Integrated Emissions Control - Process Review:

Multi-Pollutant Process Cost Comparisons

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EPRI Project Manager

C. Dene

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Washington Group International
7800 East Union Ave, Suite 100
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Principal Investigators
R. Keeth
M. Reed

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REPORT SUMMARY/PRODUCT DESCRIPTION

As the need for more stringent controls for power plant emissions increases, so does the need for more cost effective approaches to reducing these pollutants. Current methods employ technologies designed to reduce specific pollutants, which require combinations of different emission control systems. Some air pollution control suppliers and utilities are developing technologies that have the potential to reduce the emission rates for multiple pollutants simultaneously with the goal of identifying integrated systems that will require less capital investment, while lowering operating costs. It is desired to have an independent organization with the technical expertise regarding all components of such multi-pollutant control systems to evaluate these new technology opportunities for the industry.

Background

Anticipating more stringent limits for NO_x and SO_2 has led power producers to seek more versatility from the post combustion control that they plan to install on the their power plants. An example of this would be the installation of a selective catalytic reduction (SCR) system that will alter the elemental mercury in the flue gas, making it easier to capture in a wet SO_2 scrubber system operating downstream.

Challenges and Objectives

- Provide a quick overview of IEC technologies to establish technical feasibility and to assess the applicability of the test parameters and data gathered by the developer to future retrofits to utility scale power plants.
- Assess the developer's capital and operating cost projections from an engineering perspective and provide cost comparisons to current commercial technologies (± 30%).

Approach

A list of proposed integrated emissions Control (IEC) technologies was developed based on interviews with process suppliers, numerous conference proceedings, referrals from EPRI funding providers, and available literature. This is a continuing effort intended to develop a comprehensive list of potential IEC processes that are under development.

Detailed reviews of the available information were completed from technical papers and the supplier wherever possible. This information was used to provide process descriptions and assessments of the level of development that has been achieved for each IEC process. The following information will be contained in each IEC process review when available:

- Process Background and Description (environmental benefits/risks, reliability, utility and chemical usage rates)
- Technical Feasibility for Utility Applications

- Level of Development
- Materials of Construction for Major Components
- Level of Process Integration Into a Complete System
- Retrofitability into an Existing Plant
- Vendor Cost Summary/Evaluation When Available
- Identify Other Information That is Needed in Future Research

Capital and operating costs are being developed for selected IEC processes, and then these results will be compared to cost estimates developed for integrated control systems using commercially available technologies as they might be applied to boilers firing three different types of coal. IEC technologies were picked from a list previously developed in the EPRI report, *Integrated Emissions Control – Process Review: Multi-Pollutant Control Technology Descriptions and Performance*.

Results and Findings

IEC developers are in direct competition with current commercial technologies. As more testing and demonstration plants are completed, a better picture of the overall value of these IEC technologies can be developed. These developing IEC technologies are promising and initial cost estimates are in line with the costs of commercial systems currently used in the market. With further development and testing, the capability exists for some of these systems to increase performance, reliability, and to provide a reasonable alternative for power producers.

Applications, Value and Use

Many of these IEC processes will not be far enough along in the development cycle to impact NOx control strategies for the current generation of large coal-fired generating stations. However, many of these technologies may see application on future plants or smaller retrofit projects, either installed as complete processes or combined with other technologies to provide additional control. The possible implementation of further emission control requirements may change the present economic basis for evaluating optional strategies.

EPRI Perspective

Most of the processes that have been identified still require significant development before they can be considered commercial technologies. Several warrant further investigation and have been demonstrated at a level where more detailed economic analysis is justified. In addition, several process enhancements to existing technologies show promise as IEC applications, and the economic implications need to be investigated.

Keywords

Integrated Emission Control	SO_2	NOx
Emissions	Mercury	
Air toxics	Particulate mass	

ABSTRACT

Under EPRI's Integrated Environmental Control Interest Group (IECIG) and the future Integrated Environmental Control Target (IEC T75), EPRI will provide two levels of review for emerging integrated emissions control (IEC) technologies. The first, or Level 1, was an overview assessment of the technology. The second, Level 2, is a formal technical and economic assessment. In this current report, EPRI provides additional detail for assessments of promising technologies and provides a comparison with commercial technologies currently in use by the industry today.

The objectives of this current report are to provide a comprehensive review of the selected emerging technologies, as well as developer's cost and operating projections. Base case systems multi-pollutant control systems (using commercial control technologies) were defined for three types of coals, bituminous, Powder River Basin, and lignite. Costs were developed for these base case designs and the results will be compared to the cost estimates developed for the selected IEC control systems.

The database that will be developed during the course of this project will provide a central repository of essential information on many emerging IEC technologies. Target participants can quickly determine what processes are being offered, their pollution reduction and cost goals, and their state of development. Together with the Level 1 reviews, the database will also help EPRI and the IEC participants decide which technologies to pursue further for Level 2 assessments.

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INTRODUCTION

With proposed changes in current emissions regulations and recent initiatives taken by the Environmental Protection Agency (EPA), most power producers have concluded that tighter limits on mercury, NO_x, SO_2, and primary particulates are inevitable. Moreover, the potential for CO_2 emission limits loom over the horizon. In addition, the toxics release inventory (TRI) process motivates potential sources to pursue ways of reducing TRI-reportable substances, such as acid gases (H_2SO_4, HCL, and HF for example). Also, the potential remains that the EPA will eventually limit emissions on species such as cadmium, chromium, lead, selenium, and/or persistent bio-accumulative toxicants (PBT).

Anticipating more stringent limits for NO_x and SO_2 has led power producers to seek more versatility from the post combustion control that they plan to install on the their power plants. An example of this would be the installation of a selective catalytic reduction (SCR) system that will alter the elemental mercury in the flue gas, making it easier to capture in a wet SO_2 scrubber system operating downstream.

Under EPRI's Integrated Environmental Control Interest Group (IECIG) and the future Integrated Environmental Control Target (IEC T75), EPRI will provide two levels of review for emerging integrated emissions control (IEC) technologies. The first, or Level 1, was an overview assessment of the various technologies that are available. The second, Level 2, is a formal technical and economic assessment of a specific process and comparison to commercially available systems. In this current report, EPRI provides additional detail in the technical and economic assessments for promising technologies and provides a comparison with commercial technologies currently in use by the industry today.

The ECO^{tm}/Powerspan process and the LoTOx process by BOC were chosen for further analysis. Based on interviews and published literature from the respective process developers, preliminary operating costs were developed to provide comparison with current commercial technologies.

Capital and operating cost estimates were developed for multi-pollutant control systems, employing currently available commercial technology to achieve removal efficiencies that are expected from the new IEC systems. These commercial system cost estimates, developed for three different types of coal, will serve as the base cases for comparison to the Level 2 estimates developed for the IEC processes. The three different coal types were powder river basin (PRB), eastern bituminous (BIT), and lignite (LIG).

Description of Level 2 Review

The following important issues or questions will be included in each Level 2 review.

1. Process background and description

General background information is provided for the process. Controlled species are identified. Relationships and similarities to other known processes will be summarized, and the expected or demonstrated level of control will be provided.

2. Technical feasibility

An assessment will be made regarding the fundamental chemical or mechanical mechanisms for each process; are they proven, consistent with engineering practice, or reasonably expected to be feasible? What hazards, either operational or environmental, might be associated with the process, including those related to the process steps, (intermediate reaction products) or the final by-products?

3. Level of development

Proof of concept/testing – The report will document the status and results of any proof of concept or pilot tests conducted or underway on individual process steps. Do these test conditions reflect the expected operating conditions for full-scale commercial operation?

Field Testing – Actual field-testing, at any scale, provides information on the viability of the process. Such testing should identify any previously unknown interferences and integration issues.

4. Materials of construction and material handling considerations

Based on the available results from testing, special materials or material handling considerations will be summarized as they are identified during the review or are anticipated based on experience with similar processes.

5. Level of integration/retrofitability into existing plants

Operation as an integrated process will be important criteria for evaluating the potential success and applicability of a new process. The extent to which integration issues in multi-step emission control processes have been addressed will be addressed. Based on the process evaluation will also assess the integration of the proposed environmental control into the overall generating plant operation.

6. Economics

EPRI will present the developer's projected economics, indicate the developer's bases for these projections, and note the relationship between these projections and costs for comparable technologies. Where possible, EPRI will identify the assumptions or uncertainties that could have major impacts on the costs, and suggest approaches to collecting the information needed to address these assumptions. Economic factors used in cost calculations will be applied consistently throughout the project, and these factors may vary from those that have been assumed in the developer's internal costs estimates.

In some cases the report will identify areas where further development is necessary or additional process information is needed to better estimate process economics for future detailed evaluation.

