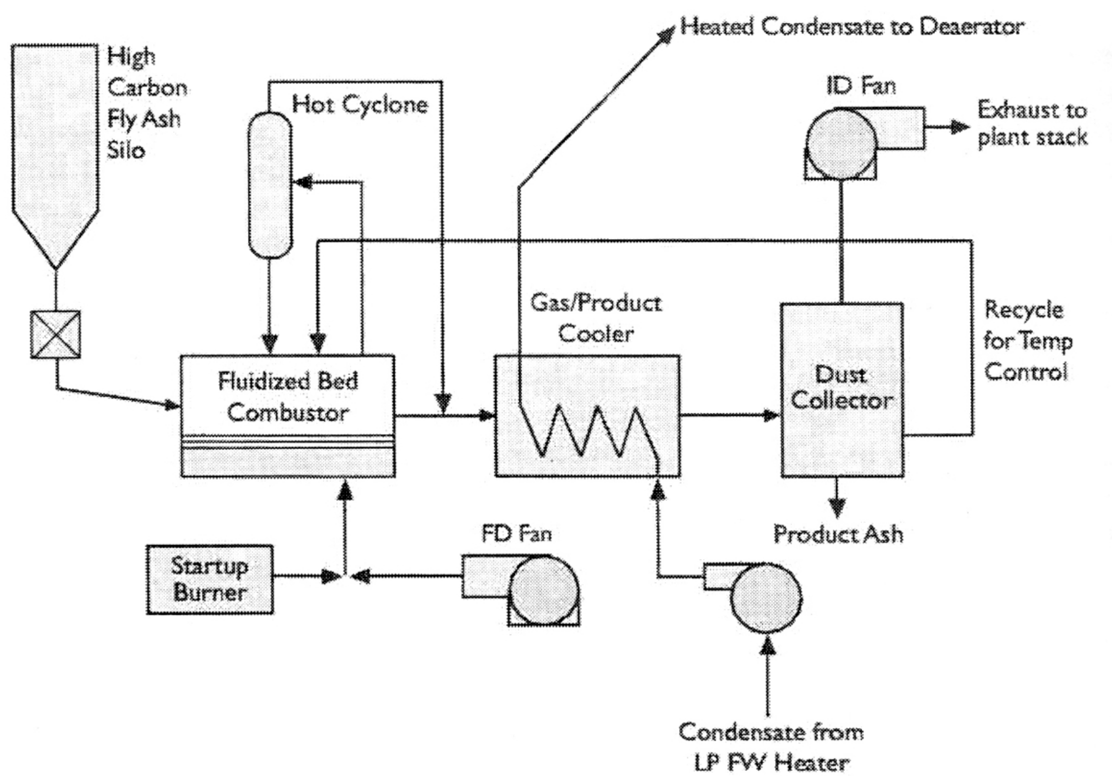
# Coal Ash Carbon Removal Technologies

*Technical Report*



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Technical Review, November 2001

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# REPORT SUMMARY

Market resistance to the use of ash containing elevated levels of carbon and/or ammonia has become a major concern for coal-fired facilities in recent years as a result of increased use of $NO_x$ reduction environmental control technologies. EPRI initiated this state of practice assessment to help power producers evaluate alternatives for ash beneficiation.

### Background

$NO_x$ reduction technologies include combustion system technologies such as low-$NO_x$ burners (LNB) or overfire air (OFA), or post-combustion system technologies such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR). Application of these technologies in electric power plants has, in some cases, negatively impacted the use of the coal ash in certain markets. The effects of increased ash coarseness and agglomeration as well as higher unburned carbon and ammonia in ash can severely impede the use of fly ash as a cement substitute in concrete. The economic impact is often substantial, since this high-value application accounts for approximately 50% (10 million tons) of the fly ash used in the United States. Changes in ash physical properties—due to the lower operating temperatures of low-$NO_x$ combustion technologies—can also impact high-value ash uses where size or color is an important part of the specification.

### Objective

- To evaluate the state of practice of coal ash beneficiation to remove high carbon levels.
- To provide information on the latest beneficiation technologies and their commercial status.

### Approach

In addition to a literature review, the project team contacted technology vendors by telephone to solicit timely information on technology advances, commercial installations and performance, and capital and operating costs. The team placed a high priority on addressing problems associated with the impact of $NO_x$ control systems on fly ash quality as well as the lack of readily available industry data. As a result, they designed this state of practice assessment to help end users evaluate various beneficiation methods for mitigating the impacts of lower quality ash.

### Results

This paper summarizes earlier findings on treatment or beneficiation of coal ash to make it usable for high-volume markets such as cement and concrete. The paper next provides an update on the status of current developments in ash beneficiation to remove carbon, with special focus on economical processes for producing usable ash.

Two general approaches effectively improve ash quality—source control and beneficiation. To date, most ash beneficiation has focused on upgrading ash quality to meet the ASTM C618 specification for use of ash in concrete applications. Several ash beneficiation technologies have reached or are nearing commercialization, including screening, grinding, air classification, carbon burn out, electrostatic separation, and carbon flotation. In addition to producing concrete "specification" ash from low-$NO_x$ sources, carefully selected beneficiation also provides opportunities for enhanced pozzolan quality as well as the generation of new and value-added products such as fillers for plastics and other composites.

### EPRI Perspective

Problems associated with high-carbon ash have become a major concern for coal-fired facilities in recent years due to increased use of $NO_x$ control technologies. EPRI initiated a research program to help power producers evaluate and mitigate the impacts of high-carbon ash. This report describes the status of developing beneficiation options for high-carbon ash and complements the technical assessment report on ammonia beneficiation options issued in October 2001 (1004609).

### Keywords

Ash beneficiation
Ash reuse
Carbon burnout
Carbon separation

# ABSTRACT


$NO_x$ reduction technologies include combustion system technologies such as low-$NO_x$ burners (LNB) or overfire air (OFA), or post-combustion system technologies such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR). Application of these technologies in electric power plants has, in some cases, had a negative impact on the use of the coal ash in certain markets.

The effects of increased ash coarseness and agglomeration as well as higher unburned carbon and ammonia in ash can severely impede the use of fly ash as a cement substitute in concrete. The economic impact is often substantial, since this high-value application accounts for approximately 50% (10 million tons) of the fly ash used in the United States. Changes in ash physical properties—due to the lower operating temperatures of low-$NO_x$ combustion technologies—can also impact high-value ash uses where size or color is an important part of the specification.

This "white paper" summarizes earlier findings on treatment or beneficiation of coal ash to make it usable for high-volume markets such as cement and concrete. The paper next provides an update on the status of current developments in ash beneficiation to remove carbon, with special focus on economical processes for producing usable ash.

