IPM Model – Updates to Cost and Performance for APC Technologies

Wet FGD Cost Development Methodology

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Establishment of Cost Basis

The 2004 to 2006 industry cost estimates for wet FGD units from the "Analysis of MOG and Ladco's FGD and SCR Capacity and Cost Assumptions in the Evaluation of Proposed EGU 1 and EGU 2 Emission Controls" prepared for Midwest Ozone Group (MOG) were used by Sargent & Lundy LLC (S&L) to develop the wet FGD cost model. In addition, S&L included 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 2010. The cost increases reported from 2007 to 2008 by G. W. Sharp in "Update: What's That Scrubber Going to Cost?" published in Power Magazine, March 2009 were also considered. The published data was significantly augmented by the S&L in-house database of recent wet FGD projects.

Cost data from the various sources showed similar trends versus generating capacity. Escalation based on the CEPI was deemed acceptable. All data sources were combined so as to provide a representative wet FGD cost basis.

The data was converted to 2012 dollars based on the Chemical Engineering Plant Index (CEPI) data. Additional proprietary S&L in-house data from 2007 to 2012 were included to confirm the index validity. Finally, 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 SO_2 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;
- SO_2 Rate = 3.0 lb/MMBtu;
- Type of Coal = Bituminous;
- Project Execution = Multiple lump sum contracts; and
- Recommended SO_2 emission floor = 98% removal efficiency or 0.06 lb/MMBtu.

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 $900/kW may be used for units below 100 MW under the premise that these will be combined.

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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 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 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. Although an option for wastewater treatment is provided, no logic has been developed to accommodate the additional wastewater treatment costs.

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

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;

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- 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 for future use.
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.

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.

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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 wet FGD installation. A future fixed O&M cost category is included to account for an extensive wastewater treatment facility. At this time, the wastewater treatment fixed O&M (FOMWW) is not estimated and is included at zero dollars. The FOM is the sum of the FOMO, FOMM, FOMA, and FOMWW.

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 + 0.4FOMM).

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
- Future variable O&M cost category is included to account for an extensive wastewater treatment facility.

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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 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% $CaCO_3$ 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.

- 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.

- A future variable O&M cost category is included to account for an extensive wastewater treatment facility. At this time, the wastewater treatment variable O&M (VOMWW) is not estimated and is included at zero dollars.

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

- Limestone cost in $/ton;
- Waste disposal costs in $/ton;
- Auxiliary power cost in $/kWh;
- 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.

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

Variable	Designation	Units	Value	Calculation
Wastewater Treatment		Minor physical/chemical		
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 **Include in VOM?** ☑	**M**	**(%)**	**1.59**	(1.05e^(0.155*D))*F*G
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 2012 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, minor physical/chemical wastewater treatment and retrofit difficulty				
BMR ($) =	584000*(B)*((F*G)^0.6)*((D/2)^0.02)*(A^0.716)	$	48,869,000	Base absorber island cost
BMF ($) =	202000*(B)*((D*G)^0.3)*(A^0.716)	$	23,674,000	Base reagent preparation cost
BMW ($) =	106000*(B)*((D*G)^0.45)*(A^0.716)	$	14,536,000	Base waste handling cost
BMB ($) =	1070000*(B)*((F*G)^0.4)*(A^0.716)	$	89,730,000	Base balance of plan costs including: ID or booster fans, new wet chimney, piping, ductwork, minor WWT, etc…
BMWW ($) =		$	-	Base wastewater treatment facility, beyond minor physical/chemical treatment
BM ($) =	BMR + BMF + BMW + BMB + BMWW	$	176,809,000	Total base cost including retrofit factor
BM ($/KW) =			354	Base cost per kW
Total Project Cost				
A1 = 10% of BM		$	17,681,000	Engineering and Construction Management costs
A2 = 10% of BM		$	17,681,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM		$	17,681,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3		**$**	**229,852,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =			**460**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$	11,493,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1		**$**	**241,345,000**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =			**483**	Total project cost per kW without AFUDC
B2 = 10% of (CECC + B1)		$	24,135,000	AFUDC (Based on a 3 year engineering and construction cycle)
TPC ($) - Includes Owner's Costs and AFUDC = CECC + B1 + B2		**$**	**265,480,000**	Total project cost
TPC ($/kW) - Includes Owner's Costs and AFUDC =			**531**	Total project cost per kW

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Variable	Designation	Units	Value	Calculation
Wastewater Treatment		Minor physical/chemical		
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 **Include in VOM?** ☑	**M**	**(%)**	**1.59**	(1.05e^(0.155*D))*F*G
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 2012 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)	$	5.30	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
FOMWW ($/kW yr) =	$	-	Fixed O&M costs for wastewater treatment facility
FOM ($/kW yr) = FOMO + FOMM + FOMA + FOMWW	**$**	**8.45**	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	$	0.95	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) =	$	-	Variable O&M costs for wastewater treatment facility
VOM ($/MWh) = VOMR + VOMW + VOMP + VOMM + VOMWW	**$**	**3.07**	