Coal Ash Use Study for Duke Energy, North Carolina

Anne Oberlink¹, Tom Robl¹, Bob Jewell¹, Ken Ladwig², Maria Guimaraes², Greg Hebeler³, Nortey Yeboah³

¹ University of Kentucky Center for Applied Energy Research, 2540 Research Park Drive, Lexington, KY 40511
² EPRI, 3420 Hillview Avenue, Palo Alto, California, 94304
³ Golder Associates Inc. 3730 Chamblee Tucker Road, Atlanta, Georgia 30341

KEYWORDS: Coal Ash Study, CCP uses, CCP markets, Duke Energy

ABSTRACT

The University of Kentucky Center for Applied Energy Research, along with the Electric Power Research Institute (EPRI) and Golder Associates, performed a coal ash study for Duke Energy. Duke Energy is a principal producer of electricity in North and South Carolina, with approximately 10 GW of coal-fired generation.

As part of the legislation establishing requirements for the management of CCP’s, the state of North Carolina included a provision to explore options for the beneficial use of CCP’s generated at North Carolina power plants to reduce the amount of CCP’s requiring disposal. The North Carolina Coal Ash Management Act of 2014 required all generating facilities owned by a public utility that produces coal combustion residuals and coal combustion products to perform a study of CCP uses and markets for submittal to the Environmental Management Commission and the Coal Ash Management Commission on or before August 1, 2016. The project completed the following components required by legislation:

1. Conduct a market analysis for the concrete industry and other industries that might beneficially use CCR’s and CCP’s;
2. Study the feasibility and advisability for installation of technology to convert existing and newly generated CCP’s to commercial-grade CCP’s suitable for use in the concrete industry and other industries that might beneficially use CCP’s;
3. Examination of all innovative technologies that might be applied to diminish, recycle or reuse, or mitigate the impact of existing and newly generated coal combustion residuals.

BACKGROUND AND APPROACH

As part of the legislation establishing requirements for the management of CCP’s, the state of North Carolina included a provision to explore options for the beneficial use of CCP’s generated at North Carolina power plants to reduce the amount of CCP’s requiring disposal. The research was divided into three phases that parallel the studies required by legislation:

Phase 1 – Market Study: the market study focused on well established, conventional products and markets, for example concrete, cement, road construction, and reclamation.
**Phase 2 – Beneficiation Technologies:** this phase explored commercial beneficiation technologies to improve ash characteristics for use in conventional applications assessed in Phase 1.

**Phase 3 – Alternative and Innovative Technologies:** this phase identified products and technologies that currently have limited or no market in the United States.

**PHASE 1:**

The Phase 1 Market Study was focused on well established, conventional products and markets, like concrete, road construction, land application, and structural fill. The approach to the market study consisted of coordinating with Duke to identify coal ash inventory and annual production across all North Carolina power plants and CCP sites, summarizing current coal ash use across all of Duke’s North Carolina power plants, defining the primary market area, identifying key market drivers, identifying potential key coal ash marketing and beneficial use opportunities within the market area, assessing each CCP site for current and future coal ash beneficial use, and identifying key opportunities for improved use across all CCP sites.

The first step for the market study was to define the market area. North Carolina was considered the primary market area focus, followed by adjacent states Georgia, Tennessee, South Carolina, and Virginia. These states were considered a secondary market, as competition from other CCP producers in those states and increasing transportation distances were expected to reduce the marketability potential.

Primary markets that were identified for ash beneficiation were concrete and concrete products, blended cement and feed for clinker, solidification and stabilization use, CCP Ponds closure caps, mining applications, structural fills and embankments, and road base/sub-base use, as well as ash use for closure of existing impoundments.

For Phase 1, potential market demands were based on the assumption that each market sector maximizes its full potential for beneficial use of CCP. The potential market demand for fly ash in ready-mix concrete is based on an annual production rate in North Carolina of 7.6 million cubic yards (2014, CRMCA) weighing approximately 2 T/yd³, with a typical mix design using approximately 600 lbs of total cementitious material per cubic yard. The 0.450 to 0.700 MT/yr range is based on 20 to 30% replacement of Portland cement with fly ash by weight for the 2014 CRMCA production value.

