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**VIA HAND DELIVERY**

Ohio Power Siting Board  
180 E. Broad Street,  
Columbus, Ohio 43215  
Attn: Docketing Division

**Re:** Supplement No. 3 to AMP-Ohio's Certificate Application. Case No. 06-1358-EL-BGN – In the matter of the Application of American Municipal Power- Ohio, Inc. for a certificate for an electric generation facility.

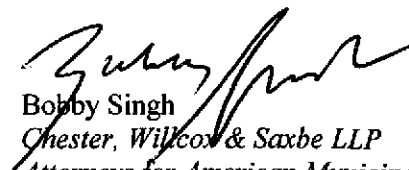
Dear Docketing Division:

Please docket in the above-referenced case, the following documents, attached hereto, relating to the Powerspan multi-pollutant control technology, that are being submitted to supplement American Municipal Power-Ohio, Inc.'s ("AMP-Ohio") application with the Ohio Power Siting Board for a certificate to construct an electric generation facility:

- Attachment 1 – Multi-Pollutant Control Technology for Coal-Fired Power Plants.
- Attachment 2 – An Economic Scoping Study for CO2 Capture Using Aqueous Ammonia
- Attachment 3 – Advanced Ammonia Scrubbing for SO2 Control
- Attachment 4 – ECO Commercial Demonstration Information
- Attachment 5 – Powerspan Press Release
- Attachment 6 – FirstEnergy News Release
- Attachment 7 – AMP-Ohio Release
- Attachment 8 – Powerspan Representative Contact Information

I appreciate your assistance with the above request. Please contact me with any questions.

Very truly yours,

  
Bobby Singh

*Chester, Willcox & Saxbe LLP*

*Attorneys for American Municipal Power-Ohio, Inc.*

Attachments

Service made to:

cc: Jon Pawley, Ohio Power Siting Board, w/additional copies

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**Multi-Pollutant Control Technology  
for Coal-Fired Power Plants**

*Phillip D. Boyle  
President and COO  
Powerspan Corp.*

Presented at  
Clean Coal and Power Conference  
Washington, DC  
November 21-22, 2005

**ATTACHMENT 1**

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## **MULTI-POLLUTANT CONTROL TECHNOLOGY**

Phillip D. Boyle  
President and COO  
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### **ABSTRACT**

Powerspan Corp.'s Electro-Catalytic Oxidation, or ECO<sup>®</sup>, technology is an integrated multi-pollutant control process that achieves major reductions in emissions of sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), fine particulate matter (PM<sub>2.5</sub>), and mercury (Hg). Powerspan has been operating a 50-MW ECO commercial demonstration unit at FirstEnergy Corp's R.E. Burger Plant near Shadyside, Ohio, since February 2004.

The unit has demonstrated ECO's performance, reliability, and economics in a commercial configuration. Fertilizer co-product from the process has been sold commercially. The Ohio Coal Development Office/Ohio Air Quality Development Authority has contributed \$5.5 million to the project in addition to FirstEnergy and Powerspan's contributions.

In September 2005, Powerspan successfully completed a 180-day reliability test of the demonstration unit, and FirstEnergy announced plans to install an ECO system at the energy company's Bay Shore Plant Unit 4 (215-MW) in Oregon, Ohio. With successful completion of the 180-day test and FirstEnergy's plans to install a full-scale ECO system, Powerspan has transitioned from development and demonstration to commercial deployment of ECO technology. This paper addresses the design, operation, and performance of the demonstration unit; process economics; and actions for commercially deploying the technology.

### **INTRODUCTION**

Coal-fired electric power generation plants are the cornerstone of America's power system, accounting for over 300,000 megawatts of generating capacity and producing approximately 51 percent of the nation's electricity. Worldwide, coal is also the leading fuel used for generating electricity, accounting for over 40 percent of the world's electricity generation. While coal is the least expensive and most abundant fuel source for power generation, the formation of NO<sub>x</sub>, SO<sub>2</sub>, particulate matter (PM), and Hg as combustion byproducts is of concern for public health and the environment.

Both existing and new standards will require additional control of SO<sub>2</sub> emissions, necessitating further installation of equipment that offers reductions similar to calcium-based flue gas desulfurization (FGD) systems. New standards will also require further NO<sub>x</sub> reductions and for the first time, control of mercury and fine particulate matter (2.5 microns and less, PM<sub>2.5</sub>). The stringency and timing of the standards have created the need for power plant owners to consider comprehensive approaches to emission reductions. A multi-pollutant control approach presents a cost-effective alternative to the tradition of deploying separate add-on devices. Multi-pollutant control

solutions that can be adapted to various units and coal types are particularly attractive to coal-fired generating fleets.

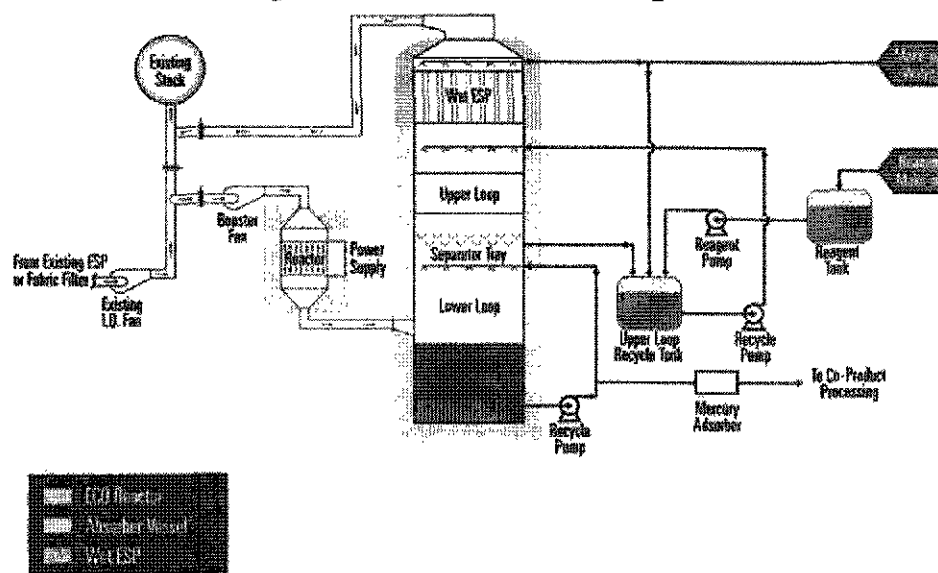
Powerspan Corp. (Portsmouth, New Hampshire) has successfully developed and demonstrated one solution. Powerspan with support from FirstEnergy Corp. of Akron, Ohio, has been engaged in the development of Electro-Catalytic Oxidation, ECO<sup>®</sup>, technology since 1998. During the past three years, Powerspan, FirstEnergy, and the Ohio Coal Development Office (OCDO)/Ohio Air Quality Development Authority (OAQDA) have participated in a joint project to build and operate a 50-MW equivalent Commercial Demonstration Unit (CDU) of the ECO technology at FirstEnergy's R.E. Burger Plant near Shadyside, Ohio. Construction of the CDU was completed in January 2004 with integrated system testing initiated in February 2004. During the first year of testing and operation, a number of changes and improvements were made. In 2005, Powerspan focused on extended runs of the unit, successfully completing a 180-day reliability test in September.

## TECHNOLOGY OVERVIEW

The ECO technology is designed to simultaneously remove SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub>, acid gases (such as hydrogen fluoride (HF), hydrochloric acid (HCl), and sulfur trioxide (SO<sub>3</sub>)), Hg<sub>x</sub> and other metals from the exhaust gas of coal-fired power plants. The ECO process converts incoming nitrogen oxide (NO) into more soluble NO<sub>x</sub> compounds, and then absorbs the SO<sub>2</sub> and NO<sub>x</sub> compounds. The ECO process also oxidizes a portion of the elemental mercury to mercuric oxide. The converted mercuric oxide as well as oxidized mercury originally in the flue gas is collected along with aerosols and fine particles in a wet electrostatic precipitator (WESP). Additionally, the ECO process produces a high value fertilizer co-product.

In commercial application, the ECO system is installed downstream of a power plant's existing electrostatic precipitator or fabric filter as depicted in the Process Flow Diagram of Figure 1.

Figure 1. ECO Process Flow Diagram



ECO treats flue gas in three process steps to achieve multi-pollutant removal. In the first process step a barrier discharge reactor oxidizes gaseous pollutants to higher oxides. For example, nitric oxide is oxidized to nitrogen dioxide and nitric acid, a small portion of the sulfur dioxide is converted to sulfuric acid, and elemental mercury is oxidized to mercuric oxide. Following the barrier discharge reactor is an ammonia scrubber, the second process step. The scrubber removes the sulfur dioxide not converted by the reactor and, utilizing novel and proprietary chemical controls, removes the oxides of nitrogen produced from the NO in the reactor. Without the conversion of the NO to higher oxides in the reactor, the NO would pass through the scrubber without being captured. Without the scrubber chemistry modified to capture the higher oxides of NO, specifically NO<sub>2</sub>, these oxides would be released and not contribute to NO<sub>x</sub> reduction. Therefore, the reactor and scrubber work in combination to achieve the NO<sub>x</sub> reduction. The third process step is a wet electrostatic precipitator (WESP) which follows the scrubber. It captures acid aerosols produced by the discharge reactor, fine particulate matter, and oxidized mercury. The WESP also captures aerosols generated in the ammonia scrubber.

An absorber tower contains the scrubber and the WESP as shown in Figure 1. The scrubber contains two liquid loops, one for quenching the gas to saturation temperature and the other for use in the mass contactor to absorb the SO<sub>2</sub> and the oxidized NO<sub>x</sub>. The WESP has a water supply to periodically rinse the walls. All the liquid coming into the absorber tower ultimately ends up in the lower quench loop. This liquid contains all the material removed from the flue gas, which is in the form of dissolved ammonium sulfate and nitrate salts, dissolved and suspended Hg and other metals, and captured fine particulate matter. The concentration of solid particulate matter in the liquid is very low and the liquid is basically clear, unlike the slurry used in calcium-based SO<sub>2</sub> scrubbers.

The evaporation of water that occurs in cooling the flue gas is used to concentrate the dissolved salts in the lower loop to just below the concentration at which the ammonium sulfate solution saturates and begins to crystallize. When the lower loop reaches this concentration, a liquid stream is drawn off the loop and pumped to the co-product processing system. This concentrated, clear liquid stream presents a very convenient opportunity to remove constituents not desired in the fertilizer co-product, for example the fine particulate ash and the mercury. Simple filters and absorbent beds in the flow stream accomplish this function. The processing options available for removing constituents from a clear liquid stream are significantly easier and cheaper than the processing that would be required for solids or slurries. The ammonium sulfate is then crystallized to produce a commercially valuable fertilizer. Some of the NO<sub>x</sub> oxidized in the barrier discharge reactor precipitates as nitrate within the ammonium sulfate crystal. This ammonium nitrate is not separable from the ammonium sulfate and adds somewhat to the value of the fertilizer because it increases the nitrogen content above that which is provided by the ammonium. However, since only a fraction of the NO<sub>x</sub> is converted to nitric acid, (most is oxidized only to NO<sub>2</sub>) and since the NO<sub>x</sub> is a small fraction of the incoming SO<sub>2</sub>, the concentration of ammonium nitrate is usually only a percent or two of the ammonium sulfate. In spite of the increased supply of AS that will occur from widespread adoption of ECO, the fertilizer market, especially the nitrogen market, can absorb this production while maintaining prices, which will at a minimum offset the reagent costs.

There is no liquid discharge from an ECO system. The only waste streams are the small quantity of ash that escaped the plant's particulate collection device and was captured in ECO's WESP and the small volume of Hg adsorbent used to remove the Hg from the fertilizer liquid stream.

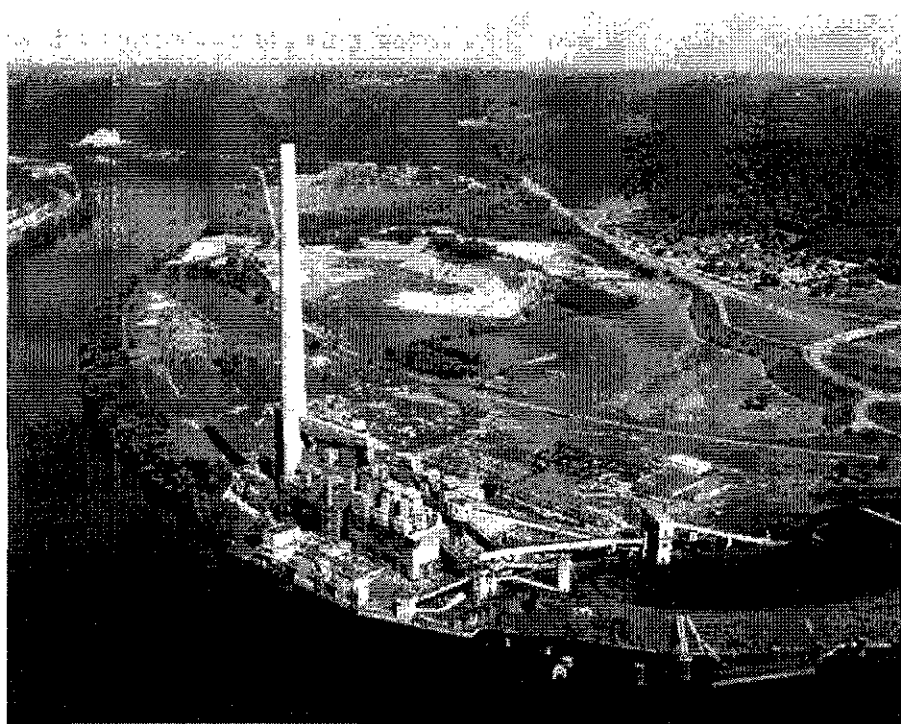
## **ECO COMMERCIAL DEMONSTRATION**

The ECO Commercial Demonstration Unit (CDU) was the last step in moving ECO technology from development scale to full commercial scale. Two of the three flue gas processing steps in ECO, the dielectric barrier discharge reactor and the WESP, are inherently modular. For each of these, scaling to treat larger gas volumes is accomplished by replicating a single gas treatment passage multiple times. The geometry and operating conditions of the gas passage are not changed as the unit is scaled up; therefore, the physics and chemistry of what happens in a gas passage are not changed. The situation is analogous to dry electrostatic precipitators, wherein once the plate geometry, electrode configuration and spacing, and gas velocity are established, the precipitator is scaled to larger units by adding gas passages. The primary variable that can affect performance with this scaling approach is uniform gas distribution. Although often challenging, gas distribution is an understood phenomenon, which can be managed.

The third processing step, the scrubber, is not modular in the same way the reactor and WESP are. However, scrubbers have been built in a wide range of sizes, and the engineering knowledge to build units to 500 MW and larger exists with many suppliers.

Powerspan's 50 MW ECO Commercial Demonstration Unit (CDU) was built at FirstEnergy's R.E. Burger Plant near Shadyside, Ohio, to demonstrate the commercial readiness of ECO technology. The plant, shown in Figure 2, is located on the Ohio River in southeastern Ohio.

**Figure 2. FirstEnergy's R.E. Burger Plant**

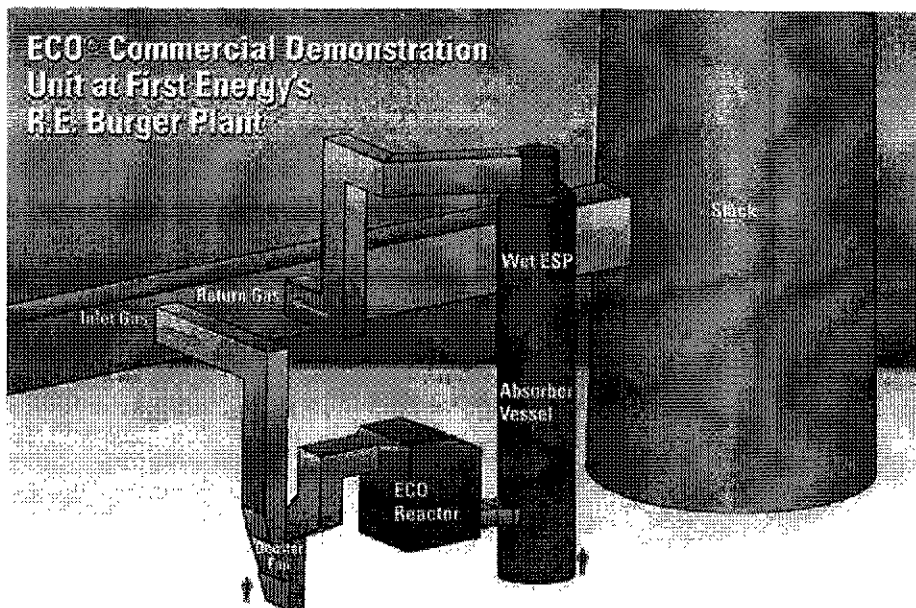


## **Background**

The primary objective of the project was to demonstrate, at commercial scale, the ECO technology as an integrated, cost-effective multi-pollutant control system, which achieves major reductions in emissions of SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub>, and air toxics, including mercury. Additionally, the ECO technology was intended to maximize byproduct utilization and minimize generation of solid and liquid wastes.

The Burger CDU was designed and constructed as a stand-alone, slipstream unit drawing flue gas from the Burger Plant Unit No. 4 or Unit 5 ductwork at a point downstream of the Plant's existing electrostatic precipitator. The treated flue gas is returned to the existing Plant ductwork just prior to the stack. The CDU consists of a barrier discharge reactor section and an absorber tower containing a wet scrubber and a wet electrostatic precipitator (WESP). Powerspan was responsible for the ECO process design, supplied the ECO reactors and power supplies as well as the WESP, and provided overall project management and direction. Wheelabrator Air Pollution Control, Inc. performed most of the detailed system design to Powerspan specifications and managed the construction. The CDU was designed and built to utility standards, with the exception that redundant components were not installed in many locations as a money-saving feature. Figure 3 below is a simplified rendering of the Burger CDU layout.

**Figure 3. Simplified Rendering of the Burger CDU Layout**



As shown in the figure above, the Burger CDU is divided into two primary structures, the ECO reactor enclosure and the absorber vessel, which also contains the WESP. CDU support buildings (not shown in figure) were designed and laid out in close proximity to the CDU to

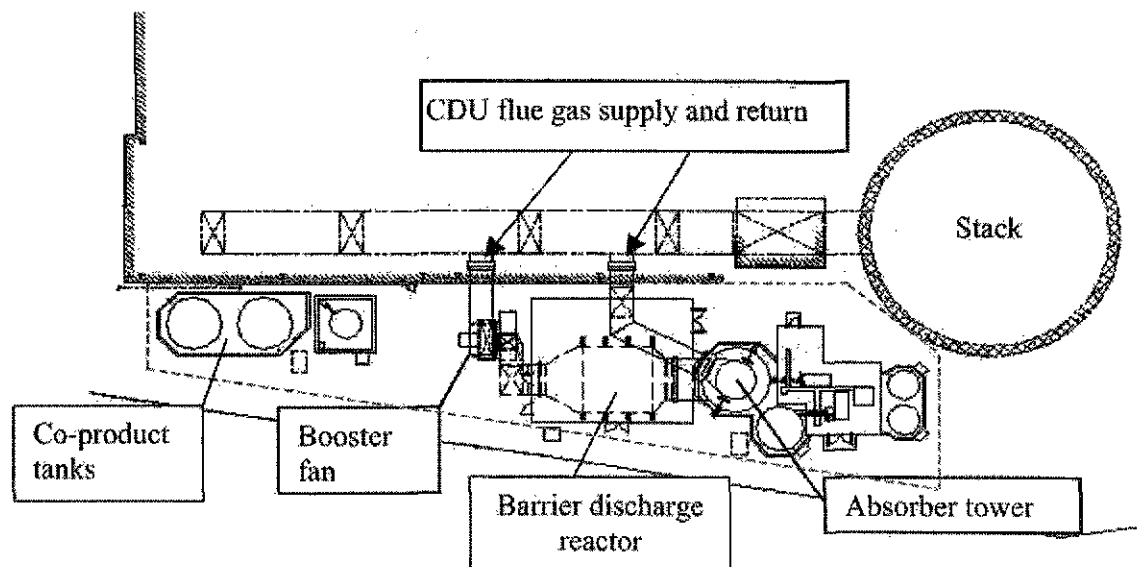


house ancillary electrical and mechanical equipment, continuous emissions monitoring system (CEMS) instrumentation, and the CDU control room. This configuration was designed to minimize the footprint of the ECO system to efficiently utilize the limited available space.