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TECHNOLOGY DESCRIPTIONS

ECO^{tm}/POWERSPAN

The ECO^{tm} process design has changed since its initial development in the mid-1990s. Pilot plant tests of the technology in various forms were conducted in 1999 and 2000, with an upgraded version of the process installed and operating at a one-megawatt pilot plant at FirstEnergy Corp's R.E Burger Plant in Ohio. Initial pilot plant results showed significant reductions in SO_2, NOx, and mercury. Powerspan reports that the test results at the upgraded pilot plant demonstrated a reduction of SO_2 by 97% and 90% reduction of NOx based on typical inlet NOx conditions. The supplier also reports that the integrated ECO^{tm} system has demonstrated the ability to oxidize high percentages of mercury (80-90% of the elemental mercury), and remove HCl (+85%), and particulate matter.

Powerspan is the primary researcher and proprietary owner for the ECO^{tm} process, but has entered into an alliance with Wheelabrator Air Pollution Control, Inc. to commercialize the system. Powerspan also entered into an alliance with The Andersons, Inc. (11/02), who will manage production and marketing of the fertilizer product from ECO systems installed on power generation systems. Powerspan and FirstEnergy jointly funded the latest pilot plant. In addition, the U.S. Department of Energy (DOE) awarded a grant to Powerspan in 2001 to optimize the mercury removal capability of the process. Installation has now begun on a 50-MW demonstration facility at the R.E. Burger Plant. Powerspan, FirstEnergy, and the Ohio Coal Development Office are providing funding, and the target date for start up is the second quarter of 2003. The unit will be burning a Ohio coal containing 2-4% sulfur. Figure 1 provides a process flow diagram for the gaseous pollutant removal portion of the ECO process; flow sheets for the byproduct management portions of the system are not provided.

Currently, the ECO^{tm} process is designed for installation downstream of an existing ESP or fabric filter. Flue gas exiting the ESP or fabric filter is routed to the ECO^{tm} Reactor where it is exposed to a high voltage discharge, which generates high-energy electrons. These high-energy electrons initiate chemical reactions that lead to the formation of oxygen and hydroxyl radicals:

- $O_2 + e \rightarrow O + O + e$
- $H_2O + e \rightarrow OH + H + e$
- $O + H_2O \rightarrow 2OH$

These radicals then oxidize the pollutants in the flue gas leading to the formation of particulate matter and aerosol mist. These components are removed downstream in a ammonium salt wet scrubber and wet ESP. Approximately 90% of the NO in the flue gas is oxidized to NO_2 and

HNO_3 and subsequently removed in the scrubber (the other 10% remains unoxidized). Less than 10% of the SO_2 in the gas is oxidized to form SO_3, which eventually forms sulfuric acid (H_2SO_4). Elemental mercury vapor is oxidized to form mercuric acid (HgO), which is removed by the wet scrubber/wet ESP. Simplified reaction paths are presented below.

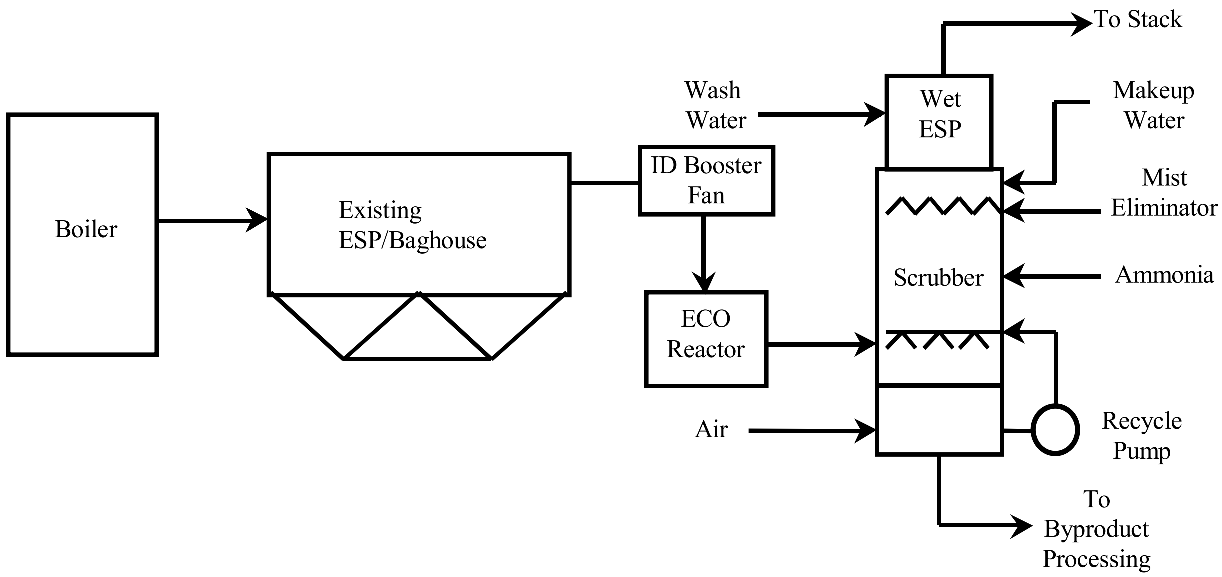
- $OH + SO_2 \rightarrow HSO_3$
- $HSO_3 + O_2 \rightarrow HO_2 + SO_3$
- $SO_3 + H_2O \rightarrow H_2SO_4$
- $NO + HO_2 \rightarrow NO_2 + OH$
- $O + NO \rightarrow NO_2$
- $OH + NO_2 \rightarrow HNO_3$
- $Hg + O \rightarrow HgO$

The gas exiting the ECO^{tm} reactor enters a double loop scrubber that removes the final products. The lower loop cools and saturates the gases while concentrating the byproducts for removal. In the upper loop, ammonia is added to form the byproducts, ammonium sulfate and ammonium nitrate. Air is introduced into the lower loop to further induce oxidation of the sulfites and nitrites. The gas then enters a mist eliminator to remove entrained droplets from the gas before entering a wet ESP. The wet ESP provides collection for the acid aerosols, particulate matter and mercuric oxide. The wet ESP also collects and recycles excess ammonia as an aqueous solution.

Powerspan indicates that the byproduct from the process is in a form that would be accepted by a fertilizer processing plant or could be further processed on-site via an in-house fertilizer granulation system. The fertilizer byproduct may be a marketable material, depending on purity/quality (e.g., absence of mercury and other trace metals from the coal ash – ECO stated that their system operates subsaturated and includes a fixed adsorbent bed to remove these compounds prior to fertilizer production) and demand within an economic haul distance of the plant. At sites where the fertilizer could be sold, but synthetic gypsum from a lime or limestone FGD system could not due to the absence of a market within an economic haul distance, the ECO™ process would avoid the disposal/landfill costs that are typically a large part of commercial FGD systems operating costs.

The ECO^{tm} reactor is similar to gas reactors used in large industrial ozonators for water purification and disinfection. The ECO^{tm} system power requirements are roughly 5% of the total power output for the plant. The absorber design is similar to those previously used for wet SO_2 scrubbing. However, the fabrication of the absorber includes an in-situ wet ESP attached to the top of the tower. There is no ductwork separating the two pieces of equipment. Typical pressure drop through the complete system is around 9 inches w.c. Typical L/G ratios for absorber operation are around 25 gpm/1000 ACFM.

Figure 1   Powerspan ECO Process Flow Diagram



LoTOx^{tm}/BOC and RAP/Beaumont IEC Demonstration

The Low Temperature Oxidation (LoTOx) system offered by BOC Gases initially was demonstrated during a project-specific agreement between Beaumont Environmental Systems and BOC for the installation and operation of an integrated multi-pollutant control system. The demonstration system consisted of Beaumont's Rapid Adsorption Process (RAP) and a fabric filter for the removal of SO_2, particulate matter, and heavy metals, followed by BOC Gases Low Temperature Oxidation (LoTOx^{tm}) system for NOx removal. This IEC system was installed and operated on a 25 MW coal fired boiler located at the Medical College of Ohio (MCO). The Medical College of Ohio site has four boilers, three burning coal and one that burns natural gas. Boiler No. 4 is equipped with an economizer and, therefore, is the boiler currently operating with the RAP & LoTOx process. This boiler is sized to produce around 70,000 lb/hr of saturated steam at 150 psig. Coal is delivered by truck to the site. Prior to installation of the demonstration facility, the plant burned low sulfur Kentucky coal. With installation of the demonstration system, high sulfur Ohio coal may be used. The cost estimates contained in this report are based on the cost of this demonstrated RAP/LoTOx system design.

LoTOx is now pursuing the development of their ozone-based, oxidation technology independent of Beaumont. They have decided to target installations where medium efficiency NOx control systems are being considered, such as selective auto-catalytic reduction (similar to SNCR technology and now offered by Mitsui-Babcock - has achieve 60+% NOx removal in demonstration tests) or downstream of a low NOx burner/over fire air installation. The LoTOx technology would be followed by a wet scrubber, which is necessary to remove the products of reaction from the LoTOx oxidation reactor. BOC feels that with the installation of the LoTOx system, these systems with moderate NOx control efficiencies can achieve 90% NOx removal at costs that will be lower than those required for SCR system.

