# IPM Model – Updates to Cost and Performance for APC Technologies

## SCR Cost Development Methodology

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**SCR Cost Development Methodology**

## Establishment of Cost Basis

The 2004 to 2006 industry cost estimates for SCR 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 SCR 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 published data was significantly augmented by the S&L in-house database of recent SCR projects. The current industry trend is to retrofit high-dust hot-side SCRs. The cold-side tail-end SCRs encompass a small minority of units and as such were not considered in this evaluation.

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 SCR projects to confirm the applicability to the current market conditions.

The available data was analyzed in detail regarding project specifics such as coal type, NOx reduction efficiency and air pre-heater requirements. The data was refined by fitting each data set with a least squares curve to obtain an average $/kW project cost as a function of unit size. The data set was then collectively used to generate an average least-squares curve fit. The curve fit indicated all the data sets produced similar average costs (within 4%) at the 200 MW range, but deviate as the unit size increases to approximately 11% at 600 MW and 13% at 900 MW.

The costs for retrofitting a plant smaller than 100 MW increase rapidly due to the economy of size. The older units which comprise a large proportion of the plants in this range generally have more compact sites with very short flue gas ducts running from the boiler house to the chimney. Because of the limited space, the SCR reactor and new duct work can be expensive to design and install. Additionally, the plants might not have enough margins in the fans to overcome the pressure drop due to the duct work configuration and SCR reactor and therefore new fans may be required.

The least squares curve fit was based upon an average of the SCR retrofit projects in recent years. Retrofit difficulties associated with an SCR may result in significant capital cost increases. A typical SCR 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; and
- Project Execution = Multiple lump sum contracts.

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# Methodology

## Inputs

To predict SCR retrofit costs several input variables are required. The unit size in MW is the major variable for the capital cost estimation followed by the type of fuel (Bituminous, PRB, or Lignite) which will influence the flue gas quantities as a result of the different typical heating values. The fuel type also affects the air pre-heater costs if ammonium bisulfate or sulfuric acid deposition poses a problem. The unit heat rate factors into the amount of flue gas generated and ultimately the size of the SCR reactor and reagent preparation. 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 catalyst required and size of the reagent handling equipment.

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 SCR 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 SCR and balance of plant costs should be increased by:

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

The NOx removal efficiency specifically affects the SCR catalyst, reagent and steam costs. The lower level of NOx removal is recommended as:

- 0.07 NOx lb/MMBtu – Bituminous
- 0.05 NOx lb/MMBtu – PRB
- 0.05 NOx lb/MMBtu – Lignite

## 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
- Average retrofit difficulty.

## SCR Cost Development Methodology

The base modules are:

| | |
|---|---|
| BMR = | Base SCR cost |
| BMF = | Base reagent preparation cost |
| BMA = | Base air pre-heater cost |
| BMB = | Base balance of plant costs including: ID or booster fans, ductwork reinforcement, piping, etc… |
| BM = | BMR + BMF + BMA + 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 6% of the CECC and owner's costs. The AFUDC is based on a two-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.

## SCR 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 SCR 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 were tabulated on a per kilowatt-year (kW yr) basis.

- In general, half of an operator's time is required to monitor a retrofit SCR. The FOMO is based on that ½ time requirement for the operations staff.

- The fixed maintenance materials and labor is a direct function of the process capital cost at 0.5% of the BM for units less than 300 MW and 0.3% of the BM for units greater than or equal to 300 MW and.

- 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;
- Catalyst replacement and disposal costs;
- Additional power required and unit power cost; and
- Steam required and unit steam 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 consumption rate is a function of unit size, NOx feed rate and removal efficiency.

- The catalyst replacement and disposal costs are based on the NOx removal and total volume of catalyst required.

- The additional power required includes increased fan power to account for the added pressure drop and the power required for the reagent supply system. These requirements are a function of gross unit size and actual gas flow rate.

## SCR 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 steam usage is based upon reagent consumption 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:

- Urea cost in $/ton;
- Catalyst costs that include removal and disposal of existing catalyst and installation of new catalyst in $/cubic meter;
- Auxiliary power cost in $/kWh;
- Steam cost in $/1000 lb; and
- Operating labor rate (including all benefits) in $/hr.

The variables that contribute to the overall VOM are:

VOMR = Variable O&M costs for urea reagent

VOMW = Variable O&M costs for catalyst replacement & disposal

VOMP = Variable O&M costs for additional auxiliary power

VOMM = Variable O&M costs for steam

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

# SCR Cost Development Methodology

## Table 1. Example Complete Cost Estimate for an SCR System

| Variable | Designation | Units | Value | Calculation |
|---|---|---|---|---|
| Unit Size | A | (MW) | 500 | <--- User Input |
| Retrofit Factor | B | | 1 | <--- User Input (An "average" retrofit has a factor = 1.0) |
| Heat Rate | C | (Btu/kWh) | 9500 | <--- User Input |
| NOx Rate | D | (lb/MMBtu) | 0.3 | <--- User Input |
| SO2 Rate | E | (lb/MMBtu) | 3 | <--- User Input |
| Type of Coal | F | | Bituminous | <--- User Input |
| Coal Factor | G | | 1 | Bit=1.0, PRB=1.05, Lig=1.07 |
| Heat Rate Factor | H | | 0.95 | C/10000 |
| Heat Input | I | (Btu/hr) | 4.75E+09 | A*C*1000 |
| NOx Removal Efficiency | K | (%) | 75 | <--- User Input |
| NOx Removal Factor | L | | 0.9375 | K/80 |
| NOx Removed | M | (lb/hr) | 1069 | D*I/10^6*K/100 |
| Urea Rate (100%) | N | (lb/hr) | 747 | M*0.525*60/46*1.01/0.99 |
| Steam Required | O | (lb/hr) | 845 | N*1.13 |
| **Aux Power**<br>**Include in VOM?** ☑ | **P** | **(%)** | **0.55** | 0.56*(G*H)^0.43 |
| Urea Cost (50% wt solution) | R | ($/ton) | 310 | <--- User Input |
| Catalyst Cost | S | ($/m3) | 8000 | <--- User Input (Includes removal and disposal of existing catalyst and installation of new catalyst) |
| Aux Power Cost | T | ($/kWh) | 0.06 | <--- User Input |
| Steam Cost | U | ($/klb) | 4 | <--- User Input |
| Operating Labor Rate | V | ($/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 ($) = | 270000*(B)*(L)^0.2*(A*G*H)^0.92 | $ 77,324,000 | SCR (Inlet Ductwork, Reactor, Bypass) Island Cost |
| BMF ($) = | 490000*(M)^0.25 | $ 2,802,000 | Base Reagent Preparation Cost |
| BMA ($) = | IF E ≥ 3 AND F=Bituminous, THEN 69000*(B)*(A*G*H)^0.78, ELSE 0 | $ 8,446,000 | Air Heater Modification / SO3 Control (Bituminous only & > 3lb/mmBtu) |
| BMB ($) = | 460000*(B)*(A*G*H)^0.42 | $ 6,123,000 | ID or booster fans & Auxiliary Power Modification Costs |
| BM ($) = | BMR + BMF + BMA + BMB | $ 94,695,000 | Total bare module cost including retrofit factor |
| BM ($/KW) = | | 189 | Base cost per kW |
| **Total Project Cost** | | | |
| A1 = 10% of BM | | $ 9,470,000 | Engineering and Construction Management costs |
| A2 = 10% of BM | | $ 9,470,000 | Labor adjustment for 6 x 10 hour shift premium, per diem, etc… |
| A3 = 10% of BM | | $ 9,470,000 | Contractor profit and fees |
| **CECC ($) = BM+A1+A2+A3** | | **$ 123,105,000** | Capital, engineering and construction cost subtotal |
| **CECC ($/kW) =** | | **246** | Capital, engineering and construction cost subtotal per kW |
| B1 = 5% of CECC | | $ 6,155,000 | Owners costs including all "home office" costs (owners engineering, management, and procurement activities) |
| **TPC' ($) - Includes Owner's Costs = CECC + B1** | | $ 129,260,000 | Total project cost without AFUDC |
| **TPC' ($/kW) - Includes Owner's Costs =** | | **259** | Total project cost per kW without AFUDC |
| B2 = 6% of CECC + B1 | | $ 7,756,000 | AFUDC (Based on a 2 year engineering and construction cycle) |
| **TPC ($) = CECC + B1 + B2** | | **$ 137,016,000** | Total project cost |
| **TPC ($/kW) =** | | **274** | Total project cost per kW |

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| SO2 Rate | E | (lb/MMBtu) | 3 | <--- User Input |
| Type of Coal | F | | Bituminous | <--- User Input |
| Coal Factor | G | | 1 | Bit=1.0, PRB=1.05, Lig=1.07 |
| Heat Rate Factor | H | | 0.95 | C/10000 |
| Heat Input | I | (Btu/hr) | 4.75E+09 | A*C*1000 |
| NOx Removal Efficiency | K | (%) | 75 | <--- User Input |
| NOx Removal Factor | L | | 0.9375 | K/80 |
| NOx Removed | M | (lb/hr) | 1069 | D*I/10^6*K/100 |
| Urea Rate (100%) | N | (lb/hr) | 747 | M*0.525*60/46*1.01/0.99 |
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**Fixed O&M Cost**

| | | | |
|---|---|---|---|
| FOMO ($/kW yr) = (1/2 operator time assumed)*2080*V/(A*1000) | $ | 0.13 | Fixed O&M additional operating labor costs |
| FOMM ($/kW yr) = (IF A < 300 then 0.005*BM ELSE 0.003*BM)/(B*A*1000) | $ | 0.57 | Fixed O&M additional maintenance material and labor costs |
| FOMA ($/kW yr) = 0.03*(FOMO+0.4*FOMM) | $ | 0.01 | Fixed O&M additional administrative labor costs |
| **FOM ($/kW yr) = FOMO + FOMM** | **$** | **0.71** | Total Fixed O&M costs |

**Variable O&M Cost**

| | | | |
|---|---|---|---|
| VOMR ($/MWh) = N*R/(A*1000) | $ | 0.46 | Variable O&M costs for Urea |
| VOMW ($/MWh) = (0.4*(G^2.9)*(L^0.71)*S)/(8760) | $ | 0.35 | Variable O&M costs for catalyst: replacement & disposal |
| VOMP ($/MWh) =P*T*10 | $ | 0.33 | Variable O&M costs for additional auxiliary power required including additional fan power |
| VOMM ($/MWh) = O*U/A/1000 | $ | 0.01 | Variable O&M costs for steam |
| **VOM ($/MWh) = VOMR + VOMW + VOMP + VOMM** | **$** | **1.14** | |