Every aspect of the CDU project was designed and constructed in accordance with utility standards. The components and materials are the same as will be used in a full-scale installation. The unit was designed to operate continuously and to follow the load of the unit flue gas is drawn from. CDU control systems are programmable logic controller (PLC)-based with an operator interface that is consistent with those currently used for other plant equipment. The design intent of the CDU is to ensure that successful operation of the unit confirms the commercial readiness of the system as it relates to performance, reliability, and economics. The CDU is currently operated such that it effectively serves as the first commercial installation and therefore allows subsequent purchasers to avoid the difficulty that goes with the first-of-a-kind installation.

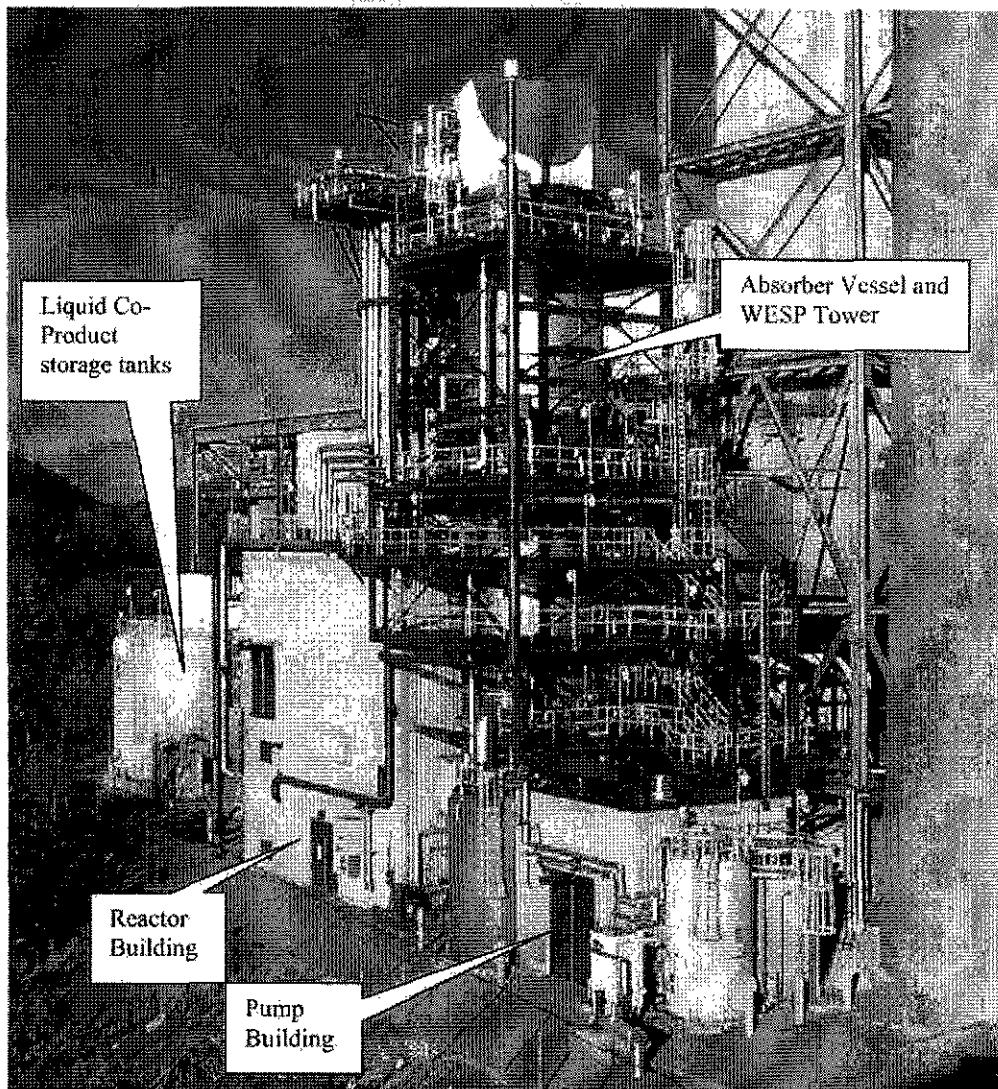
The plan view in Figure 4 shows the layout of the major CDU components as constructed in the available space between the existing Burger Plant structures and the riverbank. The CDU footprint, represented by the dashed line, is approximately 50 feet wide by 200 feet long.

**Figure 4. Plan View of Major Components**



The photograph of the completed CDU in Figure 5 below identifies the location of the major CDU components as installed. Construction of the Burger CDU was completed in January 2004. Unit startup and commissioning was completed by February 2004, and the first integrated system testing was initiated in February 2004.

**Figure 5. ECO Commercial Demonstration Unit**



## **Review of Process Components**

### **Barrier Discharge Reactor**

The dielectric barrier discharge reactor is a well-known device for creating high-energy electrons that correspond to being at a high temperature, without expending the energy to heat up the gas molecules. By placing a dielectric barrier between two electrodes, the formation of an arc is prevented when the voltage reaches the breakdown voltage of the gas. Instead of an arc, which would concentrate the electron flow in a narrow channel, thousands of micro-discharges occur over the surface of the dielectric. This discharge pattern is an efficient way to distribute the discharge over a volume. The electrons from this process have an average energy of five eV,

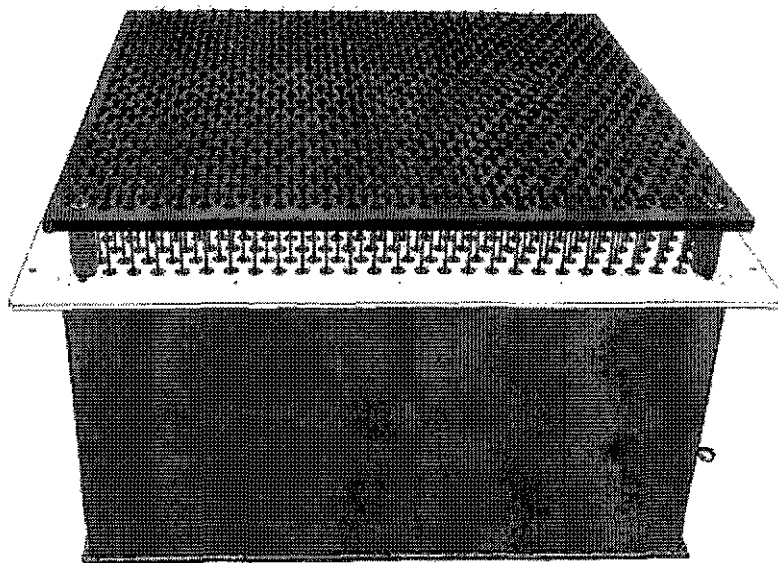
ideal for breaking down existing oxygen and water molecules in the flue gas to create atomic oxygen and hydroxyl radicals. These radicals are the foundation of the oxidation reactions initiating the ECO process chemistry summarized in the Technology Overview above.

Dielectric barrier discharge reactors have been used for many years to generate ozone. In an ozonator, cylindrical coaxial electrodes are used to treat oxygen in the annulus between the inner electrode and the outer tube. This is the same geometry used in Powerspan reactors, although ozone is not produced by the ECO reactors due to the relatively high temperature of the treated flue gas.

Powerspan's CDU reactor design employs 737 tubes in parallel as shown in Figure 6 below. Since each of the tubes is identical and runs under identical conditions, performance from electrode to electrode does not vary significantly for a given reactor. Scaling of the reactors to larger capacities is done not by changing the tube geometry to handle more gas in each tube, but by simply adding more tubes. This scaling process is the same as used to scale up a precipitator. Once the gas passage height, spacing, electrode configuration, and number of fields are determined, additional gas handling capability is obtained by adding additional gas passages. The CDU has nine reactor bundles. Each bundle contains multiple gas passages and is powered by a separate power supply.

Powerspan has gained extensive experience over the past several years designing, constructing, and operating dielectric barrier discharge reactors for flue gas processing. This experience has been important to the design and deployment of the Burger CDU reactor system. Figure 6 below is a three dimensional rendering of a single module reactor designed specifically for the Burger CDU project. Each reactor module is a cube approximately 5½ feet on a side.

**Figure 6. CDU Reactor Module**



As more reactor bundles are added to scale the unit to larger gas flows, one of the major design challenges is ensuring uniform gas distribution. If gas flow is not uniformly distributed across an array of reactors, the gas will not be uniformly treated and the efficiency of the unit will decrease. The nine reactor bundles in the CDU are positioned in a three-by-three grid. Because gas distribution is the most significant variable in scaling of the dielectric barrier discharge reactor, Powerspan used both computational fluid dynamics as well as physical modeling to design the reactor housing. The results of the model were used to design baffles and turning vanes to achieve a uniform flow distribution.

### **Reactor Power Supplies**

The dielectric barrier discharge reactor requires simple AC high voltage. The waveform is not important, and rapid rise times or power pulses are not required. Consequently, the power supplies are medium input voltage units (480V) using standard components feeding a conventional design high voltage transformer. Additionally, the peak voltage used in the reactor is less than half the voltage used in utility dry precipitators. Therefore, readily available cable and insulators provide the required isolation to route the high voltage to the reactors.

Powerspan has worked with NWL of Bordentown, NJ, to develop the reactor power supplies. NWL has provided transformer rectifier sets and precipitator controls to the utility industry for many years. NWL adapted an existing power supply design to the needs of the Powerspan dielectric barrier discharge reactor. NWL power supplies have been used for laboratory reactors at Powerspan and at the Powerspan Burger pilot. Although specifically designed to match the ECO reactor's impedance, the power supply is based on an existing NWL design. The AC output of the power supply's bridge is fed to the step-up transformer to produce the high voltage medium frequency output required by the ECO reactor. NWL has provided twelve 250 kW power supplies for the 50 MW Commercial Demonstration Unit. Figure 7 depicts the power supplies as installed at the Burger Plant.

**Figure 7. ECO Reactor Power Supplies**

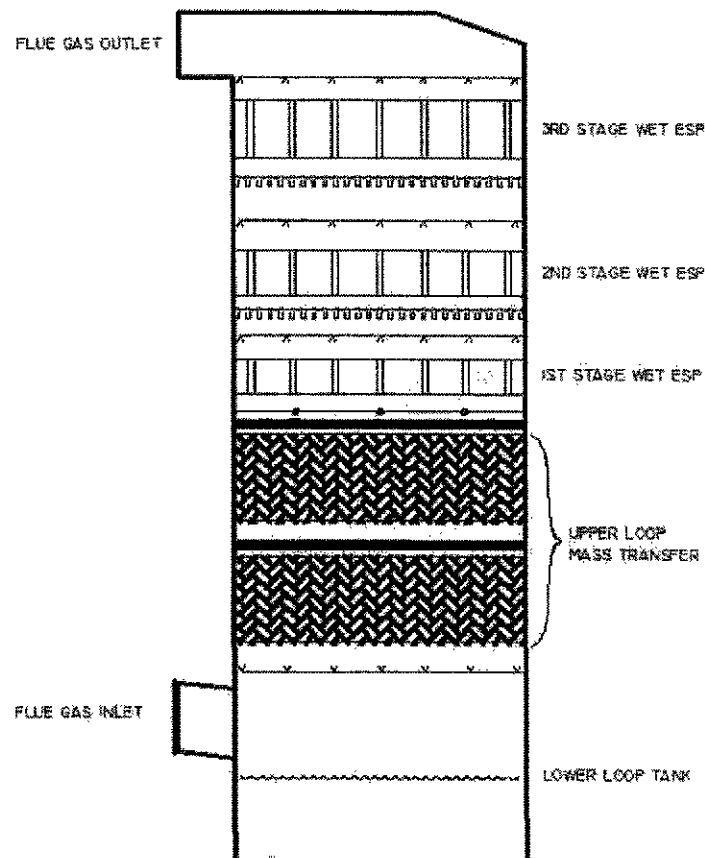


NWL and their alliance partner, Magna Power Electronics (MPE), have produced power supplies of this design in the range of 10 kW to 600 kW. To date, numerous applications have used this rugged solution, including oil processing, TV transmitters, capacitor charging, telecom, and electron beam heating. Estimated mean time between failures per Mil handbook 217E is 117,535 hours, or approximately 13.4 years.

### **Absorber Tower**

After the flue gas is treated by the dielectric barrier discharge reactor, the gas enters a vertical two-loop scrubber tower. Wheelabrator Air Pollution Control, Inc. (WAPC) and Powerspan developed the wet scrubber design for this portion of the system. The CDU scrubber utilizes a two-loop design wherein a lower loop circulates to quench the gas, and an upper loop performs the chemical scrubbing. The liquor in the two loops is kept separated by a separation tray. This design was used in some early installations of calcium-based SO<sub>2</sub> scrubbing, when it was believed that separating the quenching liquid from the scrubbing liquid would improve performance. Although current calcium-based SO<sub>2</sub> scrubbers do not need to keep these loops separated, the ECO chemistry is different in the lower loop than the upper loop, so this technology is a good match for an ECO system. Figure 8 is a drawing of the tower.

**Figure 8. Drawing of Absorber with WESP (Typical Commercial Configuration)**



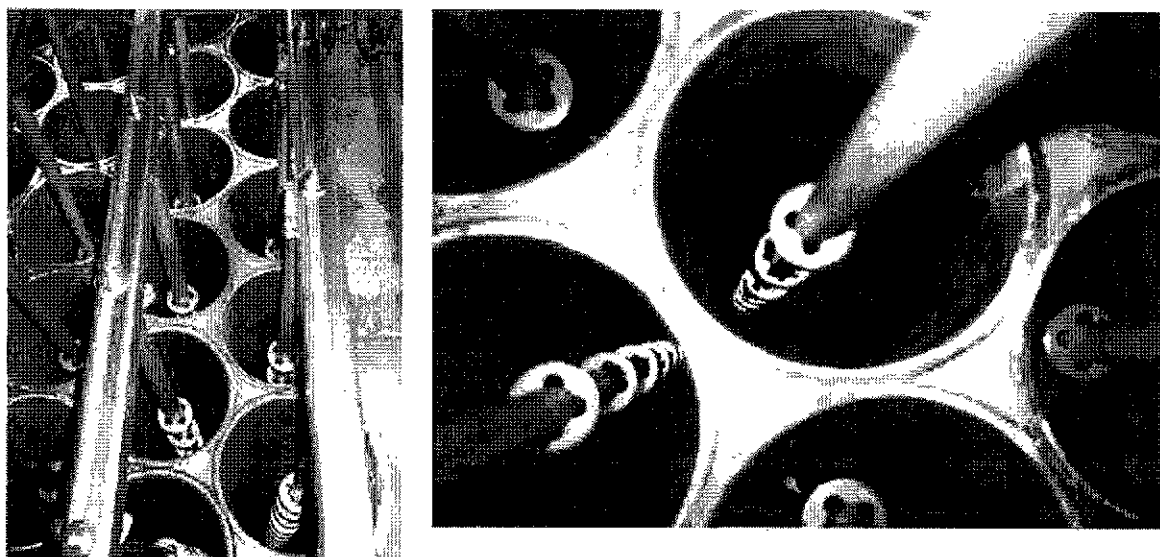
Scaling for increased gas volume is done by increasing the diameter of the tower and keeping the gas velocity, and therefore the residence time, the same in each process element independent of the quantity of gas being treated.

### **Wet Electrostatic Precipitator (WESP)**

The CDU WESP is a tubular, up-flow design and is similar to WESPs used in other applications. Such a configuration has zero bypass or sneackage and generates the most uniform corona and electric collection field of all the practical configurations. Scaling such units to larger gas flows is accomplished by simply adding more tubes.

The CDU WESP utilizes a two-field configuration. The WESP utilizes NWL switch mode power supplies that produce a near pure DC output for maximum power input to the field. The result is a very high level of collection. Spray nozzles allow for wash down of each field using service water. This water eventually mixes with the liquor in the tower and provides some of the makeup for the water lost during evaporative cooling of the incoming gas. The first field is shorter than the second field and is able to handle high inlet loading. The second field is expected to see lower loading due to the particulate removed by the first field and, as such, should not require wash down as frequently. This will minimize the loss of collection time that occurs during wash down. Figure 9 shows the original electrodes utilized in the CDU WESP. A typical commercial installation will likely use three fields to provide additional performance margin.

**Figure 9. CDU WESP Tubes and Electrodes**



### **Fertilizer Co-Product Processing**

The scrubbing liquor, which removes  $\text{SO}_2$  and oxidized  $\text{NO}_x$  products from the flue gas and forms the ammonium sulfate co-product, provides the makeup liquid to the lower loop gas quenching section. Water evaporation that occurs when quenching the flue gas to saturation concentrates the

ammonium sulfate co-product. In full-scale commercial units, a crystallizer would be constructed at or near the site to precipitate crystals from the liquid co-product feed liquor. Crystallized product can be sold directly into the market, or granulation equipment can be used to create a more regular and larger granule from the crystals.

At the Burger CDU, the relatively small quantity of co-product material generated did not warrant installation of a crystallizer to increase the value of the co-product. Instead, the co-product stream of ammonium sulfate (AS liquor) is stored and shipped as a liquid fertilizer product with an approximate analysis of 8% nitrogen, 9% sulfur, and a pH of 5.5-6.0. Total production and sale of this product averaged approximately 2,000 tons per month during continuous operations in 2005.

The liquid co-product has been distributed by both truck and rail tankers. The co-product was trucked out during initial CDU operations, prior to the installation of a rail car loading station at the Burger Site. The liquor has been primarily used as a blend with existing liquid plant nutrients, specifically, Urea Ammonium Nitrate (UAN). Continual testing of the liquor is performed on site, or at independent laboratories to verify the co-product meets commercial specifications. Additionally, batches of the liquid product have been processed in a lab-based crystallizer to demonstrate the suitability of the feed liquor for this processing.

Logistics for the CDU fertilizer product and evaluation of its quality have been conducted by The Andersons Inc., a diversified agribusiness and retailing company based in Maumee, Ohio. The Andersons are an alliance partner with Powerspan.

### **CDU Operations**

CDU integrated system testing was initiated in February 2004. During the first year of testing and operation, a number of changes and improvements were made. The CDU has one performance limitation relative to full-scale commercial ECO units. A tower height established early in the design process limited the height of the absorber section. Consequently, NO<sub>x</sub> removal does not reach the 90% reduction from 0.4 lb/mmBtu inlet of which the process is capable. Absorber height was shown to be the only constraint to achieving the design reduction of 90%. A slipstream tower with increased absorber height was constructed adjacent to the CDU. This Test Loop demonstrates 90% NO<sub>x</sub> removal.

By the start of 2005, the unit was operated generally on a five day a week basis to gain run time and provide confirmatory operating data. Periodically, the unit would be run for two weeks at a time. In March 2005, Powerspan initiated a 180-day performance and reliability test, which was successfully completed in September 2005. Operations during the 180-day run were documented three ways:

1. Daily logs recorded the operating status of the plant.
2. An automated data acquisition system recorded plant operating parameters (flows, temperatures, pressures, pH, densities, and CEM system results) continuously.
3. A spreadsheet tracking the key performance factors was updated and issued daily.