At the demonstration unit, the outlet gas stream from the LoTOx scrubber passes through a packed-bed wet scrubber where water is injected to neutralize the solution. Figure 2 provides a process flow diagram for the LoTOx control system. Future installations of the LoTOx system may be integrated with other wet scrubbing technologies, based on a recent alliance that was formed between LoTOx and Marsulex for future integration of the LoTOx system with the Marsulex ammonium sulfate scrubbing system.

RAP Reactor

The RAP Reactor uses lime slurry and recycled solids from a downstream cyclone to absorb around 90% of the SO_2 from the flue gas. The RAP operation is similar to that of a spray tower, flash drying the lime slurry using the heat of the flue gas. But instead of injecting the reagent by spray atomizers, the wetted reagent and cyclone recycle is mixed with cooling water in a mixer and chute fed into the lower portion of the vessel where it is flash dried. The dry material is fed to a baghouse. The cyclone operates in conjunction with the RAP reactor similar to that of a conventional spray dryer/baghouse system. The MCO RAP system operated with a baghouse as opposed to the use of a cyclone. The cyclone provides for better lime utilization and is used in this analysis.

A venturi section is installed in the RAP reactor to provide evaporative cooling of a water spray to allow for additional cooling of the flue gas as it enters the reactor. Material captured by the cyclone is fed to a recycle tank. The recycled solids are mixed with lime slurry and cooling water to maintain desired RAP operating temperature, and subsequently fed back to the reactor. Overflow from the recycle tank is fed to a disposal tank. This waste material is like the material produced by a conventional lime spray dryer operation and it can be disposed of in a similar manner. Tests on the waste product have shown that it does not leach any dissolved solids and can be disposed of in existing disposal sites.

Beaumont supplies their own packaged lime preparation system, consisting of a lime silo, slaking system, and slurry tank. Beaumont was also the supplier of the baghouse for the demonstration system.

LoTOx^tm^/BOC Reactor

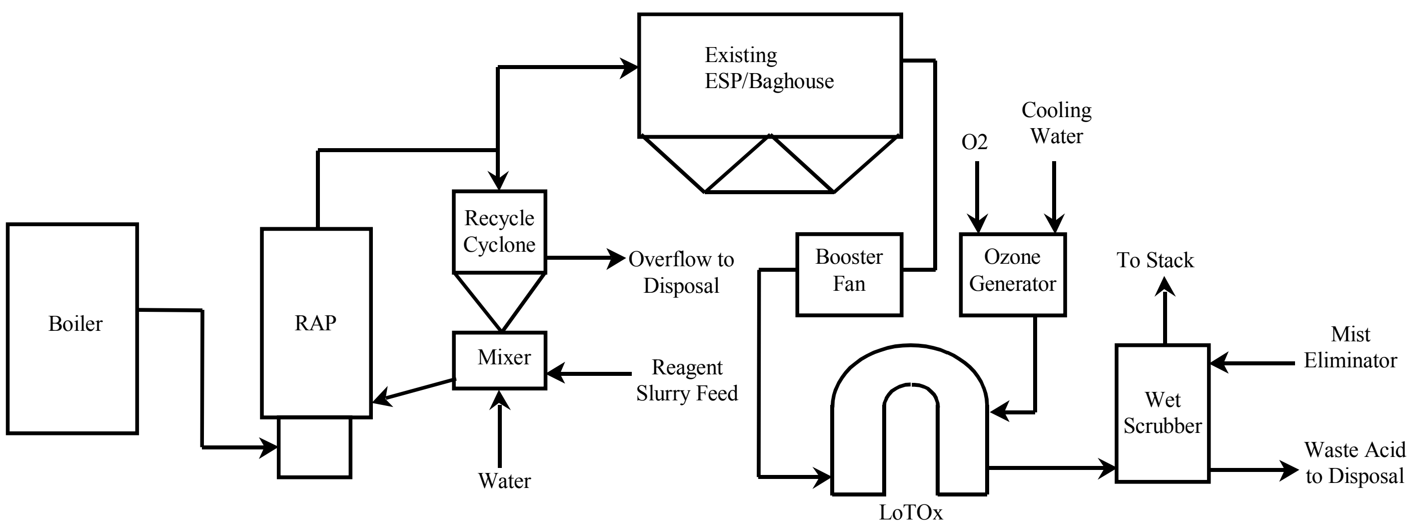
The LoTOx reactor uses ozone injection to remove NOx from the flue gas at low temperatures (150-250 °F). The LoTOx^{tm} technology is licensed by BOC Gases. The reactor uses an ozone generator to produce ozone from an oxygen (O_2) source. Ozone production is 10% by weight ozone from the feed oxygen. Oxygen can be trucked in to an on-site liquid storage vessel or can be supplied by an on-site oxygen generating plant. The ozone generator requires chilled cooling water for the unit. For the demonstration facility, the generator required cooling water at 60° F. For a large installation, it is likely that an air separation plant would be specified to produce sufficient oxygen to meet the inlet requirements of the ozone generator.

Once injected into the reactor, the ozone oxidizes the NOx to higher oxides such as NO_2, N_2O_3, N_2O_4, and N_2O_5. The solubility of these compounds increases with the degree of oxidation. As these oxides combine with water, they form a nitric acid solution that can be removed in the wet scrubber. At the demonstration facility, removal of around 90% NOx has been achieved according to the vendor. The complete NOx removal system requires the installation of the LoTOx reactor, ozone generator, on-site oxygen supply, and a wet scrubber downstream of the LoTOx reactor. Both the LoTOx reactor and wet scrubber are constructed of 316-stainless steel.

The system relies on the detection of incoming NOx levels to provide a feed forward signal to a control system. The control system then initiates a signal to the ozone generator to produce the required amount of ozone to oxidize the incoming NOx. A NOx detector is installed downstream of the scrubber to provide a feed back signal to allow fine-tuning of the system. Due to the reactivity of the ozone, no SO_3 formation occurs from residual SO_2. This has been confirmed from testing by Beaumont.

At the demonstration plant, the outlet gas stream from the LoTOx scrubber passes through a packed-bed wet scrubber where water is injected to neutralize and absorb the acidic species and dilute the solution circulating through the scrubber. This neutralized solution can then be disposed of or recycled back through the RAP system. Figure 2 provides a process flow diagram for the combined RAP/Beaumont and BOC/LoTOx^{tm} systems.

Figure 2 Combined RAP and LoTOx^{tm}/BOC Process Flow Diagram



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BASE CASE SUMMARY

The three base cases used for comparison to the IEC systems are described below. Each system is designed for emission control on a particular type of coal. Table 1 provides the coal and ash analyses and Table 2 provides combustion calculations for the three coals.

Table 1 Coal and Ash Analyses

COAL ULTIMATE ANALYSIS (weight % as received)				
		PRB	BIT	LIG
	Moisture	30.40%	6.00%	32.20%
	Carbon	47.85%	71.30%	40.60%
	Hydrogen	3.40%	4.80%	3.10%
	Nitrogen	0.62%	1.40%	0.70%
	Chlorine	0.03%	0.12%	0.04%
	Sulfur	0.48%	2.6%	1.00%
	Ash	6.40%	9.10%	9.26%
	Oxygen	10.82%	4.68%	13.10%
	TOTAL	100.00%	100.00%	100.00%
	Mott Spooner HHV (Btu/lb)	8,340	13,048	6,980
COAL ASH ANALYSIS				
	SiO2	31.60%	41.50%	46.52%
	Al2O3	15.30%	19.90%	22.99%
	TiO2	1.10%	0.80%	1.27%
	Fe2O3	4.60%	20.20%	10.78%
	CaO	22.80%	5.10%	11.50%
	MgO	4.70%	0.90%	3.16%
	Na2O	1.30%	0.90%	0.10%
	K2O	0.40%	1.90%	0.32%
	P2O5	0.80%	0.30%	0.10%
	SO3	16.60%	6.50%	1.70%
	Other Unaccounted for	0.80%	2.00%	1.56%
	TOTAL	100.00%	100.00%	100.00%

Table 2 Combustion Calculations

Boiler & Plant Data Summary			PRB	Bit	Lig
Coal Flow Rates					
	Btu Input Rate to Boiler	MMBtu/hr	4,800.00	4,800.00	4,800.00
	Coal Input Rate to Boiler	tons/hr	287.958	183.940	343.729
	Coal Input Rate to Boiler	lbs/MMBtu	119.98	76.64	143.22
	MMBtu/Hr Out of Boiler	MMBtu/hr	4,023.75	4,219.20	3,947.91
Flue Gas (lbs/MMBtu)					
	O2	lbs/MMBtu	34.45	34.53	34.43
	CO2	lbs/MMBtu	209.31	199.23	211.99
	N2	lbs/MMBtu	681.44	683.20	681.31
	NOx	lbs/MMBtu	0.319	0.524	0.365
	HCl	lbs/MMBtu	0.037	0.095	0.059
	SO2	lbs/MMBtu	1.150	3.950	2.848
	SO3	lbs/MMBtu	0.001	0.039	0.016
	H2O	lbs/MMBtu	84.468	49.037	97.325
	Gas Dry	lbs/MMBtu	926.711	921.561	931.028
	Gas Wet	lbs/MMBtu	1011.179	970.598	1028.353
	% H2O	wt%	8.35	5.05	9.46
	Theoretical Wet Air	lbs/MMBtu	749.21	750.85	748.80
	Actual Total Wet Air	lbs/MMBtu	899.05	901.02	898.56
	Mol Wt Wet, Lb/Lb-Mol	lbs/lb-mole	29.00	29.60	28.83

