PHASE 1 MARKET STUDY SUMMARY

As part of the North Carolina Coal Ash Management Act of 2014 (CAMA), all generating facilities in North Carolina owned by a public utility that produce coal ash are required to perform a study of coal combustion product (CCP) uses and markets, for submittal to the Environmental Management Commission and the Coal Ash Management Commission on or before August 1, 2016. The Electric Power Research Institute (EPRI) teamed with the University of Kentucky Center for Applied Energy Research (UK CAER) and Golder Associates to perform research on CCP use markets and technologies and provide technical support for Duke’s efforts to evaluate increased CCP use as specified under the legislation.

The research was divided into three phases that parallel the studies required by the CAMA legislation:

- **Phase 1 – Market Study.** The market study focused on well-established, conventional products and markets, such as 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 a limited market, or no market, in the United States.

This report provides the results of the Phase 1 market assessment. The objective of Phase 1 is to provide an evaluation of current market potential and opportunities for increasing use of Duke’s coal ash in those markets. Fly ash is the focus of this assessment because it represents the largest available CCP stream for increased use. Duke uses nearly all of their flue gas desulfurization gypsum in the wallboard market.

**Duke North Carolina Coal-Fired Generation Portfolio**

Duke has 14 total coal-fired generating facilities in North Carolina (7 active and 7 retired/converted) that were evaluated as part of this study (Figure ES-1). The coal-fired units at Asheville are scheduled for retirement by 2020. Ash production from the seven operating plants in 2015 was 1.58 million tons. Production of ash is concentrated primarily at three large plants: Belews Creek, Marshall, and Roxboro.

In addition to production ash, an estimated 158 million tons of coal ash is stored in ponds and landfills across Duke’s 14 North Carolina coal plants, with 124 million tons at the active plants and 34 million tons at the retired plants (Figure ES-2). Most of the stored ash is in basins, with a smaller amount in landfill storage. Allen, Belews, Marshall, and Roxboro have the largest stored volumes.
Figure ES-1
Locations of Duke North Carolina active (blue) and retired (green) coal-fired generating plants

Figure ES-2
Estimated coal ash inventory stored at Duke North Carolina plants
North Carolina Ash Use Market

Market Drivers
As with any product, coal ash has several key drivers that interact in complex ways to impact marketability.

- Supply and Competition
- Demand
- Quality
- Price
- Transportation / Cost to Market
- Regulatory Drivers / Public Perception

Figure ES-3 is a coal ash market map showing the range of supply (production and stored ash) and typical demand (use) locations for North Carolina and the surrounding states.

Supply and Competition
The total amount of combined fly ash and bottom ash produced by Duke at their North Carolina generating stations is expected to be just over 1 million tons in 2016. That is down from just over 2 million tons in 2014 and 1.58 million tons in 2015. The 2016 projected ash generation volumes include the actual production volumes from the first quarter of 2016, which were significantly lower than average ash production due to high natural gas use across Duke’s generation portfolio. The decline in coal ash production at Duke’s North Carolina facilities mirrors the general trend in the United States over the last five years due to plant retirements and competing generation (predominantly an increase in natural gas generation).

Figure ES-4 highlights the seasonality of coal-fired generation and CCP production, with peaks in the winter and summer months. Peak construction demand seasons are typically the spring, summer, and fall, resulting in fly ash oversupply in winter.

Supply locations shown on the map in Figure ES-3 include all active and retired coal-fired generation facilities in North Carolina and the surrounding four states to provide perspective on supply side drivers in the market. Several supply side items of note include:

- Duke is the main producer of CCP in North Carolina, with no significant source competition originating within the state.
- The main population corridor of North Carolina (from Charlotte to Greensboro and Raleigh/Durham) has retained much of its ash production capacity following the recent coal fired unit retirements, predominantly from the Belews, Marshall, and Roxboro plants.
- Surrounding states and markets all have active and retired coal-fired generation facilities creating significant supply competition in the surrounding markets, and possibly entering into the North Carolina market.
Figure ES-3
North Carolina coal ash market map
The Raleigh metro area no longer has a large active producer of ash within 50 miles of the city center, and will not have any coal-fired generation following the planned retirement/conversion of the UNC-Chapel Hill Cogeneration Facility in 2020.

Western North Carolina historically has had less coal-fired generation than other parts of the state and will have no Duke generation after the retirement of the Asheville coal units in 2020.