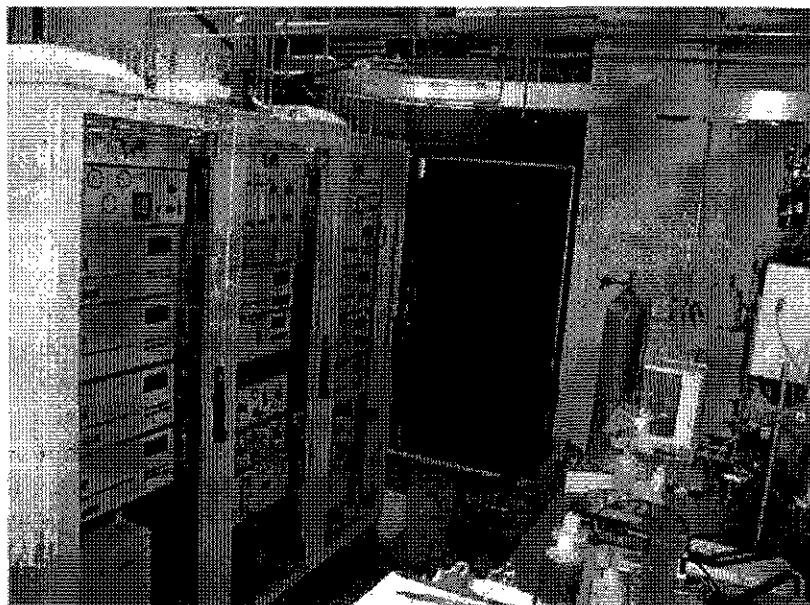
Thirty-day rolling averages for SO<sub>2</sub> and NO<sub>x</sub> emissions were calculated in accordance with U.S. EPA requirements.

Figures 10 and 11 depict the control room and inlet and outlet CEMS, respectively.

**Figure 10. Control Room with Computer Terminal Interfaces to PLC System**



**Figure 11. Inlet and Outlet CEMS and Wet Chemistry Facility for Monitoring CDU Performance**





## CDU Performance

The CDU performed steadily, achieved predictable results, and met all performance objectives over the continuous six-month period. At the end of the 180-day test, performance was essentially unchanged from the start of the run. The operating data indicates the unit could have continued to run indefinitely. Post operating run internal inspections support this conclusion. A summary of the unit's performance is included in Table 1 below.

**Table 1. Performance Summary of 180-Day Reliability Run**

SO <sub>2</sub>	> 98% removal
NO <sub>x</sub>	90% removal (CDU with limited packing height consistently achieves 70%; Test Loop adjacent to CDU proves 90% capability)
Hg	85% removal
PM <sub>2.5</sub>	< 0.01 lb/mmBtu at outlet
Reliability	Operated continuously for six months (03/20/05 – 9/20/05); > 98% on-line availability even though, as a money saving feature, the CDU was not designed with component redundancy
Operability	Maintained performance through load following, system transients, and plant upsets
Pollutants Removed	3,000 tons of SO <sub>2</sub> 125 tons of NO <sub>x</sub>
Co-Product Generated and Sold	18,500 tons of liquid ammonium sulfate fertilizer (185 railcars)

## CAPITAL AND OPERATING COSTS

### Capital Cost

Capital cost comparisons to conventional technology are strongly affected by several site specific factors, including the degree of difficulty of the retrofit, the reagent design requirements, e.g. anhydrous versus aqua ammonia and the days of storage required, and what is included in the conventional technology comparison, e.g. dry versus wet scrubbing and activated carbon injection for mercury control or relying on co-benefit removal rates. In spite of these complications, however, the ECO system has many features that are inherently simpler or that aid in construction, such that it is expected that ECO will be lower cost than conventional technology. These features include: (1) the location of the ECO unit *after* the dry electrostatic precipitator, thereby avoiding the structural difficulty of placing a selective catalytic reduction system high in the flue gas train at the boiler outlet, (2) the use of a clear liquid scrubbing system, reducing the wear on components, (3) the use of liquid reagents and co-product effluent, reducing the dry material handling required by conventional scrubbing systems. Specific cost comparisons have supported the expectation that ECO capital cost will be lower than conventional technology for the control of SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub>, and Hg. Powerspan expects ECO to be approximately 10-20% less than conventional technology on average, depending on site specifics and the conventional technology required to achieve similar performance.

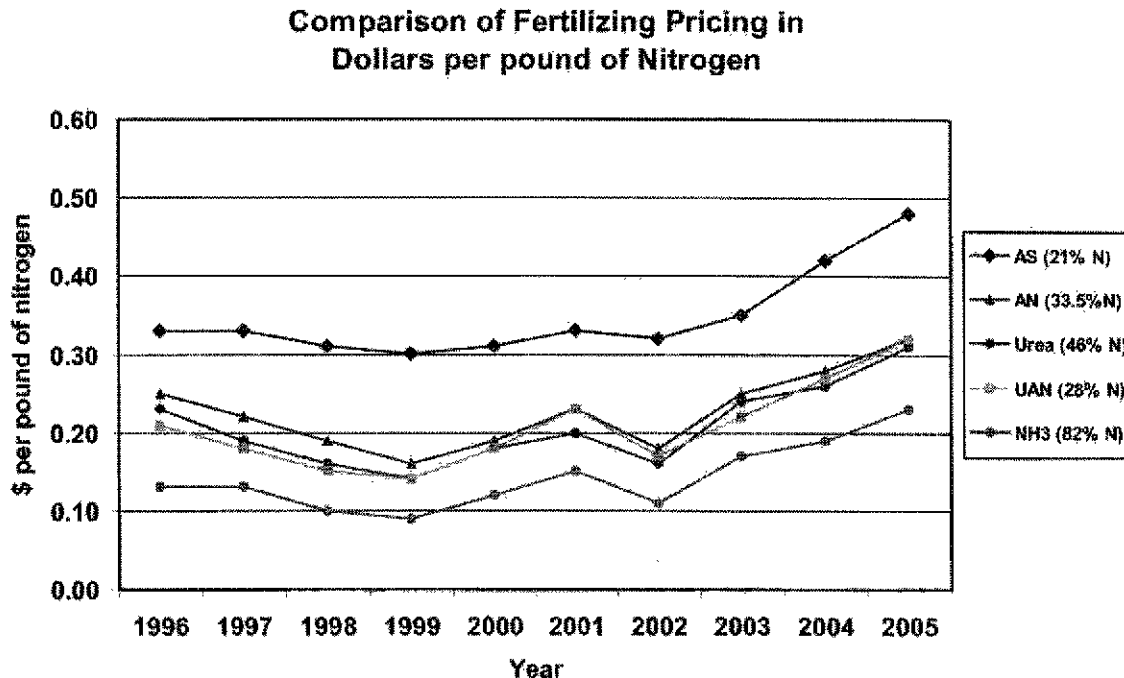
## Operating Cost

The calculation of operating costs depends on a number of factors, the most important of which are the incoming  $\text{NO}_x$  level, the cost of electricity, the cost of ammonia, and the revenue from fertilizer sales. These factors affect the operating cost calculation as follows:

1. Incoming  $\text{NO}_x$  level: The  $\text{NO}_x$  removal in an ECO system is controlled by the rate of conversion in the ECO reactor of  $\text{NO}$  to  $\text{NO}_2$  and  $\text{HNO}_3$ . The physical processes occurring in the reactor are such that the  $\text{NO}$  conversion is a mass-based process rather than a percentage-based process. That is, for a fixed energy input, a fixed mass, rather than a fixed percentage, of  $\text{NO}$  is converted. Additionally, as the mass of  $\text{NO}$  to be converted increases above a certain point, the energy required for the conversion increases per unit of mass. The result is that substantial energy reductions are achieved by lowering the inlet  $\text{NO}_x$  level.
2. Cost of electricity: The ECO reactor operates on electrical power. Consequently, electricity behaves as a reagent and the cost assigned to it affects the calculated operating cost. In assigning a cost to electrical power for estimating ECO operating cost, it is important to realize that the amount of power used by the ECO reactor is completely adjustable in real time. ECO reactor power can be turned up and down as grid requirements (and wholesale prices) warrant. At any time that a system is not operating at maximum capacity, electrical power could be valued at the marginal cost of production. Some utilities have pointed out that the ability to reduce power input to the ECO reactor instantaneously and redirect that power to the grid would allow the power to be sold as spinning reserve. The flexibility of electrical power input to the ECO reactors is valuable and should be recognized when determining what cost to use for electrical power in an economic evaluation.
3. Cost of ammonia and revenue from fertilizer sales: The cost of the ammonia reagent and the revenue from sale of ammonium sulfate are related. Ammonia is an ingredient in ammonium sulfate, and the historical trend is for the price of ammonium sulfate to rise and fall with ammonia prices. The spread between the two prices is driven by the premium form of the nitrogen in ammonium sulfate compared to the form of nitrogen in ammonia and by the presence of the sulfur in ammonium sulfate, which is a needed plant nutrient. Figure 12 shows the historical relationship by plotting the price on the basis of cost per pound of nitrogen for several of the most commonly used fertilizers. Note the top line is ammonium sulfate and the bottom line is anhydrous ammonia. Historically, ammonium sulfate prices are correlated with 0.72 correlation factor to ammonia.

Plant location is a factor in the economics of offsetting the ammonia reagent cost with the revenue from the fertilizer sales. Plant location is a factor in whether anhydrous ammonia can be used, which results in a substantial reduction in the cost of the ammonia. Plant location also plays a role in the transportation costs which have to be subtracted from the sale price of the ammonium sulfate.

Figure 12. Historical Fertilizer Pricing Trend



It should be noted that since each ton of ammonia makes about four tons of fertilizer, a \$40 increase in the per-ton cost of ammonia is recovered by a \$10 increase in the per-ton price of fertilizer.

4. Sulfur content of the coal: The sulfur content of the coal determines the quantity of ammonium sulfate generated at the plant and thus, the total revenue available to offset expenses. Some expenses are relatively fixed, such as maintenance and personnel, and some vary with conditions other than input sulfur, such as electrical power for fan pressure and ECO reactor operations. As the sulfur level in the coal rises, the revenue increases faster than the expenses increase. Thus, the net operating cost decreases for higher sulfur coals.

In addition to the above factors, as an integrated pollutant removal system, the individual operating costs are not readily aligned with a specific pollutant. Consequently, a single number cannot be used to describe the cost per ton of pollutant removed for an ECO system. Instead, the total operating cost for an ECO system should be compared with the sum of the operating costs for competitive conventional technologies required to achieve the same level of pollution control. Having done many such reviews, the ECO system is generally more economical than conventional technology, even without considering the value of the reduced PM<sub>2.5</sub> and mercury emissions.

### **Impact of Widespread ECO Adoption on the Fertilizer Market**

The economic benefits of ECO technology are dependent, in part, on the ability to market the fertilizer co-product, ammonium sulfate (AS). Powerspan and its partner, The Andersons Inc., conducted an analysis of the market for AS to understand how broad adoption of ECO could affect the long-term value of the fertilizer co-product and, hence, the annual operating costs of the system. Given the increasing demand for agronomic sulfur, the advantages of AS as a direct application fertilizer, and the price premium of AS over other nitrogen fertilizers, the analysis indicates that the U.S. fertilizer market should readily absorb AS co-product generated from ECO installations. In any foreseeable scenario, the value of the AS co-product will offset the cost of the incoming ammonia reagent as well as the operating cost of the co-product production facility. In most scenarios, the value of the AS coupled with the avoidance of landfill or disposal expenses yields a cash flow that exceeds the reagent and co-product production facility operating cost.

Powerspan's conclusions are supported by a study conducted by the Electric Power Research Institute (EPRI), which explored the market for ammonia-based fertilizers produced in power plants. Major findings of the EPRI study are: 1) Fertilizer demand is large enough to absorb AS production from ECO systems; 2) AS may continue to obtain a premium over nitrogen-based fertilizers due to growing soil deficiencies; 3) Absent increasing AS demand, AS would at least be priced equivalent to its nitrogen content; and 4) The AS price should always cover the cost of ammonia needed to produce the AS.

### **COMMERCIAL DEPLOYMENT ACTIVITIES**

With the successful completion of the 180-day performance and reliability test at the CDU, the ECO commercial demonstration is complete. Powerspan has transitioned from development and demonstration of the technology to commercial deployment. In September 2005, FirstEnergy announced plans to install a full-scale ECO system at their Bay Shore Plant Unit 4 (215-MW) in Oregon, Ohio. Design engineering will commence in the first quarter of 2006. Powerspan is also working with other generating companies to evaluate the application of ECO to their generating fleets.

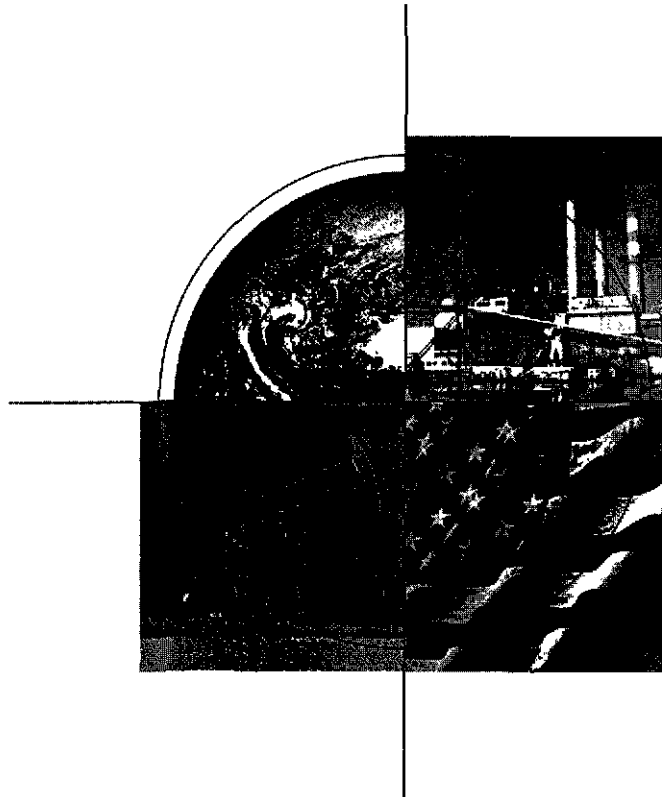
FirstEnergy's decision to move forward with a full-scale ECO system was the culmination of a detailed due diligence effort conducted by a multi-disciplinary team. In late 2004 FirstEnergy assembled a 15-member team that conducted a 10-month in-depth effort to prove ECO commercial viability. FirstEnergy also worked with the Electric Power Research Institute (EPRI) under a program to test ECO pollutant removal, audit analyzer readings, analyze the fertilizer market (summarized above), and commission the engineering firm Burns & McDonnell to conduct a reliability study. This study indicated that an ECO installation would be as reliable as conventional technology.

In addition to FirstEnergy's announcement regarding the Bay Shore Plant, FirstEnergy also announced plans in September to pilot test Powerspan's carbon dioxide (CO<sub>2</sub>) removal technology at the R.E. Burger Plant. The CO<sub>2</sub> capture process is expected to be readily

integrated with the ECO technology. Although CO<sub>2</sub> limits are not mandated by the U.S. EPA, a CO<sub>2</sub> removal process that could be cost effectively retrofitted on existing air pollution control equipment would provide generation owners with a valuable hedge against future regulatory risk.

Powerspan is developing the CO<sub>2</sub> removal process in cooperation with the U.S. Department of Energy's (DOE) National Energy Technology Laboratory. In May 2004, Powerspan and the DOE announced a cooperative research and development agreement (CRADA) to develop a cost-effective CO<sub>2</sub> removal process for coal-based power plants. The regenerative process uses an ammonia-based solution to capture CO<sub>2</sub> in flue gas and prepare it for subsequent sequestration; after regeneration the ammonia solution is recycled. The scope of the three-year CRADA includes laboratory testing, pilot testing, and detailed studies of the CO<sub>2</sub> capture process economics. The results of the pilot test at the R.E. Burger Plant will be used to confirm process design and cost estimates.

# **An Economic Scoping Study for CO<sub>2</sub> Capture Using Aqueous Ammonia**



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## **Final Report**

**Revised February 2005**

## **An Economic Scoping Study for CO<sub>2</sub> Capture Using Aqueous Ammonia**

### ***Executive Summary***

This technical and economic scoping analysis compares CO<sub>2</sub> capture from flue gas using an aqueous ammonia (AA) chemical sorbent to state-of-the art amine technology. The analysis is based on research into AA-based CO<sub>2</sub> capture conducted at NETL's Carbon Sequestration Science Focus Area. CO<sub>2</sub> capture is considered as a part of a multi-pollutant control system applied to a grass-roots coal-fired power plant.

Like amine, the AA system is a liquid chemical sorbent, but AA technology has two key advantages. First, aqueous ammonia is less expensive than amines (\$0.30/lb CO<sub>2</sub> carrying capacity versus \$3.8/lb CO<sub>2</sub>) which will lower chemical make-up costs. Second, AA has a lower heat of reaction for regenerating the chemical sorbent (262 Btu/lb CO<sub>2</sub> captured versus 825 for mono-ethanol amine). Assuming similar benefits from heat integration between the two CO<sub>2</sub> capture processes, the aqueous ammonia process is estimated to use 500 Btu of steam per lb CO<sub>2</sub> captured compared to 1,621 Btu for amines.

It is estimated that aqueous ammonia technology can reduce the heat rate of a PC power plant equipped for CO<sub>2</sub> capture from 11,896 Btu/kWh (amine capture) to 10,140 Btu/kWh. The CO<sub>2</sub> compression load is nearly the same in both cases, but the parasitic consumption of steam is 67% less in the AA case. The capital cost is reduced from \$2,231/kW to \$1,800/kW, partially due to the cascading effect of improved efficiency. AA also offers lower net cost for SO<sub>2</sub>, NO<sub>x</sub>, and mercury control that benefits the economics of a multi-pollutant system. Fertilizer by-product offers net revenue of 0.50 cents/kWh and the reduced cost for capturing mercury, negligible for AA and \$7,000/lb mercury for a carbon adsorbent system provides 0.04 cents/kWh of savings.

In a supercritical power plant with a multi-pollutant control system, aqueous ammonia has the potential to provide a net cost of CO<sub>2</sub> capture of \$14/metric ton of CO<sub>2</sub> emissions avoided (a 21% increase in COE compared to a pulverized coal power plant without CO<sub>2</sub> capture). However, in an ultra-supercritical steam cycle, aqueous ammonia has the potential to provide a net cost of CO<sub>2</sub> capture of \$13/metric ton of CO<sub>2</sub> emissions avoided with only an 18% increase in COE. The current cost of CO<sub>2</sub> capture using amines is \$47/metric ton of CO<sub>2</sub> emissions avoided (a 67% increase in COE relative to a PC power plant without CO<sub>2</sub> capture). Research challenges include accommodating the flue gas temperature of 130°F, which is hotter than optimal for aqueous ammonia capture, and minimizing ammonia loss in the absorption tower and ammonia slip out the stack.

### ***Background: Analysis Goals and Methodology***

The Carbon Sequestration Program at NETL has set the following goals for technologies developed under its CO<sub>2</sub> capture research portfolio [1]:

- Technologies for CO<sub>2</sub> capture from combustion-based steam power plants should capture at least 90% of CO<sub>2</sub> emissions while increasing the cost of electricity by no more than 20%
- Technologies for CO<sub>2</sub> capture from gasification-based systems should capture at least 90% of CO<sub>2</sub> emissions while increasing the cost of electricity by no more than 10%.

This analysis is one of several being conducted to determine the degree to which selected CO<sub>2</sub> capture technologies have the potential to achieve the program goals and to establish a framework for evaluating

progress toward the goals. The aqueous ammonia concept is being pursued within NETL's Carbon Sequestration Science Focus Area [2].

Research on aqueous ammonia use for CO<sub>2</sub> capture is at a very early stage, and a detailed system analysis at this time is not possible. Instead, an economic scoping study has been conducted to quantify the potential benefits of this technology. Our methodology is to develop a heat and material balance for a base case pulverized coal (PC) fired plant with amine-based CO<sub>2</sub> capture, using data from published studies [3, 4]. Then, the performance of the new technology is compared to that of the amine system by developing a heat and material balance and an estimate of the differences in capital and operating cost relative to the base case amine. Where possible, design heuristics (i.e. rules of thumb or guidelines from published papers) were used to estimate flows and sizes of equipment. However, some sizing and costing algorithms are employed for specific equipment such as CO<sub>2</sub> compressors and gas/liquid contact towers. For this initial assessment, a rigorous modeling of unit operations was not performed. This is an area for later work as development of the technology progresses.

Figure 1 shows the system boundary used for this analysis. In estimating the impact of CO<sub>2</sub> sequestration on the cost of electricity, the cost and energy consumption of pipeline transport for 10 miles and injection into a saline formation 1,500 ft below the surface was included. The CO<sub>2</sub> transport and storage performance/economics were based off data presented in a recent DOE/TVA study entitled, "Economic Evaluation of CO<sub>2</sub> Storage and Sink Enhancement Options" [16]. The revenue from by-products, which is an important consideration in the aqueous ammonia analysis, was also assessed and incorporated into the economics.