For the precast concrete market, potential demand estimates are based on reported actual mix designs from plant interviews in North Carolina, with annual per plant production ranging from approximately 13,000 to 25,000 cubic yards/year, and with 150 to 200 lbs of fly ash used per cubic yard across the 14 precast facilities in North Carolina.

The potential market demand for fly ash and bottom ash in cement production is based on total annual production (9.3 MT of cement) for the 6 cement producing plants within the North Carolina expanded market area (2 in GA, 2 in SC, 1 in TN, and 1 in VA), although none of the kilns are located in NC. Fly ash typically accounts for 6% of the finished product when beneficially used this way, while bottom ash typically accounts for 3% of the produced cement/clinker.

The available volume for use at coal fired generation sites for either solidification/stabilization of wastewater or as a soil replacement in closure configurations are very site specific. Beneficial use of CCP’s in closure configurations as a soil replacement to provide positive drainage and to limit infiltration in closure covers ranges based on the size of the impoundment being closed.
The available fill volume for all of the fill applications will vary based on the applications. For the purpose of this market study, a range of 1 to 10 MT per mine was determined to be a reasonable upper limit to describe the potential fills available.

Key drivers for North Carolina coal ash interact in complex ways and necessitate a proactive marketing effort to optimize beneficial use of Duke’s coal ash. Market drivers that were considered were:

**Supply:** this included the inventory of stored CCP as well as the CCP production stream. Without a reliable and consistent supply, it would be difficult to develop and grow markets.

**Demand:** demand arises from industries that currently use CCP as well as industries that may develop around the use of CCP

**Quality:** for some beneficial use applications, the quality of CCP is critical and higher quality material may generate greater demand and higher prices

**Price:** until the recent regulatory changes in the industry, on-site storage and disposal of coal ash was relatively inexpensive, such that pricing of CCP to potential users was not typically incentivized. With the new regulatory environment, the avoided cost of ash disposal may allow for increased potential beneficial use, this is especially true if stored CCP required to be excavated and transported to off-site storage can be diverted to new and existing beneficial use industries.

**Transportation:** CCPs are a bulk material of generally low to moderate value, and transportation costs have a large impact on their value and marketability. As such, plant specific evaluations have concentrated on areas within a 50 mile radius of each plant.

**Regulatory/Public Perception Risk:** The risk of future regulatory changes can impact some beneficial use and/or regulations could encourage certain use opportunities and markets. Public perception also influences the market, either positively or negatively, and will likely continue to do so into the future.

**Competition:** Most if not all CCP generators are looking for markets to beneficially use both newly produced and stored CCP, creating a large but competitive market.

**Phase 1 Conclusion:** Although specific details of the Phase 1 Market Study cannot be discussed, it was found that sales of CCP’s into products are generally the preferred use for ash, with fills and other uses providing a secondary option for beneficial use. The existing ash use markets in North Carolina includes: ready-mix concrete, precast concrete, concrete block, soil replacement in required CCP closure caps, solidification/stabilization of wastewater, structural fills for transportation and other infrastructure, and mine reclamation fills.

**PHASE 2:**

The objective of Phase 2 was to provide a review and assessment of technologies that are currently available for beneficiating coal combustion fly ash and improving its marketability.