Two general approaches effectively improve ash quality—source control and beneficiation. To date, most ash beneficiation has focused on upgrading ash quality to meet the ASTM C618 specification for use of ash in concrete applications. Several ash beneficiation technologies have reached or are nearing commercialization, including screening, grinding, air classification, carbon burn out, electrostatic separation, and carbon flotation. In addition to producing concrete "specification" ash from low-$NO_x$ sources, carefully selected beneficiation also provides opportunities for enhanced pozzolan quality as well as the generation of new and value-added products such as fillers for plastics and other composites.

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# 1
# INTRODUCTION

Many U.S. utilities with coal-fired boilers are being required to reduce emissions of nitrogen oxides (NOx). All new facilities must meet even lower emission limits. Many older units used combustion techniques based on high single stage combustion efficiency. Under these conditions, NOx emissions are rather high. The use of NOx reduction technologies – combustion system technologies such as low NOx burners (LNB) or overfire air (OFA), or post-combustion system technologies such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) – on electric power plants has, in some cases, had a negative impact on the utilization of the coal ash in certain markets. This is largely as a result of increased levels of unburned carbon and other chemical residuals that are left in the ash, and changes in the physical properties of the ash due to the lower operating temperatures of low NOx combustion technologies.

Combustion modifications seek to reduce the creation of NOx by reducing the peak flame intensity – lowering the temperature, reducing the oxygen levels, etc. These changes also impact important fly ash characteristics. Typically, the unburned carbon (UBC) level in the ash increases. Lower flame temperatures also cause less ash melting. As a consequence, the ash morphology is coarser, less spherical, and may be more prone to agglomerate (3). These changes lead to greater variability in fly ash properties that are important to ash users.

Post-combustion controls use chemical reagents (usually ammonia) to react with NOx and reform $N_2$ and water. Traces of the reagents are adsorbed on the fly ash and can affect by-product markets. A common problem is the odor of ammonia when the ash is wetted.

The effects of increased ash coarseness and agglomeration, and higher unburned carbon and ammonia in ash are severe impediments to the use of fly ash as a substitute for cement in concrete, a high-value use which currently accounts for approximately 50 percent (10 million tons) of the fly ash utilized in the United States (1).

The increased coarseness and agglomeration of ash particles also impedes sales of ash as a filler in asphalt roofing shingles, joint compounds, carpet backing, vinyl flooring, plastics, and industrial coatings, where fineness and uniformity are critical requirements. The critical product performance characteristics that fly ash must exhibit when used as a filler are listed in Table 1-1 (17). Fillers represent a $1 billion per year market which consumes approximately 10 million tons per year of fillers, primarily kaolin clays, calcium carbonate, and talc. Other fillers used in much lower quantities include silica, alumina, mica, feldspar, and ash (16). Only about 160,000 tons of fly ash are currently sold as filler in the United States (1).

**Table 1-1**
**Critical Product Performance Characteristics of Fly Ash Used as Filler**

| |
|---|
| **Asphalt Roofing Shingles**<br>• 55% to 75% passing 200 mesh<br>• no free silica |
| **Joint Compounds**<br>• 90% to 95% passing 325 mesh<br>• light color, chemical consistency |
| **Carpet Backing**<br>• 75% to 99% passing 325 mesh<br>• chemical consistency |
| **Vinyl Flooring**<br>• 95% to 99% passing 325 mesh<br>• white color, chemical consistency |
| **Plastics**<br>• 1 to 15 micron average particle size<br>• chemical consistency |
| **Industrial Coatings**<br>• 1 to 15 micron average particle size<br>• chemical consistency |

In order to reverse the adverse effects of combustion modification and post-combustion controls, fly ash must be processed to meet the various product requirements. This report provides an update on several ash beneficiation technologies that are available commercially or are under development. The information was compiled from the proceedings of recent symposia and conferences, other EPRI publications, and direct contacts with several prominent ash marketing organizations. The telephone numbers of several of the organizations offering beneficiation processes and other contacts are provided in Table 1-2.

**Table 1-2**
**Beneficiation Process Suppliers**

| Organization | Individual | Telephone |
|---|---|---|
| *American Coal Ash Association* | Executive Director | 703-317-2400 |
| *Boral Material Technologies* | *Harry Roof* | 210-349-4069 |
| *Center for Applied Energy Research, University of Kentucky* | *D. N. Taulbee* | 859-257-0238<br>859-257-0250 |
| Electric Power Research Institute | Dean Golden | 650-855-2516 |
| *Energy Resource Center, Lehigh University* | E. K. Levy | 610-758-4090 |
| ISG Resources | Bruce Boggs | 770-218-6404 |
| Mineral Resource Technologies | Howard Fitzgerald | 770-989-0089 |
| National Energy Technology Laboratory | Yee Soong | 412-386-4935 |
| Pittsburgh Mineral and Environmental Technologies | Casimir Koshinski | 724-843-5000 |
| Progress Materials, Inc. | Peter Hay | 727-824-6693 |
| Separation Technologies, Inc. | James Bittner | 781-455-6600 |
| Solvera Controls/Stock Equipment Company | Charles Lockert | 440-543-6000 |
| Sortech Separation Technologies | Haim Levy | 011-972-2587-0662 |
| TriboFlow Separations | John Stencel | 859-257-0250 |
| Wisconsin Electric Power Company | Bruce Ramme | 414-221-2345 |

# 2
# ASH BENEFICIATION PROCESSES

Usually it is the higher value uses of fly ash, such as the concrete and filler markets, that produce enough sales revenue to support an ash beneficiation system. Ash beneficiation processes are typically used to enhance the fineness of fly ash or to remove unwanted constituents such as carbon and ammonia.

Four approaches to minimizing the impact of NOx controls that impair ash quality directly affecting ash utilization are indicated, as follows:

Combustion optimization, for prevention of carbon accumulation in fly ash;

Selective collection;

Carbon removal; and

Ammonia removal.

## 2.1 Combustion Optimization

Operational optimization of boiler functions can be the lowest cost way of reducing unburned carbon (UBC) and hence minimizing its impact on ash utility. It also can provide cost savings through improved boiler efficiency. Operators have numerous points of control that impact boiler performance. While an expert operator can maintain good performance conditions, the application of advanced models or intelligent systems for boiler control improves the potential for optimization through more complex analysis and real-time support to the operator. While a number of such systems exist based on advanced adaptive technology, their ability to reduce UBC to acceptable levels for fly ash use is limited by the constraints of the boiler design and coal properties. The use of combustion optimization strategies does not affect ammonia absorption rates on the fly ash, per se, but may be able to reduce ammonia slip from post-combustion NOx controls through better matching of the ammonia injection rates with the NOx flux.

## 2.2 Selective Collection

Electrostatic precipitators typically have three, four, or even five fields that remove consistently finer ash fractions. This finer ash may be suitable for the filler or concrete markets, if other product specifications are met. Also, the coarser fractions may be carbon rich and therefore, preferentially captured in the first fields. If ash from these fields can be selectively discharged, contamination of otherwise acceptable ash can be reduced. Some evidence indicates that the more porous carbon fraction of the higher LOI ashes may entrap more of the ammonia than the "ash" fraction, but no consistent relationship has been found between ammonia absorption and LOI levels.

