

IPM Model – Updates to Cost and Performance for APC Technologies

Wet FGD Cost Development Methodology

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The logo for Sargent & Lundy features a stylized, grey, curved shape resembling a '3' or a '5' on the left side. To its right, the company name 'Sargent & Lundy' is written in a bold, blue, sans-serif font.

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Wet 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 SO₂ 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

Industry Data from “Current Capital Cost and Cost-effectiveness of Power Plant Emissions Control Technologies” prepared by J. E. Cichanowicz for the Utility Air Regulatory Group (UARG) in 2012 to 2017 were used by Sargent & Lundy LLC (S&L) to update the wet FGD cost algorithms from 2016. The published data was significantly augmented by S&L in-house database of recent wet FGD and wet FGD wastewater treatment system projects. Due to recently published Effluent Limitation Guidelines (ELG), it is expected that all future wet FGDs will have to incorporate a waste water treatment facility. The capital cost of physical/chemical treatment along with selenium control with biological treatment is included in the base scope. Other feasible technologies such as evaporation, waste fixation/stabilization, and slip stream dry scrubbing would have to be evaluated on case by case basis.

Cost data from the various sources showed similar trends versus generating capacity. Escalation based on Chemical Engineering Plant Cost Index (CEPCI) was deemed acceptable. All data sources were combined so as to provide a representative wet FGD cost basis. The cost estimation tool was benchmarked against recent wet FGD projects to confirm the applicability to the current market conditions.

The least squares curve fit of the data was defined as a “typical” wet FGD retrofit for removal of 98% of the inlet sulfur. It should be noted that the lowest available SO₂ emission guarantees, from the original equipment manufacturers of wet FGD systems, are 0.04 lb/MMBtu. The typical wet FGD retrofit was based on:

- Retrofit Difficulty = 1 (Average retrofit difficulty);
- Gross Heat Rate = 9500 Btu/kWh;
- SO₂ Rate = 3.0 lb/MMBtu;
- Type of Coal = Bituminous;
- Project Execution = Multiple lump sum contracts; and
- Recommended SO₂ emission floor = 98% removal efficiency or 0.06 lb/MMBtu.



Wet FGD Cost Development Methodology

Units below 100 MW will typically not install a wet FGD system. Sulfur reductions for the small units would be accomplished by; treating smaller units at a single site with one wet FGD system, switching to a lower sulfur coal, repowering or conversion to natural gas firing, dry sorbent injection, and/or a reduction in operating hours. Capital costs of approximately \$1330/kW may be used for units below 100 MW under the premise that these will be combined.

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 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. The cost algorithm does incorporate the cost for wet FGD wastewater treatment system to include the capital and O&M cost associated with retrofitting the wet FGD wastewater treatment to meet ELG regulation.

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 difficulty in construction of the system must be defined. The costs herein could increase significantly for congested sites. The gross unit 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 SO₂ 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 evaluation includes a user selected option for a wastewater treatment facility. The base capital cost includes minor physical and chemical wastewater treatment. However, in the future more extensive wastewater handling may be required due to compliance associated with ELG. The physical and chemical wastewater treatment system and biological treatment system costs are developed based on fixed parameters associated with the wet FGD system. It is assumed that the waste water would be approximately 0.4 gpm/MW. For example, for 500 MWW unit, waste water treatment will be designed for 200 gpm of waste water. Any changes from the base assumptions should be incorporated to derive more accurate cost. Other available wastewater treatment technology systems are not considered in this cost algorithm.

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 between sea level and 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:

$$14.7 \text{ psia}/12.2 \text{ psia} = 1.2 \text{ multiplier to the base absorber island and balance of plant costs}$$



Wet 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;
- Minor physical and chemical wastewater treatment (WWT); and
- Retrofit difficulty.

The base modules are:

BMR	=	Base absorber island cost
BMF	=	Base reagent preparation cost
BMW	=	Base waste handling cost
BMB	=	Base balance of plant costs including: ID or booster fans, new wet chimney, piping, ductwork and reinforcement, minor WWT, etc.
BMWW	=	Base wastewater treatment facility to comply with ELG
BM	=	BMR + BMF + BMW + BMB + BMWW

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.