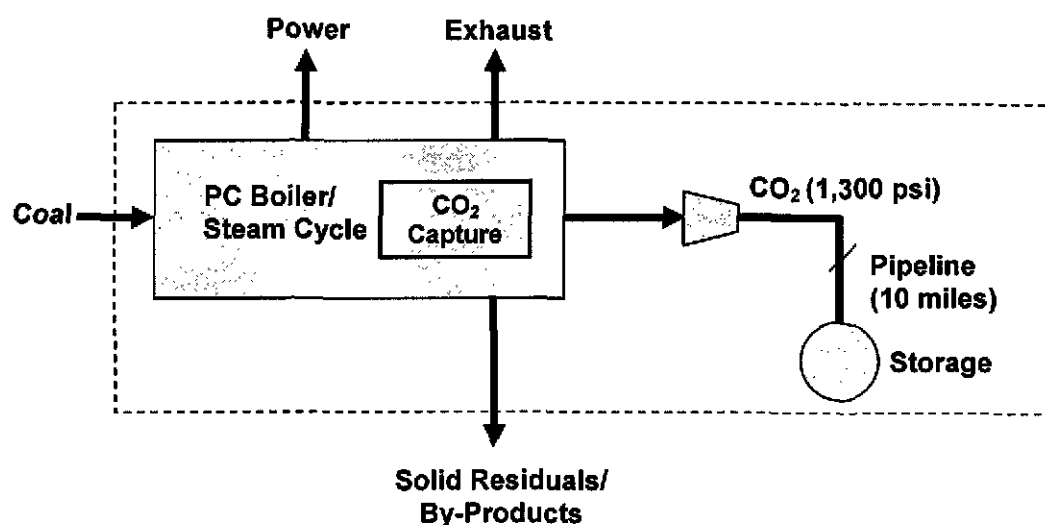


Figure 1. Analysis Boundary



### Base Case PC Plant with Amine-based CO<sub>2</sub> Capture

Aqueous ammonia capture of CO<sub>2</sub> is compared to a base case PC plant using conventional amines. A spreadsheet model was developed that is consistent with a previous DOE/EPRI study (Case 7A from [3]) extrapolated to 400 MW net power output. The DOE/EPRI study is based on a supercritical pulverized coal boiler with a net amine reboiler steam consumption of 1,621 Btu/lb of CO<sub>2</sub> captured. Figure 2 and Table 1 show outputs from the model's amine capture case. Parasitic or auxiliary load, shown as 92 MW in Figure 2, is the electric power used to operate pumps, compressors and other equipment in the power plant.

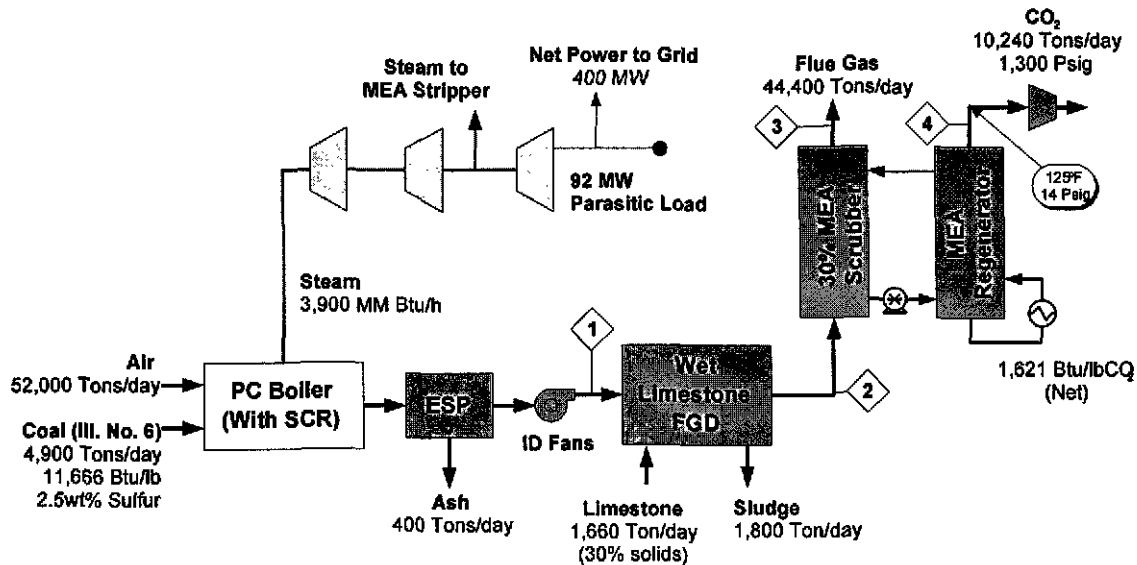
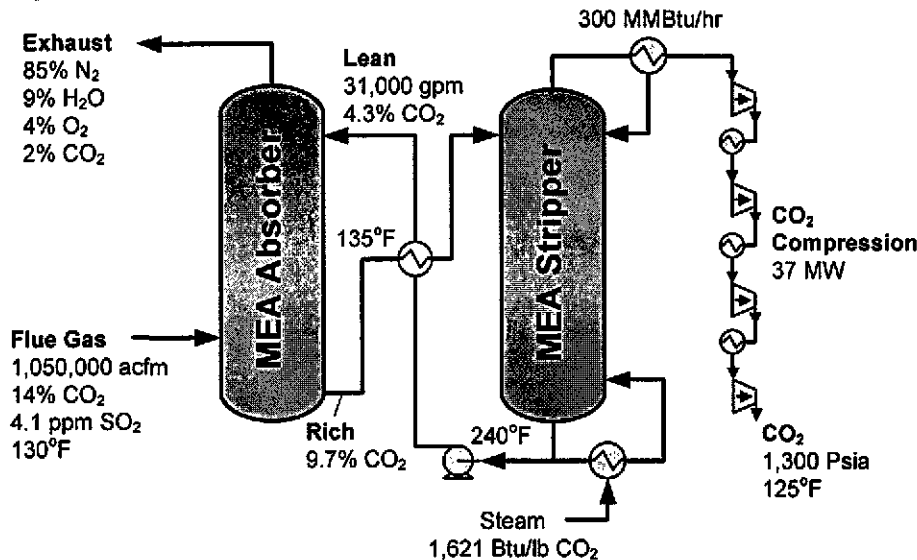


Figure 2. PC Power Plant with Amine CO<sub>2</sub> Capture (DOE/EPRI Case 7A [3])

Table 1. Selected Process Flow Rates and Compositions

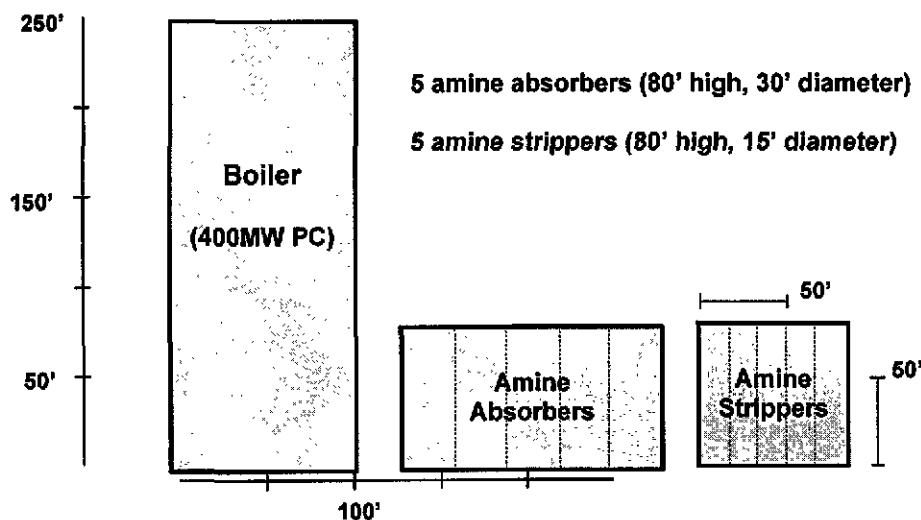
	1	2	3	4
	Boiler Effluent	Absorber Inlet	Flue gas Exhaust	CO <sub>2</sub> Product
Temperature, °F	281	131	136	125
Pressure, psia	14	17	14	1,500
Volume %	CO <sub>2</sub>	14%	12%	2%
	O <sub>2</sub>	3%	3%	4%
	N <sub>2</sub>	74%	70%	77%
	H <sub>2</sub> O	8%	14%	16%
	SO <sub>2</sub>	0.2%	4.1 ppm	0%
	Argon	1%	1%	1%
Molar flow (lbmoles/hr)	153,383	153,066	133,790	19,500
Vol. flow (10 <sup>6</sup> ACFM)	1.57	1.05	1.12	0.0011
Mass flow (tons/day)	55,346	54,602	44,424	10,240

Figure 3 presents a more detailed look at the amine capture system. The size and cost of the absorber tower are functions of the actual volumetric flow rate of flue gas (1.05 million scfm) and percent CO<sub>2</sub> removal (90%). CO<sub>2</sub> in the flue gas is reduced from 14 vol% to 2 vol%. The size and cost of the CO<sub>2</sub> stripper are primarily functions of the amine solution volumetric flow rate, which is calculated from the concentration difference between the rich amine solution (30 wt% MEA, 9.7 wt% CO<sub>2</sub>) and the lean amine solution (4.3 wt% CO<sub>2</sub>) [5, 6, 7]. The steam load for the amine stripper reboiler is large and pulls steam from the low-pressure turbine as shown in Figure 2. The reboiler provides the net sensible heat required, the heat of reaction, and the heat for stripping steam. The reported 1,621 Btu/lb of CO<sub>2</sub> is the enthalpy change in the steam across the reboiler.



**Figure 3. Amine Capture System used in the PC Base Case**

Figure 4 shows the size of the CO<sub>2</sub> capture equipment relative to the boiler. This gives a sense of the magnitude of impact that CO<sub>2</sub> capture will have on a PC power plant.



**Figure 4. Amine CO<sub>2</sub> Capture Relative Equipment Sizing**

A discounted cash flow model was developed that inputs the capital expenditures for a 400 MW PC power plant, variable operating costs including coal use and chemical makeup, fixed operating costs, and by-product revenues. Using a plant economic life of 20 years and a capital charge factor of 14.8%, a cost of electricity that balances expenditures and revenues was calculated. Table 2 shows the results from the cash flow analysis, which closely replicates the results from the DOE/EPRI study [3]. The cost of electricity goes from 4.6 cents/kWh in the no-capture case to 7.6 cents/kWh in the MEA capture case, a 67% increase.

**Table 2. Economic Results**

		No CO <sub>2</sub> Capture	MEA CO <sub>2</sub> Capture
<b>CO<sub>2</sub> Capture</b>	Base Plant (\$/kWe)	1,072	1,460
	Gas Cleanup (\$/kWe)	197	239
	CO <sub>2</sub> Capture (\$/kWe)	-	310
	Compression (\$/kWe)	-	122
	<b>Total (\$/kWe)</b>	<b>1,270</b>	<b>2,132</b>
	Capital COE (c/kWh)	2.68	4.50
	Variable COE (c/kWh)	1.90	2.91
	<b>Total COE (c/kWh)</b>	<b>4.58</b>	<b>7.41</b>
	<b>\$/tonne CO<sub>2</sub> Avoided</b>	<b>-</b>	<b>43</b>
<b>Including CO<sub>2</sub> Transportation and Storage*</b>			
<b>Total</b>	<b>Total Capital (\$/kWe)</b>	<b>1,270</b>	<b>2,231</b>
	<b>Total \$/tonne CO<sub>2</sub> Avoided</b>	<b>-</b>	<b>47</b>
	<b>Total COE (c/kWh)</b>	<b>4.58</b>	<b>7.64</b>
	<b>Increase in COE</b>	<b>-</b>	<b>67%</b>

Basis: 90% CO<sub>2</sub> Capture, 80% Capacity Factor, 2003 Dollars, Coal \$28/ton  
\*CO<sub>2</sub> Compression to 1,300 Psig, Transport 10 miles and Stored in Saline Formation 1,500 ft  
Sources: NETL Carbon Sequestration Economic Model; Evaluation of Innovative Fossil Fuel Power Plants with CO<sub>2</sub> Removal, DOE/EPRI, 1000316

The overall performance for both cases is presented in Table 3. As shown, the current state of amine CO<sub>2</sub> capture is very energy intensive requiring an additional 56.5 MW for capture and compression (an additional 1,415 ton coal/day and approximately 30% decrease in efficiency).

**Table 3. Power Plant Performance**

		No CO <sub>2</sub> Capture	MEA CO <sub>2</sub> Capture
<b>Auxiliary Load (MWe)</b>	<b>Total Gross Power (MWe)</b>	<b>425</b>	<b>492</b>
	Base Plant	22.1	28.1
	CO <sub>2</sub> Capture	-	21.3
	CO <sub>2</sub> Compression	-	35.2
	NO <sub>x</sub> and SO <sub>x</sub>	3.1	4.2
	Transport & Storage	-	2.7
	<b>Total</b>	<b>25</b>	<b>92</b>
<b>Net Power</b>		<b>400</b>	<b>400</b>
<b>Coal Flowrate (ton/day)</b>		<b>3,480</b>	<b>4,895</b>
<b>Net Heat Rate (Btu/kWh, HHV)</b>		<b>8,453</b>	<b>11,896</b>
<b>Efficiency</b>		<b>40%</b>	<b>29%</b>
<b>Energy Penalty</b>		<b>-</b>	<b>29%</b>

Energy Penalty: Percent decrease in power plant efficiency due to CO<sub>2</sub> capture

### PC with Aqueous Ammonia CO<sub>2</sub> Capture

AA is used in commercial applications to capture SO<sub>2</sub> from power plant flue gas. Marsulex and Alstom Power both offer commercial processes for SO<sub>2</sub> removal using ammonia. Powerspan Corp. recently conducted a commercial-scale demonstration of an AA-based multi-pollutant control technology called "ECO™" for scrubbing SO<sub>2</sub>, NO<sub>x</sub>, and mercury from flue gas.

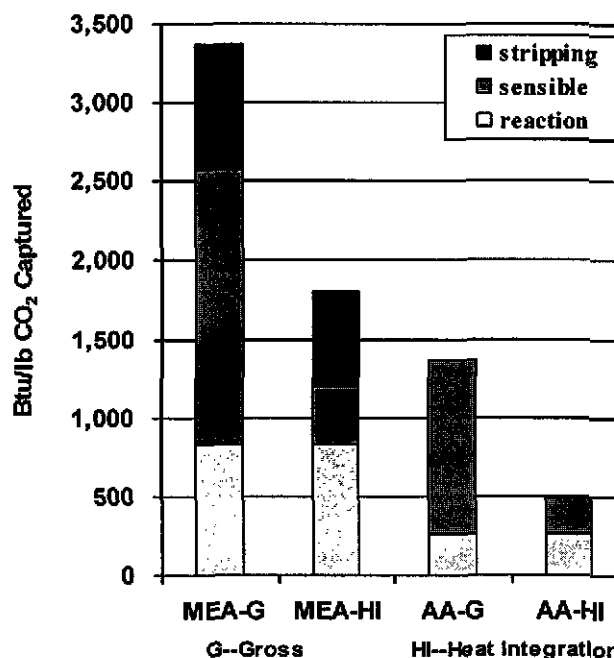
The following advantages of the aqueous ammonia process compared to conventional amines have been identified: (1) reduced steam load, (2) more concentrated CO<sub>2</sub> carrier, (3) lower chemical cost, and (4) multi-pollutant control with salable by-products. The impact of each is discussed below.

1) *Reduced steam load.* In a system that captures and releases CO<sub>2</sub> by cycling between carbonate and bicarbonate, the heat of reaction is reduced to 262 Btu/lb CO<sub>2</sub>, which is much less than the 825 Btu/lb CO<sub>2</sub> needed with MEA [Appendix A]. Also, it is possible that the carbonate/bicarbonate system will exhibit a higher CO<sub>2</sub> carrying density than MEA (carrying density is the delta in CO<sub>2</sub> weight percent between rich and lean solutions), reducing sensible heat requirements. Finally, it is possible the carbonate/bicarbonate system may require little or no stripping steam for regeneration, compared to one mole steam per mole of CO<sub>2</sub> captured typical of amine systems. Figure 5 compares the heat requirements for an MEA CO<sub>2</sub> capture system versus one using aqueous ammonia. The total heat requirement is divided into heat of reaction, sensible heat, and stripping steam. Figure 5 shows that heat integration enables significant reduction in the net heat requirement for the amine system. The gross heat requirement for an aqueous ammonia system was calculated, and heat integration savings similar in magnitude to those achieved by the amine were assumed. For example, the gross turbine heat rate for the MEA-HI CO<sub>2</sub> capture is estimated to be 9,672 Btu/kWh, and for the AA-HI CO<sub>2</sub> capture the estimate is 8,482 Btu/kWh, a 12% improvement in gross turbine heat rate.

2) *More concentrated CO<sub>2</sub> carrier.* In addition to affecting sensible heat, the CO<sub>2</sub> carrying density also affects the size of the CO<sub>2</sub> absorber and the circulation pump size and load. Laboratory data from NETL indicate the carbonate/bicarbonate system could exhibit a carrying capacity of 0.068 lb CO<sub>2</sub> per lb solution versus 0.054 for amines. Based on cost and sizing heuristics, the reduced liquid flow lowers the stripper cost from \$36.4 to \$25.2 million (four strippers in parallel vs. five) and reduces the circulation pump power requirement from 1.8 to 1.2 MW.

3) *Lower chemical cost.* Amine costs are estimated to be \$1,360/ton (\$1.5/kg), which is high compared to anhydrous ammonia at \$263/ton (\$0.29/kg). The calculations below show that ammonia is roughly a factor of ten less expensive per unit of CO<sub>2</sub> absorption capacity.

Figure 5. Heat Requirements for CO<sub>2</sub> Capture



#### Mono-ethanolamine Cost:

$$\left( \frac{\$0.6803}{\text{lbMEA}} \right) \times \left( \frac{0.3 \text{ lbMEA}}{\text{lbSolution}} \right) \times \left( \frac{\text{lbSolution}}{0.054 \text{ lbCO}_2} \right) = \frac{\$3.78}{\text{lbCO}_2}$$

#### Aqueous Ammonia Cost:

$$\left( \frac{\$0.1315}{\text{lbNH}_3} \right) \times \left( \frac{0.15 \text{ lbNH}_3}{\text{lbSolution}} \right) \times \left( \frac{\text{lbSolution}}{0.068 \text{ CO}_2} \right) = \frac{\$0.29}{\text{lbCO}_2}$$

The cost of the absorbent is particularly important for coal-fired power plant applications, where residual SO<sub>2</sub>, SO<sub>3</sub>, and other species cause solvent degradation. For amines, the attrition was estimated from the following heuristics: general loss of 3.2 lb MEA/ton CO<sub>2</sub> (1.6 kg MEA/tonne CO<sub>2</sub>), and SO<sub>x</sub> loss of 2 mole MEA/mole SO<sub>x</sub> in absorber inlet [7]. Based on normal limestone scrubber operation removal (98%), amine make-up costs could be \$60/ton CO<sub>2</sub> captured. A \$7.5/CO<sub>2</sub> was assumed for aggressive limestone scrubbing (4.1 ppm SO<sub>2</sub> in the effluent), recognizing that flue gas treatment options to reduce SO<sub>x</sub> upstream from the CO<sub>2</sub> absorber may be cost effective. A detailed analysis to accurately estimate ammonia attrition has not been performed. Instead, it was assumed that it will be similar on a molar basis to amine and that the total cost will be less because of the lower cost of ammonia. Furthermore, the reaction by-products can be sold as fertilizer, so there is no ammonia penalty for their production; however, there are expected to be small ammonia losses in the exhaust gas.