## 2.3 Carbon Removal

If ash contamination with UBC cannot be prevented, economical removal of carbon may be an option to meet ash specification demands. There are a number of options available for reducing or removing the UBC content of ash by employing some form of post-collection processing, the major ones being:

Thermal processes

Particle size control (screening, grinding, air classification)

Electrostatic separation

Wet separation (flotation).

### *2.3.1 Thermal Processes*

#### 2.3.1.1 Carbon Burn-Out (CBO)

This commercially available process was developed by Progress Materials, Inc. with support from EPRI and South Carolina Electric & Gas (see Figure 2-1). The process burns the residual carbon in fly ash in an auxiliary fluidized bed combustor, producing a high-quality pozzolan of less than 2 percent carbon. In the process, heat is recovered and returned to the power plant that originally produced the high carbon ash. The Wateree Station of South Carolina Electric & Gas, a two unit, 772 MW plant southwest of Columbia, SC, started operation of its carbon burnout unit in mid-1998. This unit is designed to process 180,000 tons of high carbon ash a year, while producing 475,000 MM BTUs of heat (steam) for power production at the power plant (9).

Over 18,000 tons per month of premium fly ash have been sold from the Wateree CBO. Feed ash loss-on-ignition (LOI) to the CBO has ranged from 6.5 to 18 percent, averaging 10.9 percent, while product ash has consistently averaged 2.5 percent, as targeted, and performed well in the marketplace. It should be noted that product LOI can be lowered to a target of 2 percent or less if desired. However, experience with product performance on CBO ash yields most acceptable results at the current target (14).

Carbon Burn-Out's fluid bed technology provides heat and residence time dictated by conditions for optimal combustion of carbon found in fly ash. Fly ash residence times of forty-five minutes and temperatures in the 1,300°F range are characteristic of the CBO process. Kinetic theory suggests that CBO conditions should be ideal for ammonia removal.

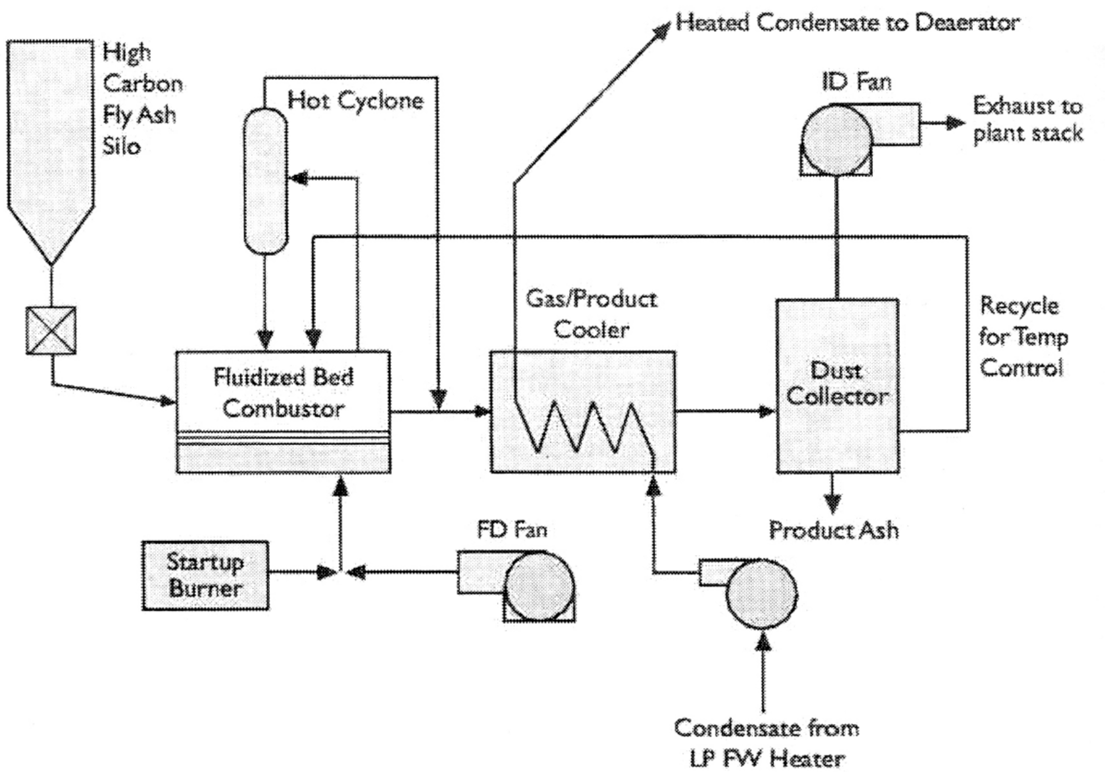


**Figure 2-1**
**Simplified Process Flow Diagram of a Commercial-Scale CBO Facility**

Test results on fly ash samples processed through Progress Material's one ton per hour continuous CBO pilot plant indicate that under normal Carbon Burn-Out operating conditions essentially all ammonia was liberated from the fly ash feed material. Carbon Burn-Out does not require additional equipment or processing expense for ammonia removal.

Carbon Burn-Out successfully removed ammonia from feed ash containing ammonia at concentrations less than 1000 ppmw. The type of NOx control device and/or system reagents had no effect on ammonia removal efficiency. The Carbon Burn-Out process produced ash with less than five ppmw ammonia content for all feed stocks tested. Future work involves the determination of the fate of released ammonia in the flue gas (10).

### *2.3.2 Particle Size Control (Screening, Grinding, Air Classification)*

Processing ash to change the bulk composition or particle size distribution has long been practiced to increase reactivity, improve recovery of metal values, and in some cases, to reduce carbon content (or recover a carbon-rich fraction). Such processing, frequently termed beneficiation, is normally achieved through one or more common separation techniques, such as: 1) screening with or without grinding; 2) mechanical size-classification; 3) density separation; 4) magnetic separation; 5) electrostatic separation; and 6) flotation or related wet processing (2).

Fineness is one of the most important properties for many uses of fly ash, so many processes concentrate on producing a “fine” product. In general, the finer the fly ash, the lower the LOI, and the greater the long-term compressive strength. Fineness also lowers the water demand and increases resistance to sulfate attack in concrete made with such fly ash.

Grinding is a way to obtain finer fly ash and, when combined with screening, can be used to separate out the coarser fraction. Grinding can be especially effective in improving fly ash from power plants with low NOx burners, which typically produce a coarse ash. KEMA has found that by appropriate grinding it is possible to micronize fly ash to sizes under 5µm, producing an excellent high performance filler for concrete (5). The ultra-fine range was also reached in Japan, by vaporization at about $2400^{o}$ C and condensation of fly ash (18).

An alternative approach is to employ some form of physical separation, such as air classification. This may be conducted in a number of different ways, but in general the processes rely on similar physical principles – namely, the balance of aerodynamic and centrifugal (inertial) forces on particles in a moving fluid (air).

