IPM Model – Updates to Cost and Performance for APC Technologies

SDA FGD Cost Development Methodology

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LEGAL NOTICE

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SDA FGD Cost Development Methodology

Establishment of Cost Basis

Cost data for the SDA FGD systems based on actual installations was more limited than that for the wet FGD systems. 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.

Units below 50 MW will typically not install an SDA FGD system. Sulfur reductions for the 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 conversion to natural gas firing, dry sorbent injection, and/or a reduction in operating hours. Capital costs of approximately $1,000/kW may be used for units below 50 MW under the premise that these 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.

An alternate dry technology, circulating dry scrubber (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.

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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 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 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; and
- Retrofit difficulty.

The base modules are:

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BMR =	Base absorber island cost
BMF =	Base reagent preparation 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.

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.

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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, 8 additional operators are required for a SDA FGD system. The FOMO was based on the number of additional operations staff required.
- The fixed maintenance materials and labor (includes bag replacement) 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; 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.

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- 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.

- 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.

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;
- 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 lime 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.

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Table 1. Example Complete Cost Estimate for an SDA FGD System

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 2012 dollars

		Example	Comments
Capital Cost Calculation			
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty			
BMR ($) =	if (A>600 then (A*98000) else 600000*(A^0.716))*B*(F*G)^0.6*(D/4)^0.01	$ 51,886,000	Base module absorber island cost
BMF ($) =	if (A>600 then (A*52000) else 320000*(A^0.716))*B*(D*G)^0.2	$ 31,337,000	Base module reagent preparation and waste recycle/handling cost
BMB ($) =	if (A>600 then (A*138000) else 848000*(A^0.716))*B*(F*G)^0.4	$ 73,422,000	Base module balance of plan costs including: ID or booster fans, piping, ductwork, electrical, etc...
BM ($) =	BMR + BMF + BMW + BMB	$ 156,645,000	Total Base module cost including retrofit factor
BM ($/KW) =		313	Base module cost per kW
Total Project Cost			
A1 = 10% of BM		$ 15,665,000	Engineering and Construction Management costs
A2 = 10% of BM		$ 15,665,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc...
A3 = 10% of BM		$ 15,665,000	Contractor profit and fees
CECC ($) - Excludes Owner's Costs = BM+A1+A2+A3		**$ 203,640,000**	Capital, engineering and construction cost subtotal
CECC ($/kW) - Excludes Owner's Costs =		**407**	Capital, engineering and construction cost subtotal per kW
B1 = 5% of CECC		$ 10,182,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC' ($) - Includes Owner's Costs = CECC + B1		**$ 213,822,000**	Total project cost without AFUDC
TPC' ($/kW) - Includes Owner's Costs =		**428**	Total project cost per kW without AFUDC
B2 = 10% of (CECC + B1)		$ 21,382,000	AFUDC (Based on a 3 year engineering and construction cycle)
TPC ($) - Includes Owner's Costs and AFUDC = CECC + B1 + B2		**$ 235,204,000**	Total project cost
TPC ($/kW) - Includes Owner's Costs and AFUDC =		**470**	Total project cost per kW

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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)
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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 2012 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)	$	4.70	Fixed O&M additional maintenance material and labor costs
FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM)	$	0.12	Fixed O&M additional administrative labor costs
FOM ($/kW yr) = FOMO + FOMM + FOMA	**$**	**6.81**	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**	