4) *Value-added by-products.* The use of ammonia-based systems to react NO<sub>x</sub> and SO<sub>x</sub> in flue gas to form fertilizer (ammonia sulfate, (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and ammonia nitrate, NH<sub>4</sub>NO<sub>3</sub>) has been demonstrated at commercial scale. A comparison of an amine system plus an SCR (Selective Catalytic Reduction) unit and limestone scrubber to an aqueous ammonia system in which ammonia is used for NO<sub>x</sub>, SO<sub>x</sub>, and CO<sub>2</sub> control was made. Table 4 compares the aqueous ammonia process to a limestone scrubber. It has advantages if there is a market for the byproduct fertilizer, which is primarily ammonium sulfate (AS). The domestic market for ammonium sulfate is roughly 2 million tons/yr [8]. One 400 MW coal-fired power plant with AA SO<sub>2</sub> control will produce about 100,000 tons AS per year. Therefore, twenty power plants could supply all the AS currently used by the domestic market. However, as domestic SO<sub>2</sub> emissions have been reduced, the need for additional sulfur fertilizer has grown, and this trend is likely to continue. The domestic and international markets for nitrogen fertilizers are 12 and 83 million tons per year [9] respectively, so the worldwide potential for the aqueous ammonia fertilizer byproduct is significant. Also, at the right price, ammonium sulfate could displace urea or other forms of nitrogen fertilizer.

**Table 4: Aqueous Ammonia versus Limestone Scrubbers for SO<sub>x</sub> Control**

	<b>Limestone Scrubber</b>	<b>Aqueous Ammonia</b>
<b>Parasitic Load (MWe)</b>	<b>4-7</b>	<b>4-7</b>
<b>Reactant Consumption (\$/ton SO<sub>2</sub>)</b>	<b>22</b>	<b>136</b>
<b>By-Product Revenue (\$/ton SO<sub>2</sub>)</b>	<b>0</b>	<b>314</b>
<b>Net Material Revenue (\$/ton SO<sub>2</sub>)</b>	<b>-22</b>	<b>178</b>
Basis: Limestone at \$13/ton [3, 10], Anhydrous ammonia \$255/ton [12], no market for FGD sludge, Ammonia sulfate at \$152/ton [12]		

Capturing NO<sub>x</sub> is more difficult than capturing SO<sub>2</sub>. In order for aqueous ammonia to react with NO<sub>x</sub>, NO, which is 95% of the NO<sub>x</sub>, must be oxidized to NO<sub>2</sub>. This requires another unit operation or use of an oxidant, such as ozone. The NO oxidation process represents a significant cost. However, when NO is oxidized, some elemental Hg in the flue gas will also be oxidized, enabling it to be captured in the aqueous ammonia solution and removed from the flue gas. The aqueous solution containing mercury, ammonium nitrate and ammonium sulfate would be run through a carbon adsorbent bed to remove the mercury so that it does not contaminate the fertilizer. The current cost estimate for carbon-based mercury capture in flue gas is estimated at between \$50,000 and \$70,000/pound [14]. This analysis assumes that mercury control will be required and that there is a 10 percent increase in removal efficiency with the ECO<sup>TM</sup> process compared to conventional technology. Therefore, a credit of \$7,000/lb Hg removed was allocated to the aqueous ammonia process.

Table 5 shows the relative operating cost impact of the by-products. The first thing to note is that the flow rate of CO<sub>2</sub> is very large compared to the other species. Even if revenues from one of the by-products is high on a per pound basis, it is low on a per ton of CO<sub>2</sub> captured basis. At this time, the value of the avoided cost of mercury control is highly uncertain.

**Table 5: By-product Flows and Revenues for Multi-Pollutant Control Using Aqueous Ammonia**

	Production Rate (lb/kWh)	Value (\$/ton)	Feedstock Cost (\$/ton)	Operating Revenue (\$/ton)	Operating Revenue (cents/kWh)	Revenue (\$/ton CO <sub>2</sub> captured)
Ammonium Nitrate	0.0016	175	90	85	0.009	0.10
Ammonium Sulfate	0.091	152	66	86	0.493	5.3
Mercury	5.9E-8	14E+6	0	14E+6	0.038	.45
Carbon Dioxide	1.70	--	--	--	--	--

Basis: 80% Capacity Factor

#### *Aqueous Ammonia Multi-pollutant Capture System*

Figure 6 shows outputs from the spreadsheet model for the aqueous ammonia multi-pollutant capture case. This analysis assumes NO<sub>x</sub> and elemental mercury are oxidized by the reactor in the ECO<sup>TM</sup> system after exiting the particulate filter [14]. The flue gas is contacted with aqueous ammonia to form ammonia nitrate, ammonia sulfate, and a non-gaseous mercury specie. The solution is then passed through an activated carbon bed for mercury removal before passing to a crystallizer and granulator for solid fertilizer production. CO<sub>2</sub> is removed from the flue gas in an ammonia scrubber, and then compressed to 1,300 psi for injection.

The boiler island and power cycle shown in Figure 6 are those of a supercritical steam cycle system, modeled from Cases 7A and 7C presented in a recent DOE /EPRI study [3]. The gross turbine heat rate using MEA to capture CO<sub>2</sub> (Case 7A) is 9,672 Btu/kWh compared to 7,951 Btu/kWh for the no capture case (7C). The 1,721 Btu/kWh increase in turbine heat rate is attributed to steam used for MEA regeneration. Due to less regeneration steam required for AA regeneration, the gross turbine heat rate was estimated to be 8,482 Btu/kWh (12% lower than the MEA case). An analysis using AA on an ultra-supercritical steam cycle (USC) was also carried out using Cases 7B and 7D of reference [3]. The USC cycle efficiency combined with a lower steam requirement for AA regeneration (compared to MEA)

The diagram illustrates a chemical process for producing Ammonium Nitrate and Ammonium Sulfate. The process begins with the input of Air (43,700 Tons/day) and Coal (III. No. 6) (4,200 Tons/day, 11,666 Btu/lb, 2.5wt% Sulfur) into a PC Boiler. The PC Boiler produces Steam (3,900 MM Btu/h) which is used in an Ammonia Stripper. The Ammonia Stripper also receives Net Power to Grid (400 MW) and 82 MW Parasitic Load. The Ammonia Stripper outputs Steam to Ammonia Scrubber. The Ammonia Scrubber outputs Flue Gas (38,000 Tons/day) and Ammonia Gas (8,780 Tons/day, 1,500 Psig). The Ammonia Gas is then processed by an Ammonia Regenerator, which outputs Steam (125°F, 14 Psig) and Ammonia Gas (8,780 Tons/day, 1,500 Psig). The Ammonia Gas is then processed by an Ammonia Contactor, which outputs Ammonia Gas (8,780 Tons/day, 1,500 Psig) and Ammonia Gas (8,780 Tons/day, 1,500 Psig). The Ammonia Gas is then processed by an Activated Carbon unit, which outputs Mercury (0.45 lbs/day) and Ammonia Gas (8,780 Tons/day, 1,500 Psig). The Ammonia Gas is then processed by a Crystallizer, which outputs Ammonium Nitrate (443 Tons/day) and Ammonium Sulfate (443 Tons/day). The Ammonium Nitrate and Ammonium Sulfate are then processed by a Granulator, which outputs Ammonium Nitrate (443 Tons/day) and Ammonium Sulfate (443 Tons/day). The Ammonium Nitrate and Ammonium Sulfate are then processed by a Dryer, which outputs Ammonium Nitrate (443 Tons/day) and Ammonium Sulfate (443 Tons/day).

**Base Plant:**  
H Supercritical Steam Cycle  
H Case 7C of Reference [3] with  
steam rate adjusted for AA

**Table 6. Power Plant Performance**10

## Results

The overall performance for the supercritical and ultra-supercritical cases is presented in Table 6. As shown, the current state (Case 2) of amine CO<sub>2</sub> capture is very energy intensive, requiring 57 MW for capture and compression (an additional 1,415 ton coal/day and approximately 30% decrease in efficiency). The benefits of higher CO<sub>2</sub> capacity and lower heat of reaction (compared to MEA) using aqueous ammonia results in a 15% decrease in parasitic load (from 92MW to 78MW) and 15% decrease in net power plant heat rate for Case 3. The same proportional amount of energy savings is also obtained in the ultra-supercritical cases (5 and 6) with the use of aqueous ammonia.

Table 7 presents the results of a cash flow analysis of the no-CO<sub>2</sub>-capture, amine, and aqueous ammonia cases. Capturing only CO<sub>2</sub> using aqueous ammonia (Cases 3 and 5) has potential advantages over the amine case, but the multi-pollutant system with revenue from the sale of fertilizer is needed for aqueous ammonia to approach the NETL program goal of only a 20% increase in COE.

**Table 7. Economic Results**

Case		1	2	3	4	5	6
Sorbent		None	MEA	AA	AA	AA (USC) <sup>1</sup>	AA (USC) <sup>1</sup>
Component(s) Removed		None	CO <sub>2</sub>	CO <sub>2</sub>	CO <sub>2</sub> , SO <sub>x</sub> , NO <sub>x</sub> , Hg	CO <sub>2</sub>	CO <sub>2</sub> , SO <sub>x</sub> , NO <sub>x</sub> , Hg
CO <sub>2</sub> Capture	Base Plant (\$/kWe)	1,072	1,460	1,218	1,225	1,157	1,164
	Gas Cleanup (\$/kWe)	197	239	288	215	277	215
	CO <sub>2</sub> Capture (\$/kWe)	-	310	187	188	178	179
	Compression (\$/kWe)	-	122	108	108	103	103
	Total (\$/kWe)	1,270	2,132	1,801	1,736	1,715	1,661
	Capital COE (c/kWh)	2.68	4.50	3.80	3.66	3.62	3.51
	Variable COE (c/kWh)	1.90	2.91	2.36	1.67	2.24	1.73
	Total COE (c/kWh)	4.58	7.41	6.16	5.34	5.86	5.24
	\$/tonne CO <sub>2</sub> Avoided	-	43	23	11	20	10
Including CO <sub>2</sub> Transportation and Storage <sup>2</sup>							
Total	Total Capital (\$/kWe)	1,270	2,231	1,890	1,824	1,800	1,746
	Total \$/tonne CO <sub>2</sub> Avoided	-	47	27	14	23	13
	Total COE (c/kWh)	4.6	7.6	6.4	5.5	6.1	5.4
	Increase in COE	-	67%	39%	21%	32% <sup>1</sup>	18% <sup>1</sup>

Basis: 90% CO<sub>2</sub> Capture, 80% Capacity Factor, 2003 Dollars, Coal \$28/ton  
<sup>1</sup>USC—Ultra-Supercritical Steam Cycle  
<sup>2</sup>CO<sub>2</sub> Compression to 1,300 Psig, Transport 10 miles and Stored in Saline Formation 1,500 ft  
Sources: NETL Carbon Sequestration Economic Model; Evaluation of Innovative Fossil Fuel Power Plants with CO<sub>2</sub> Removal, DOE/EPRI, 1000316

The cost of the multi-pollutant gas cleanup system (NO<sub>x</sub> and SO<sub>2</sub> to fertilizer) estimated for Cases 4 and 6 are lower than conventional NO<sub>x</sub> and SO<sub>2</sub> controls (SCR and Wet Limestone FGD). However, to reach the DOE's program goal of 20% increase in COE, the operating revenue from the sale of the ammonium sulfate/nitrate fertilizer is necessary; decreasing the current CO<sub>2</sub> capture COE from 67% (amine scrubbing) to 21%. The cost associated with CO<sub>2</sub> transport and storage increases the CO<sub>2</sub> avoided cost by \$3/tonne and COE by 4-6 percent.



Figure 8 shows the breakdown of the parasitic load for each case. The results show that since CO<sub>2</sub> is produced from a low pressure system, the largest power requirement is for CO<sub>2</sub> compression. Therefore, any technology that has the potential to recover CO<sub>2</sub> at a higher pressure will have a large impact on the overall efficiency and cost of electricity.

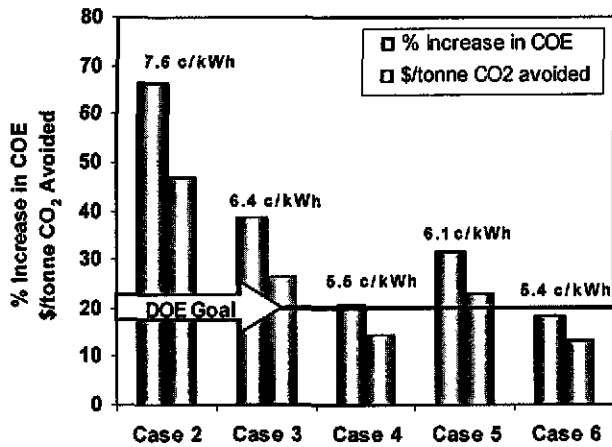


Figure 7. Economic Results

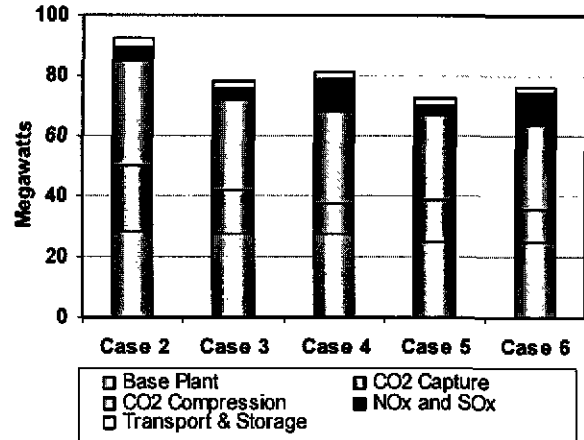


Figure 8. Auxiliary Power

### Recommendations for Future Work

This initial analysis shows that aqueous ammonia technology has the potential to achieve the goals of NETL's Carbon Sequestration Program, but challenges remain. The temperature of the flue gas is hotter than is optimal for carbonate/bicarbonate absorption. Researchers are investigating options to accommodate this higher temperature. Also, ammonia may vaporize in the absorption tower, due both to high temperatures and operational transients. Ammonia loss would hurt the economics directly and may require costly tail gas control. Laboratory-scale testing and more rigorous process analyses and modeling to address these issues is recommended.

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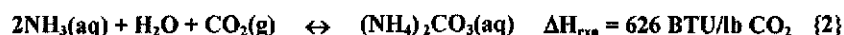
## Appendix A.

### I. Assumptions

Financial structure	
Capital Cost Year Dollars	2001
Project Book Life (n)	20 (years)
Projected Tax Life	20 (years)
Design/Construction	2.5 (years)
Inflation rate (e <sub>i</sub> )	3.0 (%)
Real Escalation Rate (e <sub>r</sub> )	0.7 (%)
Real Escalation Rate (O & M)	0.0 (%)
Federal Tax Rate	34.0 (%)
State Tax Rate	4.2 (%)
Federal & State Tax Rate	38.2 (%)
Investment Tax Credit	0 (%)
Property Tax Rate	1 (%)
Insurance Tax Rate	1 (%)
Initial Tax Depreciation Rate	0.075 (%)

Capital Structure					
	% of Total	Current Dollar		Constant Dollar	
		Cost (%)	Return (%)	Cost (%)	Return (%)
Debt	45	9.0	4.1	5.8	2.6
Preferred Stock	10	8.5	0.9	5.3	0.5
Common Stock	45	12.0	5.4	8.7	3.9
Discount rate (cost of capital)		Before Tax		7.09	
		After Tax		6.09	

### II. Chemistry of CO<sub>2</sub> Capture with Aqueous Ammonia



### III. Solvent Steam Load Requirements

$$\text{Total}_{\text{regen energy}} = Q_{\text{sensible}} + Q_{\text{reaction}} + Q_{\text{strip}}$$

#### Q sensible

MEA: 1,750 Btu/lb CO<sub>2</sub> vs. AA: 1,100 Btu/lb CO<sub>2</sub>

#### Q reaction

MEA: 825 Btu/lb CO<sub>2</sub> captured vs. AA: 262 Btu/lb CO<sub>2</sub> (via Rxn #3)

#### Q stripping

MEA: 800 Btu/lb CO<sub>2</sub> (1 mole steam/mole CO<sub>2</sub>) vs. AA: assume no stripping steam required

Case 1 (SC)		Case 2 (SC)		Case 3 (SC)		Case 4 (SC)		Case 5 (USC)		
No CO2 Capture		Amine Scrubbing		Aminetia CO2		Aminetia CO2		Aminetia CO2		
NETL		NETL		NETL		NETL		NETL		
Source	0 % CO2	0 % CO2	0 % CO2	0 % CO2	0 % CO2	0 % CO2	0 % CO2	0 % CO2	0 % CO2	
Emissions(C) Captured	No CO2 Capture	Amine Scrubbing	Aminetia CO2	Aminetia CO2	Aminetia CO2	Aminetia CO2	Aminetia CO2	Aminetia CO2	Aminetia CO2	
Capital Cost (\$MM)	400	400	400	400	400	400	400	400	400	
Net Power (MW)	426	426	426	426	426	426	426	426	426	
Gross Power (MW)	426	426	426	426	426	426	426	426	426	
<b>Power Plant CO2 Capture</b>										
Base Plant (\$MM)	1,013	79.8 % of Tot.	1,360	64.8 % of Tot.	1,218	67.8 % of Tot.	1,225	70.6 % of Tot.	1,191	67.5 % of Tot.
Gas Cleanup (\$MM)	257	20.2 % of Tot.	316	14.9 % of Tot.	288	16 % of Tot.	215	12.4 % of Tot.	271	16.2 % of Tot.
CO2 Capture (\$MM)	0	0 % of Tot.	310	14.8 % of Tot.	187	10.4 % of Tot.	188	10.4 % of Tot.	178	10.4 % of Tot.
Compression & Drying (\$MM)	0	0 % of Tot.	122	5.7 % of Tot.	106	6 % of Tot.	103	6 % of Tot.	103	6 % of Tot.
Total Plant Capital Cost (\$MM)	1,271	N/A	2,130	68 % Increase	1,801	42 % Increase	1,726	37 % Increase	1,681	27 % Increase
Capital COE (¢/kWh)	2.68	N/A	4.50	68 % Increase	3.80	42 % Increase	3.66	37 % Increase	3.52	27 % Increase
Variable Cost (¢/kWh)	1.80	N/A	2.91	61 % Increase	2.36	34 % Increase	2.36	16 % Increase	2.34	15 % Increase
Total Capital Cost COE (¢/kWh)	4.48	N/A	7.40	61 % Increase	6.16	34 % Increase	5.94	16 % Increase	5.86	14 % Increase
Stonne CO2 Avoided	N/A	N/A	42.8 (115.6 tonnesC)	92 % of Tot.	23.4 (66 tonnesC)	68 % of Tot.	11.2 (41 tonnesC)	78 % of Tot.	19.8 (72.5 tonnesC)	88 % of Tot.
<b>CO2 Pipeline Transportation</b>										
Equipment (\$MM)	0.0	N/A	15.1	13.3 %	13.3	13.3 %	13.3	13.3 %	13.2	13.2 %
Equipment COE (¢/kWh)	N/A	N/A	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Variable COE (¢/kWh)	N/A	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Transportation COE (¢/kWh)	0.00	N/A	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Stonne CO2 Avoided	N/A	N/A	0.5 (2 tonnes C)	1 % of Tot.	0.5 (1.7 tonnes C)	2 % of Tot.	0.5 (1.7 tonnes C)	3 % of Tot.	0.5 (1.7 tonnes C)	2 % of Tot.
<b>CO2 Underground Storage</b>										
Storage Type	N/A	N/A	Saline Aquifer	Saline Aquifer	Saline Aquifer	Saline Aquifer	Saline Aquifer	Saline Aquifer	Saline Aquifer	
Equipment Cost (\$MM)	0.0	N/A	8.8	7.8 %	7.8	7.8 %	7.8	7.8 %	7.8	7.8 %
Equipment COE (¢/kWh)	0.00	N/A	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Variable COE (¢/kWh)	0.00	N/A	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Total Storage COE (¢/kWh)	0.00	N/A	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Stonne CO2 Avoided	N/A	N/A	3.2 (11.8 tonnes C)	7 % of Tot.	2.7 (10.1 tonnes C)	10 % of Tot.	2.6 (10.1 tonnes C)	19 % of Tot.	2.6 (9.7 tonnes C)	12 % of Tot.
<b>Carbon Sequestration Summary</b>										
Total COE (¢/kWh) (Case 1) (SC)	4.59	N/A	7.69	67 % Increase	6.36	39 % Increase	5.94	21 % Increase	5.86	22 % Increase
Total Capital Cost (\$MM)	1,271	N/A	2,228	75 % Increase	1,889	49 % Increase	1,824	44 % Increase	1,801	38 % Increase
Total COE (\$/MMBtu)	0.00	N/A	46.70	171.4 % Increase	26.66	87.8 % Increase	14.40	62.8 % Increase	22.87	83.9 % Increase
CO2 Emissions (kg/kWh)	0.764	0.208 kg/kWh	0.108	0.028 kg/kWh	0.022	0.028 kg/kWh	0.022	0.028 kg/kWh	0.066	0.028 kg/kWh
Efficiency (kWh/kWh)	40 %	40 %	39 %	39 %	39 %	39 %	39 %	39 %	39 %	39 %
Heat Rate (\$/MMBtu)	8.453	N/A	11.858	10.138 %	10.138	10.138 %	10.138	10.138 %	9.468	9.468 %
Energy Penalty (%)	N/A	N/A	28.94	16.6 %	17.24	16.6 %				



## **Advanced Ammonia Scrubbing for SO<sub>2</sub> Control**

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# **Advanced Ammonia Scrubbing for SO<sub>2</sub> Control**

**Paper #135**

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## **ABSTRACT**

Powerspan Corp.'s Electro-Catalytic Oxidation, or ECO<sup>®</sup>, technology incorporates an advanced ammonia scrubber in a multi-pollutant control system. In applications where additional nitrogen oxide (NOx) removal is not required, the ECO technology can be installed without the NOx control component. The resultant scrubber installation achieves major reductions in emissions of sulfur dioxide (SO<sub>2</sub>), fine particulate matter (PM<sub>2.5</sub>), and oxidized mercury (Hg). Powerspan's 50-MW ECO commercial demonstration unit at FirstEnergy's R.E. Burger Plant near Shadyside, Ohio, has been operated without the NOx removal component activated to demonstrate the advanced ammonia scrubbing for SO<sub>2</sub> control.