This phase focused on beneficiating ash for use in ordinary Portland cement (OPC) concrete and mortars. OPC concrete is the most important and valuable use for conventional fly ash. Fly ash improves strength, durability and resistance to chemical degradation of concrete, decreases water demand, and improves workability (EPRI 2007). Among with the environmental benefits of using fly ash in concrete are reduced carbon footprints and lower energy demand compared to OPC concrete. Of particular importance in North Carolina is its ability to control alkali silica reaction (ASR) which affects many aggregates.
Fly ash samples were collected from several of the Duke plants and tested for index characteristics. These results were used to provide a preliminary indication of ash quality and the need for beneficiation. The primary technologies for fly ash beneficiation were reviewed and described. The technologies reviewed include only those that are commercially available, and can be specified, fabricated, delivered, and installed without any further research or development work: Modifying Power Plant Operations, Chemical Treatment or Passivation, Size Classification, Electrostatic Separation, Thermal Processing, and Integrated Technologies.

Power plants generally have not been designed and operated to optimize fly ash quality for end use applications such as OPC concrete. As a result, some fly ash does not meet the minimum specifications for concrete contained in ASTM C618 (ASTM International 2012). The primary reason for beneficiating fly ash is to improve its quality so that it can be used in concrete. Issues like carbon content, fineness and uniformity, and ammonia/sorbent impacts can be addressed by fly ash processing and beneficiation. Samples were collected from each of the plants by Duke and sent to the University of Kentucky CAER for analysis, looking specifically at testing for Loss on Ignition (LOI), Particle Size Analysis, X-Ray Fluorescence (XRF), and X-Ray Diffraction (XRD). In most cases a dry sample directly from production was not obtainable and instead a recent production ash sample was collected from a landfill. A second sample was collected from a pond or basin.

Phase 2 looked at the most common technologies for beneficiating production fly ash collected dry at the power plant. Costs and existing installations are also provided, along with some advantages and disadvantages of the technologies.

**Power Plant Operating Procedures:** The least expensive method for ash beneficiation is enhanced quality control at the power plant. This is accomplished by monitoring of the various ash streams for quality, and segregating ash. The LOI in the ash is sometimes found to vary as a function of load; the lowest LOI produced during constant load and higher LOI during periods of increasing or decreasing load. Large coal-fired plants typically consist of 2 to 6 individual units which may vary in age and design, resulting in variation in ash quality. By selectively collecting and segregating ash from selected units or electrostatic precipitator fields, a higher quality ash can sometimes be recovered for sale.

Modifying coal source and boiler operating conditions are another means of improving ash quality. Some coals produce a higher quality ash than others due to their chemical and combustion characteristic. Boiler operations such as temperature and residence time can affect the LOI of the resultant ash. However, fuel selection and boiler operations have a major impact on efficiency of the plant and the cost of electricity, and these types of modifications are often difficult to justify based on ash sales.

Selection of technologies to meet evolving air emissions control regulations can also impact fly ash use. For example, alkaline sorbents are used for acid gas capture at some power plants. Use of calcium-based sorbents instead of sodium-based sorbents will generally have less impact on the resulting fly ash for use in concrete (EPRI 2014). However, the impact of the sorbent on the fly ash use is only one consideration; cost of the sorbents, their effectiveness in controlling acid gases, and their impacts on ESP performance are also significant concerns. While these practices can improve ash quality, they cannot be implemented at all power plants due to plant design, negative impacts on plant or emission control performance, and costs. While operational controls appear simple to implement, they require careful sampling to understand the variations in ash quality as a function of unit design and combustion cycling, as well as balance of plant impacts.

**Advantages**- Modifying operations at the plant can yield a substantial return for the smallest investment, particularly if the infrastructure for selective collection and storage is already in place, and
the modifications do not impede efficient operation of the plant. As selective collection recovers only a fraction of the ash produced, it may be best suited for plants in small ash markets.

**Disadvantages**- Depending on plant operations, selective collection may still leave a large percentage of the ash requiring disposal. Instituting operational changes to improve ash sales are often met with resistance, due to concerns that they may negatively affect the plant performance.

**Pneumatic or Air Classification**: Pneumatic or air classification uses centrifugal force to selectively separate the coarser fractions of the ash from the finer fractions. This is a well-established technology with many equipment manufacturers, such as Progressive Industries, Sturtevant, Hosokowa-Alpine, RSG, Inc., Williams Crusher, and Metso Minerals to name a few. Air classifiers have been used for many years to control fineness of the fly ash by rejecting coarse ash particles.