Wet FGD Cost Development Methodology

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 wet FGD installation. The fixed O&M cost category to account for a wastewater treatment facility that meets ELG regulations is included in the fixed cost for maintenance labor and materials (FOMM). 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, 12 additional shift operators are required for a 500 MW or smaller installation. Units larger than 500 MW require a total of 16 additional shift operators. The FOMO was based on the number of additional operations staff required as a function of generating capacity.
- The fixed maintenance materials and labor is a direct function of the process capital cost at 1.5% of the BM.
- The administrative labor is a function of the FOMO and FOMM at 3% 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;
- Makeup water required and unit water cost; and
- Operation of a wastewater treatment facility to meet ELG regulations.

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, SO₂ feed rate, and removal efficiency. While the capital costs are based on a 98% sulfur removal design, the operating sulfur removal percentage can be adjusted to reflect actual variable operating costs.
- A calcium-to-sulfur stoichiometric ratio of 1.03 was used as the basis for the reagent use rate. In addition, a limestone purity of 90% CaCO₃ with the balance being inert material was defined to establish the total reagent feed rate.
- The waste generation rate is directly proportional to the reagent usage and is estimated based on 10% moisture in the by-product.
- The additional power required includes increased fan power to account for the added wet FGD pressure drop. This requirement is a function of gross unit size (actual gas flow rate) and sulfur rate.



Wet FGD Cost Development Methodology

- The additional power is reported as a percent 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.

Due to wide range of variability of FGD wastewater chemistry, power and chemicals consumption of the wastewater treatment system associated with wet FGD, the variable O&M cost is developed as a fixed amount based upon S&L in-house project data and design assumptions identified capital cost section of this report.

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:

- Limestone 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; 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; and
- 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
- VOMWW = Variable O&M costs for wastewater treatment

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



Wet FGD Cost Development Methodology

Table 1. Example Complete Cost Estimate for the Wet FGD System

Variable	Designation	Units	Value	Calculation
Wastewater Treatment		Phys Chem-Biological		
Unit Size (Gross)	A	(MW)	500	<--- User Input (Greater than 100 MW)
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)	3	<--- User Input
Type of Coal	E	Bituminous		<--- User Input
Coal Factor	F		1	Bit=1, PRB=1.05, Lig=1.07
Heat Rate Factor	G		0.95	C/10000
Heat Input	H	(Btu/hr)	4.75E+09	A*C*1000
Operating SO ₂ Removal	J	(%)	95	<--- User Input (Used to adjust actual operating costs)
Design Limestone Rate	K	(ton/hr)	12	17.52*A*D*G/2000 (Based on 98% Removal)
Design Waste Rate	L	(ton/hr)	23	1.811*K (Based on 98% Removal)
Aux Power	M	(%)	1.69	(1.12e^(0.155*D))*F*G
Include in VOM? <input checked="" type="checkbox"/>				
Makeup Water Rate	N	(1000 gph)	38	(1.674*D+74.68)*A*F*G/1000
Limestone Cost	P	(\$/ton)	30	<--- 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

Includes - Equipment, installation, buildings, foundations, electrical, minor physical/chemical wastewater treatment and retrofit difficulty

BMR (\$) = $863000 \cdot (B) \cdot ((F \cdot G)^{0.6}) \cdot ((D/2)^{0.02}) \cdot (A^{0.716})$
 BMF (\$) = $298000 \cdot (B) \cdot ((D \cdot G)^{0.3}) \cdot (A^{0.716})$
 BMW (\$) = $157000 \cdot (B) \cdot ((D \cdot G)^{0.45}) \cdot (A^{0.716})$

BMB (\$) = $1581000 \cdot (B) \cdot ((F \cdot G)^{0.4}) \cdot (A^{0.716})$

BMWW (\$) = $15661000 \cdot (B) \cdot (A/500)^{0.6}$

BM (\$) = BMR + BMF + BMW + BMB + BMWW
 BM (\$/KW) =

Total Project Cost

A1 = 10% of BM
 A2 = 10% of BM
 A3 = 10% of BM

CECC (\$) - Excludes Owner's Costs = BM + A1 + A2 + A3
 CECC (\$/kW) - Excludes Owner's Costs =

