IPM Model – Revisions to Cost and Performance for APC Technologies

SNCR Cost Development Methodology

FINAL

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Establishment of Cost Basis

The formulation of the SNCR cost estimating model is based upon a proprietary Sargent & Lundy LLC (S&L) in-house data base of recent (2009) quotes for both lump sum contracts and EPC. The S&L data was analyzed in detail regarding project specifics such as coal type, boiler type, and NOx reduction efficiency. The S&L in-house data includes projects that involved cyclone boilers, T-fired and wall fired systems with multiple levels of injection. The cyclone boiler costs include rich reagent injection (RRI). The data was the basis for the cost estimate formulations developed.

The S&L data was fitted with a least squares curve to establish the trend in $/kW as a function of gross MW. The EPA/IPM SNCR cost model parameters were adjusted to account for market changes and escalation, and then the model output was compared to the S&L data. The EPA/IPM model output followed a $/kW correlation very similar to the S&L in-house data, once the adjustments were made to the model.

The rapid rise in project costs at the lower end of the MW range is due primarily to economies of scale. Additionally, older power plants in the 50 MW range tend to have plant sites that are more compact and therefore difficult to accommodate the reagent storage areas and piping, injection mixing/dilution equipment and construction activities. The smaller power plants also tend to have older control systems which may require upgrades to accommodate the new SNCR control system.

The S&L data includes SNCR projects with various types of boilers, coals, sulfur levels and retrofit complexities. The data represents an average of boiler effects, such as cyclone, wall fired or CFB. The least squares curve fits were based upon the following assumptions:

- Retrofit Factor =1
- Gross Heat Rate = 10,000
- SO_2 Rate = < 3 lb/MMBtu
- Type of Coal = PRB
- Project Execution = Multiple lump sum contracts

Methodology

Inputs

To predict future retrofit costs several input variables are required. The unit size in MW and NOx levels are the major variables for the capital cost estimation followed by the type of fuel (high sulfur Bituminous). The fuel type affects the air pre-heater costs if sulfuric acid or ammonium bisulfate deposition poses a problem. In general, if the level of SO_2 is above 3 lb/MMBtu, it is assumed that air heater modifications will be required. The unit heat rate factors into the amount of NOx generated and ultimately the size of the

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SNCR reagent preparation system. A retrofit factor that equates to difficulty in construction of the system must be defined. The NO_x rate and removal efficiency will impact the amount of urea required and size of the reagent handling equipment.

The inputs that impact the variable O&M costs are based primarily on the plant capacity factor and the removal efficiency. The NOx removal efficiency specifically affects the reagent and dilution water costs.

Outputs

Total Project Costs (TPC)

The base module costs are calculated for each required module (BM). The base module costs include:

- Equipment;
- Installation;
- Buildings;
- Foundations;
- Electrical; and
- Retrofit factor.

The base module costs do not include:

- Engineering and Construction Management
- Owner's cost; and
- AFUDC.

The base modules are:

BMS =	Base module SNCR cost.
BMA =	Base module air pre-heater cost.
BMB =	Base module balance of plant costs including: piping, electrical, site upgrades, etc…
BM =	BMS + BMA + BMB

The total base module cost (BM) is 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.

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

Additional expenditures for the project are computed based on the CECC. The additional project costs include:

- Owner's home office costs (owner's engineering, management, and procurement) at 5% of the CECC.

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 Owner's home office costs. An example of the capital cost estimation is included in Table 1.

Fixed O&M (FOM)
The fixed operating and maintenance cost is a function of the additional operations staff (FOMO) and maintenance labor and materials (FOMM) associated with the SNCR installation. The FOM is the sum of the FOMO and the FOMM.

The following factors and assumptions underlie calculations of the FOM:

- In general, 1 additional operator is required for all installations. The FOMO is based on the number of additional operations staff required; and

- The fixed costs for maintenance materials and labor are a direct function of the base module cost (BM) at a retrofit factor of 1.0.