Ammonia has been used as a reagent in other SO<sub>2</sub> scrubber designs. However, the ECO ammonia scrubbing process has some fundamental differences that result in improved performance and reduced cost. The process generates the same ammonium sulfate fertilizer co-product that is generated by the full multi-pollutant ECO system. At a time when landfill options are becoming more expensive and the value of sulfur in fertilizer is increasing, economics may favor the production of ammonium sulfate fertilizer over gypsum.

This paper describes Powerspan's advanced ammonia scrubbing process, including the operating experience at the 50 MW ECO commercial demonstration unit. Performance and cost estimates are also included.

## **INTRODUCTION**

Coal-fired electric power generation plants are the cornerstone of America's power system, accounting for over 300,000 megawatts of generating capacity and producing approximately 51 percent of the nation's electricity. Worldwide, coal is also the leading fuel used for generating electricity, accounting for over 40 percent of the world's electricity production. While coal is the least expensive and most abundant fuel source for power generation, the formation of NOx, SO<sub>2</sub>, particulate matter, and Hg as combustion byproducts is of concern for public health and the environment.

Both existing and new standards will require additional control of SO<sub>2</sub> emissions, necessitating further installation of control equipment. Calcium-based flue gas desulfurization (FGD) systems are the most common form of such control equipment. However, with the increasing supply of

synthetic gypsum, the opportunity for beneficial re-use of the material is declining at the same time the regulatory requirements and cost for landfilling options are increasing.

Ammonia scrubbing is an alternative to calcium based systems and produces an ammonium sulfate fertilizer. Ammonia scrubbing is an existing technology that has not seen widespread use in the power generating industry. The pH range of ammonia scrubbing, typically between four and six, has been a compromise between two competing factors. On the one hand, ammonium sulfate solution is capable of absorbing SO<sub>2</sub> more rapidly when pH is higher. More rapid absorption of SO<sub>2</sub> results in reducing the size of the scrubber tower and reducing the required liquid to gas (L/G) ratio, saving both capital and operating cost. On the other hand, higher pH levels are also associated with the release of free ammonia. In addition to the economic loss due to lost ammonia, there are performance and regulatory issues associated with ammonia slip.

Advanced ammonia scrubbing technology incorporates a number of technical changes in the process, which address these concerns, and improves the system's performance and cost-effectiveness. Consequently, advanced ammonia scrubbing can be a cost-efficient SO<sub>2</sub> control technology for many applications.

Powerspan's ECO multi-pollutant control system uses advanced ammonia scrubbing principles to remove NO<sub>x</sub>, SO<sub>2</sub>, fine particulate matter, Hg, and many Hazardous Air Pollutants (HAPs)<sup>1</sup>. With some modification, advanced ammonia scrubbing can be used without the NO<sub>x</sub> removal component, providing a standalone SO<sub>2</sub> removal process. Powerspan's 50 MW Commercial Demonstration Unit (CDU) at FirstEnergy's R.E. Burger Plant in Ohio has been successfully operated in the advanced ammonia scrubbing mode without the NO<sub>x</sub> removal component active. The system achieves high removal rates for SO<sub>2</sub>, Hg, fine particulate matter, and HAPs (e.g. HCl and HF).

Because fluid, electrical, and control systems are similar between the ECO multi-pollutant system and the advanced ammonia scrubbing system, the CDU's six-month continuous, performance test in multi-pollutant mode also provides representative operating experience for advanced ammonia scrubbing.

## **TECHNOLOGY OVERVIEW**

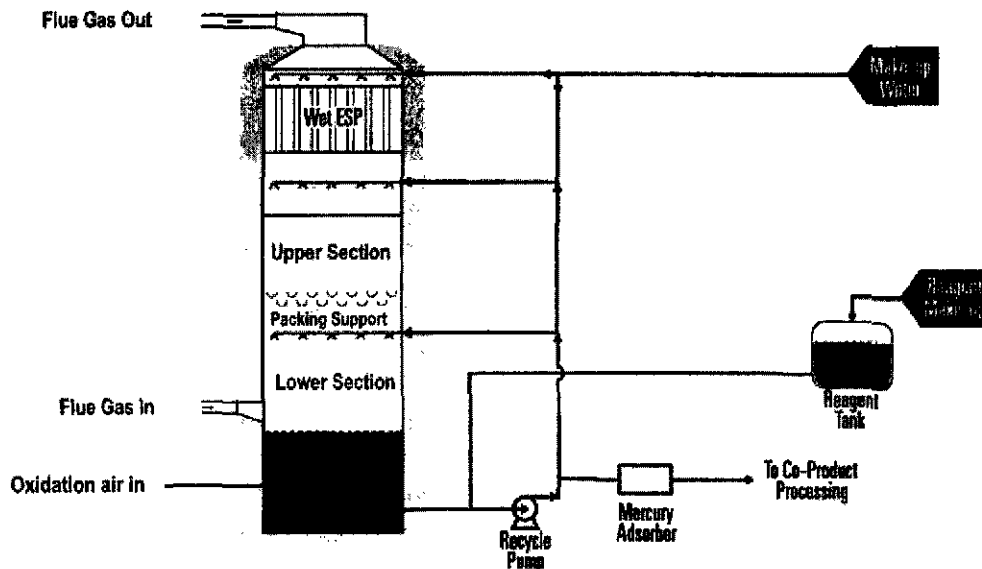
Use of ammonia as an SO<sub>2</sub> scrubbing agent is not new. Advancements to ammonia scrubbing were developed in conjunction with Powerspan's ECO multi-pollutant process. The advanced SO<sub>2</sub> scrubbing process can be used without the NO<sub>x</sub> oxidation and removal component. Efficiencies and benefits of the advanced scrubbing process are maintained even without the NO<sub>x</sub> removal.

### **Process**

Powerspan's advanced ammonia scrubbing technology utilizes an absorber tower. As shown in the process flow diagram, Figure 1, the absorber tower consists of a saturation section, an absorption section, and a wet electrostatic precipitator (WESP).



Figure 1: Advanced Ammonia Process Flow Diagram



The saturation (lower) section uses spray nozzles to distribute droplets of ammonium sulfate liquor into the flue gas stream as it enters the tower. This serves two purposes. The droplets of ammonium sulfate solution evaporate as they contact the hot flue gas stream, cooling the flue gas to saturation. At the same time, the evaporation concentrates the ammonium sulfate fertilizer produced, minimizing the energy requirements for crystallization of the fertilizer product.

The absorption (upper) section is a mass transfer section, which is used to create gas-liquid contact between the flue gas and the ammonia scrubbing solution. Sulfur dioxide chemistry in the advanced ammonia system is similar to calcium systems in that, as shown in equation (1), the absorption of  $\text{SO}_2$  leads to the creation of sulfite.



Once formed, the sulfite is oxidized by injecting air into the scrubbing solution of the tower using a system with similar design parameters to those currently used in limestone forced oxidations (LSFO) systems. This reaction is shown in equation (2).



The solution operates at a pH of 4 – 6 with higher pH increasing the rate of absorption of  $\text{SO}_2$  and decreasing the oxidation requirements to achieve >98%  $\text{SO}_2$  removal. However, the operating pH is maintained below the point where ammonia vapor can be released from the solution into the flue gas. The combination of absorbing the  $\text{SO}_2$  at high pH and oxidizing the resultant sulfite enhance the efficiency of the absorber and minimize the mass transfer

requirements. In addition, the liquid used for the saturation and the absorbing steps comes from the same source, minimizing the requirements for equipment.

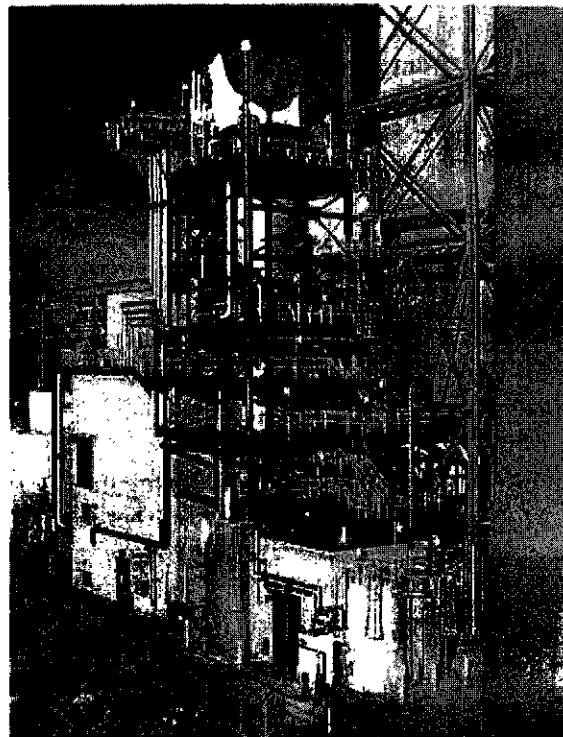
To allow the scrubber to operate at the most efficient scrubbing pH, a WESP is used to capture ammonium bisulfate aerosols created by the use of ammonia-based scrubbing at high pH. In addition to aerosol capture, the WESP also captures fine particulate matter not captured by the plant's particulate collection device. Mercury capture as a co-benefit in advanced ammonia scrubbing is similar to that of limestone scrubbing with oxidized Hg efficiently captured in the scrubbing solution. The total mercury removal in advanced ammonia scrubbing is enhanced by the WESP.

### **Commercial Demonstration Testing & Results**

Powerspan has been operating a 50-MW ECO Commercial Demonstration Unit (CDU) at FirstEnergy's R.E. Burger Plant near Shadyside, Ohio, since February 2004. The technology has proven effective in reducing NO<sub>x</sub>, SO<sub>2</sub>, mercury, acid gases, and fine particulate matter. Fertilizer produced by the process has been sold commercially. In September 2005, Powerspan successfully completed a 180-day continuous performance test at the CDU.

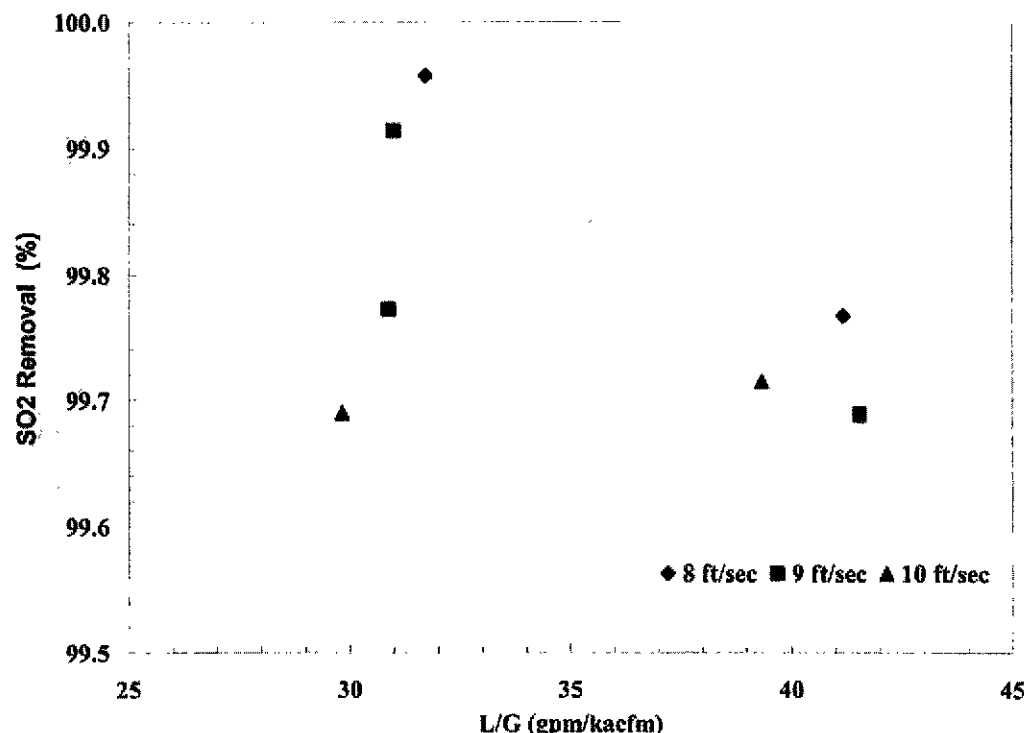
The CDU is a standalone, slipstream unit drawing flue gas from the Burger Plant Unit 4 or 5 ductwork at a point downstream of the plant's existing electrostatic precipitator. The treated flue gas is returned to the existing plant ductwork just prior to the stack. The CDU processes flue gas from high-sulfur, Eastern bituminous coals; from mid- and low-sulfur Eastern bituminous coals; and from blends of these coals with PRB (Powder River Basin) coals. Figure 2 depicts the completed demonstration unit.

Figure 2: ECO Commercial Demonstration Unit



Powerspan has operated the CDU as an advanced ammonia scrubber. In this mode, the NO<sub>x</sub> removal component is not operated, and the lower and upper loop liquid streams are combined and mixed so as to provide common chemistry for the lower and upper sections. This arrangement corresponds to the arrangement shown in the Process Flow Diagram of Figure 1. Operation of the CDU in this mode demonstrates the process chemistry for advanced ammonia scrubbing; however, since the height of the mass transfer section is limited in the CDU due to initial design constraints, the capability of advanced ammonia scrubbing is better demonstrated in the CDU Test Loop. The CDU Test Loop is a thirty-inch diameter column constructed alongside the CDU and runs in parallel with the CDU. The Test Loop contains twenty-five feet of packing and operates at design gas velocity. Results from parametric testing of SO<sub>2</sub> removal in the Test Loop are shown in Figure 3.

Figure 3: Parametric measurements of SO<sub>2</sub> removal with advanced ammonia scrubbing

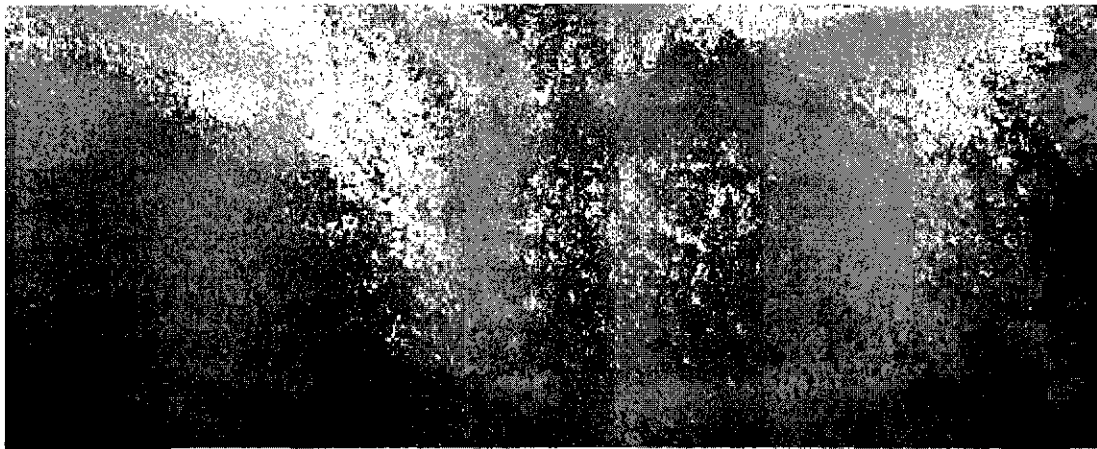


The flue gas conditions during the testing were: SO<sub>2</sub> concentration of 1.2 to 1.4 lb/mmbtu; gas velocity between 8 and 10 ft/sec; and L/G ratios between 31 and 42 gpm/kacfm. The data shows the SO<sub>2</sub> removal as a function of L/G in gpm/kacfm for the three different gas velocities. The general trend shows that the removal efficiency is independent of the L/G ratio in the range of 30 to 40 gpm/kacfm and shows a slight decrease in performance with increased gas velocity. However, the removal at all L/G ratios and gas velocities tested is above 99.5%. Similar performance with removal percentages consistently above 99% have been achieved with incoming SO<sub>2</sub> concentrations as high as 6.0 lb/mmbtu. There is no process limitation in

advanced ammonia scrubbing to  $\text{SO}_2$  removal based on incoming  $\text{SO}_2$  concentrations, and removal percentages greater than 99% would be achievable from any inlet  $\text{SO}_2$  value.

The product of advanced ammonia scrubbing is liquid ammonium sulfate. As is done with a full ECO system, the clear liquid ammonium sulfate is drawn off the scrubber, filtered for ash, passed through an activated carbon adsorption bed to remove mercury, and then crystallized. The crystallization process consists of heating the liquid under a slight vacuum, boiling off the excess water. Crystallizer design and operating parameters are established so as to produce crystals of the required size for sale into the fertilizer market without additional processing. A crystallizer is installed at the CDU to process a portion of the product stream for the purpose of demonstrating this step. Figure 4 is a photo of the crystalline ammonium sulfate fertilizer product produced from the ammonium sulfate product liquid generated at the CDU during advanced ammonia scrubbing operations.

Figure 4: Ammonium Sulfate crystals produced from advanced ammonia scrubbing liquor



### **Comparison to Other $\text{SO}_2$ Control Processes**

As described below, there are a number of differences between Powerspan's advanced ammonia scrubbing technique and other ammonia scrubbing technologies and limestone forced oxidation.

#### ***Clear liquor vs. slurry***

Unlike limestone applications and other ammonia scrubbing technologies, Powerspan's  $\text{SO}_2$  removal process does not operate with a slurry as the scrubbing liquor. Instead, the solution specific gravity is maintained below the solubility limit, which creates a scrubbing liquor that is a clear liquid rather than a slurry. This results in increased absorption rates of  $\text{SO}_2$  into the solution in addition to a more benign environment for pumps and valves. Since there are no solids in the scrubbing liquor, plugging is not an issue, and it is possible to use high efficiency mass transfer media (packing) rather than trays. Therefore the expected L/G ratios and pressure drop associated with the mass transfer compared to limestone or ammonia scrubbing systems with solids is lower.

### ***Fast process chemistry***

Unlike in limestone forced oxidation scrubbing systems where rates of limestone dissolution and absorption reactions are rate limiting, the acid – base reaction between  $\text{SO}_2$  and  $\text{NH}_3$  is a fast reaction occurring almost instantaneously in the ammonium sulfate scrubbing solutions. This rapid process chemistry inherent in Powerspan's  $\text{SO}_2$  Control technology eliminates the requirement for the recycle tank to be sized to allow time for reactions to occur. In advanced ammonia scrubbing, the limitation on the size of the tank will be related to the requirement for hold up in the system and specifications for the pumps leading to smaller, less expensive tanks.