There are two different types of classifiers, cyclonic and centrifugal and each has its merits. A typical cyclone classifier uses centrifugal force to separate fine particles from an air stream. The particles enter tangentially into a cylindrical chamber dispersed in an air stream. Centrifugal force pushes the coarser particles to the wall of the cylinder and finer particles spiral to an inner vortex. The air exits from the inner core via an outlet port while the particles slide down the chamber walls and exit the bottom. Devices vary in the feed arrangement and location of fan and other equipment and may or may not have reject wheels or selector blades.

Centrifugal force air classifiers use a rotating disc which generates a centrifugal force. The coarse particles fall to the inside and a fan lifts finer particle thorough rotating selector blades which control the separation or cut point of the product.

**Advantages**- Air classification has been a successful technology with a long history. Air classification equipment has relatively low capital costs, but installation costs can vary widely. Low maintenance costs were also cited by the vendors.

**Disadvantages of Air Classification**- This technology is not consistent or predictable for LOI reduction. If the carbon in the ash is very coarse, which is often the case, some LOI reduction will occur. Air classification produces a coarse reject stream, which can be high in carbon with the potential for being recycled, but often must be landfilled.

**Electrostatic Separation**: Electrostatic separation (ES) is accomplished by exploiting the differences in electrical properties between silicate and carbon particles in the ash. This technique has been employed on a variety of mineral separations for many years. Particles are electrically charged, and depending on their conductivity, will gain or lose electrons and thus become differentially charged. Separation occurs by diverting the particles to electrodes of opposite charge.

The first commercial application of electrostatic separation to fly ash was developed by Separation Technologies, Inc. (STI), now ST Equipment and Technologies (STET) in the 1990s. The ST unit has become the most successful and dominant ES method in ash processing with a long history of operational success from over a dozen installations. In this approach, particle charging is accomplished by inter-particle contact or “tribo”-charging, whereby charges are transferred between particles by differences in electron affinity. Carbon particles, having a lower electron affinity, lose electrons and become positively charged, while the ash particles gain electrons and become negatively charged. Note this is different from the electrostatic separation used to remove fly ash particulates from flue gas, which charges particles by a corona field mechanism.

The technology works by feeding ash from the raw ash silo through a vibrating screen to distribute the ash uniformly into a thin gap (0.635 to 1.9 cm) between two parallel plane electrodes. The particles are
then swept up by a moving open mesh belt and conveyed in opposite directions, depending on their charge. The belt moves particles adjacent to each electrode toward opposite ends of the separator, which is approximately 6.1 m long. The moving belt is the key to this technology as it continuously wipes off the plates as it moves, refreshing the attraction of the plates. Without this, the plates would quickly be blinded from the particles coating them.

**Advantages**- the STET process has a long proven track record of producing large quantities of consistent pozzolan from high LOI fly ash. It has a modest capital cost relative to thermal beneficiation, and is well suited for smaller power plants. The unit is relatively small with modest installation requirements.

**Disadvantages**- the process is not effective at separating fine carbon. It produces a reject stream of 25% or more, typically requiring disposal. The process does little to improve the fineness of the non-carbon portion of the ash. Also, as is the case of all electrostatic technologies, the efficiency can be affected by humidity and the feed to the process must be dry.

**Thermal Beneficiation:** Thermal beneficiation is the use of combustion to reduce the level of carbon in the ash. Thermal beneficiation also eliminates ammonia issues and can improve fineness and uniformity. Successful thermal beneficiation technologies have been commercially deployed for over 15 years and represent more than a million tons of marketable fly ash per year. There are two technologies that can be considered proven: PMI’s Carbon Burnout (CBO) system and the SEFA Group’s STAR® technology.

Both are based upon atmospheric fluidized bed combustion (FBC), which is capable of operating on fuels with low heating values. In FBC, a large inventory of the fuel is maintained which provides a thermal mass that allows low value fuels to sustain combustion.