Variable O&M (VOM)
Variable O&M is a function of:

- Reagent consumption;
- Dilution water consumption.

All of the VOM costs must be adjusted for the plant capacity factor.

The reagent consumption rate is a function of unit size, NO_x feed rate and removal efficiency. A utilization factor of 15% is used for units with an inlet NOx of 0.3 lb/MMBtu or lower and 25% for units with an inlet NOx greater than 0.3 lb/MMBtu. For CFB boilers a utilization factor of 25% is used. A reagent cost of $620 per ton of 100%

urea is used in the model. The dilution water usage is based upon reagent consumption rate.

The auxiliary power required for the SNCR system is not included in the VOM. The major systems that impact the power requirements are compressed air or blower requirements for the urea injection system and the reagent supply system.

The variables that contribute to the overall VOM are:

VOMR = Variable O&M costs for urea reagent.

VOMM = Variable O&M costs for dilution water.

VOM = VOMR + VOMM.

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Table 1. Example of the Capital Cost Estimate Work Sheet (for T-fired boilers).

Variable	Designation	Units	Value	Calculation
Boiler Type			Tangential	<--- User Input
Unit Size	A	(MW)	300	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Heat Rate	C	(Btu/kWh)	10000	<--- User Input
NOx Rate	D	(lb/MMBtu)	0.22	<--- User Input
SO2 Rate	E	(lb/MMBtu)	2	
Type of Coal	E		Bituminous	<--- User Input
Coal Factor	F		1	Bit=1.0, PRB=1.05, Lig=1.07
Heat Rate Factor	G		1	C/10,000
Heat Input	H	(Btu/hr)	3.00E+09	A*C*1000
Capacity Factor	I	(%)	85	<--- User Input
Nox Removal Efficiency	J	%	25	
Nox Removed	K	lb/h	1.65E+02	D*H/10^6*J/100
Urea Rate (100%)	L	(lb/hr)	717	K/UF/46*30; IF Boiler Type = CFB OR D > 0.3 THEN UF = 0.25; ELSE UF = 0.15
Water Required	M	(lb/hr)	6457	L*9
Aux Power	N	(%)	0.05	Auxiliary Power is not used in the Variable O&M Costs
Dilution Water Rate	O	(1000 gph)	0.77	M*0.12/1000
Urea Cost 50% wt solution	P	($/ton)	310	
Aux Power Cost	Q	($/kWh)	0.06	
Dilution Water Cost	R	($/kgal)	1	
Operating Labor Rate	S	($/hr)	60	Labor cost including all benefits

Costs are all based on 2009 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BMS ($) =	B*F/1.05*200000*(A*G)^0.42	$	2,090,000	SNCR (Injectors, Blowers, DCS, Reagent System) Cost
BMA ($) =	IF E ≥ 3 THEN 65000*(B)*(A*G)^0.78; ELSE 0	$	-	Air Heater Modification / SO3 Control (Bituminous only & > 3lb/mmBtu)
BMB ($) =	270000*(A)^0.33*(K)^0.12	$	3,273,000	Balance of Plant Cost (Piping, Including Site Upgrades)
BM ($) =	BMS + BMA + BMB	$	5,363,000	Total bare module cost including retrofit factor
BM ($/KW) =			18	Base cost per kW
Total Project Cost				
A1 = 10% of BM		$	536,000	Engineering and Construction Management costs
A2 = 10% of BM		$	536,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM		$	536,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$**	**6,971,000**	Capital, engineering and construciton cost subtotal
CECC ($/kW) =			**23**	Capital, engineering and construciton cost subtotal per kW
B1 = 5% of CECC		$	349,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC ($) = CECC + B1		**$**	**7,320,000**	Total project cost
TPC ($/kW) =			**24**	Total project cost per kW

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Table 2. Example of the Fixed and Variable O&M Cost Estimate Work Sheet (for T-fired boilers).