A second advantage to the fast process chemistry and small volumes in the system is the ability of the system to quickly respond to changes in the flue gas being treated. The control system will measure changes in  $\text{SO}_2$  concentrations based on fuel or load changes and will respond immediately, adjusting the ammonia addition rate required.

### ***Isolation and sequestration of mercury***

In addition to the operational and equipment advantages of a clear liquor solution, this solution can be passed through a filter or absorption bed to remove ash and mercury. The advanced ammonia scrubbing system utilizes a treated activated carbon adsorption bed that removes the mercury captured in the scrubber and WESP from the co-product stream. This allows for isolation and control of removed mercury—a distinct advantage in light of recent reports of mercury release from gypsum used in wallboard<sup>2</sup>.

### ***Saleable co-product***

The advanced ammonia scrubbing process produces a commercial fertilizer, in the form of solid ammonium sulfate crystals, which can be sold. The ammonium sulfate solution produced in the absorber is close to saturation prior to being fed to a crystallizer. The production of the crystalline product outside of the absorber tower allows for better control of crystal formation and ability to sell crystals directly without the added expense of compaction. The crystallization process is controlled to produce a specific crystal habit, crystal size distribution, and crystal purity. In addition, the water removed during the crystallization process is returned to the system to minimize water usage.

### ***Integral WESP***

The WESP captures aerosols from the scrubber, allowing a higher pH than conventional ammonia scrubbers, which are limited by ammonium bisulfate aerosol production. The WESP captures  $\text{SO}_3$  and fine particulates that get through the scrubber, and other Hazardous Air Pollutants (e.g. HCl, HF). For  $\text{SO}_3$  and particulate matter, the WESP meets BACT standards.

### ***Reduced logistics***

The advanced ammonia scrubbing process can reduce the volume of reagent and co-product compared to limestone forced oxidation wet FGD (WFGD), thereby improving logistics. Figure 5 below compares the logistics of an ECO advanced ammonia scrubbing system to that of a limestone forced oxidation system by identifying the number of railcars required per week for incoming reagent and outbound co-product for a hypothetical 500 MW plant burning 3% sulfur coal.

Figure 5: Logistics of Advanced Ammonia Scrubbing Compared to Limestone WFGD

Sample: 500 MW Plant burning 3% Sulfur Coal			
	ECO Advanced Ammonia		LSFO
Inbound (Railcars per wk)	Ammonia (100%) 13	Urea 19	Limestone 36
Outbound (Railcars per wk)	Ammonium Sulfate 37		Gypsum 68

### **Cost Benefits**

- The elevated pH of Powerspan's advanced ammonia scrubbing process allows for high SO<sub>2</sub> removal rates (>99%) with low L/G (30-50gpm/kacfm), resulting in smaller pumps and lower operating costs.
- Because there is no wastewater discharge stream, there is no need for wastewater treatment systems and permitting.
- Because chlorides become part of the fertilizer stream, the chloride concentration in the scrubber is reduced. Near neutral pH combined with low chlorides means a less aggressive environment.

## **ECONOMICS**

### **Capital Cost**

The cost of absorber construction will be similar to limestone wet FGD (WFGD). The key differences affecting capital cost between an ammonia scrubber installation and a limestone WFGD would be:

- The advanced ammonia scrubbing system would have either liquid ammonia tanks or urea-to-ammonia conversion skids for reagent prep rather than ball mills and solid handling equipment to grind and transport the limestone.
- The advanced ammonia scrubbing installation would have smaller pipes and pumps because of the lower required L/G.
- The limestone WFGD system requires a wastewater treatment system. The advanced ammonia scrubbing installation does not.
- The SO<sub>3</sub> control provided by the WESP results in essentially SO<sub>3</sub>-free outlet gas (less than 1 ppm) and reduces the material requirements of the outlet duct material and the stack liner.
- Advanced ammonia scrubbing includes a WESP. If the limestone WFGD is required to meet BACT, a WESP will likely be required. The WESP used in the advanced ammonia scrubbing installation is cylindrical, vertical, up-flow and is installed on top of the

absorber tower. In many limestone WFGD installations, the WESP is a horizontal flow, plate type installation which requires a separate structure and enclosure.

- The advanced ammonia scrubbing system requires a co-product processing facility to convert the 40 wt% ammonium sulfate co-product into crystals. If capital outlay is a limitation, this facility can be built and owned by others.

## **Operating Cost**

The operating cost comparison between advanced ammonia scrubbing and limestone WFGD are strongly influenced by the following factors:

- The form of the ammonia reagent used for the advanced ammonia scrubbing
- The netback price (revenue realized by the power plant after any transportation and warehousing costs) of the ammonium sulfate fertilizer co-product from the advanced ammonia scrubbing system
- The cost of disposal of the gypsum from the limestone system
- The quantity of sulfur removed from the flue gas stream

### ***Form of the ECO ammonia reagent***

The ammonia reagent for the advanced ammonia scrubbing system can be provided in any form (anhydrous, aqueous, or urea using urea-to-ammonia conversion technology). The cost per ton of provided ammonia is lowest with anhydrous and, thus, produces the best economics. However, transportation or permitting constraints may prevent the use anhydrous. Aqueous ammonia at 29% is used at Powerspan's ECO Commercial Demonstration Unit. Aqueous ammonia may be acceptable where anhydrous is not. However, the large quantity of water associated with 29% aqueous ammonia increases the cost of ammonia per delivered ton. Additionally, the increased volume of 29% aqueous ammonia (approximately three times the volume of anhydrous) significantly increases the tankage required for a given number of days of on-site storage. Even with the diluted form of ammonia, permitting concerns may still exist. Urea to ammonia conversion can provide ammonia for an ECO system at a cost per ton of delivered ammonia comparable to 29% aqueous ammonia. Use of urea avoids permitting issues. Additionally, dry storage of urea is cheaper than storage of liquid ammonia. Powerspan's analysis shows that the economics of 19% aqueous ammonia are poor. If ammonia on site is a permitting concern, urea is a better alternative to diluted ammonia.

### ***Netback revenue from sale of ECO's ammonium sulfate***

The netback revenue (revenue realized by the power plant after any transportation and warehousing costs) of ammonium sulfate depends mostly on the location of the installation and the quantity of the ammonium sulfate produced. Either of these factors may warrant transport of some of the product to locations of higher consumption. The transport cost plus warehousing at the receiving point will reduce the netback revenue from sale of the ammonium sulfate to the power plant.

### ***Cost of disposal of limestone WFGD gypsum***

Disposal costs for gypsum vary widely, from actually producing a small revenue to costing over \$50 per ton for disposal. Often, the cost of gypsum disposal is the largest single line item for operation of a limestone WFGD. With the increasing supply of synthetic gypsum, the opportunity for beneficial re-use of the material is declining at the same time the regulatory requirements and cost for landfilling options are increasing. An analysis of the cost of operating a limestone WFGD should consider the risk associated with changes in regulatory requirements (such as regulatory requirements that might be generated to maintain control of mercury in the gypsum), which could prevent the sale of the gypsum or could significantly increase the cost of disposing gypsum.

### ***Quantity of sulfur removed***

For the advanced ammonia scrubbing system where the co-product is more valuable than the incoming reagent, higher SO<sub>2</sub> levels can result in improved economics. Figure 6 below provides an example of the operating cost benefits of advanced ammonia scrubbing using typical Midwest values for reagents and co-products. For the cited case, cost or revenue is calculated per ton of SO<sub>2</sub> removed for advanced ammonia scrubbing (using either anhydrous ammonia or urea for the reagent) and for a limestone forced oxidation WFGD system. This chart addresses reagent costs and co-product cost or revenue only.

Figure 6: Operating Cost Comparison

	Anhydrous Ammonia	Urea	Limestone	AS Fertilizer	Gypsum
Representative net revenue ( ) or cost per ton	\$425	\$275	\$15	(\$150) Net back	\$15 Landfill

Per ton of SO <sub>2</sub> removed	Advanced Ammonia		LSFO
Reagent	Anhydrous Ammonia	Urea	Limestone
Tons required/Cost	0.55 / \$248	1 / \$275	1.8 / \$27
Product	AS fertilizer	AS fertilizer	Gypsum
Tons generated / (revenue) or cost	2.0 / (\$300)	2.0 / (\$300)	3.8 / \$57
Total (revenue) or cost per ton of SO <sub>2</sub>	(\$52)	(\$25)	\$84

### **Reagent/Fertilizer Spread**

The economic benefits of ECO technology are dependent, in part, on the ability to market the fertilizer co-product, ammonium sulfate (AS). Powerspan and its partner, The Andersons Inc., conducted an analysis of the market for AS to understand how broad adoption of ECO could affect the long-term value of the fertilizer co-product and, hence, the annual operating costs of the system<sup>3</sup>. Given the increasing demand for agronomic sulfur, the advantages of AS as a direct application fertilizer, and the price premium of AS over other nitrogen fertilizers, the analysis indicates that the U.S. fertilizer market should readily absorb AS co-product generated from

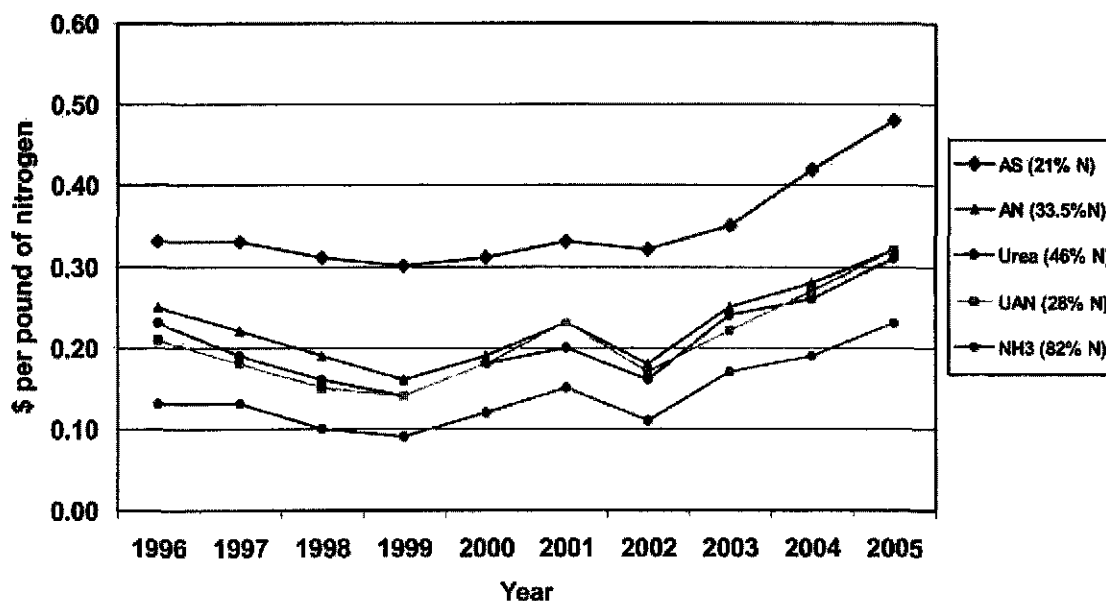


ECO installations. In any foreseeable scenario, the value of the AS co-product will offset the cost of the incoming ammonia reagent as well as the operating cost of the co-product production facility. In most scenarios, the value of the AS coupled with the avoidance of landfill or disposal expenses yields a cash flow that exceeds the reagent and co-product production facility operating cost.

Powerspan's conclusions are supported by a study conducted by the Electric Power Research Institute (EPRI), which explored the market for ammonia-based fertilizers produced in power plants<sup>4</sup>. Major findings of the EPRI study are: 1) Fertilizer demand is large enough to absorb AS production from ECO systems; 2) AS may continue to obtain a premium over nitrogen-based fertilizers due to growing soil deficiencies; 3) Absent increasing AS demand, AS would at least be priced equivalent to its nitrogen content; and 4) The AS price should always cover the cost of ammonia needed to produce the AS.

The cost of the ammonia reagent and the revenue from sale of ammonium sulfate are related. Ammonia is an ingredient in ammonium sulfate, and the historical trend is for the price of ammonium sulfate to rise and fall with the price of ammonia and the prices of other nitrogen sources, such as urea. The spread between the two prices is driven by the premium form of the nitrogen in ammonium sulfate compared to the form of nitrogen in ammonia and by the presence of the sulfur in ammonium sulfate, which is a needed plant nutrient. Figure 7 shows the historical relationship of these prices by plotting the price on the basis of cost per pound of nitrogen for several of the most commonly used fertilizers. Note the top line is ammonium sulfate and the bottom line is anhydrous ammonia. Historically, ammonium sulfate prices are correlated with 0.72 correlation factor to ammonia.

Figure 7: Historical Fertilizer Pricing Trend  
Comparison of fertilizer pricing in dollars per pound of nitrogen



It should be noted that since each ton of ammonia makes about four tons of fertilizer, a \$40 increase in the per-ton cost of ammonia is recovered by a \$10 increase in the per-ton price of fertilizer.

## CONCLUSIONS

Advanced ammonia scrubbing of SO<sub>2</sub> overcomes many of the limitations of earlier forms of ammonia scrubbing. The integral WESP allows operating the scrubbing section to maximize SO<sub>2</sub> capture, achieving lower outlet emissions than limestone forced-oxidation systems, with substantially lower L/G's than utilized in other forms of ammonia scrubbing or with limestone systems, while avoiding release of aerosols. The WESP results in the system achieving BACT standards for fine particulate matter and SO<sub>3</sub>. The absence of a liquid purge from the scrubber avoids the difficulty of obtaining a water discharge permit and avoids the cost of a water treatment facility. Operating the scrubber at an ammonium sulfate concentration below saturation allows filtering the liquid co-product for ash and mercury. Removing the ash improves the quality of the co-product, and removing the mercury eliminates potential future liabilities associated with potential future release, or perceived hazards, of the mercury in the co-product. Additionally, crystallizing the ammonium sulfate separately from the scrubber vessel allows optimizing the crystallization process, forming crystals ready for market without additional processing. The high value of the crystallized ammonium sulfate co-product results in attractive economics.

## ACKNOWLEDGMENTS

The author thanks FirstEnergy Corp. for their support of the ECO commercial demonstration testing at the R.E. Burger Plant. The author also thanks The Andersons, Inc., for information regarding the market for the fertilizer co-product.

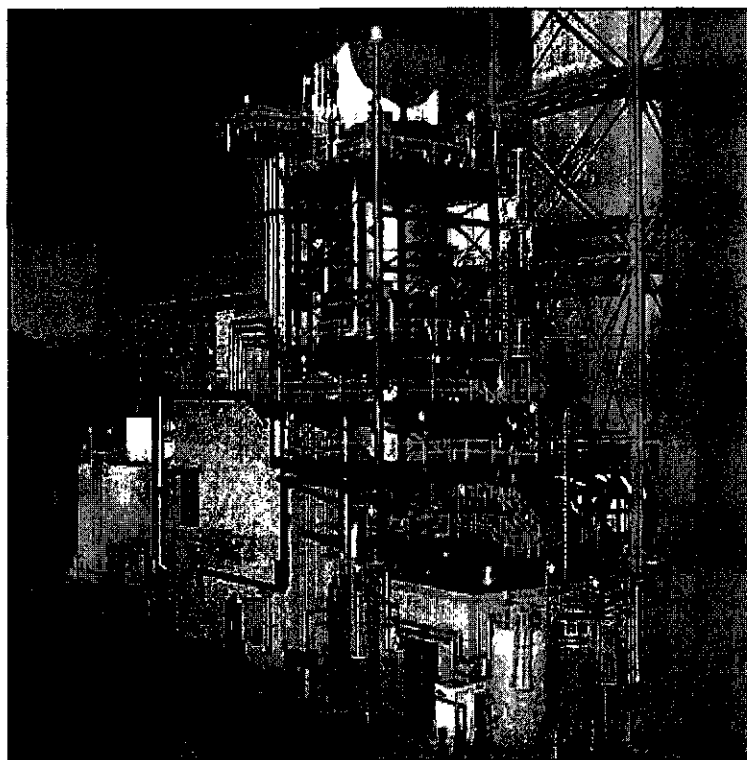
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4. Golden, D.; Offen, G.; "Markets for Ammonia-Based Fertilizers Produced in Power Plants: A Synopsis;" Electric Power Research Institute, November 2003.



## ECO® Commercially Demonstrated; Full-Scale Installation Proceeding

*FirstEnergy Corp., R.E. Burger Plant, Shadyside, Ohio*



*Powerspan has successfully demonstrated the ECO multi-pollutant control process in a 50-MW commercial configuration at FirstEnergy's R.E. Burger Plant. The unit has met commercial performance objectives and has demonstrated the capability to control outlet emissions to best available control technology standards. FirstEnergy is now moving ahead with a 312-MW ECO system on units 4 & 5 of the Burger Plant.*

### Project Team

- ✧ Powerspan
- ✧ FirstEnergy
- ✧ Wheelabrator Air Pollution Control
- ✧ Fluor Power
- ✧ The Andersons

**FirstEnergy**

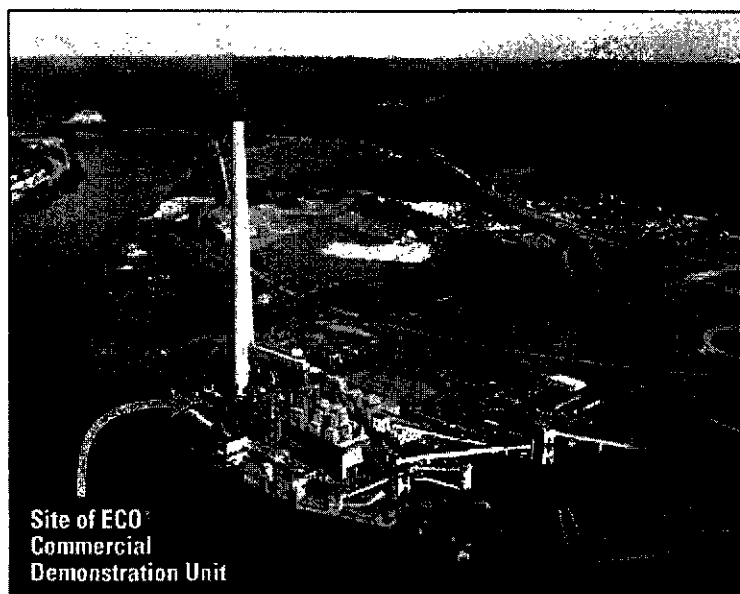


### Achievements

- ✧ Commenced operation in January 2004
- ✧ Successfully completed 180-day reliability run in 2005
- ✧ Commercially sold fertilizer co-product
- ✧ FirstEnergy announced plans to:
  - Pilot test ECO's CO<sub>2</sub> capture capability at R.E. Burger Plant: expected to begin in early 2008.
  - Install ECO system at Burger Plant units 4 & 5 (312-MW) with start-up expected in early 2011.