The ability to use size separation to also remove carbon by beneficiation depends upon two factors: the degree to which the carbon-rich particles are discrete, and the size and shape of the carbon particles. Size-fractionation (using dry or wet methods) and electrostatic separation techniques have been used to remove the coarse carbon particles. More complex processes such as froth floatation are necessary to remove or concentrate the fine carbon materials.

Air classification was investigated in an extended research program at KEMA with respect to the effect of fly ash fineness, grading and packing on mortar and concrete properties (3). The experimental air classifier used in this project has an internal diameter of 1.20 meters. An internal air circulation is created by the ventilator (fan) in the upper section of the apparatus. A secondary air circulation is created by a ventilator situated behind the bag filter. In this installation the input fly ash is separated into four fractions, i.e. coarse, medium, fine and ultra-fine. As the medium fraction appeared to be a very small weight fraction (about 3%) of the input material, only the three remaining fractions were investigated. In this installation a number of parameters can be varied such as input speed, velocities of the ventilator and the centrifugal system, as well as the suction speed of the ventilator behind the bag filter.

Two typical fly ashes (with average grain sizes of 39.3 microns and 24.2 microns) were classified into three fractions. It was shown that an effective separation of different particle sizes can be achieved. The D50 values of the various fractions were between 10.3 and 86.3 microns. This technique, however, proved to be less suited for carbon removal from the fly ash. Because of the different density and aerodynamic behavior of carbon compared with fly ash, coarse carbon particle appeared also in the fine and ultra fine fractions. This resulted in an even distribution of carbon over the three fractions.

### 2.3.3 Electrostatic Separation

This process uses triboelectrostatic charging to separate high carbon and low carbon ash particles, resulting in a higher quality fly ash stream for subsequent sale. Several specific electrostatic separation processes are described below.

#### 2.3.3.1 Separation Technologies, Inc.

Separation Technologies, Inc. (STI) has been operating commercial fly ash beneficiation systems for over five years. STI reports that its electrostatic beneficiation technology reduces the carbon content of coal fly ash, producing a consistent, low loss-on-ignition (LOI) ash for use as a substitute for cement in concrete applications. The STI process reportedly generates uniform quality fly ash (± 0.5 percent LOI) from highly variable LOI ash. Presently, five STI electrostatic separators are operating at three electric utilities to produce concrete-grade fly ash: U.S. Generating Co. Brayton Point Station (two separators), Carolina Power and Light (CP&L) Roxboro Station (two separators), and Constellation Power Source Generation (formerly Baltimore Gas and Electric) Brandon Shores Station (one separator).

In the STI separator (Figure 2-2), material is fed into the thin gap between two parallel planar electrodes. The particles are triboelectrically charged by interparticle contact. The positively charged carbon and the negatively charged mineral are attracted to opposite electrodes. The particles are then swept up by a continuous moving belt and conveyed in opposite directions. The belt moves the particles adjacent to each electrode toward opposite ends of the separator. The counter current flow of the separating particles and continual triboelectric charging by carbon-mineral collisions provides for a multi-stage separation, which STI states results in excellent purity and recovery in a single-pass unit. The high belt speed also enables very high throughputs, up to 40 tons per hour on a single separator. By controlling various process parameters, such as belt speed, feed point, and feed rate, the STI process produces low carbon fly ash at LOI contents of 2 percent, ± 0.5 percent from feed fly ashes ranging in LOI from 4 to 25 percent.

The separator design is relatively simple. The belt and associated rollers are the only moving parts. The electrodes are stationary and composed of an appropriately durable material. The belt is made of plastic belting material. The separator electrode length is approximately 20 feet and the width is dependent on the capacity desired. The power consumption is about 1 kilowatt-hour per ton of material processed with most of the power consumed by two motors driving the belt.

The small gap, high voltage field, counter current flow, vigorous particle-particle agitation and self-cleaning action of the belt on the electrodes are the critical features of the STI separator. The process is entirely dry, requires no additional materials other than the fly ash and produces no wastewater or air emissions. The recovered material consist of fly ash reduced in carbon content (LOI) to levels suitable for use as a pozzolanic admixture in concrete, and a high carbon fraction which can be reburned at the generating plant.