Variable	Designation	Units	Value	Calculation
Boiler Type			Tangential	<--- User Input
Unit Size	A	(MW)	300	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Heat Rate	C	(Btu/kWh)	10000	<--- User Input
NOx Rate	D	(lb/MMBtu)	0.22	<--- User Input
SO2 Rate	E	(lb/MMBtu)	2	
Type of Coal	E		Bituminuous	<--- User Input
Coal Factor	F		1	Bit=1.0, PRB=1.05, Lig=1.07
Heat Rate Factor	G		1	C/10,000
Heat Input	H	(Btu/hr)	3.00E+09	A*C*1000
Capacity Factor	I	(%)	85	<--- User Input
Nox Removal Efficiency	J	%	25	
Nox Removed	K	lb/h	1.65E+02	D*H/10^6*J/100
Urea Rate (100%)	L	(lb/hr)	717	K/UF/46*30; IF Boiler Type = CFB OR D > 0.3 THEN UF = 0.25; ELSE UF = 0.15
Water Required	M	(lb/hr)	6457	L*9
Aux Power	N	(%)	0.05	Auxiliary Power is not used in the Variable O&M Costs
Dilution Water Rate	O	(1000 gph)	0.77	M*0.12/1000
Urea Cost 50% wt solution	P	($/ton)	310	
Aux Power Cost	Q	($/kWh)	0.06	
Dilution Water Cost	R	($/kgal)	1	
Operating Labor Rate	S	($/hr)	60	Labor cost including all benefits

Costs are all based on 2009 dollars			
Fixed O&M Cost			
FOMO ($/kW yr) = (1/2 operator time assumed)*2080*S/(A*1000)	$	0.21	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = 0.012*BM/A/1000	$	0.21	Fixed O&M additional maintenance material and labor costs
FOM ($/kW yr) = FOMO + FOMM	**$**	**0.42**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = L*P/A/1000	$	0.74	Variable O&M costs for Urea
VOMM ($/MWh) = O*R/A	$	0.00	Variable O&M costs for dilution water
VOM ($/MWh) = VOMR + VOMM	**$**	**0.74**	

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Table 3. Example of the Capital Cost Estimate Work Sheet (for CFB boilers).

Variable	Designation	Units	Value	Calculation
Boiler Type			CFB	<--- User Input
Unit Size	A	(MW)	300	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Heat Rate	C	(Btu/kWh)	10000	<--- User Input
NOx Rate	D	(lb/MMBtu)	0.15	<--- User Input
SO2 Rate	E	(lb/MMBtu)	0.2	
Type of Coal	E		Bituminuous	<--- User Input
Coal Factor	F		1	Bit=1.0, PRB=1.05, Lig=1.07
Heat Rate Factor	G		1	C/10,000
Heat Input	H	(Btu/hr)	3.00E+09	A*C*1000
Capacity Factor	I	(%)	85	<--- User Input
Nox Removal Efficiency	J	%	25	
Nox Removed	K	lb/h	1.13E+02	D*H/10^6*J/100
Urea Rate (100%)	L	(lb/hr)	293	K/UF/46*30; IF Boiler Type = CFB OR D > 0.3 THEN UF = 0.25; ELSE UF = 0.15
Water Required	M	(lb/hr)	2641	L*9
Aux Power	N	(%)	0.05	Auxiliary Power is not used in the Variable O&M Costs
Dilution Water Rate	O	(1000 gph)	0.32	M*0.12/1000
Urea Cost 50% wt solution	P	($/ton)	310	
Aux Power Cost	Q	($/kWh)	0.06	
Dilution Water Cost	R	($/kgal)	1	
Operating Labor Rate	S	($/hr)	60	Labor cost including all benefits