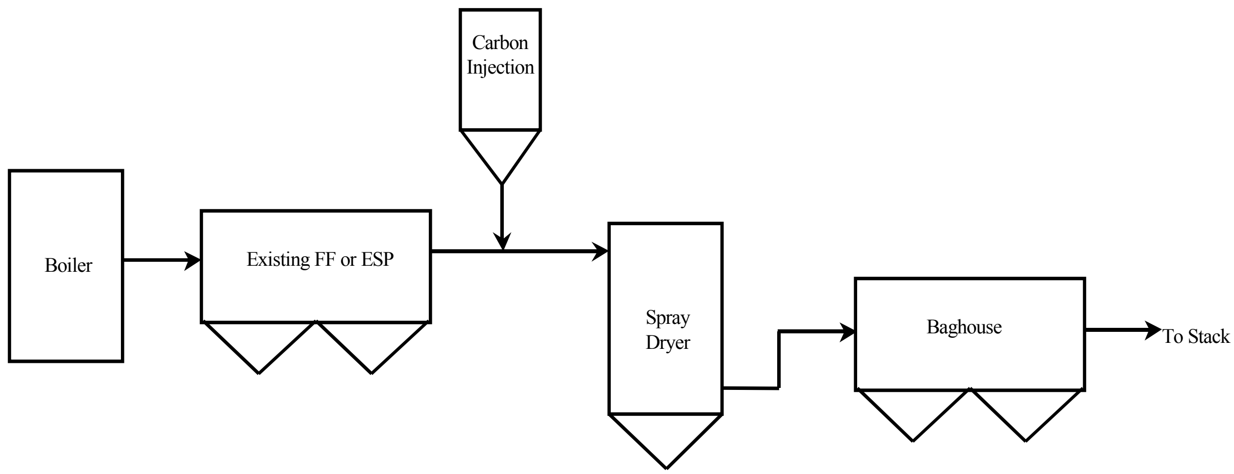
Base Case for PRB Coal-Fired Generating Plant

The PRB base case for multi-pollutant control assumes that the following subsystems will be added:

- Overfire air for NOx control
- Carbon Injection for Hg control
- Lime spray dryer and baghouse for SO_2 and particulate control

It is assumed that for this base case, low-NOx burners were already installed on the boiler. It was also assumed that the base plant would currently have an ESP but that the system would still require the construction of a new baghouse downstream of the carbon injection and spray dryer. Carbon injection vendors have suggested this approach since it increase Hg capture and does not lead to flyash contamination. Figure 3 is a process flow diagram illustrating the gas path for the PRB base case system:

Figure 3 PRB Base Case Process Flow Diagram



Current carbon injection systems installed upstream of an FGD system have the capability to reduce mercury by around 90%. This assumption was made when estimating costs for mercury removal for the PRB base case. Current installations of lime spray dryers have a maximum SO_2 removal rate of 90%. This efficiency was assumed in the cost estimates. A pulse jet baghouse was assumed to maintain particulate removal rate at greater than 99.5%.

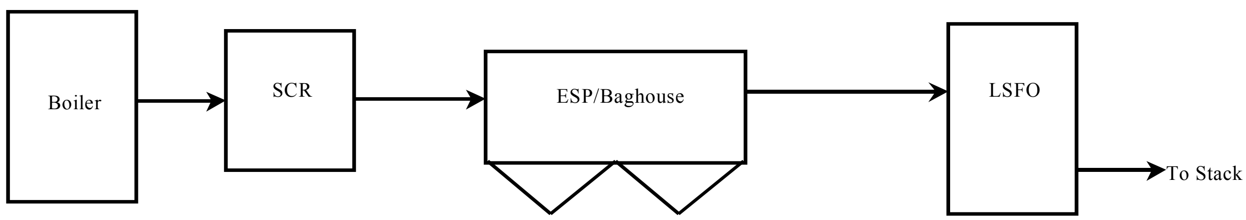
Base Case for Eastern Bituminous Coal Fired Generating Plant

The BIT base case for multi-pollutant control assumes that the following subsystems will be added:

- SCR for NOx control
- Limestone Forced Oxidation (LSFO) for SO_2 and Hg control.

It is assumed that an existing ESP or baghouse will be available for particulate control. Figure 4 is a process flow diagram illustrates the gas path for the BIT base case system:

Figure 4   BIT Base Case Process Flow Diagram



Removal efficiencies for the SCR and LSFO were based on current installation experience, achieving NOx removal of 90% and SO_2 removal of 95%.

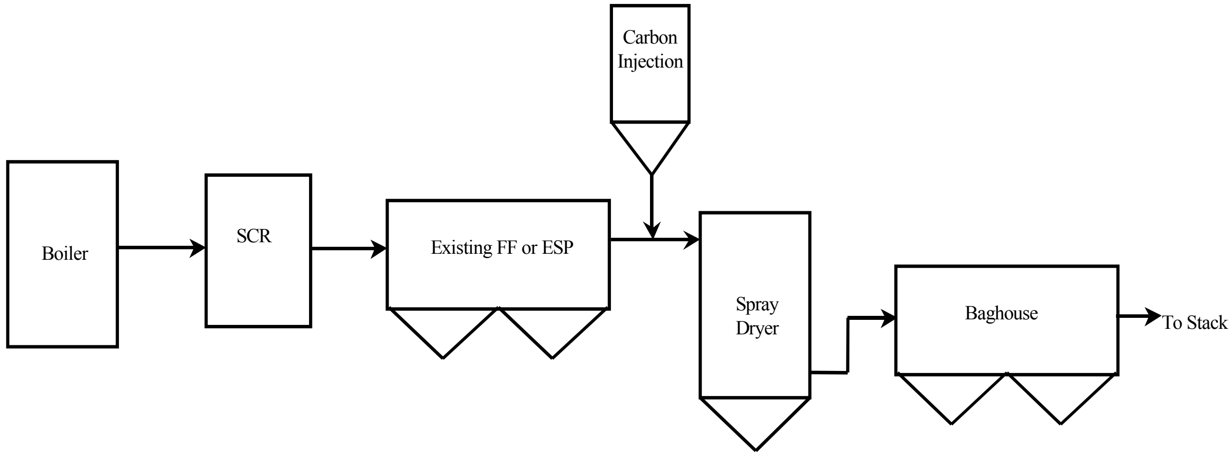
<u>Base Case for Lignite Coal Fired Generating Plant</u>

The LIG base case for multi-pollutant control assumes that the following subsystems will be added:

- SCR for NOx control
- Carbon Injection for Hg control
- Lime spray dryer and baghouse for SO_2 and particulate control

It is assumed that an existing ESP or baghouse will be available for particulate control. As stated previously in the PRB base case, this would be the preferred arrangement to reduce flyash contamination. Figure 5 is a process flow diagram illustrates the gas path for the LIG base case system:

Figure 5   LIG Base Case Process Flow Diagram



As stated in the PRB, removal efficiencies for the SCR and LSD were based on current installations with a NOx removal of 90% and SO_2 removal of 90%, and the carbon injection system removing 90% of the mercury. As stated in the PRB base case, the baghouse will be of the pulse jet type with removal rates of particulate at greater than 99.5%.

4
TECHNOLOGY ASSESSMENT

Assumptions were made to allow for direct comparison of the IEC technologies with the base cases. As stated in the base case summaries, it was assumed that the existing power plant would already have low-NOx burners installed on the boiler and have an existing ESP or baghouse for primary particulate emission control.

ECO^{tm}/POWERSPAN

Based on data from the initial pilot plants, the ECO^{tm} process has demonstrated continual improvement in performance. Design changes have addressed technical issues identified in earlier versions of the system (marketable byproduct, retrofitting ECO^{tm} reactor into an existing ESP field, scrubbing of acidic flue gas prior to entering wet ESP, et al.). The demonstration facility currently under development is expected to achieve even better performance and provide data for future retrofits into full-scale facilities. Powerspan has stated that multiple sites have expressed interest for full-scale projects pending the success of this latest demonstration plant.