PMI’s technology is based upon dense phase or “bubbling bed” technology. In this approach the velocity of the fluidizing air is lower than that needed to entrain the ash particles. The ash is expanded into a moving bed of materials with an identifiable free board. Fine materials that are elutriated are collected in a hot cyclone and returned to the bed.

The SEFA STAR® (staged turbulent air reactor) technology is based upon entrained or dilute phase fluid bed technology (Knowles and Fedorka 2015). In this approach the velocity of the air is greater than that needed to entrain the ash particles, and the “bed” is fully expanded. Supplementary air is added as needed to combust the carbon in the ash. STAR® is a stand-alone unit capable of processing either dry or wet ash. It can beneficiate ash with up to 25% LOI.

**Advantages**- Thermal beneficiation is a proven and highly flexible technology that can operate on a variety of ash types with a wide range of carbon concentrations. It produces an ash that is low or even free of carbon. It also eliminates ammonia from fly ashes impacted by nitrous oxide controls. In addition, the process also produces ash with improved fineness by liberating the very small particles that are trapped in the carbon particles.

**Disadvantages**- Thermal beneficiation is by far the most capital intensive of all the technologies considered. A large facility can cost more than 50 million dollars when all installation and storage costs are included. That level of investment suggests the need to sell several hundred thousand tons of ash per year for 20 or more years to be economically feasible. This generally limits the technology to larger plants with access to large and stable markets, which are expected to provide baseload operations over the 20-year period. Construction of a thermal beneficiation facility may require significant plant modifications and systems integration. Because this is a combustion process, the plants air emissions permits may be affected.

**Chemical Passivation:** Chemical passivation uses chemicals to reduce the activity of the carbon in the ash with regard to air entrainment reagents. This reduces the need to add large or variable amounts of
air entraining agents to the concrete mix. Several passivation methods have been developed and a few are commercially available from large concrete marketers. One approach has been to add low dosages of a “sacrificial chemical” to the ash which react with the active sites on the carbon, neutralizing them. Another approach uses chemicals to encapsulate the carbon. Both result in the ash having less effect on air entrainment, with more predictable results. Successful technologies have been demonstrated by Headwaters (RestoreAir™; Minkara 2015), Boral (Powder Activated Carbon Technology®; Boral 2014), and Fly Ash Direct (Carbon Blocker™; Kabis 2015). SEFA, Inc. stated they have a technology but without a current installation.

**Advantages**- Chemical passivation is a low capital cost solution for marginal ash. Operating costs are in the range of a few dollars per ton of ash for chemicals. This approach can improve a problematic ash and make it more acceptable in the market place.

**Disadvantages**- Early systems suffered from inconsistent distribution of chemicals on ash, which appears to have been largely corrected. This approach has a limited LOI range, as neither ASTM nor the North Carolina Department of Transportation make LOI adjustment for treated ash. Certain types of passivation agents can result in overdosing of air entraining agents at the ready mix plants. Chemical treatment does not lower LOI, so it is not a solution if specification require strict adherence to the ASTM or NCDOT LOI limits.

**Phase 2 Conclusions** - Although specific details of the Phase 2 Study cannot be discussed, it is to be noted that beneficiation represents a significant investment and should be carefully considered based on many factors beyond the scope of this investigation, such as plant-specific operations, economics, company policy, and externalities. The final decision to proceed with a beneficiation technology at a specific plant will require collection of data on the time-varying quality of the ash, working with the vendor to test the technology for specific ashes and operating conditions, working with ash marketers to verify market potential, and working with the power plant personnel to design a plant integration plan. As noted below, the final economic structure is then negotiated with the vendors.

**PHASE 3:**

The objectives of Phase 3 were to identify, categorize, and describe alternative and innovative technologies and products for the use of coal ash. These technologies were defined as products and processes that currently have limited or no commercial markets.