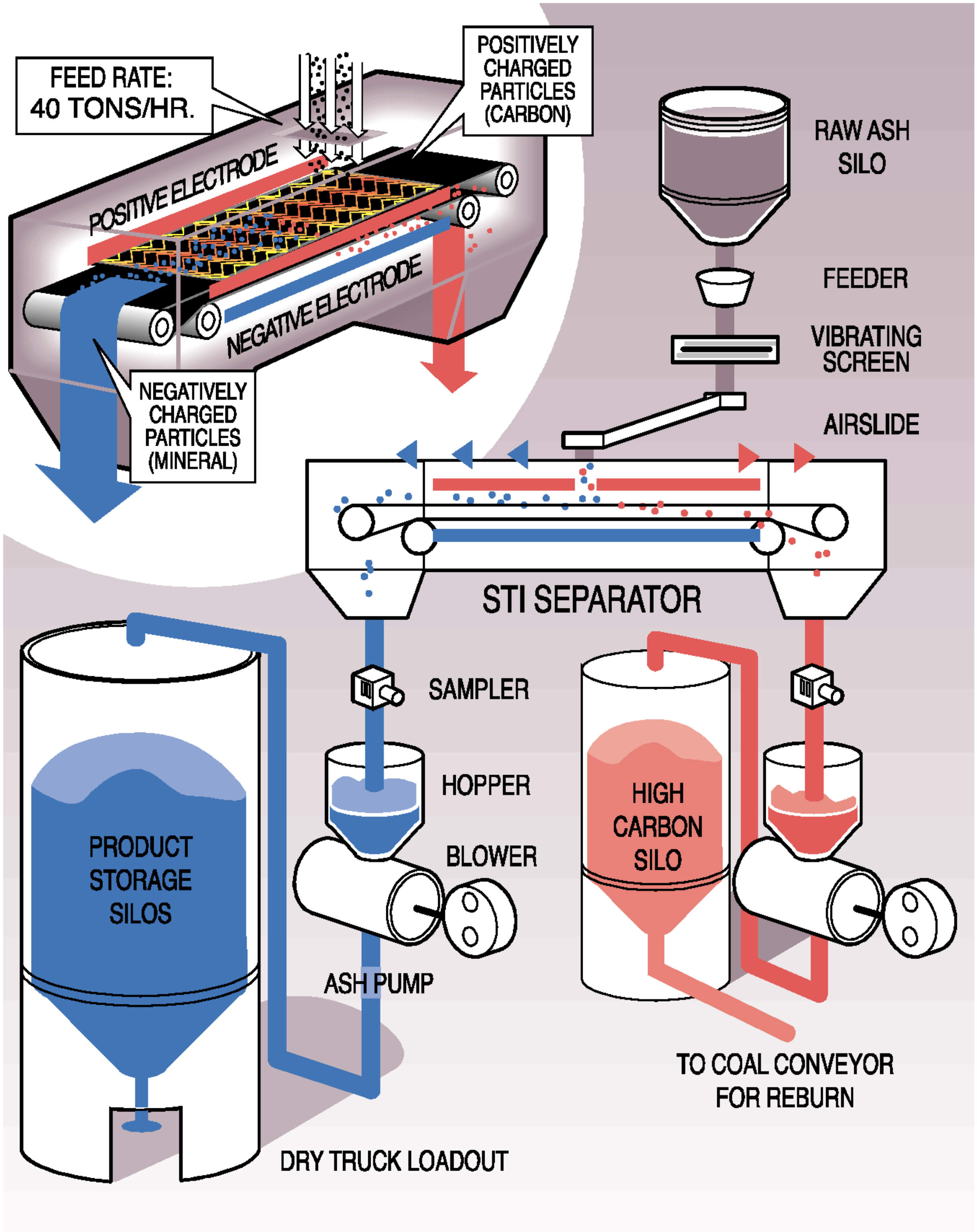


**Figure 2-2**
**Overview of STI Process**

The STI separator is relatively compact. A machine designed to process 40 tons per hour is approximately 30 feet long, 5 feet wide, and 9 feet high. The required balance of plant consists of systems to convey dry fly ash to and from the separator. The compactness of the system allows for flexibility in installation designs.

Capital costs are site-specific. The installation at Roxboro utilizes the existing four 3000-ton storage silos on site. STI engineers designed a system which houses two STI separators, the balance-of-plant systems, and two product loadout stations within these 44-foot diameter silos. Wet truck loadout stations from two of the silos and the full storage volume of 12,000 tons of material were preserved. According to STI, the capital investment for installing the systems was minimized by this method: the first separator and necessary conveying equipment and a loadout station were installed for $3.1 million. A second separator was added along with a second truck loading bay in 1998 for an additional $2 million. The processing capacity of the CP&L Roxboro facility is over 450,000 tons annually (4).

### 2.3.3.2 CAER Triboelectric Ash Beneficiation System

The Center for Applied Energy Research at the University of Kentucky, with EPRI support, has developed a dry beneficiation technology based on pneumatic transport triboelectric principles. The process, which separates high carbon ash into high and low carbon fractions, has the potential for high efficiency removal of carbon at low cost and with no secondary waste products. An integrated, proof-of-concept processing facility has been constructed that has an estimated feed rate capacity of 500lb/hr (~ 227 Kg/hr) (22). A schematic is shown on Figure 2-3.

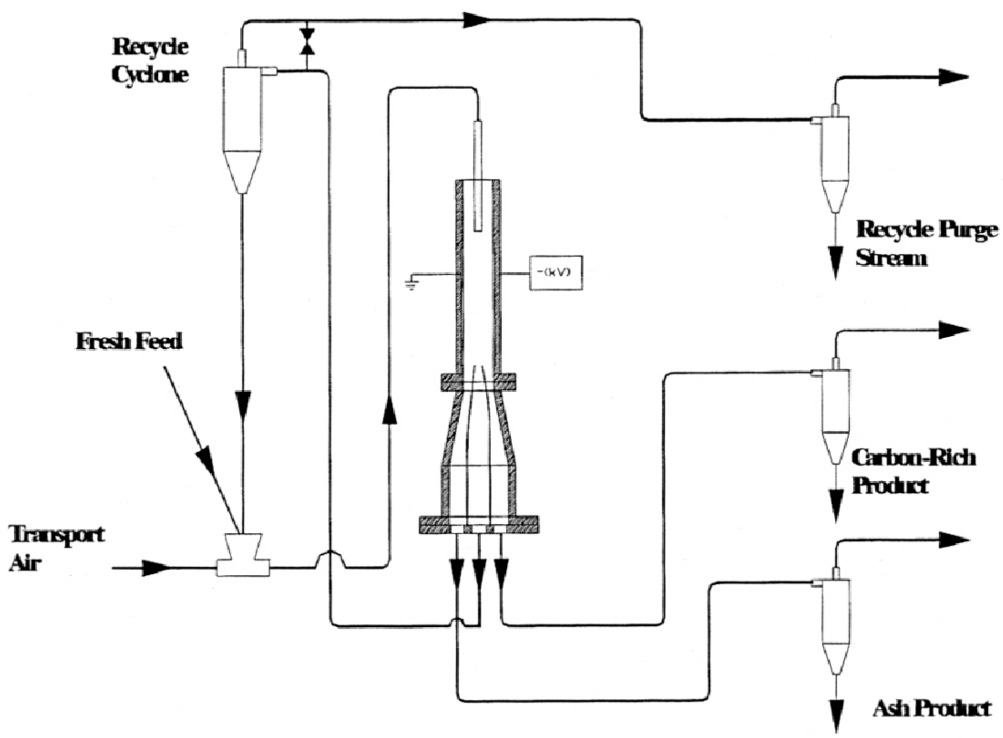


**Figure 2-3**
**Schematic of the Proof of Concept, Pneumatic Transport, Triboelectric Separator System**

The Triboelectric Ash Beneficiation System (TABS) device separates carbon from ash by electric forces on the ash particles imposed in a direction perpendicular to the flow of the transport air. In the pneumatic ash transport system, tribocharging is affected by particle-particle and particle-wall contacts. The electrostatic separation chamber consists of parallel electric plates across which DC voltage is applied, producing an electric field strength between 100-200 kV/m.

Fly ash is typically fed to the tribocharging unit with a screw feeder. Ash is pneumatically transported into the separation chamber where the velocity is maintained between 10-20 m/s. The particle laden flow is separated in three streams: a high carbon content product near the negative electrode, a low carbon content product near the positive electrode, and a stream that contains about the same carbon as the original ash at the middle of the separator. These streams are sent to individual silos with the exception of middle product, which is sent to a cyclone and recycled to the original stream. The baghouses on the silos are connected to an ID fan to overcome the pressure drop in the system.

Full-scale TABS systems will be built by running smaller TABS modules in parallel. The assembly of 6 modules required for a 250 MW size power plant is shown in Figure 2-4.

A comprehensive economic assessment examined the costs of constructing and operating a completely new pneumatic transport, dry triboelectric ash beneficiation system at or near a utility. The feed rate capacity of the separation system was 10.2 ton/hr and was designed for fly ash from a 250 MW coal-fired power plant. The key findings were that: the process will be economical relative to disposal as long as the plant has to pay less than $6.6/ton to a buyer for transportation costs; a low LOI ash yield of 42 percent or higher will be required to make the process commercially successful if a utility spends approximately $10/ton for disposal; a low LOI ash yield of only 15 percent will be required to make the process commercially successful if a utility spends approximately $30/ton for disposal; and, the installation of the process will reduce the levelized cost of electricity by 0.16 mil/kWh if disposal costs are reduced by 60 percent (6, 7, 13, 21).