### Description

- ✧ 110,000 scfm (50 MW) slipstream from a 156 MW front wall boiler
- ✧ Stand-alone tower design with integrated wet ESP
- ✧ Designed and constructed to utility standards
- ✧ Processes flue gas from high sulfur, Ohio coal
- ✧ Jointly funded by Powerspan, FirstEnergy, and the Ohio Coal Development Office/Ohio Air Quality Development Authority

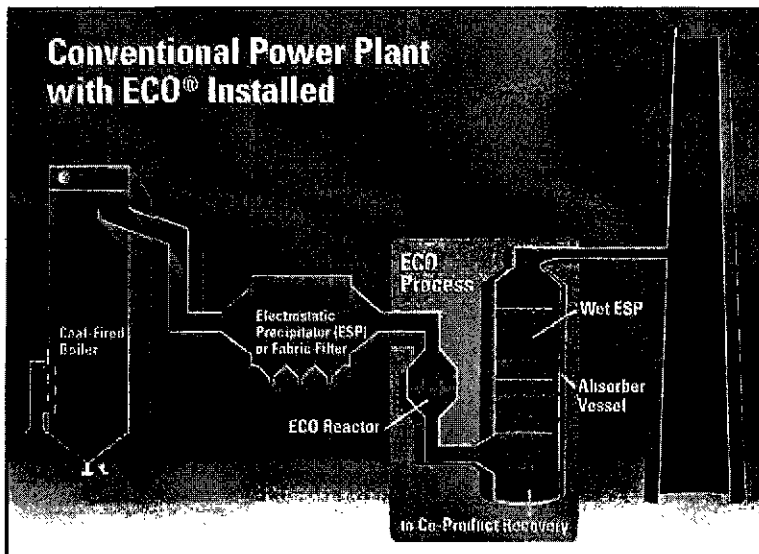


Site of ECO Commercial Demonstration Unit

## ECO® – Multi-Pollutant Control of Coal-Fired Power Plants

*Electro-Catalytic Oxidation (ECO) technology removes sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), mercury, and fine particulate matter (PM<sub>2.5</sub>) from the flue gas of coal-fired power plants.*

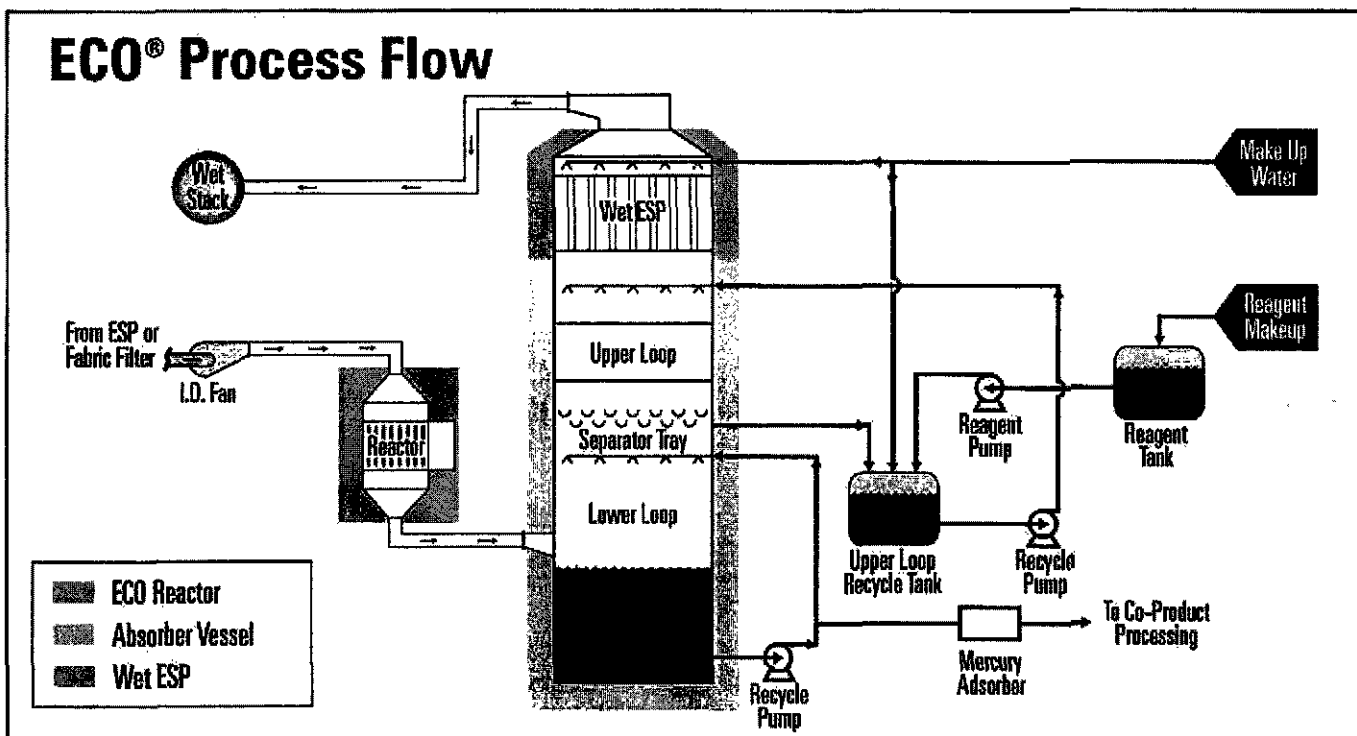
### Conventional Power Plant with ECO® Installed



### ECO Advantages

- High removal of SO<sub>2</sub>, NO<sub>x</sub>, mercury, and PM<sub>2.5</sub> in a single unit
- Cost-effective alternative for existing and new coal-fired power plants
- Produces a commercial fertilizer co-product
- Adapts to various types and sizes of coal-fired power plants
- Connected to the plant during a short outage
- Integrates proven technologies
- CO<sub>2</sub> capture capability under development with U.S. DOE National Energy Technology Laboratory. Pilot testing at Burger Plant beginning in 2008.

### ECO® Process Flow



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## **PRESS RELEASE**

**For Immediate Release**

### **Powerspan CO<sub>2</sub> Pilot Combined with FirstEnergy Carbon Sequestration Project Offers Unique Testing Opportunity**

**Portsmouth, NH – May 30, 2006—**The combined efforts of Powerspan Corp., a clean energy technology company, and FirstEnergy Corp. (NYSE: FE) have resulted in a unique opportunity to demonstrate both carbon dioxide (CO<sub>2</sub>) capture and sequestration at a coal-fired power plant in the United States. Powerspan and FirstEnergy previously announced plans to pilot test a promising CO<sub>2</sub> capture technology at FirstEnergy's R.E. Burger Plant in Shadyside, Ohio. Last week, FirstEnergy announced that its Burger Plant was selected as a carbon sequestration test site by the Midwest Regional Carbon Sequestration Partnership (MRCSP), one of seven regional partnerships set up by the U.S. Department of Energy (DOE) to research carbon sequestration projects throughout the country.

Although both programs are multi-year efforts currently in the preliminary stages, plans are moving forward for the demonstration of CO<sub>2</sub> capture at the pilot scale and subsequent injection of the captured CO<sub>2</sub> into a test well on the Burger Plant property. Powerspan's CO<sub>2</sub> pilot unit will process a 1-megawatt (MW) slipstream from the company's 50-MW Electro-Catalytic Oxidation (ECO®) commercial demonstration unit, which has proven effective in reducing sulfur dioxide, nitrogen oxides, mercury, and fine particulate matter. The pilot program will demonstrate the ability of the CO<sub>2</sub> capture process to be integrated with the ECO® multi-pollutant control process, and will confirm process design and cost estimates.

"To our knowledge, this will be the first time that combined CO<sub>2</sub> capture and sequestration from a conventional pulverized coal-fired power plant will be demonstrated in the U.S. If successfully proven, this technology could help keep existing coal-fired power plants economically competitive in a carbon-constrained world," said Frank Alix, chairman and CEO of Powerspan.

*-more-*

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**ATTACHMENT 5**

[www.powerspan.com](http://www.powerspan.com)

"Based on the encouraging results of the commercial demonstration of the ECO system, we are pleased that the Burger Plant is also one of the first sites in the country where there is the potential to test CO<sub>2</sub> capture and sequestration at the same time," said Guy L. Pipitone, senior vice president of FirstEnergy and president of FirstEnergy Solutions.

Both test programs are moving forward with the help of the U.S. DOE's National Energy Technology Laboratory (NETL). Under a cooperative research and development agreement (CRADA), Powerspan is developing a cost-effective CO<sub>2</sub> removal process for coal-based power plants. The regenerative process uses an ammonia-based solution to capture CO<sub>2</sub> in flue gas and prepare it for subsequent sequestration; after regeneration the ammonia solution is recycled to capture additional CO<sub>2</sub>. Powerspan has conducted initial laboratory testing at the company's research & development facility, with promising results.

The carbon sequestration test project planned for the Burger Plant is one of about 25 projects that are being planned across the country by the DOE to test the commercial viability of carbon sequestration as a CO<sub>2</sub> storage method. In Ohio, DOE is working with MRCSP, a 30-member team led by Battelle, a leader in science and technology with over a decade of research on CO<sub>2</sub> capture and storage technologies. The Burger Plant test project will involve geological site characterization to determine potential suitability for carbon sequestration in the area. If test results prove favorable, next steps involve obtaining permits required to drill a test well, followed by injection of a small amount of CO<sub>2</sub> into the well.

Powerspan Corp., a clean-energy technology company based in Portsmouth, New Hampshire, is engaged in the development and commercialization of proprietary multi-pollutant control technology for the electric power industry. Visit [www.powerspan.com](http://www.powerspan.com) for more information.

###

**Powerspan Corp.**

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**News Release**

**For Release: Upon Receipt**

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**FIRSTENERGY TO INSTALL EMISSION CONTROL  
TECHNOLOGY AT R. E. BURGER PLANT**

Akron, Ohio – FirstEnergy Corp. (NYSE: FE) announced today that FirstEnergy Generation Corp. plans to install an Electro-Catalytic Oxidation (ECO®) system on units 4 and 5 of its R. E. Burger Plant in Shadyside, Ohio. Combined, the units produce 312 megawatts (MW) of electricity, or enough to serve approximately 190,000 homes.

ECO is a multipollutant control technology for coal-based electric generating plants that was developed by Powerspan Corp., a New Hampshire-based clean energy technology company in which FirstEnergy has a minority ownership interest. The Burger Plant ECO scrubber system will reduce sulfur dioxide, mercury, other gases resulting from combustion, and fine particulates. The ECO process also will produce a highly marketable ammonium sulfate fertilizer co-product that will be sold in the fertilizer market.

Since early 2004, an ECO commercial demonstration unit has been operating successfully at the Burger Plant. It continues to operate and collect data regarding the ECO process. The Ohio Coal Development Office, a program of the Ohio Air Quality Development Authority, has been a major supporter of the ECO demonstration, contributing more than \$5.5 million to the project.

“We believe installing ECO enhances the viability of the Burger Plant and gives us more flexibility in our use of eastern coal,” said Richard R. Grigg, executive vice president and chief operating officer for FirstEnergy. “In addition, we believe that ECO provides a cost-effective method for meeting environmental regulations, including the Clean Air Interstate Rule and the Clean Air Mercury Rule.”

In 2005, FirstEnergy announced plans to install ECO on its 215-MW Unit 4 of the Bay Shore Plant in Oregon, Ohio. The decision to install ECO at the Burger Plant instead will result in additional scrubbed megawatts and better fits the coal-purchasing strategy for both plants.

Design engineering for the new Burger Plant ECO system will begin in 2007 with an anticipated start-up during the first quarter of 2011. The estimated cost of the system is approximately \$168 million.

Because FirstEnergy is planning to install Selective Non-Catalytic Reduction technology at the Burger Plant to remove nitrogen oxides (NO<sub>x</sub>), the ECO unit will not be equipped with NO<sub>x</sub> controls. However, due to ECO’s unique design capabilities, the NO<sub>x</sub> controls could be added later.

Powerspan also is developing a carbon-capture process – known as ECO<sub>2</sub><sup>TM</sup> – that has demonstrated the capability to capture significant amounts of carbon dioxide (CO<sub>2</sub>) in a laboratory environment. Pilot scale testing of this new technology is expected to begin at the Burger Plant in early 2008. The goal of this test project is to capture power plant CO<sub>2</sub>, transport it to an 8,000-foot test well that was drilled at the Burger Plant earlier this year, and then sequester it underground. It could be the first such program to demonstrate both CO<sub>2</sub> capture and sequestration at a conventional coal-fired power plant.



FirstEnergy is a diversified energy company headquartered in Akron, Ohio. Its subsidiaries and affiliates are involved in the generation, transmission, and distribution of electricity, as well as energy management and other energy-related services. Its seven electric utility operating companies comprise the nation's fifth largest investor-owned electric system, based on 4.5 million customers served within a 36,100-square-mile area of Ohio, Pennsylvania, and New Jersey; and its generation subsidiaries control more than 14,000 megawatts of capacity.

Powerspan Corp., a clean-energy technology company based in Portsmouth, New Hampshire, is engaged in the development and commercialization of proprietary multi-pollutant control technology for the electric power industry.

**Forward-Looking Statements:** This news release includes forward-looking statements based on information currently available to management. Such statements are subject to certain risks and uncertainties. These statements typically contain, but are not limited to, the terms "anticipate," "potential," "expect," "believe," "estimate" and similar words. Actual results may differ materially due to the speed and nature of increased competition and deregulation in the electric utility industry, economic or weather conditions affecting future sales and margins, changes in markets for energy services, changing energy and commodity market prices, replacement power costs being higher than anticipated or inadequately hedged, the continued ability of FirstEnergy's regulated utilities to collect transition and other charges or to recover increased transmission costs, maintenance costs being higher than anticipated, legislative and regulatory changes (including revised environmental requirements), and the legal and regulatory changes resulting from the implementation of the Environmental Policy Act of 2005 (including, but not limited to, the repeal of the Public Utility Holding Company Act of 1935), the uncertainty of the timing and amounts of the capital expenditures needed to, among other things, implement the Air Quality Compliance Plan (including that such amounts could be higher than anticipated) or levels of emission reductions related to the Consent Decree resolving the New Source Review litigation, adverse regulatory or legal decisions and outcomes (including, but not limited to, the revocation of necessary licenses or operating permits and oversight) by the NRC (including, but not limited to, the Demand For Information issued to FENOC on May 14, 2007) and the various state public utility commissions as disclosed in our SEC filings, the timing and outcome of various proceedings before the PUCO (including, but not limited to, the Distribution Rate Cases for the Ohio Companies and the successful resolution of the issues remanded to the PUCO by the Ohio Supreme Court regarding the Rate Stabilization Plan) and the PPUC (including the transition rate plan filings for Met-Ed and Penelec and the Pennsylvania Power Company Default Service Plan filing), the continuing availability and operation of generating units, the ability of generating units to continue to operate at, or near full capacity, the inability to accomplish or realize anticipated benefits from strategic goals (including employee workforce initiatives), the anticipated benefits from voluntary pension plan contributions, the ability to improve electric commodity margins and to experience growth in the distribution business, the ability to access the public securities and other capital markets and the cost of such capital, the outcome, cost and other effects of present and potential legal and administrative proceedings and claims related to the August 14, 2003 regional power outage, the successful structuring and completion of a potential sale and leaseback transaction for Bruce Mansfield Unit 1 currently under consideration by management, any final adjustment in the purchase price per share under the accelerated share repurchase program announced March 2, 2007, the risks and other factors discussed from time to time in our SEC filings, and other similar factors. We expressly disclaim any current intention to update any forward-looking statements contained herein as a result of new information, future events, or otherwise.



# News from AMP-Ohio

*AMERICAN MUNICIPAL POWER-OHIO IS DEDICATED TO PROVIDING SUPPORT SERVICES  
AND LOW-COST POWER SUPPLIES TO MEMBER MUNICIPAL ELECTRIC COMMUNITIES*

## **For Immediate Release**

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## **AMP-Ohio Finalizes Plans for Powerspan Emission Control Technology at Proposed Plant**

(COLUMBUS) American Municipal Power-Ohio, Inc. (AMP-Ohio) has committed to the use of Powerspan emissions control technology on the proposed American Municipal Power Generating Station (AMPGS) Project and has executed a memorandum of understanding with The Andersons, Inc. (NASDAQ:ANDE) to process and market the ammonium sulfate fertilizer by-product of the process. The project is under development near the Ohio River in southern Meigs County, Ohio.

In October 2005, AMP-Ohio and its partners, the Blue Ridge Power Agency (Blue Ridge) and Michigan South Central Power Agency (MSCPA), announced plans for the new electric power plant. The proposed 1,000 megawatt (MW) facility will utilize pulverized coal and incorporate the best of the latest generation of available and proven emissions control technology to ensure that it meets or exceeds all environmental regulations and emissions limitation requirements. Once on-line, it will be one of the cleanest facilities of its type in the nation.

Developed and patented by Powerspan Corp. the pollutant control technology achieves outlet emissions levels at or below those of best available control technologies and produces a valuable fertilizer co-product instead of synthetic gypsum produced from traditional limestone scrubbing technologies. The AMPGS facility will use the ECO-SO<sub>2</sub> technology to control sulfur dioxide (SO<sub>2</sub>) emissions with co-benefits for control of mercury and particulate matter. The use of Powerspan technology will greatly reduce the annual volume of material from the power plant that needs to be placed in a landfill. In addition, the Powerspan

system will be designed with features that allow for future expansion to make the plant "CO<sub>2</sub> capture ready," preparing the plant for the possibility of future CO<sub>2</sub> emission limits.

"AMP-Ohio originally announced our intent to pursue Powerspan technology at AMPGS last November," said AMP-Ohio President/CEO Marc Gerken, PE. "At that time, we made the final decision contingent upon a technology study and contractual discussions. Since then, we have conducted due diligence, completing the study that determined that the Powerspan technology is a good fit for the AMPGS project. We're pleased to be working with Powerspan and The Andersons and look forward to moving forward with the permitting on the new facility."

The AMP-Ohio Board of Trustees has adopted a resolution declaring the organization's intent to utilize Powerspan at the AMPGS facility and approved a memorandum of understanding with The Andersons. The Andersons will handle processing and sale of the fertilizer by-product produced by the emission control system.

"We are very pleased with the successful outcome of AMP-Ohio's due diligence and their commitment to proceed with ECO on the new Meigs County plant," said Frank Alix, CEO of Powerspan. "We believe that ECO is the most advanced environmental control technology commercially available today, which will not only minimize air emissions and production of landfill waste, but also prepare the plant to add CO<sub>2</sub> emission controls if required by future regulations."

"We are pleased to partner with AMP-Ohio on this important and environmentally pro-active project," said Mike Anderson, President and CEO of The Andersons, Inc. "We are excited to be part of this project and a member of the AMP-Ohio and Powerspan team."

Denny Addis, President of the company's Plant Nutrient Group added: "Powerspan's state of the art multi-pollution control technology promises to produce high quality ammonium sulfate plant nutrient for our Midwest customer base. Serving AMP-Ohio's plant nutrient operational and distribution needs is a natural extension to our core production and distribution business."

AMP-Ohio filed the air permit-to-install application with the Ohio EPA in May 2006. Additional major path permit applications were filed in May 2007, including Ohio Power Siting Board generation application, Army Corps of Engineers Section 10/404 permit, OEPA 401 certification, solid waste permit-to-install, NPDES permit.

In May 2004, Powerspan and the Department of Energy's (DOE) National Energy Technology Laboratory announced a cooperative research and development agreement (CRADA) to develop a cost effective CO<sub>2</sub> removal process for coal-based power plants. The regenerative process uses an ammonia-based solution to capture CO<sub>2</sub> in flue gas and prepare it for subsequent sequestration; the ammonia solution is recycled after regeneration. In September 2005, FirstEnergy and Powerspan announced plans to pilot test the CO<sub>2</sub> capture process at the R.E. Burger Plant, with testing scheduled to begin in late 2007 or early 2008. Initial cost estimates developed by the DOE indicate that the ammonia-based process could provide significant savings compared to commercially available amine-based CO<sub>2</sub> capture technologies. AMP-Ohio is a partner in that pilot program.

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**About AMP-Ohio** – *AMP-Ohio is the Columbus, Ohio-based nonprofit wholesale power supplier and services provider for 121 member municipal electric systems in Ohio, Pennsylvania, Virginia, West Virginia and Michigan. The organization provides a diverse mix in its wholesale generation resources, which in addition to fossil fuel, includes wind, hydroelectric, landfill gas and distributed generation. [www.amp-ohio.org](http://www.amp-ohio.org)*

**About Powerspan**– *Powerspan Corp., a clean-energy technology company based in Portsmouth, New Hampshire, is engaged in the development and commercialization of proprietary multi-pollutant control technology for the electric power industry. [www.powerspan.com](http://www.powerspan.com)*

**About The Andersons, Inc.** – *The Andersons, Inc. is a diversified company with interests in the grain, ethanol and plant nutrient sectors of U.S. agriculture, as well as in railcar leasing and repair, turf products production, and general merchandise retailing. Founded in Maumee, Ohio, in 1947, the company now has operations in seven U.S. states plus rail leasing interests in Canada and Mexico. For more, visit The Andersons online at [www.andersonsinc.com](http://www.andersonsinc.com).*



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ATTACHMENT 8