Pilot plant testing has demonstrated ammonia slip rates of 1 ppm. This is well below the normal 3 ppm slip typical for SCR installations. One other benefit of the system is the production of a marketable fertilizer byproduct. This will help to offset the considerable power requirements of the system. Other benefits include the modular design of the system, which will aid in fabrication and erection of the system while reducing the footprint for retrofit into an existing plant. And since the flue gas is treated downstream of an existing ESP/baghouse, ductwork and construction cost associated with the installation of an SCR can be reduced. In addition, the flyash will not be contaminated. Also, ID booster fans can be installed downstream of the ESP.

Although the pilot test results are encouraging, results of the demonstration facility will provide the best data to assess the potential of the ECO^{tm} system. Since the byproduct of the reactor produces a mixture of acidic gases, corrosion resistant materials will be required for downstream equipment. Also, the ability to market the mixed sulfate/nitrate byproduct could limit the availability of the system to certain areas. This issue needs to be addressed by potential users before utilization of the system can be considered.

The commercial system arrangements for the three types of coal will all have their own inherent limitations on control of the primary pollutants. It would be expected that for the bituminous coal case, the ECO system performance with respect to SO_3, fine particulate and Hg may exceed the performance of the commercial components selected (the wet ESP would provide 50-90% removal of these materials beyond the performance of the dry ESP, SCR and wet FGD system).

The Powerspan system would be expected to exceed the NOx reduction that can be achieved using the low NOx burners and over fire air system that was selected for the PRB case.

LoTOx

The LoTOx consists primarily of the LoTOx reactor and the ozone generator, followed by an operating wet scrubbing system to remove the products of the ozone oxidation reactions. The LoTOx reactor may require some form of gas conditioning upstream of the ozone injection reactor enhance the oxidation of NOx. The reactor operates at low temperatures, but tests have shown a high level of NOx reduction, while an SCR requires high operating temperatures. This plays a factor in the costs associated with an SCR installation. The gas exiting the reactor, as described above, is scrubbed to produce a mild nitric acid. According to the vendor, this dilute solution poses no corrosion problems if reused in the wet scrubbing system. The vendor stated that there is the potential to recover the nitrates from the solution to produce a marketable fertilizer byproduct. Full-scale disposal options have not been fully addressed. Also, due to the saturated gas emitting from the wet scrubbing system, stack lining may become an issue.

5
CAPITAL AND OPERATING COST ANALYSIS

Equipment capital and operating costs were calculated using various economic cost models and vendor supplied information. Economic models used to compile information included the EPRI FGDCOST, *Flue Gas Desulfurization Cost Estimating Workbook*, the EPA CUECost, *Coal Utility Environmental Cost Workbook*, and Activated Carbon Injection Cost Equations from Appendix 5.3 from the EPA Modeling Applications (v.2.1) Using the Integrated Planning Model.

Economic analyses were completed for all three base cases using the models mentioned above. Costs were calculated based on the assumption that the equipment would be retrofit into an existing plant site in Wisconsin with a retrofit factor of 1.30 and seismic zone of 1. Equipment costs and variable operating costs were derived from calculated material balances for specific process criteria, which included flue gas flow rate, pollutant removal efficiency, chemical consumption rates, and waste production rates. Economic and plant inputs for each specific FGD model are provided in Table 3. Included in Table 3 are the specific economic factors that were used in the cost analyses for the base cases as well as cost information provided for the ECO^{tm} system.

The cost models provide equipment capital and installation costs for each component of the various base case systems as well as support equipment. These support items include the ID Booster fans, ductwork (including bypass), and construction costs. Operating costs for the various systems are based on normal requirements for yearly operation, including operating/maintenance labor costs and variable operating costs (reagent, disposal, water, power, byproduct credits, etc.

Economic data is presented in Table 4. Cost estimates are rough-order-of-magnitude (ROM) (± 30% accuracy). The table presents the Total Capital Requirement ($/kW), Annual O&M (mills/kWh) and Total Annual Costs (Mills/kWh) for each case. Annual O&M costs include fixed O&M costs (operators, maintenance, and administrative costs) and variable O&M costs (reagent, disposal, water, power). Total Annual Costs include Annual O&M and fixed charges calculated based on the capital requirement.

The three different coals from the base cases were used for equipment sizing and costs for the ECO^{tm} system. Consumables and operating costs are presented in the data in Tables 4 and 5.

The methodology used to generate the cost estimates for the ECO^{tm} system economic analysis involved using all-in capital cost data provided by Powerspan and applying our retrofit factors and Allowance for Funds During Construction (AFDC) to develop capital requirements for the system. Operating costs were based on the consumables for the system, mainly, power, water, and reagent (ammonia). The system included the ability to generate a marketable byproduct. The operating costs reflect this benefit. More detailed economic data is currently being solicited from the vendor through further interviews with Powerspan. Cost estimates for the LoTOx system have not been completed at this time. Table 6 lists the major equipment for each case. Data from Table 3 is depicted graphically in Figures 6-8.

Table 3 Economic Factors and Plant Data

Total Gross Rating	MW	500
Gross Plant Heat Rate (GPHR)	Btu/KWhr	9,600
Plant Capacity Factor	%	65%
Technical Inputs For Boiler:		
Total Air Downstream of Economizer	%	120%
Air Heater Leakage (% of econ. flue gas)	%	13.7%
Air Heater Outlet Gas Temp.	°F	280
Pressure After Air Heater	in. H2O	-12
Particulate in Gas Downstream of ESP	lb/MMBtu	0.03
Discount Rate (MAR)	%	8.78%
AFUDC Rate	%	10.3%
Construction Period	years	3
Levelized Fixed Charge Rate (FCR)	%	14.4%
Service Life	years	30
Start-Up Date	year	2002
Inflation Rate	%	3.0%
General Facilities (% of installed cost)	%	10
Engineering Fees (% of installed cost)	%	10
Materials/Operating Cost Inputs:		
Construction Labor Rate	$/hr	$35.00
Prime Contractor's Markup (% of equip. cost)	%	10%
Reagent Bulk Storage	days	60
FGD Operating Labor Rate	$/hr	$31.30
Power Cost	Mills/KWh	40
Replacement Power Cost	Mills/KWh	40
Steam Cost - medium pressure	$/1000 lbs	$3.86
Water Cost:		
Fresh	$/1000 gal	$0.40
Blowdown	$/1000 gal	$0.00
Cooling	$/1000 gal	$0.16
Particulate Control Inputs		
Outlet Particulate Emission Limit	lbs/MMBtu	0.03
Fabric Filter:		
Pressure Drop	in. H_2O	6
Gas-to-Cloth Ratio	$ACFM/ft^2$	3.5
Bag Life	Years	5
Selective Catalytic Reduction (SCR) Inputs		
NH_3/NOX Stoichiometric Ratio	NH_3/NOX	0.9

NOX Reduction Efficiency	%	90
Overall Catalyst Life	years	5
Ammonia Cost	$/ton	145
Catalyst Cost	$/ft3	360
LSFO - BITUMINOUS COAL		
Overall Percent SO_2 Removal	%	95%
LSFO Absorber Tower Inputs:		
L/G Ratio, gpm/1000 Saturated ACFM	gpm/Kacfm	95.0
Reagent Ratio, LbMol CaCO3/LbMol SO2 Removed		1.05
Oxidation Air, LbMol O2/LbMol SO2 Removed		1.0
Absorber Tower Pressure Drop	" H_2O	6
Materials / Operating Cost Inputs Associated with LSFO		
Reagent Cost: Bulk Limestone (FOB)	$/ton	$12.30
FGD Sludge Disposal Cost	$/ton	$16
Process Contingency (% of installed cost)	%	2
Project Contingency (% of installed cost)	%	15
General Facilities (% of installed cost)	%	10
Engineering / Home Office Fees (% of installed cost)	%	10
LSD – POWDER RIVER BASIN COAL		
Percent SO_2 Removal	%	90%
Adiabatic Saturation Temp.	°F	127
Flue Gas Approach to Saturation	°F	20
Spray Dryer Inputs:		
Reagent Ratio, lbmol CaO/lbmol Inlet SO2		0.95
Materials / Operating Cost Inputs Associated with LSD		
Reagent Cost (FOB)	$/ton	$60
FGD Solids Disposal Cost	$/ton	$16
Process Contingencies (% of installed cost)	%	2-5
Project Contingencies (% of installed cost)	%	10-15
General Facilities (% of installed cost)	%	10
Engineering / Home Office Fees (% of installed cost)	%	10
LSD – LIGNITE COAL		
Percent SO_2 Removal	%	90%
Adiabatic Saturation Temp.	°F	127
Flue Gas Approach to Saturation	°F	20
Spray Dryer Inputs:		
Reagent Ratio, lbmol CaO/lbmol Inlet SO2		1.10
Materials / Operating Cost Inputs Associated with LSD		
Reagent Cost (FOB)	$/ton	$60
FGD Solids Disposal Cost	$/ton	$16
Process Contingencies (% of installed cost)	%	2-5
Project Contingencies (% of installed cost)	%	10-15
General Facilities (% of installed cost)	%	10
Engineering / Home Office Fees (% of installed cost)	%	10
ECO/POWERSPAN		
SO_2 Removal	%	97+
NOx Removal	%	90
Hg, SO_3 and Fine Particulate Removal	%	80-90
Materials / Operating Cost Inputs		

Ammonia Cost	$/ton	$145
Credit for Byproduct	$/ton	$50*

*ECO feels that the $50/ton value assumed in this analysis overly conservative – they referenced a ten year market price for ammonium sulfate that ranged from $110-140/ton.