The TABS technology is being commercialized by a partnership of TriboFlow Separations and Solvera Controls. The first full-scale installation was accomplished in collaboration with Boral Material Technologies and Georgia Power/Southern Company at the Jack McDonough Plant in Atlanta, Georgia (15).

The demonstration system contains all components needed for ash transport, product generation and collection, and control of operational parameters. The separator module began operation in February 2001. It contains parallel plate electrodes which have a rated throughput of greater than $1.1 \times 10^5$ kg/m$^3$, i.e. for an equivalent volume of 1 m$^3$, over 110,000 kg (121 tons) of ash would be able to be processed per hour of operation. The sponsors report that performance is as good as or better than that measured for operation of the prototype and smaller-scale systems at the University of Kentucky.

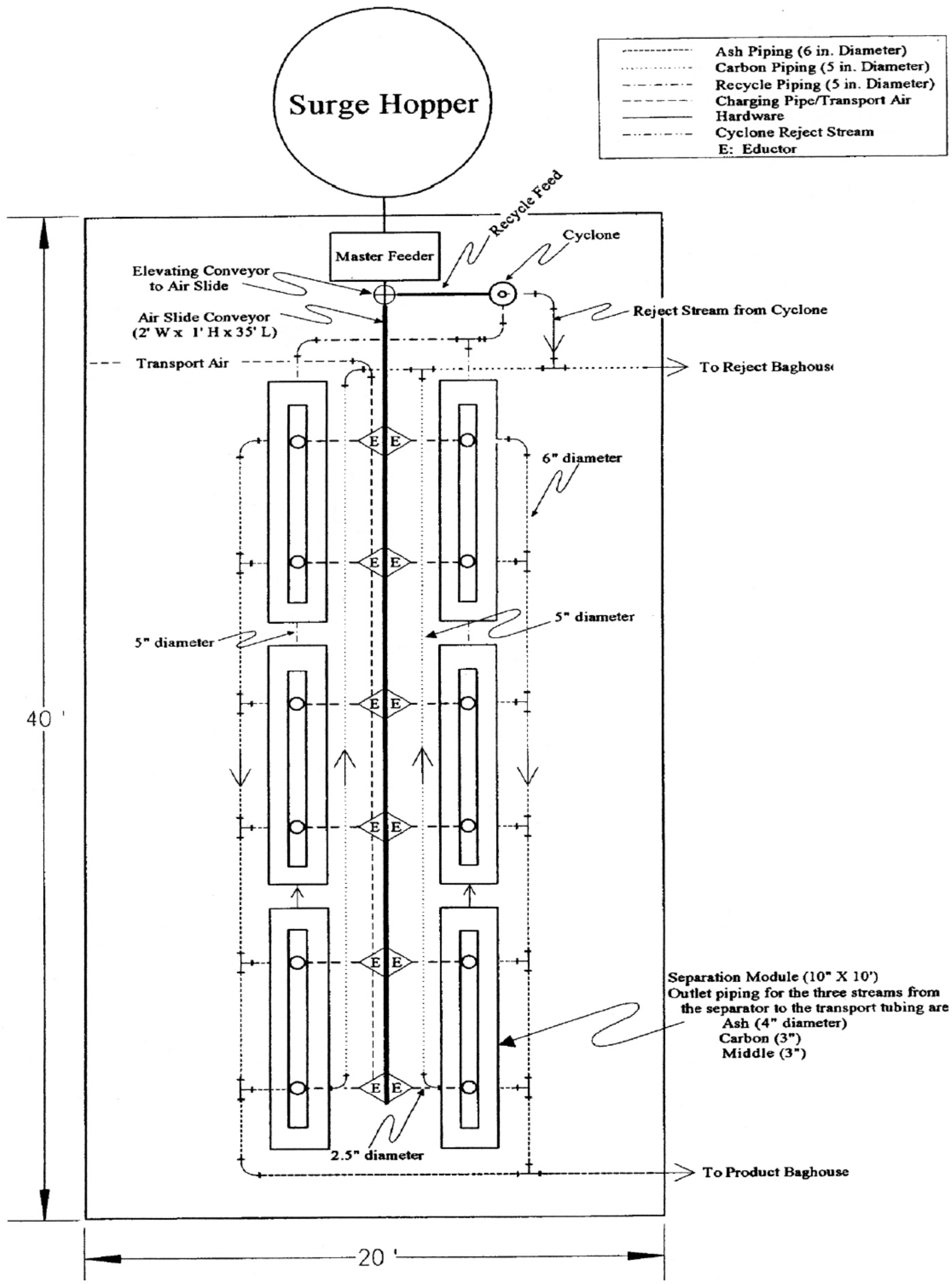


**Figure 2-4**
**Assembly of Six Modules for a 250 MW (10.2 t/h ash) Power Plant**

#### 2.3.3.3 Sortech Separation Technologies Ltd.

Sortech Separation Technologies Ltd., Israel, has developed a patented process of dry powder separation. The Dry TriboMechanical TriboClassifier is based on interaction of different forces (centrifugal, frictional and gravitational) applied to the powder's particles that are on the inner surface of a conical bowl rotating around its vertical axis. This method allows separation of particles to two fractions according to their size and their friction coefficient with the rotating inner surface of the bowl.

Initial tests using the TriboClassifier show that it is possible to separate the ash with a wide range of initial fineness and LOI with resulting fine fraction that conforms to ASTM C 618 and AASHTO M 295 specifications. The coarse fraction can be utilized in Portland cement kilns to save energy, by using the higher LOI content. The relatively small dimensions of TriboClassifier, its low power consumption and ecological friendliness contribute to the cost competitiveness of this new technology. It is estimated that total separation costs are about $4 per metric ton. Presently, Sortech Separation Technologies Ltd. is engaged in negotiations with the Israeli Electric Company to establish a pilot unit for fly ash beneficiation (8).

#### 2.3.3.4 NETL Dry Separation of High LOI Ash

The U.S. Department of Energy, National Energy Technology Laboratory is conducting an in-house research effort to develop technologies for separation of the inorganic and unburned carbon phases in pulverized coal combustor fly ashes. The studied concept employs dry physical techniques – ultrasonic sieving and triboelectrostatic separation – that maximize the yield of products while reducing the quantity of waste produced. Valuable products such as unburned carbon with a low ash content and ash with a low carbon content are produced.

Sieving fly ash capitalizes on the tendency of carbon and mineral to have different particle size distributions within fly ash. Carbon and mineral particle size distributions can be widely different and may exhibit a clear trend. For instance, fly ashes sieved through a 325 mesh screen in NETL tests exhibited a measurable reduction in LOI, but this is not true of all fly ashes.

