sulfur feed rate.

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:

- Lime cost in $/ton. No escalation is observed in pebble lime cost. However, the cost could significantly vary with the location.
- Waste disposal costs in $/ton. The site-specific cost could be significantly different.
- Auxiliary power cost in $/kWh. No noticeable escalation has been observed for auxiliary power cost since 2013.
- Makeup water costs in $/1000 gallon.
- Operating labor rate (including all benefits) in $/hr.

The variables that contribute to the overall VOM are:

VOMR = Variable O&M costs for limestone reagent

VOMW = Variable O&M costs for waste disposal

VOMP = Variable O&M costs for additional auxiliary power

VOMM = Variable O&M costs for makeup water

The total VOM is the sum of VOMR, VOMW, VOMP, and VOMM. Table 1 shows a complete capital and O&M cost estimate worksheet for an SDA FGD.

Sargent & Lundy

SDA FGD Cost Development Methodology

Table 1. Example of a Complete Cost Estimate for an SDA FGD

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input (Greater than 50 MW)
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9800	<--- User Input
SO2 Rate	D	(lb/MMBtu)	2	<--- User Input (SDA FGD Estimation only valid up to 3 lb/MMBtu SO2 Rate)
Type of Coal	E		PRB	<--- User Input
Coal Factor	F		1.05	Bit=1, PRB=1.05, Lig=1.07
Heat Rate Factor	G		0.98	C/10000
Heat Input	H	(Btu/hr)	4.90E+09	A*C*1000
Operating SO_2 Removal	J	(%)	95	<--- User Input (Used to adjust actual operating costs)
Design Lime Rate	K	(ton/hr)	7	(0.6702*(D^2)+13.42*D)*A*G/2000 (Based on 95% SO2 removal)
Design Waste Rate	L	(ton/hr)	16	(0.8016*(D^2)+31.1917*D)*A*G/2000 (Based on 95% SO2 removal)
Aux Power **Include in VOM?** ☑	**M**	**(%)**	**1.35**	(0.000547*D^2+0.00649*D+1.3)*F*G
Makeup Water Rate	N	(1000 gph)	29	(0.04898*(D^2)+0.5925*D+55.11)*A*F*G/1000
Lime Cost	P	($/ton)	125	<--- User Input
Waste Disposal Cost	Q	($/ton)	30	<--- User Input
Aux Power Cost	R	($/kWh)	0.06	<--- User Input
Makeup Water Cost	S	($/kgal)	1	<--- User Input
Operating Labor Rate	T	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2024 dollars

Capital Cost Calculation		**Example**	**Comments**
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BMR ($) =	if (A>600 then (A*145000) else 941000*(A^0.716))*B*(F*G)^0.6*(D/4)^0.01	$ 81,375,000	Base module absorber island cost
BMF ($) =	if (A>600 then (A*77000) else 499000*(A^0.716))*B*(D*G)^0.2	$ 48,867,000	Base module reagent preparation and waste recycle/handling cost
BMB ($) =	if (A>600 then (A*204000) else 1328000*(A^0.716))*B*(F*G)^0.4	$ 114,981,000	Base module balance of plant costs including: ID or booster fans, piping, ductwork modifications and strengthening, electrical, etc…
BM ($) =	BMR + BMF + BMW + BMB	$ 245,223,000	Total Base module cost including retrofit factor
BM ($/KW) =		490	Base module cost per kW

Total Project Cost	**Example**	**Comments**
A1 = 10% of BM	$ 24,522,000	Engineering and Construction Management costs
A2 = 10% of BM	$ 24,522,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM	$ 24,522,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3	**$ 318,789,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =	**638**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC	$ 15,939,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1	**$ 334,728,000**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =	**669**	Total project cost per kW without AFUDC
B2 = 10% of (CECC + B1)	$ 33,473,000	AFUDC (Based on a 3 year engineering and construction cycle)
C1 = 15% of (CECC + B1)	$ -	EPC fees of 15%
TPC ($) - Includes Owner's Costs and AFUDC = CECC + B1 + B2	**$ 368,201,000**	Total project cost
TPC ($/kW) - Includes Owner's Costs and AFUDC =	**736**	Total project cost per kW

SDA FGD Cost Development Methodology

Table 1. Example of a Complete Cost Estimate for an SDA FGD (Continued)

Variable	Designation	Units	Value	Calculation
Unit Size (Gross)	A	(MW)	500	<--- User Input (Greater than 50 MW)
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Gross Heat Rate	C	(Btu/kWh)	9800	<--- User Input
SO2 Rate	D	(lb/MMBtu)	2	<--- User Input (SDA FGD Estimation only valid up to 3 lb/MMBtu SO2 Rate)
Type of Coal	E		PRB	<--- User Input
Coal Factor	F		1.05	Bit=1, PRB=1.05, Lig=1.07
Heat Rate Factor	G		0.98	C/10000
Heat Input	H	(Btu/hr)	4.90E+09	A*C*1000
Operating SO_2 Removal	J	(%)	95	<--- User Input (Used to adjust actual operating costs)
Design Lime Rate	K	(ton/hr)	7	(0.6702*(D^2)+13.42*D)*A*G/2000 (Based on 95% SO2 removal)
Design Waste Rate	L	(ton/hr)	16	(0.8016*(D^2)+31.1917*D)*A*G/2000 (Based on 95% SO2 removal)
Aux Power **Include in VOM?** ☑	**M**	**(%)**	**1.35**	(0.000547*D^2+0.00649*D+1.3)*F*G
Makeup Water Rate	N	(1000 gph)	29	(0.04898*(D^2)+0.5925*D+55.11)*A*F*G/1000
Lime Cost	P	($/ton)	125	<--- User Input
Waste Disposal Cost	Q	($/ton)	30	<--- User Input
Aux Power Cost	R	($/kWh)	0.06	<--- User Input
Makeup Water Cost	S	($/kgal)	1	<--- User Input
Operating Labor Rate	T	($/hr)	60	<--- User Input (Labor cost including all benefits)

Costs are all based on 2024 dollars

Fixed O&M Cost			
FOMO ($/kW yr) = (8 additional operators)*2080*T/(A*1000)	$	2.00	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = BM*0.015/(B*A*1000)	$	7.36	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.15	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**9.50**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = K*P/A*J/95	$	1.81	Variable O&M costs for lime reagent
VOMW ($/MWh) = L*Q/A*J/95	$	0.96	Variable O&M costs for waste disposal
VOMP ($/MWh) =M*R*10	$	0.81	Variable O&M costs for additional auxiliary power required including additional fan power (Refer to Aux Power % above)
VOMM ($/MWh) = N*S/A	$	0.06	Variable O&M costs for makeup water
VOM ($/MWh) = VOMR + VOMW + VOMP + VOMM	**$**	**3.64**	