Table 4 Results of the Economic Analysis

Process Type	Coal Type	Control Technology	Total Capital Requirement ($/kW)	O & M Cost (Levelized Mills/KWh)	Total Annual Cost (Levelized Mills/KWh)
PRB Base Case		Overfire Air	24	0.10	0.64
		Carbon Injection	14	0.29	2.26
		Spray Dryer	127	3.99	7.20
		Baghouse	97	1.16	3.59
		Total	**262**	**5.5**	**13.7**
Bit Base Case		SCR	130	1.57	4.86
		LSFO	158	5.32	9.31
		Total	**288**	**6.9**	**14.2**
Lig Base Case		Carbon Injection	23	2.3	5.6
		SCR	148	1.6	5.4
		Spray Dryer	138	5.86	9.36
		Baghouse	97	1.6	4.0
		Total	**407**	**11.3**	**24.3**
ECO	**PRB**	ECO System	281	5.74	12.83
		Total	**281**	**5.7**	**12.8**
	Bit	ECO System	265	5.9	12.6
		Total	**265**	**5.9**	**12.6**
	Lig	ECO System	287	5.9	13.2
		Total	**287**	**5.9**	**13.2**

Table 5 Consumption Rates and Product Production Rates

Consumable		Control Technology System		
		PRB	BIT	LIG
Ammonia	tons/yr	-	1,879	1,597
Activated Carbon	tons/yr	68	-	808
Lime	tons/yr	14,520	-	41,623
Limestone	tons/yr	-	172,642	-
Oxygen	tons/yr	-	-	-
Byproduct	tons/yr	120,200	284,130	237,840
Water	1000 gal/yr	154,421	172,870	176,286
Power	kW	8,753	9,600	8,259
Methane	1000 scf/yr	-	-	-
		ECO		
		PRB	**BIT**	**LIG**
Ammonia	tons/yr	9,625	30,258	21,700
Activated Carbon	tons/yr	-	-	-
Lime	tons/yr	-	-	-
Limestone	tons/yr	-	-	-
Oxygen	tons/yr	-	-	-
Byproduct	tons/yr	39,000	121,100	86,850
Water	1000 gal/yr	60,010	196,340	33,820
Power	kW	28,534	29,863	29,451
Methane*	1000 scf/yr	14,916	50,922	36,630

*Note that the methane consumption rates provided for the ECO process are strictly for byproduct drying equipment (thermal source)

Table 6 Major Equipment List - Base Cases

Equipment Area	PRB	BIT	LIG
Reagent	Rail spur Lime Receiving System Lime Unloading System Lime Bulk Storage Silo Silo Pressure Feeders Lime Live Storage Trans System Lime Day Bin Ball Mill Slaker System Lime Slurry Tank	Rail spur Limestone Receiving System Limestone Bulk Storage/Transfer System Limestone Live Storage/Transfer System Limestone Day Bin Pre-Ground Limestone Bulk Storage Silo Ball Mill & Hydroclone System Limestone Slurry Tank	Rail spur Lime Receiving System Lime Unloading System Lime Bulk Storage Silo Silo Pressure Feeders Lime Live Storage Trans System Lime Day Bin Ball Mill Slaker System Lime Slurry Tank
Hg	Carbon Injection System Carbon Holding Tank		Carbon Injection System Carbon Holding Tank
SO2	Spray Dryer Rotary Atomizer Lime Slurry Feed Pump Recycle Solids Bin Spray Dryer Solids Transfer System Recycle Transfer Conveyors Recycle Slurry Tank	Absorber Tower Spray Pump Reaction Mix Tank Oxidation Air Compressor	Spray Dryer Rotary Atomizer Lime Slurry Feed Pump Recycle Solids Bin Spray Dryer Solids Transfer System Recycle Transfer Conveyors Recycle Slurry Tank
NOx	Overfire Air Modifications	Reactor Housing Ammonia Handling and Injection	Reactor Housing Ammonia Handling and Injection
Particulate	Existing ESP Baghouse	Existing ESP/Baghouse	Existing ESP Baghouse
Byproduct	Solids/Recycle Conveying System Disposal Solids Storage Silo Pug Mill	Thickener System Thickener Overflow Pump Thickener Underflow Pump Thickener Underflow Tank Vacuum Filter Solids Handling System Process Water Storage Tank	Solids/Recycle Conveying System Disposal Solids Storage Silo Pug Mill

Table 7 Major Equipment List – ECO/Powerspan Process

Equipment Area	ECO*
Reagent	Rail spur Ammonia Storage System Ammonia Handling System Reagent Pump
Hg	Removed in Absorber
SO2	ECO Reactor Reactor Power Supply Absorber Tower Spray Pumps Absorber Reaction Mix Tank Oxidation Air Compressor
NOx	Removed in the Absorber
Particulate	Wet ESP at FGD outlet
Byproduct**	Hydroclone Centrifuge Centrifuge Conveyor Dryer Dryer Conveyor Storage Bin Centrate Pump

*For the ECO system, SO2 and NOX removal equipment share the same components
**Condensed equipment list for byproduct production.