The types of physical separation techniques that were investigated include a dry ultrasonic sieve and a parallel plate tribo-separator. The study involved the dry separation of a variety of coal fly ash samples from commercial power plants that contain varying amounts of unburned carbon. Researchers report that the combination of ultrasonic sieving and triboelectrostatic separations provided effective separation in producing an ash-rich stream for concrete additive applications as well as a carbon rich stream under some circumstances.

A deblinding sieving system, model RBF equipped with 100 (149 microns), 200 (74 microns) and 325 (44 microns) - mesh screens manufactured by MM Industries, Inc., that utilized high speed gyration (up to 3450 RPM) and ultrasonic energy (130 watt x 40 KHz transducers) was used for the size separation.

The parallel plate separator used consists of a venturi feed system driven by pressurized nitrogen gas, an injection nozzle and a high voltage separation section. The fly ash particles pass through the venturi feeder and become charged in this turbulent flow zone by contact with the copper tubing and with one another. These charged particles then are forced out the nozzle in a ribbon of entrained particles approximately 7.62 x 0.3175 cm. This plume of particles is directed between two parallel charged plates 15.24 cm long and 7.62 cm apart. For fly ash separations this unit is operated ± 25,000 volts on the separator plates. The positively charge unburned carbon particles are attracted to the negative electrode and the negatively charged mineral particles are attracted to the positive electrode. A splitter is placed 15.24 cm downstream from the nozzle to separate the unburned carbon rich and ash rich fractions and direct them to two collection cyclones. The entire separator is swept with laboratory air by applying vacuum to the outlets of the collection cyclones. Sweep flow enters the separator through flow straighteners around the nozzle to control the flow in the separator section. This separator has a capacity of about 8 Kg/hr in continuous operation and can be used in the batch mode using as little as 100g fly ash feed. The recovery efficiency of the cyclones is typically greater than 95 percent (20).

### *2.3.4 Wet Separation (Flotation)*

The application of ultrasonic energy to mineral slurries has been the subject of numerous studies to improve the various stages of mineral processing including liberation, reagent dispersion, and dewatering. Applying this method to carbon rich coal ash has shown that ultrasonic energy effectively fractured the carbon particles and reduced the size distribution of the carbon while releasing the fine ash particles trapped in the carbon matrices (12). If the dispersent is water it would liberate ammonia; however, this might not be optimal for carbon removal because the ash would then need to be dried for sale in concrete.

Mineral Resource Technologies (MRT) and Michigan Technological University (MTU) finalized an agreement that permits MRT to offer MTU’s advanced carbon removal technology process for power plant coal fly ash. The agreement encompasses the dominant existing US patents using a wet process for fly ash enhancement. This process involves four steps. First, a slurry mixture is formed of a fly ash material and a liquid. Second, gravity is used to separate and collect a first-material fraction of the fly ash, having a density less than the liquid. This is done by skimming off the flotation slurry material. The third step separates the unburned carbon from the remaining slurry components, by adding a frothing agent and an effective amount of an oil that has a carbon chain greater than octane. The oil coats the unburned carbon, forming hydrophobic carbon materials. Air is introduced into the system for frothing the slurry mixture. The hydrophobic, unburned carbon froths to the surface and is removed by skimming off the frothing layer. The final step involves collecting the remaining fraction of fly ash. The products are then dewatered and dried for shipment to their respective markets.

#### 2.3.4.1 Care Fuel-Float™ Process

The overall concept of Fuel-Float™ is to process the ash that has accumulated in coal burning utility ponds and landfills to recover unburned carbon as a fuel source. Recovering carbon from stored ash does not require the utilities to alter their ash disposal practice. It also avoids costly plant modifications and the construction of temporary ash storage facilities, as in the case for a dry process, and adds significantly to available disposal capacity.

The Fuel-Float™ approach is relatively simple and relies on proven components. It includes: the separation of the ash into narrow size ranges via hydraulic classification; the recovery of a coarse carbon product via gravity (or spiral) concentration; the recovery of a coarse lightweight aggregate as a by-product of the hydraulic classifier; and the recovery of a fine carbon product via froth flotation. The key innovative features of the approach include a patented flotation reagent system that results in the low cost recovery of the carbon by flotation and a unique patented processing configuration that integrates hydraulic classification with flotation and centrifugal classification, which allows the concentration of pyrite for ash so contaminated.

The reject stream from recovering coarse carbon may be marketable as a lightweight aggregate or "block sand", while the reject stream from recovering fine carbon may be marketable as a pozzolan in concrete.

A technical and economic assessment was made of the feasibility of recovery of carbon fuel from coal ash ponds. Samples from two different utilities were investigated. Hydraulic classification was used to produce a –200 mesh froth feed, two midrange size fractions (~50 x 100 mesh and 100 x 200 mesh) and a coarse (+50 mesh) underflow reject. An aggregate for block production was produced as well. Both of the "middlings" were sent to the spiral classifiers. The spirals produced an optimum carbon fuel product on a combined feed of both middlings. Light frothy ash was a problem to remove in the spirals for some samples. Flotation release analysis was performed on all substrates, and a wide range of flotation behavior was found. There were strong differences in flotation reagent requirements between the two utility ponds as well. The spirals produced carbon grades typically of about 50% with maximum grades of 70%. Carbon grades from flotation were typically lower. A heating value target of 6000 Btu/ton was easily achieved for the combined spiral and froth product for all substrates investigated.

An economic evaluation of this application at a power plant located in the Southeastern U.S. was made by the sponsors. A value of $0.83 per million Btu was assumed for the ash carbon, which is about half the cost of coal as delivered to that plant (i.e.$40/ton for 12,500 Btu/lb coal or $1.60/million Btu). A value of $12 per ton of by-product aggregate was assumed. This is $1 below the price for which it is currently sold from this plant. Applicable utilities and labor costs were used. Capital plant costs and installation factors were all derived from the mineral industry practice. The economic analysis did not include avoided cost consideration or complex tax or investment strategies.

Three cases were assumed representing three different regions of the pond. These are: a high carbon, low aggregate case for an area with finer ash, a higher spiral carbon, higher aggregate case for an area of the pond with intermediate materials, and a high aggregate, lower carbon case for the coarsest area of the pond.

The use of conventional mineral processing equipment and circuitry helps to reduce the overall capital costs of the Fuel-Float™ technology, approximately $1.5 million dollars for a case using some reconditioned equipment. This capital cost along with the other assumptions as listed above results in a required total feed capacity of 50-60 tons/hr to achieve economic viability for the process. Although all three scenarios produced profit, the best strategy would probably be to maximize spiral carbon and aggregate, and minimize reagent expense, at least until the plant is amortized.

The overall economics are sensitive to substrate, in particular to the grade of the +100 mesh material (carbon recovery via spirals) and the reagent demand of the target froth grade. (23)

## 2.4 Ammonia Removal

The status of ammonia removal processes are described in a recent EPRI report (11). The report also describes research in this area. Most research involves thermal destruction methods such as carbon burnout (CBO), microwave, combinations of moisture and a chemical admixture using alkali, and conventional thermal destruction. Some general observations summarized in recent technical papers are: (1) the thermal destruction processes appear to suffer a cost disadvantage due to the price of natural gas (the typical amount mentioned was \$3 to \$4/ton ash for energy costs); (2) combination processes, like CBO, have the potential to remove both $NH_3$ and carbon; and (3) processes that add alkali salts or other constituents to the ash or concrete mixer raise questions about the impact of the concrete engineering properties, such as the risk of flash set of the concrete or corrosion problems with rebar.