Costs are all based on 2009 dollars

Capital Cost Calculation		Example		Comments
Includes - Equipment, installation, buildings, foundations, electrical, and retrofit difficulty				
BMS ($) =	B*F/1.05*200000*(A*G)^0.42	$	1,568,000	SNCR (Injectors, Blowers, DCS, Reagent System) Cost
BMA ($) =	IF E ≥ 3 THEN 65000*(B)*(A*G)^0.78; ELSE 0	$	-	Air Heater Modification / SO3 Control (Bituminous only & > 3lb/mmBtu)
BMB ($) =	270000*(A)^0.33*(K)^0.12	$	2,344,000	Balance of Plant Cost (Piping, Including Site Upgrades)
BM ($) =	BMS + BMA + BMB	$	3,912,000	Total bare module cost including retrofit factor
BM ($/KW) =			13	Base cost per kW
Total Project Cost				
A1 = 10% of BM		$	391,000	Engineering and Construction Management costs
A2 = 10% of BM		$	391,000	Labor adjustment for 6 x 10 hour shift premium, per diem, etc…
A3 = 10% of BM		$	391,000	Contractor profit and fees
CECC ($) = BM+A1+A2+A3		**$**	**5,085,000**	Capital, engineering and construciton cost subtotal
CECC ($/kW) =			**17**	Capital, engineering and construciton cost subtotal per kW
B1 = 5% of CECC		$	254,000	Owners costs including all "home office" costs (owners engineering, management, and procurement activities)
TPC ($) = CECC + B1		**$**	**5,339,000**	Total project cost
TPC ($/kW) =			**18**	Total project cost per kW

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Table 4. Example of the Fixed and Variable O&M Cost Estimate Work Sheet (for CFB boilers).

Variable	Designation	Units	Value	Calculation
Boiler Type			CFB	<--- User Input
Unit Size	A	(MW)	300	<--- User Input
Retrofit Factor	B		1	<--- User Input (An "average" retrofit has a factor = 1.0)
Heat Rate	C	(Btu/kWh)	10000	<--- User Input
NOx Rate	D	(lb/MMBtu)	0.15	<--- User Input
SO2 Rate	E	(lb/MMBtu)	0.2	
Type of Coal	E		Bituminuous	<--- User Input
Coal Factor	F		1	Bit=1.0, PRB=1.05, Lig=1.07
Heat Rate Factor	G		1	C/10,000
Heat Input	H	(Btu/hr)	3.00E+09	A*C*1000
Capacity Factor	I	(%)	85	<--- User Input
Nox Removal Efficiency	J	%	25	
Nox Removed	K	lb/h	1.13E+02	D*H/10^6*J/100
Urea Rate (100%)	L	(lb/hr)	293	K/UF/46*30; IF Boiler Type = CFB OR D > 0.3 THEN UF = 0.25; ELSE UF = 0.15
Water Required	M	(lb/hr)	2641	L*9
Aux Power	N	(%)	0.05	Auxiliary Power is not used in the Variable O&M Costs
Dilution Water Rate	O	(1000 gph)	0.32	M*0.12/1000
Urea Cost 50% wt solution	P	($/ton)	310	
Aux Power Cost	Q	($/kWh)	0.06	
Dilution Water Cost	R	($/kgal)	1	
Operating Labor Rate	S	($/hr)	60	Labor cost including all benefits

Costs are all based on 2009 dollars			
Fixed O&M Cost			
FOMO ($/kW yr) = (1/2 operator time assumed)*2080*S/(A*1000)	$	0.21	Fixed O&M additional operating labor costs
FOMM ($/kW yr) = 0.012*BM/A/1000	$	0.16	Fixed O&M additional maintenance material and labor costs
FOM ($/kW yr) = FOMO + FOMM	**$**	**0.37**	Total Fixed O&M costs
Variable O&M Cost			
VOMR ($/MWh) = L*P/A/1000	$	0.30	Variable O&M costs for Urea
VOMM ($/MWh) = O*R/A	$	0.00	Variable O&M costs for dilution water
VOM ($/MWh) = VOMR + VOMM	**$**	**0.30**	