Figure 6

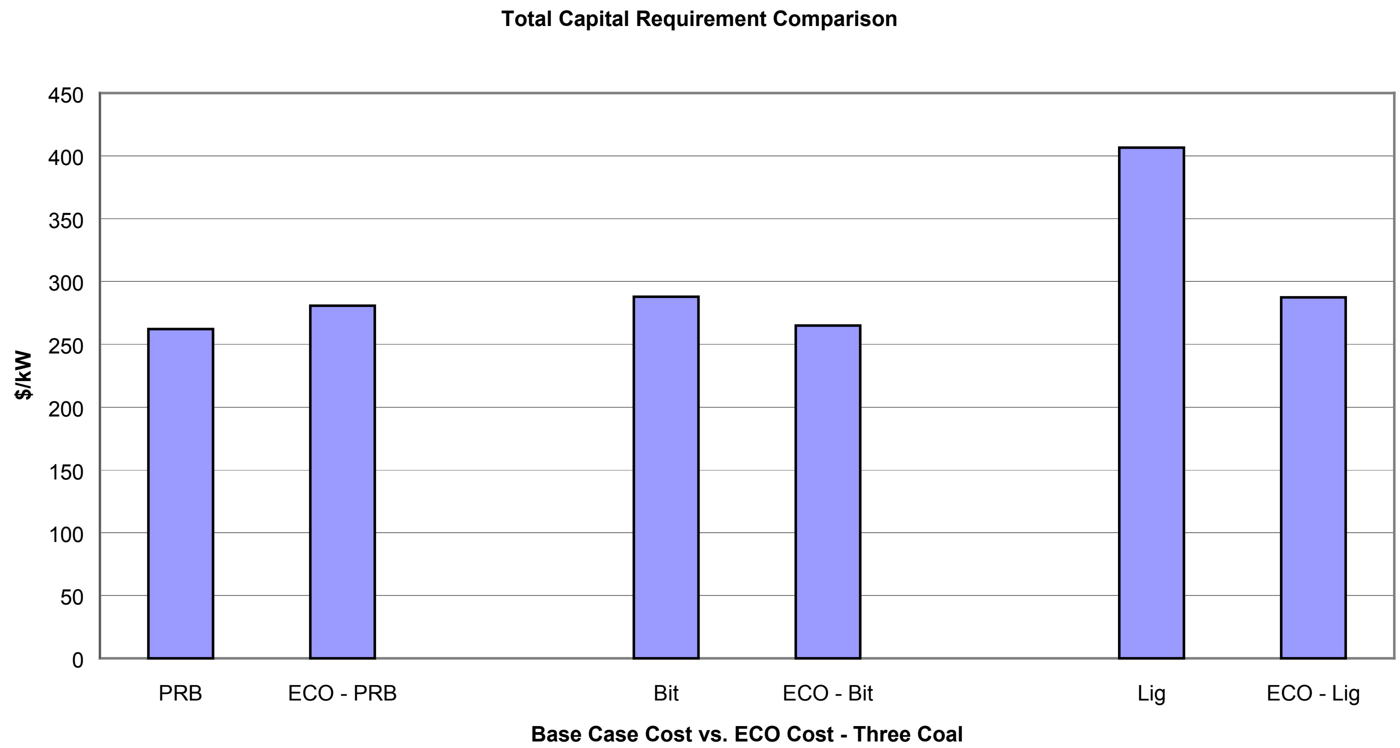


Figure 7

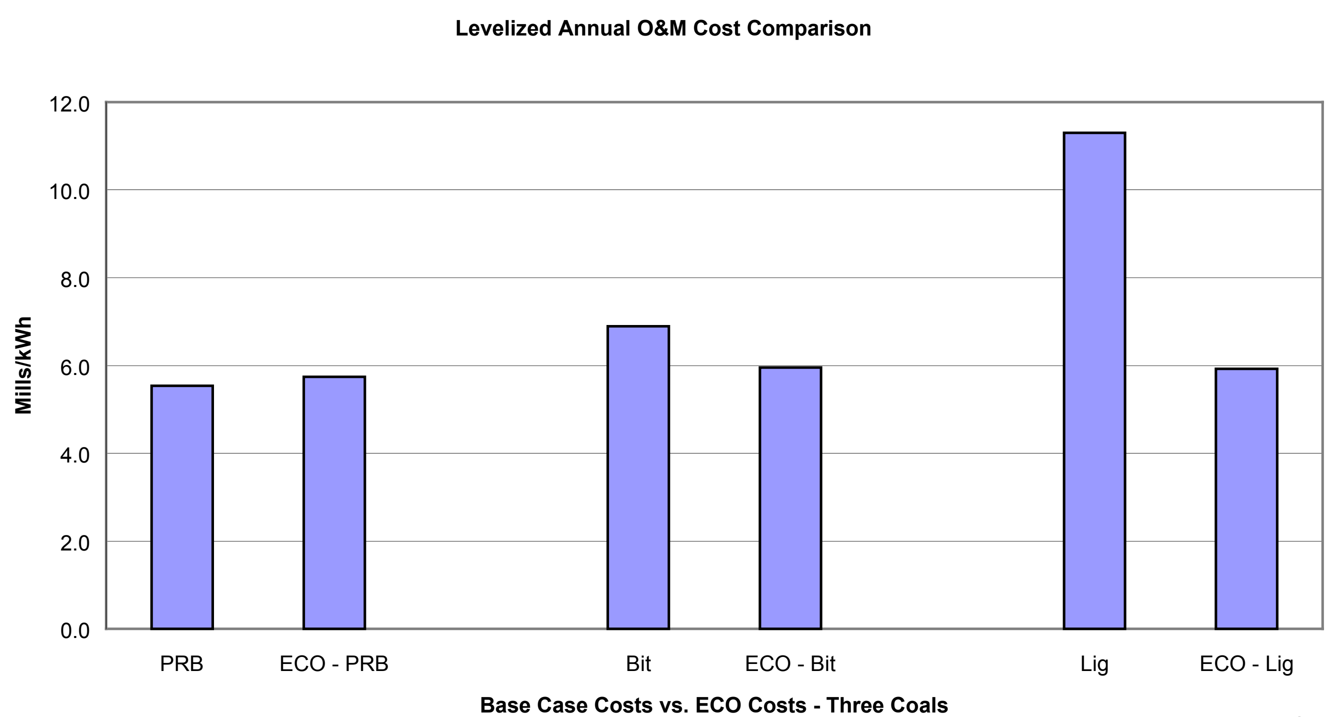
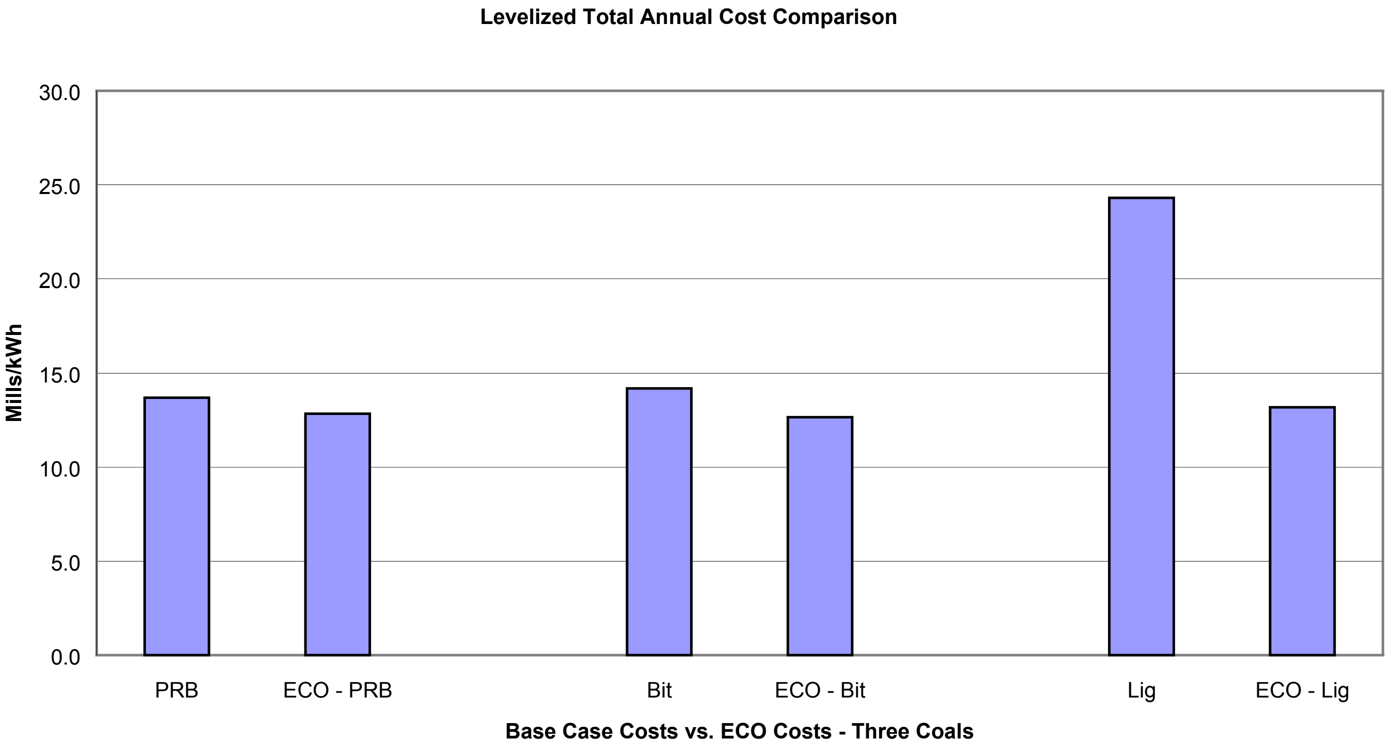


Figure 8



Levelized Total Annual Cost Comparison
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Mills/kWh
PRB
ECO - PRB
Bit
ECO - Bit
Lig
ECO - Lig
Base Case Costs vs. ECO Costs - Three Coals

6
CONCLUSIONS

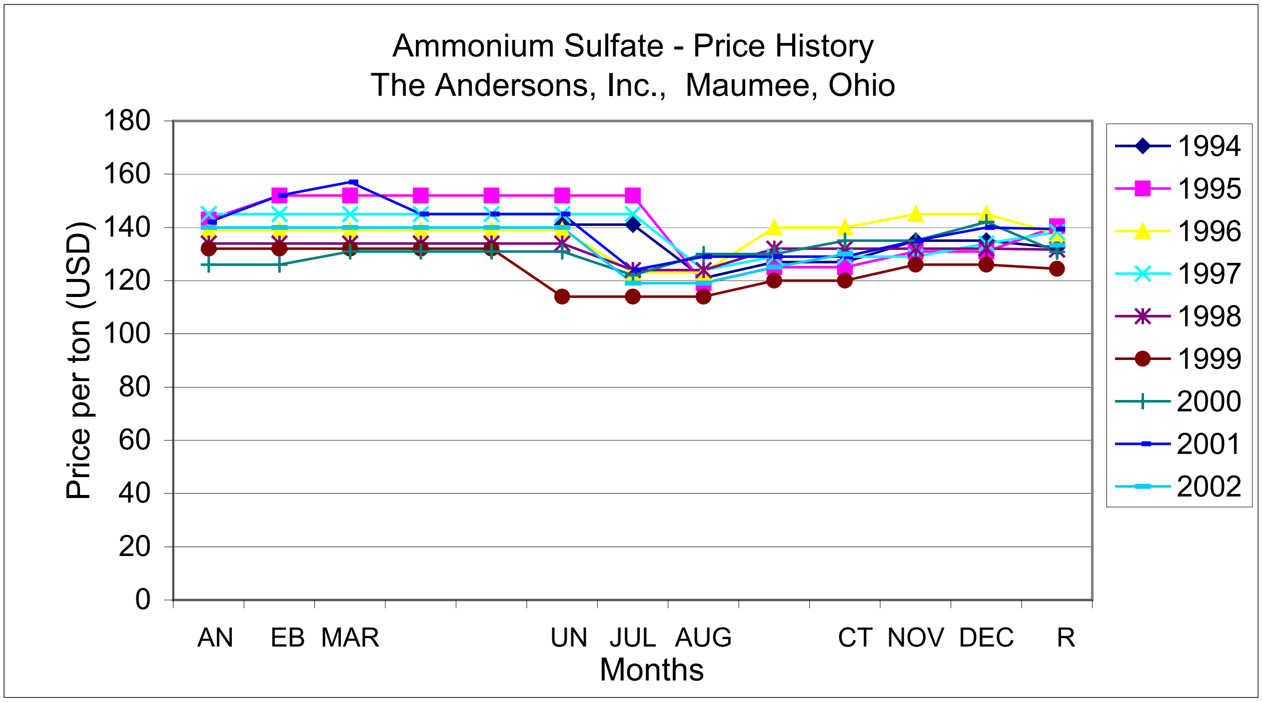
As more IEC technologies emerge, the potential for a cost competitive integrated pollutant control system will increase. However, development of capable technologies is limited by the capital expenditures required for research into these technologies. Current environmental technologies employed today for pollution reduction have many years of successful operating experience, which enhances their reliability and availability. Multiple suppliers of the same technology help to reduce cost and increase competition for better performance. IEC developers are in direct competition with current commercial technologies. As more testing and demonstration plants are completed, a better picture of the overall value of these IEC technologies can be developed. These developing IEC technologies are promising and initial cost estimates are in line with what is currently used in the market. With further development and testing, the capability exists for some of these systems to increase performance, reliability, and to provide a reasonable alternative for power producers.