Recent coal unit retirements have left coastal eastern North Carolina and the adjacent coastal areas of southern Virginia (Norfolk / Virginia Beach) and northern South Carolina without active ash production, with the exception of three smaller (<250 MW capacity) non-Duke generation facilities in North Carolina.

Duke has a competitive supply advantage in the North Carolina ash use markets but faces competition from sources outside of North Carolina in the surrounding states. Duke may be competitive in northern South Carolina, southern Virginia, Florida, and the northeast corridor from Washington DC to Boston. Exports of Duke ash from North Carolina across the rest of the South or Midwest would likely not be competitive unless highly subsidized due to transportation costs and competing supply.

**Demand**

Demand (potential use) locations for ash shown on the North Carolina market map in Figure ES-3 include concrete products facilities (block, precast, and ready mixed) as well as cement kilns. The map also shows the inventory of active and inactive clay mines in North Carolina.
Demand for use in concrete products typically shows direct correlation with population centers and active construction activity; these trends are seen with respect to the spatial distribution and density of concrete product facilities in North Carolina.

None of the cement kilns are located in North Carolina, requiring out-of-state transportation to access this market.

Clay mines are located primarily in the center of the state where the geology currently and historically has supported clay resource development and clay brick production.

Uses other than concrete products and mine reclamation, such as structural and roadway fills, also typically follow construction activity and population centers.

Concrete production in North Carolina for 2014 has been reported by the Portland Cement Association (PCA) and National Ready Mixed Concrete Association (NRMCA) as:

- Total Concrete Products = 9.19 million cubic yards
- Ready Mixed Concrete = 7.64 million cubic yards
- Other (Precast, Block, etc.) = 1.55 million cubic yards

No definitive tracking data regarding the exact amount of fly and bottom ash used in the production of concrete products were available; estimates and projections are made based on the average or typical reported use and/or total portland cement production and an average ash replacement ratio.

Two estimates of the fly ash market demand into concrete products in North Carolina are provided in Table ES-1. The variation in the two estimates stems primarily from the cement replacement percentage assumed. Duke’s estimate follows their historic fly ash use trend data and represents an 18-20% replacement rate, whereas the Leming study used total portland cement output and a 35% cement replacement rate.

<table>
<thead>
<tr>
<th>Estimate by</th>
<th>2014</th>
<th>2015 to 2019</th>
<th>2020 to 2030</th>
</tr>
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<tr>
<td>Duke</td>
<td>0.550</td>
<td>0.600</td>
<td>0.800</td>
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<tr>
<td>Leming (2015)</td>
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<td>0.997</td>
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</table>

**Ash Quality**

Ash quality is critical to many beneficial use options, particularly in concrete/cement applications. The North Carolina Department of Transportation (NCDOT) or ASTM C618 both contain specifications for ash quality for use in concrete. Limits are specified for carbon content (measured as loss-on-ignition, LOI), fineness, and uniformity, among other things. In addition,
coal ash quality in the United States has been impacted in recent years as power plants add new air emissions controls to meet the requirements of the Mercury and Air Toxics (MATs) rule. Examples of air emissions controls that can impact fly ash composition include the use of powdered activated carbon injection to control mercury; sodium- or calcium-based sorbents to control acid gases; and nitrogen oxide (NOx) controls.

Inconsistent and/or poor quality production ash may require some level of beneficiation prior to use in conventional concrete applications. Moreover, ash placed in impoundments over many years is unlikely to be a consistent product meeting the concrete-quality requirements without significant beneficiation. Beneficiation options for production and ponded ash are discussed in the Phase 2 report. Fill applications are relatively insensitive to ash quality from an engineering perspective. Some of the alternative products discussed in the Phase 3 report are also less sensitive to variations in ash quality.

Summary plots of LOI and primary oxide content for production ash from the seven operating plants are presented in Figures ES-5 and ES-6. All of the production fly ash is categorized as ASTM C618 Class F, based on the primary oxide content. Only Belews Creek fly ash consistently meets both the ASTM C618 and NCDOT specification for LOI. Cliffside, Mayo, and Marshall are close to the ASTM specification, but are typically above the NCDOT specification. All of the production fly ash meets the ASTM fineness specification.

![Figure ES-5](image_url)

Summary of typical LOI reported by Duke and for samples analyzed at University of Kentucky (UK) for Duke’s operating North Carolina plants.
Figure ES-6
Summary of primary oxide content ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) for bulk and fine fractions of all samples analyzed at UK.