# 3
# CONCLUSIONS

Combustion modifications, such as low-NOx burners or overfire air, and post-combustion NOx control technologies, such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) systems, at electric power plants may increase the levels of carbon and other residuals in the fly ash. As a result, ash sales may decline, particularly in product-sensitive markets such as the cement and concrete market and the filler market.

There are two general approaches to improve ash quality: source control and beneficiation.

Unburned carbon content in the ash can be controlled at the source by optimizing the combustion processes to maximize fuel burnout – an approach that has the added benefit of improving combustion efficiency. Another option at the plant involves selective collection of low UBC ash from designated hoppers in the dust collection system. However, even in the best optimized circumstances, NOx reduction technologies will produce additional carbon and other contaminants in the coal ash, and the only remedial solution will be to attempt to upgrade or “beneficiate” the ash by removing or reducing the contaminants. This is an approach which is used extensively in the mineral processing industry and has also been used successfully to upgrade “problem” fly ashes for sale.

There are several ash beneficiation technologies, some of which have reached or are nearing commercialization. These include: screening, grinding, air classification, carbon burn out, electrostatic separation, and carbon flotation. In addition to producing concrete “specification” ash from low-NOx sources, carefully selected beneficiation also opens up opportunities for the generation of new and value-added products, such as fillers (e.g. for plastics and other composites), enhanced pozzolans, and carbon products.

Despite the technological advances of recent years, selective collection of ash from the electrostatic precipitators, and the use of air classification systems, continue to be the most prevalent forms of ash beneficiation in use today. The more advanced processes are receiving greater attention, especially power plants where both disposal costs and revenues from ash sales are moderate-to-high.

The carbon burn-out system is receiving much attention due to its ability to remove both carbon and ammonia, but costs have prevented implementation in some market areas. The triboelectric separation processes are also promising, with development still ongoing to reduce costs.

# 4
# REFERENCES


1. 1999 Coal Combustion Product (CCP) Production and Use (Short Tons), ACAA, Alexandria, VA: 2000.

2. Assessment of Impacts of NOx Reduction Technologies on Coal Ash Use, Volume 1: North American Perspective, EPRI, Palo Alto, CA: 1996. Report TR-106747-V1.

3. Assessment of Impacts of NOx Reduction Technologies on Coal Ash Use, Volume 2: European Perspective, EPRI, Palo Alto, CA: 1997. Report TR-106747-V2.

4. Bittner, James D. and Gasiorowski, Stephen A., "*Commercial Beneficiation of High LOI Fly Ash: 1 Million Tons of Processed Ash Delivered*", Proceedings: 14th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 2001. Report 1001158-V1.

5. Cornelissen, H.A.W., "*Micronized Fly Ash a Valuable Resource for Concrete*", Proceedings: 12h International Symposium on Coal Combustion By-Products (CCB) Management and Use, EPRI, Palo Alto, CA: 1997. Report TR-107055-V2.

6. Dry Triboelectric Separation of Carbon from Fly Ash: Proof of Concept Testing, EPRI, Palo Alto, CA: 1977. Report TR-109016.

7. Economics of Triboelectric Ash Beneficiation System, EPRI, Palo Alto, CA: 1999. Report TE-113673.

8. Eiderman, B., Voskoboinik, M., Levy, H. and Shechtman, J., "*Fly Ash Beneficiation with Dry TriboMechanical Classification*", Proceedings: 14th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 2001. Report 1001158-V1.

9. Frady, T., and Hay, P., "*Carbon Burn-out at the Wateree Station of South Carolina Electric and Gas*", Proceedings: 13th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 1999. Report TR-111829-V1.

10. Giampa, Vincent M., "*Ammonia Removal from Coal Fly Ash by Carbon Burn-Out*", Proceedings: 14th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 2001. Report 1001158-V1.

11. Golden, Dean M., "*Impacts of Ammonia Contamination of Fly Ash on Disposal and Use*", EPRI, Palo Atlo, CA: 2001. Product ID 1004609.

12. Hobbs, A. D., Groppo, J. G., Graham, U. M., and Robl, T. L., "*Effect of Ultrasonic Energy on Products Recovered from Fly Ash by APT's Fast Float Process*", Proceedings: 13th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 1999. Report TR-111829-V1.

13. Investigation of Ammonia Adsorption on Fly Ash and Potential Impacts of Ammoniated Ash, EPRI, Palo Also, CA: 1999. Report TR-113777.

14. Keppeler James G. and Frady, Sr., W. T., "*Carbon Burn-Out, Commercialization and Experience Update*", Proceedings: 14th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 2001. Report 1001158-V1.

15. Lockert, Charles, Lister, Robert and Stencel, John, "*Commercialization Status of a Pneumatic Transport, Triboelectrostatic System for Carbon/Ash Separation*", Proceedings: 2001 Unburned Carbon Conference, U.S.D.O.E., NETL, Pittsburgh, PA.

16. Mainieri, John, "*CCP's and the Filler Industry*", Educational Program for Managers of Coal Combustion Products (CCPs), ACAA, Alexandria, VA: 2000.

17. Market Opportunities for Fly Ash Fillers in North America, EPRI, Palo Alto, CA: 1990. Report GS-7059.

18. Matsufuji, Y., et al, "*Studies on Properties of Concrete with Ultra Fine Particles Produced from Fly Ash, Silica Fume, Slag and Natural Pozzolan in Concrete*", Proceedings: International Conference, ACI SP 132, Istanbul: 1993

19. "*New Technology Transforms Coal Fly Ash to Mineral filler*", Mining Engineering, October, 1996.

20. Soong, Yee, Schoffstall, Michael R., and Link, Thomas A., "*Dry Separation of High LOI Fly Ash*".

21. Stencel, J. M., Ban, H., Li, T. X., and Neathery, J. K., "*Beneficiation of Combustion Fly Ash by Triboelectrostatic Techniques after Carbon Burnout*", Proceedings: 13th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 1999. Report TR-111829-V1.

22. Triboelectric Fly Ash Beneficiation, Phase III Status Report, EPRI, Palo Alto, CA: 1999. Interim Report TE-114556.

23. Groppo, Jack, Robl, Tom and Rathbone, Robert, " *The Recovery of High Quality Fuel from Ponded Utility Coal Combustion Ash*", Proceedings: 14th International Symposium on Use and Management of Coal Combustion Products (CCPs), EPRI, Palo Alto, CA: 2001. Report 1001158-V1.

*Target:*
*High-Value Uses of Fly Ash*

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