B1 = 5% of CECC

TPC' (\$) - Includes Owner's Costs = CECC + B1
 TPC' (\$/kW) - Includes Owner's Costs =

B2 = 10% of (CECC + B1)
 C1 = 15% of (CECC + B1)

TPC (\$) - Includes Owner's Costs and AFUDC = CECC + B1 + B2
 TPC (\$/kW) - Includes Owner's Costs and AFUDC =

Example

Comments

\$ 72,215,000	Base absorber island cost
\$ 34,925,000	Base reagent preparation cost
\$ 21,530,000	Base waste handling cost
\$ 132,582,000	Base balance of plant costs including: ID or booster fans, new wet chimney, piping, ductwork modifications and strengthening, etc...
\$ 15,661,000	Base wastewater treatment facility to comply with ELG. Based on ~ 0.4 gpm/MW waste water treatment facility
\$ 276,913,000	Total base cost including retrofit factor
554	Base cost per kW
\$ 27,691,000	Engineering and Construction Management costs
\$ 27,691,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
\$ 27,691,000	Contractor profit and fees
\$ 359,986,000	Capital, engineering and construction cost subtotal
720	Capital, engineering and construction cost subtotal per kW
\$ 17,999,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
\$ 377,985,000	Total project cost without AFUDC
756	Total project cost per kW without AFUDC
\$ 37,799,000	AFUDC (Based on a 3 year engineering and construction cycle)
\$ -	EPC fees of 15%
\$ 415,784,000	Total project cost
832	Total project cost per kW



Wet FGD Cost Development Methodology

Table 1. Example Complete Cost Estimate for the Wet FGD System (Continued)

Variable	Designation	Units	Value	Calculation
Wastewater Treatment		Phys Chem-Biological		
Unit Size (Gross)	A	(MW)	500	<--- User Input (Greater than 100 MW)
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)	3	<--- User Input
Type of Coal	E		Bituminous	<--- User Input
Coal Factor	F		1	Bit=1, PRB=1.05, Lig=1.07
Heat Rate Factor	G		0.95	C/10000
Heat Input	H	(Btu/hr)	4.75E+09	A*C*1000
Operating SO ₂ Removal	J	(%)	95	<--- User Input (Used to adjust actual operating costs)
Design Limestone Rate	K	(ton/hr)	12	17.52*A*D*G/2000 (Based on 98% Removal)
Design Waste Rate	L	(ton/hr)	23	1.811*K (Based on 98% Removal)
Aux Power	M	(%)	1.69	(1.12e*(0.155*D))*F*G
Include in VOM? <input checked="" type="checkbox"/>				
Makeup Water Rate	N	(1000 gph)	38	(1.674*D+74.68)*A*F*G/1000
Limestone Cost	P	(\$/ton)	30	<--- 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) = (if MW>500 then 16 additional operators else 12 operators)*2080*T/(A*1000)	\$	3.00	Fixed O&M additional operating labor costs
FOMM (\$/kW yr) = BM*0.015/(B*A*1000)	\$	8.31	Fixed O&M additional maintenance material and labor costs
FOMA (\$/kW yr) = 0.03*(FOMO+0.4*FOMM)	\$	0.19	Fixed O&M additional administrative labor costs
FOMWW (\$/kW yr) =	\$	-	Fixed O&M costs for wastewater treatment facility
FOM (\$/kW yr) = FOMO + FOMM + FOMA + FOMWW	\$	11.49	Total Fixed O&M costs

Variable O&M Cost

VOMR (\$/MWh) = K*P/A*J/98	\$	0.73	Variable O&M costs for limestone reagent
VOMW (\$/MWh) = L*Q/A*J/98	\$	1.32	Variable O&M costs for waste disposal
VOMP (\$/MWh) =M*R*10	\$	1.02	Variable O&M costs for additional auxiliary power required including additional fan power (Refer to Aux Power % above)
VOMM (\$/MWh) = N*S/A	\$	0.08	Variable O&M costs for makeup water
VOMWW (\$/MWh) = 0.17 (Approximate for Phys-Chem biological system)	\$	0.17	Variable O&M costs for wastewater treatment facility
VOM (\$/MWh) = VOMR + VOMW + VOMP + VOMM + VOMWW	\$	3.30	