**Price**

Ash use applications range from moderate to high value, such as concrete and cement, to relatively low value, such as non-select fill material. For concrete, fly ash is priced competitively with portland cement and represents a potential revenue stream. Duke has indicated that the beneficiated ash from Roxboro generally sells for a premium above standard market rates due to its consistency.

Disposal costs will increase under the new federal and state ash management regulations. The avoided cost of ash disposal in the future may allow for increased potential beneficial use; this is especially true if stored ash required to be excavated and transported to off-site disposal under the state regulated closure activities can be diverted from disposal to new and existing beneficial use applications.

**Transportation and Cost to Market**

Fly ash is a bulk material, 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.

Wet ash in impoundments presents considerable challenges with respect to transportation. The ponded ash has a very high water content and requires double-handling for dewatering. If the ash become too dry, dusting must be controlled. Typically, ash needs to be moisture conditioned for handling and to control dusting without releasing water during transport.

Most ash use markets are associated with the construction industry. Some potential destination locations for coal ash use include:

- Ready Mixed Concrete Batch Plants
• Cement Plants
• Block Plants
• Mine Reclamation of Clay Pits
• Large Transportation Projects (e.g., roads and airports)

With the exception of mine reclamation sites, these sites tend to be concentrated near population centers and transportation networks between population centers (see Figure ES-3). Transportation required to move the supply of ash to these markets is a critical challenge to the use of large volumes of CCPs.

Figures ES-7a and b summarize the count of concrete product facilities and clay mines, respectively, within 50 miles of each of the 14 Duke North Carolina facilities. As would be expected the graphs indicate that the plants nearest to the largest North Carolina population centers (Cape Fear, Buck, HF Lee, Riverbend, Marshall and Allen) have the largest nearby concrete product facilities. Additionally, the plants near the historic clay mining areas (Cape Fear and Buck) have the highest number of nearby mine sites.

Figure ES-7
Duke power plants (active on left, retired on right) and selected CCP use markets within 50 miles of each plant within North Carolina: (a) concrete products, (b) clay mines
Regulatory Drivers and Public Perception

Regulations and public perception can have either a positive or negative impact on ash use projects. For example, well-conceived and supportive regulatory environments have been shown in many areas (e.g. Wisconsin, Europe, Asia, etc.) to significantly enhance and grow use of CCPs. Whereas the risk of future regulatory changes can negatively impact some applications.

The North Carolina CAMA provides a wide range of opportunities for use of CCPs and encourages increased use through currently available technologies and future innovative applications. While some regulatory uncertainty remains, especially at the state and local levels, the regulatory environment should provide a growing forward market environment that encourages innovation and development of new use technologies.

Ash Use in North Carolina

The following summarizes observations of the potential for increased use of ash from the Duke plants in North Carolina.

- Existing ash use markets in North Carolina include:
  - Ready mixed concrete
  - Precast concrete
  - Concrete block
  - Portland cement production (out of state only)
  - Soil replacement in required CCP closure caps
  - Solidification/stabilization of wastewater
  - Structural fills for transportation and other infrastructure
  - Mine reclamation fills

- About one-half of Duke’s 2015 production ash of 1.58 million tons was used in concrete and other applications. Use was concentrated at three facilities over that period: Asheville, Belews Creek, and Roxboro (Figure ES-8). Belews Creek and Roxboro fly ash was sold into the concrete market, while all of the ash from the Asheville plant was used for structural fill at the Asheville Airport project.

- Duke is expected to continue to produce ash at an average rate of slightly more than 1 million tons/year from the seven active plants in North Carolina through 2020.

- An additional 158 million tons of coal ash is stored at their 14 active and retired plants in ash basins and landfills, primarily ash basins. Several of the basins will require excavation over the next decade, which may provide an opportunity for beneficiation and use of the ash.
• Sales of CCPs into products are generally the preferred use for CCP where available, with fills and other uses providing secondary markets.

• The North Carolina market demand for ash in concrete products can generally be met by the three largest producing plants (Belews Creek, Marshall, and Roxboro), suggesting focusing attention on those sites as the highest priority for production ash.
  
  o Belews Creek is Duke’s largest ash producing plant. Belews produces concrete-quality ash and a high percentage is sold into the concrete market. This is expected to continue into the future.
  
  o Roxboro currently operates an electrostatic separation beneficiation system to process about one-third of its fly ash for use in concrete. Sales from Roxboro should continue to be strong, and may offer the opportunity for expanding the amount of ash processed from Roxboro and/or developing a combined beneficiation program with nearby plants to increase sales into the concrete market.
  
  o While a high generation rate and a good surrounding market for concrete products exists at Marshall, sales into the concrete products market have not been realized in significant quantities in the past. Marshall has marginal ash quality for use in concrete, with LOIs slightly above acceptable levels. Ammonia-based NOx controls that are planned for Marshall may further impede ash use in concrete in the future. Marshall may be a candidate for beneficiation due to the high volume of ash produced, good market location, and marginal ash. Marshall also has a large volume of stored ash that can also be considered as part of a beneficiation plan.

• Fly ash at the other active North Carolina coal-fired plants does not consistently meet NCDOT and ASTM specifications for use in concrete, due primarily to high LOI. It is questionable whether the ash volumes from an individual plant would be sufficient to justify investment in expensive beneficiation technologies, although lower cost
beneficiation technologies are a possibility. Combining beneficiation of ash from multiple plants, or ponded ash with production ash, may increase the feasibility.

- Use of stored ash in products (such as concrete or other higher value products) will require significant processing of the ash. Due to the decreasing production ash facilities outside of the narrow corridor from Charlotte to Greensboro and continuing to the northeast, consideration of beneficiation of stored ash at retired sites may prove to be economically viable. Beneficiation technologies are discussed in the Phase 2 report.
  - The best candidates for potential stored ash beneficiation are likely the sites ranked as intermediate risk by the state regulated closure activities, due to the required excavation of all ash providing a potential offset of excavation and transportation costs. The high risk sites offer less opportunity for investing in beneficiation due to the short closure period (2019).
  - Based on an evaluation of location, risk ranking, and considering current beneficial use plans during closure, HF Lee among the retired sites appears to be the strongest candidate for consideration of beneficiation of stored ash into markets near Raleigh, across eastern North Carolina, and potentially into northern South Carolina and southern Virginia.
  - Evaluation of ash quality and other factors will need to be completed to determine suitability for beneficiation of the stored ash. In addition, a longer closure period than currently allowed for CAMA Intermediate Risk sites may be required to justify the capital investment in beneficiation, or possibly combined beneficiation with a production ash source that will continue beyond 2024.

- Large embankment fills/mine reclamation such as Asheville Airport and Colon/Brickhaven Mines can absorb large volumes of coal ash, including low quality ash, in short periods, making them good candidates for stored ash sites requiring excavation (Figure ES-9). Public and regulatory acceptance of large structural fills and mine fills requires evaluation on a site by site basis and will likely require engineering control measures to limit environmental risk.

- NCDOT highway and other development construction projects provide well accepted avenues for high volume use of stored or production ash. The recent US EPA regulations exempt use in roadways, and many states welcome ash use in road construction. Development of this market will require close coordination with the NCDOT and the public to generate support for these applications.

- It is expected that opportunities for use for solidification/stabilization of wastewater will likely increase in the future due to recent and forthcoming wastewater regulations, as discussed in the Phase 3 report. The Mayo plant currently uses all of its production fly ash for solidification/stabilization.
Another potential large volume ash use for stored ash is for closure of existing impoundments. Wet sluicing and placement of coal ash in impoundments produces relatively flat impoundment surfaces, with poor drainage slopes that are not well suited for capping. Ash fills can be used in place of soil fills that would otherwise be needed to contour the sites.

The Phase 3 report describes alternative and new uses for fly ash. These use opportunities (even for moderate to small quantities) should continually be evaluated for technical and economic feasibility.

Bottom ash sales to concrete block and other products and uses have decreased in recent years due to both quality issues and internal Duke policies. Operational changes and/or alternate marketing of these materials should be considered as applicable.

One of the most important steps Duke can take to facilitate increased beneficial use opportunities is to develop a comprehensive characterization program for production ash at all of their operating plants. This will help identify operational processes, sourcing, or other factors that cause inconsistent material properties, and further help to define appropriate markets. This should include:

- Generation of a robust database of ash quality data over time to allow for more holistic decision-making.
- Considering ash quality to the extent feasible with respect to coal sourcing and emissions control strategies to produce higher quality fly ash that can be used in high value applications.

A program for evaluations of stored ash quality can be implemented by leveraging the significant pond characterization efforts ongoing throughout the Duke North Carolina
portfolio as part of regulated closure activities. An ash pond characterization program will provide information needed to evaluate the potential for beneficiation and use of stored ash, taking advantage of the equipment and crews already planned and mobilized for these activities.