A
Review Comments - Powerspan

ECO Cost Modeling – Basis for Co-Product Pricing

An important element of the ECO system is the generation of a salable co-product, ammonium sulfate fertilizer, that is not only a revenue source, but which avoids landfill disposal costs. An economic model of ECO must assume a selling price for this fertilizer co-product. Powerspan understands that in a cost comparison of multi-pollutant control technologies, EPRI is using $50/ton as the price that would be realized by the sale of granulated ammonium sulfate nitrate fertilizer generated at an ECO equipped power plant. Powerspan believes an analysis based on current and historical prices supports an assumed sale price of $110/ton.

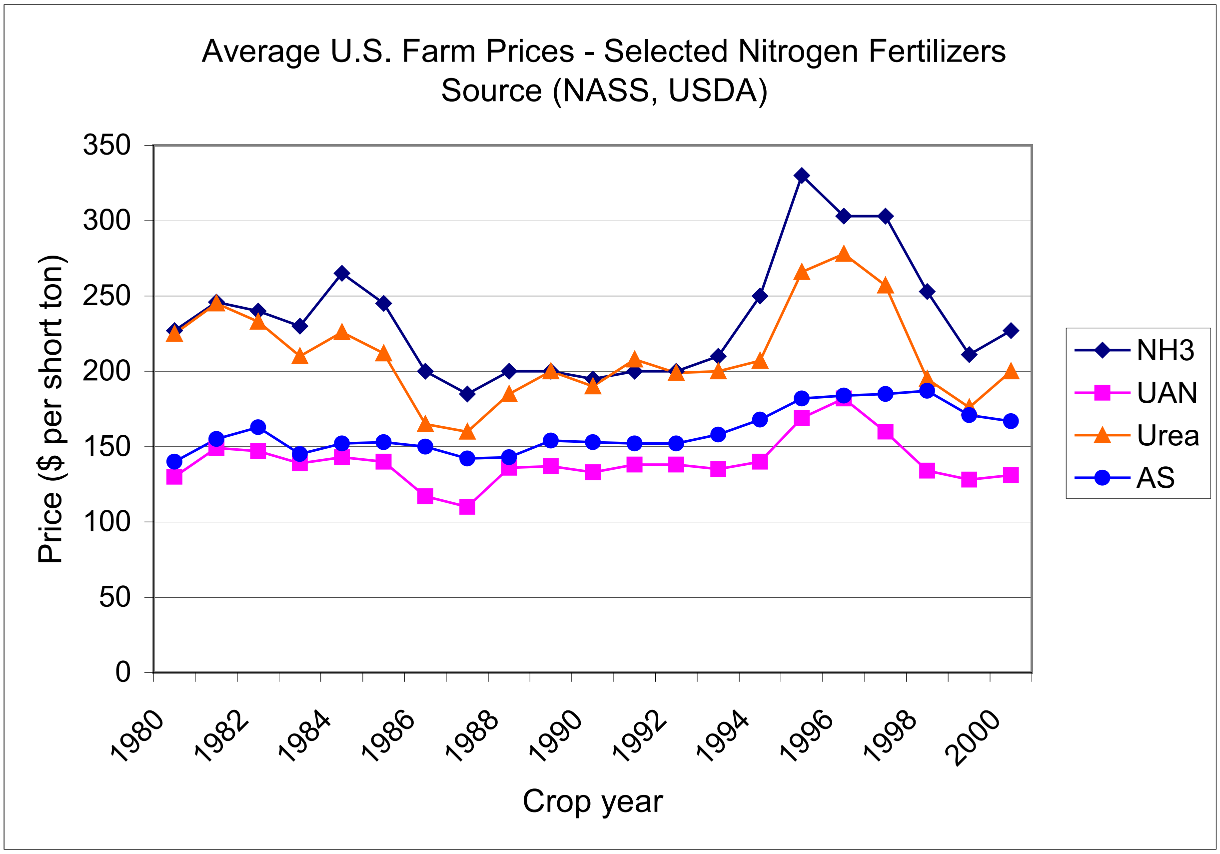
The chart below identifies the Midwest FOB spot price per ton of granulated ammonium sulfate over the last nine years from The Andersons' distribution point in Maumee, Ohio. The prices range from a low of $114/ton in mid-1999 to $157/ton in early 2001. The price clearly varies with the season, but has averaged about $134/ton for the time period shown.



1994						141	141	121	127	127	135	135	132
1995	143	152	152	152	152	152	152	119	125	125	131	131	141
1996	139	139	139	139	139	139	123	123	140	140	145	145	138
1997	145	145	145	145	145	145	145	124	129	129	129	134	138
1998	134	134	134	134	134	134	124	124	132	132	132	132	132
1999	132	132	132	132	132	114	114	114	120	120	126	126	125
2000	126	126	131	131	131	131	122	130	130	135	135	142	131
2001	142	152	157	145	145	145	124	129	129	129	135	140	139
2002	140	140	140	140	140	140	119	119	125	130			133

Many of the coal-fired power plants for which ECO would be a good solution are in the Midwest. It is reasonable to assume that the Midwest FOB prices identified above will be available to the generation facility if it is located in the Midwest and has the storage capacity to operate as a distributor/warehouse facility. Because the ammonium sulfate production rate from a 500 MW plant could be substantial and will be controlled by the power plant operating schedule and not by fertilizer demand, some transportation costs to widen the distribution area may reduce the realized price below the values listed above. For transportation within the region, an expense of $5 – 10/ton may be expected. However, even with this reduction, it is reasonable to assume an average of $110/ton realized for the sale of ammonium sulfate from a Midwest ECO unit.

An economic model of ECO will include an expense for the incoming ammonia, and it is important that the assumed value of the ammonium sulfate co-product is consistent with the assumed ammonia cost. Some may be concerned that reductions in natural market variations in ammonia cost may result in significant decreases in the value of ammonium sulfate. Historical trends do show a relationship between ammonia and ammonium sulfate prices. The chart below provides the historical price for ammonia, ammonium sulfate (AS), and two other nitrogen sources (urea and urea nitrate) over the last 20 years. As the data show, the price of ammonium sulfate follows the trend of the price of ammonia. However, it is clear from the data that the relationship is not one-for-one. Ammonium sulfate has a value beyond just the worth of the nitrogen in it and therefore its pricing is less volatile than that of the nitrogen component, ammonia. Consequently, historical data would not support a deep discount of the ammonium sulfate value from its current value on the basis of reductions in ammonia cost of 10 or 20 percent.



Two other factors merit noting:

1. The sulfur content in farmland is decreasing as the SO_2 release from power plants decreases. Sulfur is an important nutrient for some crops, for example corn. The amount of sulfur that needs to be applied via fertilizer is likely to increase in the future as the amount of sulfur that is deposited via acid rain decreases.
2. The ammonium sulfate generated from an ECO system will be of high quality. Testing to date using liquor from the ECO pilot installation has generated high quality, clean crystals. These crystals will be granulated at the generation site. Once granulated, this fertilizer product can be blended with other fertilizers. The Andersons commented on this aspect as follows:

"Blending of dry granulated fertilizers is a common practice in both the commercial and consumer markets today. Ammonium sulfate is currently being blended with other nutrients for use in the industry today, and we anticipate that this will increase as more ammonium sulfate is produced in the future. As long as the physical properties of ammonium sulfate are suitable for blending and for commercial application, there should be no issue in this area. Ammonium Sulfate Nitrate that will be manufactured as part of the ECO process will be the best available sulfate on the market today. Plant designs are taking co-product quality into account relative to size of product, hardness, uniformity, color and friability. We anticipate that this product will be superior to others on the market today, and will be an excellent nitrogen and sulfur form for both blending and direct application."

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EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com