In recent years, there have been a plethora of new, modified, and revived uses of CCPs in the literature and introduced to the marketplace. In this Phase these products and processes were identified, assessed, and organized to facilitate evaluation of their efficacy as viable and sustainable applications. A primary consideration was whether the barriers to increased application of the products and processes are imposed by technology deficiencies or market factors.

The summary below places the technologies presented in Phase 3 into four groups. Overall, the groups progress from lowest investment and business risk to highest investment and business risk, based on the assessment done by UK CAER, EPRI, and Golder. The primary consideration distinguishing the first three groups was technical maturity and market development. The fourth group represents technologies which are either very early stage technologies requiring significant basic R&D and long development time, or products that are developed technically but have failed to gain traction in the U.S. market.

**Group 1: Market-ready Technologies - Low Risk and Small Investment**-

This group included technologies that have penetrated existing markets in the U.S. to some degree, and require no basic research. Some product testing would be required to demonstrate and customize the
applications for Duke’s (or other utilities) ash and market areas. Group 1 technologies include Flowable Fill and Foamed Concrete, Cenospheres and Ultrafine Materials, and Superpozzolans,

**Group 2: Mature Technologies - Moderate Risk and Moderate Investment**-

This group consists of products that are well developed technically and have demonstrated some market potential in the U.S. They do not require basic research, but generally may require some R&D to further develop, test, and/or demonstrate the products. These products are typically entering existing markets for similar materials that do not use ash as a raw material. As such, the primary market development activities are aimed at demonstrating equivalent performance at a lower cost, or better performance at a similar or slightly higher cost. Vendors may be well-established companies, or may be smaller start-ups seeking partnering opportunities. Development of these technologies and products represent a moderate risk and investment to Duke, or other utilities. Group 2 technologies include Manufactured Aggregates, Geopolymers, Masonry Units, and Alternative Cements.

**Group 3: Emerging Technologies - High Risk and Large Investment**-

This group includes products and technologies that have potential for large or high value markets, but will likely require a significant investment in basic research and market development. These are farther from commercialization than Group 2 technologies, and will require more investment to bring to market. Group 3 technologies include Wastewater Stabilization/Solidification, Metal Matrix Composites, Proppants, and Polymer Composites.

**Group 4: Technologies with Limited Near-term Market Potential**-

Technologies in this group may be technology-limited or market-limited. In either case, these are considered the most difficult to commercialize in the short term. Market-limited technologies may be well developed but have shown to date an inability to gain acceptance in the U.S. due to possible underlying market constraints. The technology-limited products are at early stage development and will require substantial R&D investment. They are considered to be at least five to ten years or more from commercial implementation, and may never be economically feasible. This is considered the highest risk group. Group 4 technologies include Autoclave Aerated Concrete, Zeolites and Water Treatment, Metal Recovery (aluminum, gold, and magnesium), Rare Earth Elements (REE) Recovery, Nanotechnology, and Plasma-Arc/Vitrification.

**Phase 3 Conclusion:** Phase 3 was contained information on more than technologies. The results were published by the Electric Power Research Institute (EPRI) under their Technology Innovation Program.

**CONCLUSION:**

The University of Kentucky Center for Applied Energy Research, along with the Electric Power Research Institute (EPRI) and Golder Associates, performed a coal ash study for Duke Energy, following the legislation established requirements for the management of CCP’s in the state of North Carolina. UK CAER, EPRI, and Golder provided a three phase report to Duke Energy based on these guidelines that consisted of: a Phase 1 Market Analysis for the concrete industry and other industries that might beneficially use CCR’s and CCP’s; a Phase 2 study of the feasibility and advisability for installation of technology to convert existing and newly generated CCP’s to commercial-grade CCP’s suitable for use in the concrete industry and other industries that might beneficially use CCP’s; and a Phase 3 examination of all innovative technologies that might be applied to diminish, recycle or reuse, or mitigate the impact of existing and newly generated coal combustion residuals.
REFERENCES:


