Beneficial Reuse of Coal Ash from Dominion Energy Coal Ash Sites

Feasibility Assessment

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EXECUTIVE SUMMARY

Dominion Energy Virginia stores approximately 30 million tons of waste coal ash in impoundments at four different sites in Virginia: the Possum Point Power Station (Dumfries, Va.); the Chesterfield Power Station (Chester, Va.); the Bremo Power Station (Bremo Bluff, Va.); and the Chesapeake Energy Center (Chesapeake, Va.). The Virginia Department of Environmental Quality has documented the presence of coal ash-associated contaminants in the groundwater at each of these sites. In 2017, the Virginia General Assembly passed Senate Bill 1398 instructing the utility to assess the feasibility of excavation and the beneficial reuse of legacy ash for use in concrete as a mechanism for closing the impoundments at each of the four sites. This report examines the technical feasibility and market conditions for recycling impounded coal ash for use in concrete in Virginia.

Technology currently exists at commercially available levels to excavate, recover, and beneficially use legacy coal ash stored in impoundments in Virginia for concrete. Similar efforts in the nearby states Maryland and South Carolina have demonstrated success excavating, recovering and beneficially using coal ash in encapsulated beneficial reuse applications to manage and close legacy impoundments. As of 2015, approximately 1.5 million tons of impounded ash from the R. Paul Smith Landfill has been beneficially used in the cement industry, currently at a rate of 450,000 tons per year (TPY). It is expected that complete excavation of all ash will occur by 2020. In South Carolina a Staged Turbulent Air Reactor (STAR) facility became commercially operational at the Santee Cooper Winyah Generation Station in 2015. The 400,000 TPY facility was constructed to process impounded ash into a high-quality, specification grade product for the concrete industry. Three additional 300,000 TPY STAR facilities are planned for construction in North Carolina in 2018 and 2019. These facilities will be located at Duke Energy power stations with totals of 6.2, 6.4, and 5.7 million tons of legacy ash. Collectively, the proposed North Carolina facilities will process 900,000 tons/year. Construction costs for the facilities have been estimated at approximately $50 million each, while the price of high quality, specification grade ash materials, on the order of $50/ton, contributes significantly to the financial viability of this approach.

Coal ash has a long history of use in concrete applications because it increases the durability and strength of the final product. The first major domestic project using coal ash as a concrete supplement was repair of the Hoover Dam in 1942. Today, the recycling of impounded ash at Dominion's power plants will supply a critical construction material to the industry that builds and maintains transportation infrastructure in Virginia and the southeast region. Nationwide, coal ash is used in 75% of all concrete used for transportation projects, significantly reducing project costs. The Virginia Department of Transportation estimates that fly ash is used in 60 to 70% of all concrete used in transportation projects in the state, all of which, to the best of our knowledge, is currently fully sourced outside of the state due to the lack of beneficiation facilities operating in Virginia.

Demand for processed, impounded ash is expected to increase as coal fired power plants are shuttered or switched to other fuels. The overall demand for coal fly ash in Virginia is estimated to be 16 million tons from 2015-2030 and 46 million tons for Virginia, North Carolina, and South Carolina collectively during this period.

The beneficial use of impounded coal ash for concrete from Dominion's power plants will produce multiple benefits for Virginia.

- First, it will eliminate the long-term risk of groundwater and surface water contamination and eliminate the utility’s liability for that contamination. Given the record of contamination from the Dominion sites and their location adjacent to waterways, these unlined legacy coal ash impoundments may continue to contaminate state waters with coal ash constituents even when capped with an impermeable cover.
- Second, beneficial use will create jobs to support an industry that is not currently operating in Virginia, and also generate tax revenue.
- And third, beneficial use will provide increased competition for a high value product, lowering state funded construction costs and limiting the import of foreign ash into the state.

Based on the data collected for this report, the beneficial use of impounded coal ash for concrete is a feasible, cost effective alternative for cleanly closing legacy ash ponds at Dominion Energy Virginia power stations.

TABLE OF CONTENTS

INTRODUCTION

This report was prepared at the request of the Southern Environmental Law Center and the Potomac Riverkeeper Network to evaluate the feasibility of recycling ash that is currently stored by Dominion Energy at four electrical generation facilities in Virginia: Chesapeake Energy Center, Chesterfield Power Station, Possum Point Power Station, and Bremo Power Station. Alternatives for the final disposition of ash stored at these sites is currently being evaluated by Dominion Energy in accordance with Virginia Senate Bill 1398 (VADEQ, 2017; https://lis.virginia.gov/cgi-bin/legp604.exe?171+ful+ CHAP0817).

This report provides detail on four considerations important to evaluating the feasibility of the beneficial use of ash contained in these impoundments:

- The historic use of ash materials from coal combustion in the US and the mid-Atlantic region.
- Regulations and materials specifications that govern the safe and effective beneficial use of coal ash materials in Virginia.
- Evidence for the demand for coal ash materials in the marketplace.
- Technology readiness and commercial availability of technologies for the beneficial use of ponded ash materials.

Together, analysis of these four aspects demonstrate that 1) coal ash has a long history of successful use in infrastructure construction; 2) coal ash is a valuable product that improves the quality of concrete products, reduces the cost of projects, and is supported from both materials and environmental quality perspectives via regulation and specifications; 3) there is a continued market demand for coal ash and reductions in coal-fired electric power generation amplify the opportunity for legacy ash materials; and 4) technology exists and has been operating commercially in South Carolina and Maryland to recover coal ash from legacy impoundments and produce high quality ash that is sold in the marketplace.

HISTORIC USE OF COAL ASH MATERIALS

Coal combustion products (CCPs), also known as coal combustion residuals (CCRs) or coal combustion byproducts (CCBs), are produced when coal is combusted to generate energy. Historically, the majority of coal burned in the United States was for the generation of electricity at coal-fired power plants. CCPs include a number of distinct, specific products, each having unique physical and chemical properties briefly described below.

- Fly Ash – A fine powdery material that “flies up” during the coal combustion process and is captured by emission control devices at the power plant. Fly ash historically comprised approximately 75% of the coal ash generated annually in the US. Because modern coal-fired power plants produce a number of other products besides ash, fly ash currently only represents about 40% of the total CCPs generated in the US (other CCPs include non-ash products such as FGD materials, defined below).
- Bottom Ash – Porous, dark, angular agglomerated ash particles that fall through open grates at the bottom of the furnace or are impinged on the walls. Bottom ash historically comprised approximately 20% of the coal ash generated annually and about 10% of the CCPs produced in the US.

- Boiler Slag - Hard, black, angular particles that from the quenching of collected molten bottom ash from the bottom of the coal-fired furnaces. Boiler slag historically comprised 4% of the coal ash generated annually and about 2% of the CCPs produced.
- Fluidized Bed Combustion ash – FBC ash is generated from a modern coal combustion technology which burns coal in the presence of a limestone sorbent for environmental emissions control. As a result, FBC ash is alkaline and self-cementing, similar to class C coal fly ash. FBC ash comprises about 10% of the total CCPs produced.
- Flue Gas Desulfurization Gypsum – A fine, light powdery material that is produced by emission control systems. FGD gypsum is not a direct ash product derivative of coal but a product resulting from the flue gas scrubbing systems included in modern coal-fired power plants to control air emissions. FGD gypsum comprises about 30% of the CCPs produced.
- Additional Materials- Additional materials include FGD scrubber material and comprise approximately 10% of CCP production.

Throughout this report, “CCP” will be used to refer generally to the materials listed above. Because coal fly ash is the primary constituent of the ash ponds that are the subject of this report and is a material with a high economic value when replacing Portland Cement in concrete mixtures, it is used as an additional term in this report to refer specifically to that material.

CCP production is differentiated above between historic ash and total CCP materials because FGD gypsum and FBC systems are recent technology advancements to the coal-fired power plant industry and therefore do not represent the characteristics of legacy ash disposed of in waste ponds and landfills. Among the 4 Dominion plants with ash ponds evaluated in this report, only Chesterfield has installed environmental emissions equipment that generates FGD products, a change that occurred between 2008 and 2011 (Power Engineering, 2011). This report focuses on the materials produced historically that are relevant for understanding the options available for reuse of historic ash materials held in ponds or landfills at Dominion Energy facilities in Virginia. Coal fly ash has historically been the primary CCP generated from electric power generation and therefore represents the majority of legacy ash currently stored at power plant waste ponds and landfills across the four Dominion sites investigated.

Coal fly ash has a long and successful history of re-use in the US and many other countries in the world. Coal fly ash was recognized as a pozzolanic material (material with cementitious properties when mixed with calcium hydroxide) as early as 1914 and started to be used in concrete in the 1930s (Aggarwal et al., 2010; ARTBA, 2011). This experience led to the first major domestic project using coal fly ash to repair the Hoover Dam Spillway in 1942. The size of the structure was causing cracks due to the heat generated by the massive volumes of concrete required. Engineers found that they were able to control the temperature and increase the strength by substituting a portion of the cement with coal fly ash in the concrete mixture (EPA, 2005). The next major project was utilization of over 120,000 metric tons of fly ash in the Hungry Horse Dam in 1948 (ARTBA, 2011). Fly ash then started to be used in roadways and interstate highways in the early 1950s. The Association Society for Testing and Materials (ASTM) developed standards for the use of coal fly ash in concrete in the 1960’s. In 1974 the Federal Highway Administration officially began encouraging the use of coal fly ash in concrete pavement (FHWA, 2003). The USEPA published federal comprehensive procurement guidelines on January 28, 1983 for cement and concrete containing fly ash to encourage its use (US EPA, 1992): this guideline requires all federal agencies and all state and local government agencies and contractors that use federal funds to purchase concrete to have a preference program that advantages the purchase of concrete containing coal fly ash.

The American Coal Ash Association (ACAA) was founded in 1968 to encourage the beneficial use of CCPs in ways that are protective of the environment, technically appropriate, commercially competitive, and supportive of a more sustainable society. In 2000 they began reporting on the national production and use of CCPs, taking over the national public reporting responsibilities from the USGS who began tracking CCP usage in 1966. Since that time, annual CCP production has risen from 25.2 million tons (MT; 1966) to a maximum production of 135.5 MT in 2007 and most recently 116.8 MT in 2015 (USGS, 2017). The percent reuse in beneficial use applications has risen as well from 12% in 1966 to 52% in 2015.

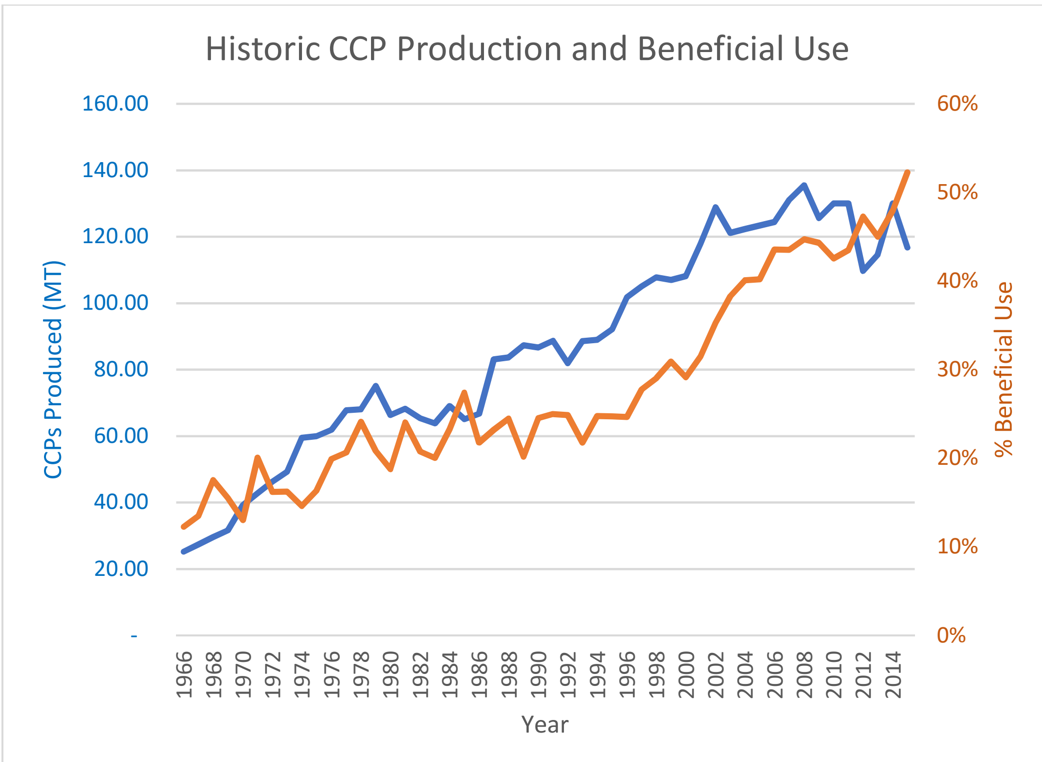

Figure 1 Historic Production and Use of CCPs in the US. (Source: USGS, 2017)

BENEFICIATION OF COAL FLY ASH FOR USE IN CONCRETE

Because coal-fired power plants have to carefully control their operating conditions to meet regulations for air emissions, the ash typically produced is not of acceptable quality for direct reuse in high-value applications, such as a substitute cementitious material for Portland Cement in the production of concrete. Substitution for Portland Cement means that coal ash can replace some of the portion of a concrete mixture that is responsible for binding the concrete together. Coal ash must have the proper chemical and physical characteristics so that properties of the concrete are maintained. Because coal fly ash recovered directly from the flue or mined from legacy ponds often does not consistently meet these target specifications, a **beneficiation** step is commonly necessary to condition the ash so it is of acceptable quality for use in concrete. For example, one key parameter that is typically not met is Loss-on-Ignition (LOI). LOI refers to the remaining combustible content of the material and is typically required to be below 1% for use in concrete (ASTM C618 requires <6%). Beneficiation technologies have been designed to condition production ash generated from power plants into a specification grade product that meets all required state and federal requirements. These technologies are well established and have been commercially operating for decades to supply concrete manufacturers a consistent material for production of their product. In the last decade, beneficiation technologies have become commercially available to reclaim legacy ash that was previously disposed of in landfills and impoundments (ponds). These technologies produce the same product (high quality coal fly ash for market) but begin with a more heterogeneous product with a much higher moisture content and therefore, require additional processes. These technologies are discussed in a separate section later in this report with a particular focus on technologies available for beneficiating ponded ash materials.

CONTEMPORARY USE OF CCPS

Today coal fly ash is a well-understood, well-regulated material that has a significant and steady demand for use in concrete products. ASTM International has published over 12 standards related to beneficial use of CCPs. Similarly, the American Association of State Highway and Transportation Officials (ASHTO) has published numerous standards for CCP use in highway construction (FHWA, 2003). Two of the most often used coal fly ash specifications, ASTM C 618 and AASHTO M 295, define acceptable physical and chemical properties of coal fly ash as well as acceptable replacement ratios for cement used in concrete.

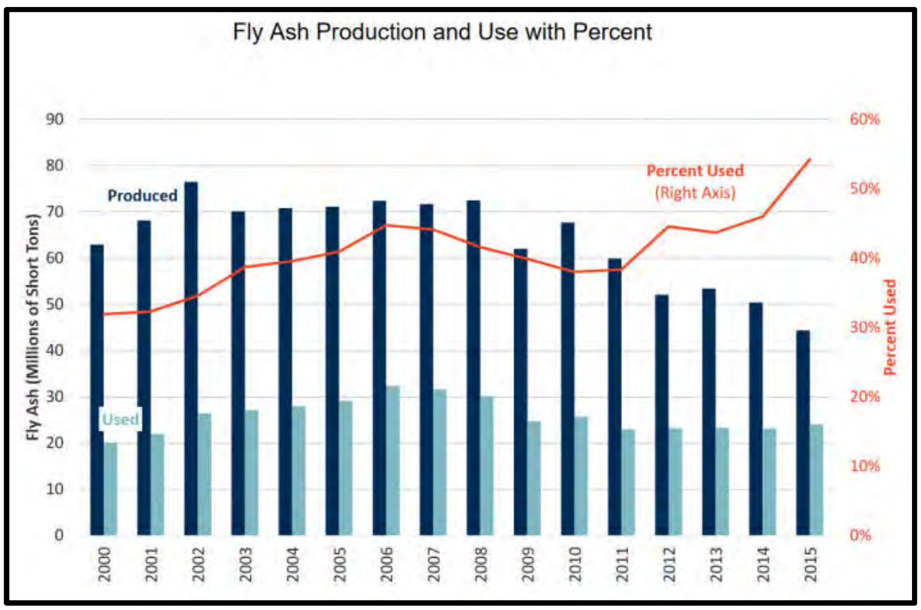

Figure 2 Contemporary ash production and reuse in the US: 2000-2015 (source ACAA, 2017)

National data shows that a steady demand for CCPs has resulted in the consistent beneficial use of coal fly ash since 2000 (between 20 and 32 million tons annually). ACAA data from 2015, which is consistent with most recent years, reports that the majority of coal fly ash was used in concrete/grout applications (65%) and substitute clinker feedstock for cement manufacturing (15%). Coal fly ash was also used in structural fills, mining applications and waste stabilization applications at rates of 5.3%, 4.7% and 4.7%, respectively. Although these un-encapsulated applications are allowable under existing regulations, they require long-term monitoring to ensure that ash will not leach contaminants into the environment.

While the industry expectations and specification for coal fly ash quality beneficially used in concrete are among the most demanding among all use scenarios, states such as Maryland with the highest beneficial use rates credit their high beneficial use rate to a strong concrete industry (Erbe et al., 2013). It's estimated that fly ash is used in 75% of the concrete associated with transportation construction in the US (ARTBA, 2011). This is due to performance-enhancing benefits including: increased pumpability, increased ultimate compressive strength, reduced permeability and reduced material costs. The Federal Highway Administration (FHWA) estimates that concrete is used in 25% of all highways (>52,000 mi.) and 65% of bridges (>390,000) in the United States (FHWA, 2008). The availability of fly ash reduces the cost of transportation projects because the price for fly ash is approximately ½ the price for the Portland Cement it replaces; it is estimated to reduce costs by $104 billion over the next 20 years (ARBTA, 2011).

Many market analyses for the beneficial use of CCPs have focused on the demand within a 50 mile radius for transportation to market (EPRI, 2016a). However, testimony from ready mix personnel suggest that sourcing of specification grade ash covers a much wider region. Henry Batten, the President of Concrete Supply Co. based out of Charlotte, NC, has stated that he sources fly ash from 5 states (NC, SC, GA, WV & MD), due to the low availability of the material in the region (Southeast Energy News, 2016). Virginia concrete representatives from S.B. Cox and Chandler Concrete have also expressed the desire to use specification grade ash in all their concrete and believe there is a shortage in the marketplace (Associated Press, 2017). While regional concrete companies have stated that they are committed to purchasing American derived coal ash, other concrete companies may not have the same resolve. Import registers from the Port of Virginia show a rise in foreign imported coal ash from 1 to 22 shipping containers between 2015 and 2016 (Associated Press, 2017). The final destinations were not reported.

Another result of the lack of adequate local ash supply for concrete production is the import of foreign iron and steel blast furnace slag. Like coal fly ash, ground granulated blast furnace slag (GGBFS) can be milled to serve as a replacement for Portland Cement in concrete production and competes directly with coal fly ash. Iron and steel slag are generally imported unground and require milling to reduce the particle size for use in concrete (van Oss, 2016). Imports of foreign ferrous slags have risen from approximately 11,000 tons in 1985 to just over 1.4 million tons in 2015 (USGS, 2016). This massive increase in foreign imports is due to the decline in American steel production and the relatively consistent demand for the construction, cement and concrete industries. Granulated blast furnace slag represents 15 to 20% of the total slag sales in US (by mass), which is almost entirely used as a cementitious material (USGS, 2016). Economically, GGBFS is much more expensive than fly ash, leading to higher concrete prices, and in turn higher prices for public construction projects such as highways, bridges and buildings. The existence of a healthy market for GGBFS from overseas is a clear indication that there is market demand for less expensive, locally sourced coal fly ash.

COAL ASH USE IN THE MID-ATLANTIC

In addition to the national perspective provided above, some state and utility reports are available describing the production and final disposition of CCPs in the mid-Atlantic region. The neighboring states of Maryland (to the north) and North Carolina (to the south) present useful, comparable examples of regional market demand that are illustrative for a potential market in Virginia. The following sections evaluate recent cement consumption, transportation infrastructure containing concrete and modeled future demand to describe the market for fly ash in these 3 states. It also includes the most recent assessment of coal ash utilization rates within the 3 states. 2016 data was publicly available for North Carolina and Maryland, however 2013 data from a 2014 Dominion Report was the most recent information available for Virginia.

BENEFICIAL USE OF CCPS IN MARYLAND

National data show that cement and concrete industries are the primary markets for coal ash in the US and account for approximately 50% of the total use. Therefore, an evaluation of cement and concrete markets is important to describe demand. The State of Maryland has 2 Portland cement plants, Lehigh Hanson and Lafarge Holcim, that have a combined clinker capacity of 3.1 million metric tons. The Portland Cement Association estimated Maryland's cement consumption at 1.2 million metric tons in 2015, up for the 5th year in a row. Fly ash usage in concrete is allowable at a replacement rate between 20 and 25% by the Maryland Department of Transportation (MDOT). Use of fly ash in MD concrete is believed to be extensive state wide (ARTBA, 2011).

The state of Maryland reports and tracks the production and final disposition of CCPs through the Power Plant Research Program (PPRP), a division of the Department of Natural Resources which provides a relatively unique and detailed look at CCP usage in the state and region. Maryland has beneficially used >80% of its annually generated CCPs since 2011 (including FGD gypsum). However, when the reclamation of legacy ash is considered, Maryland utilized 130% of the coal ash generated in 2016. This is due to the active mining of the R. Paul Smith Landfill (Discussed below; ACAA, 2016b). There are 2 cement plants and 2 beneficiation facilities designed to process production ash (i.e. ash that comes directly from the coal-fired power plant as it is produced) so that it meets specifications for use in concrete. PPRP attributes Maryland's high rate of encapsulated beneficial use to 2 main factors: the presence of a strong concrete industry, and the work of key regulatory and NGO partners to help establish connections in the marketplace. Maryland's experience is detailed in two case studies below.

Case study one: Beneficial Use Expected to Empty a Historic Landfill by 2020 (Erbe et al., 2013; ACAA, 2016b)

In 2008 owners of the R. Paul Smith Power Plant began working with the Maryland Environmental Restoration Group (MERG) and local cement producers to beneficially use legacy CCPs that had been landfilled since 1947 on the banks of the Potomac River. Within 3 years, approximately 250,000 tons of ash had been removed from the landfill and beneficially used in cement production. As of 2015, approximately 1.5 million tons of ash had been removed from the landfill. It's expected that the ash will be fully mined by 2020, allowing the area to be regraded, vegetated, and closed, eliminating any remaining environment risks and liabilities of large scale CCP storage. The total amount of ash originally in the landfill that is expected to be completely removed and reused from 2008-2020 is estimated to be 3.6 million tons from current utilization rates. As mining nears an end, cement manufactures are actively seeking similar stockpiles for continued reuse in the future.

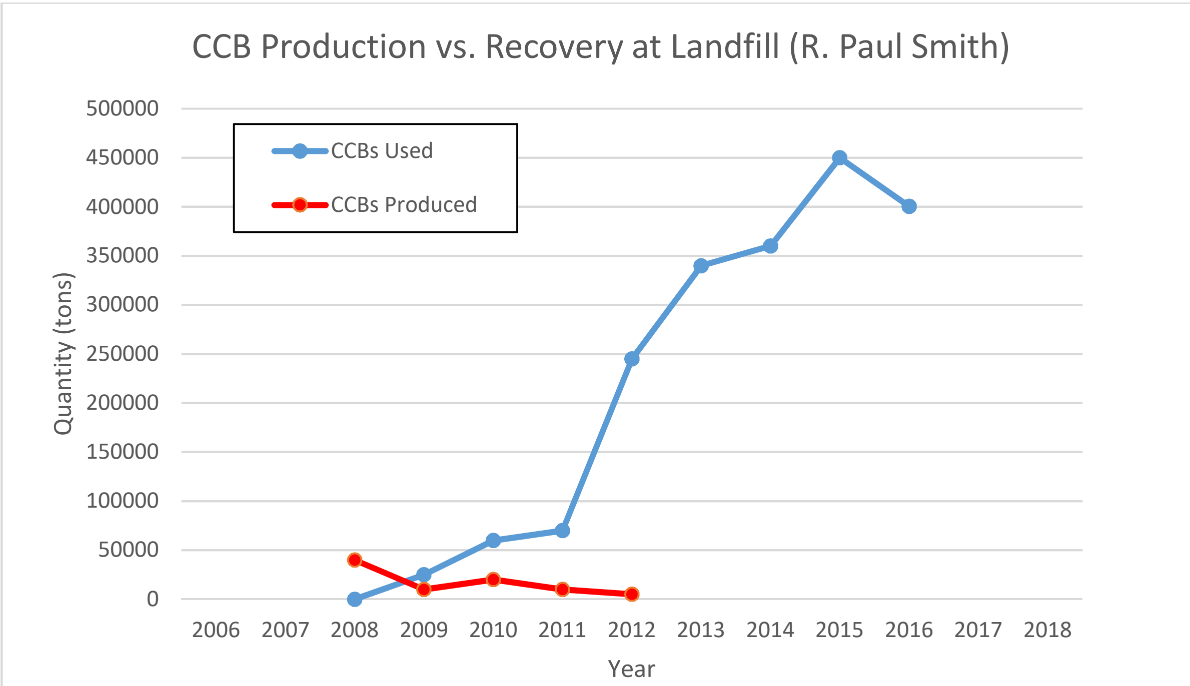

Figure 3 Successful legacy ash beneficial use in cement (ACAA, 2016b)

Case Study 2: Installation of Beneficiation Technology Transitions Maryland Beneficial Use Market (Lee et al., 2015; ACAA, 2016b)

Between 2007 and 2010, the end of several large-scale un-encapsulated beneficial use projects left a void in Maryland's beneficial use of CCPs which led to large increases in landfilling rates (Figure 4). Prior to this period, CCPs had been predominantly used in un-encapsulated applications, including structural fills and roadway traction applications (winter seasons). Althouth these un-encapsulated applications are allowable, they require long-term monitoring to ensure that ash will not leach contaminants into the environment. The decline in CCP beneficial use in large un-encapsulated projects led to the expansion of fly ash beneficiation facilities that were able to condition production ash into high quality specification grade ash for concrete markets. The 2011 STAR Thermal Beneficiation Facility in Morgantown was opened in 2011 to work alongside STI's electrostatic separator technology to condition fly ash from 3 coal-fired power plants for use in the concrete industry. Over the same time period, FGD systems were installed in a number of Maryland power plants to control air emissions. These systems generate large volumes of FGD gypsum, which was subsequently used as synthetic gypsum for the construction of wallboard. The impact of these two beneficial use pathways had a dramatic effect on the disposal rate of CCPs, bringing disposal rates down from above 50% in 2008 to approximately 10% in four years from 2012 to 2016 (Figure 4), and concomitantly increasing beneficial use from approximately 50% to 90%. The pathways also dramatically shifted use from un-encapsulated field applications to encapsulated products, which support existing markets and are considered preferred according to the US EPA (USEPA, 2015).

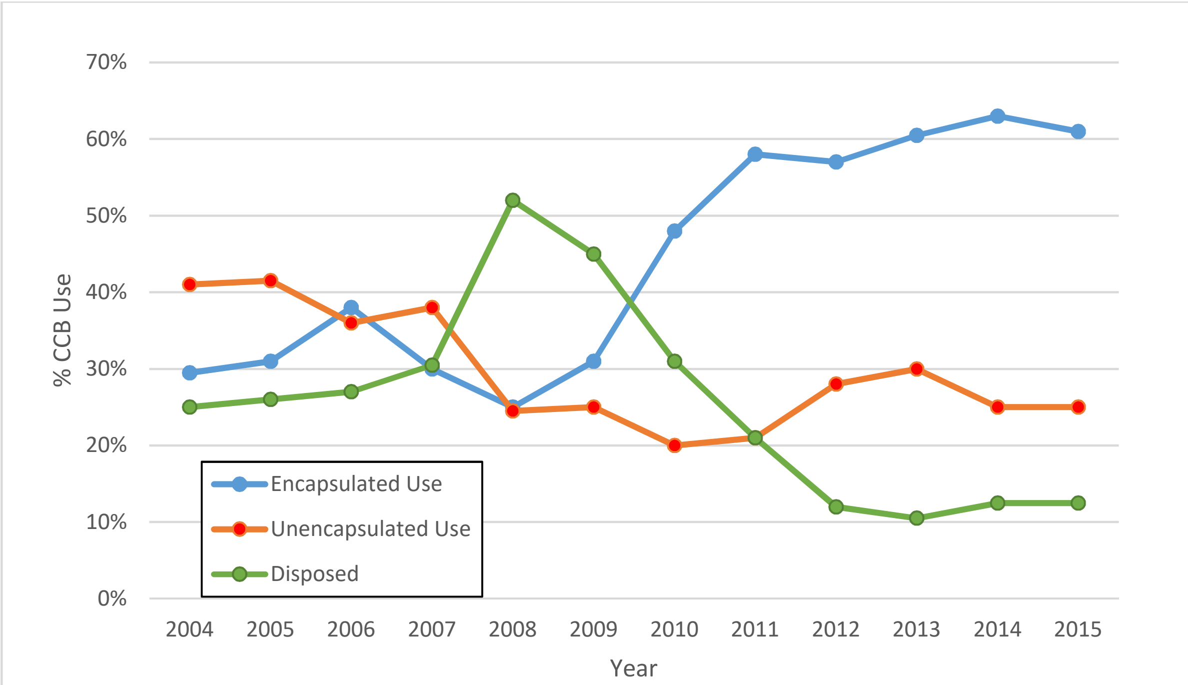

Figure 4 Increased encapsulated beneficial re-use keeps CCPs out of landfills in MD (ACAA, 2016b)

COAL ASH USE IN VIRGINIA

The Commonwealth of Virginia has one cement plant, Roanoke Cement (Titan America), that has a clinker capacity of 1.2 million metric tons. The Portland Cement Association estimated the state's cement consumption at 1.8 million metric tons in 2015, up for the 4th year in a row. Fly ash is estimated to be used in 60 to 70% of all concrete used in transportation projects in Virginia (ARTBA, 2011). VDOT specifies a replacement ratio of fly ash for cement at 20% in concrete mixtures (replacement ratio refers to coal fly ash replacement of Portland cement in the concrete mix). VDOT specifications also allow the use of fly ash in flowable fill and structural fills. Flowable fill is a low-strength concrete mix that is used to backfill around pipes and similar applications – it flows well so does not leave voids and sets up at a strength similar to a well-compacted soil. Structural fill is a fill that meets specific structural requirements, such as a road base material (as opposed to a non-structural fill that would be, for example, an embankment or roadway shoulder). Again, as we noted earlier, un-encapsulated applications like structural fill require long-term monitoring and institutional controls over decades or longer to ensure that coal ash will not leach contaminants into the environment. Estimates of future fly ash demand for the concrete industry based upon cement consumption, population growth and market strength are available from Leming (2017). The Leming (2017) analysis predicts fly ash demand will be over 16 million tons in the state of Virginia for concrete production between 2015 and 2030. This is based upon a replacement ratio of 35% (fly ash replaces 35% of cement in a concrete mix) and was calibrated using 2014 North Carolina data. Industry expert opinions vary if this value is too high or low; however, a comparison between the original 2015 projections and updated 2017 data found the analysis to be accurate and within the variability expected (Leming, 2017).

Virginia CCP use is not publicly available from any government or NGO organization, so there is limited knowledge of production and use within the state. Dominion Energy did produce a report in 2014 that provides a limited assessment of beneficial use activities between 2009 and 2013 (Dominion, 2014). Specific beneficial uses of coal ash products that were identified include beneficiation of fly ash at Chesapeake Energy Center that was used in concrete using a technology referred to as "carbon burn out." This activity accounted for approximately 4% of the total beneficial use noted and was abandoned in 2014 when the plant stopped burning coal and switched over to natural gas as the fuel supply. Bottom ash reutilization for concrete pavers was also noted at Chesterfield Power Station which accounted for approximately 1% of average total ash beneficial use between 2009 and 2013. Other FGD gypsum utilization in wallboard and mine reclamation was also noted. Currently, to our knowledge, there is no source of acceptable specification-grade fly ash for use in concrete in the state of Virginia due to the lack of beneficiation facilities that can condition production or legacy ash to the proper physical and chemical specifications in the state of Virginia.

COAL ASH USE IN NORTH CAROLINA

The State of North Carolina has no cement manufacturing plants. The Portland Cement Association estimated the state's cement consumption at 1.4 million metric tons in 2015, which was relatively consistent for the past 5 years. NCDOT specifies that coal fly ash can be substituted for Portland cement at a replacement rate up to 20%. NCDOT representatives indicated that fly ash has been beneficially incorporated into concrete mixes since 1983 and is currently widespread throughout North Carolina.

Three predictions for fly ash demand in the NC concrete industry are publicly available. The first, previously discussed, is the Leming Model which predicts 21 million tons of coal ash demand from the concrete industry between 2015 and 2030 (Leming, 2017). The second, in a study by Duke Energy, is based upon internal historic use trends and uses a lower replacement ratio of 18-20%, and estimates demand for coal fly ash use in concrete of 1.4 million tons between 2015 and 2030 (Duke Energy, 2015). A more recent study from the University of Kentucky uses a replacement ratio of 20-30% and estimate a coal fly ash demand between 0.45 to 0.7 million tons/year (Oberlink, 2017), or 7 to 11 million tons over the 2015-2030 period.

CCP use in North Carolina has become more consistent in North Carolina since the Coal Ash Management Act (CAMA) study (EPRI, 2016a,b,c). Recent (and incomplete) 2016 beneficial use figures were available in a presentation by EPRI (2016c). The presentation indicates that approximately 58% of production ash, which is approximately 700,000 tons (not including FGD products), is currently being beneficially used in concrete, cement structural fills and miscellaneous products. Earlier reports indicate that beneficial use is distributed regionally. Between 2014 and 2015, the Ashville Plant used 100% of its production ash, Bellow's Creek used >70%, and Roxboro used >40%. The other 4 active plants used <10% (Duke, 2016). Currently, one ash beneficiation facility (which uses electrostatic separation) is operated at Roxboro and operational conditions at Bellow's Creek enable the plant to produce acceptable fly ash for direct use in concrete without any beneficiation. One of the most significant developments in North Carolina that is relevant to understand the potential of legacy ash reuse in VA is that Duke has contracted the SEFA Group to construct an additional 3 STAR facilities to begin reclaiming 900,000 tons of legacy ash per year.

Table 1. Summary of coal ash beneficial use in Maryland, Virginia and North Carolina

	Maryland[a] All 7 Coal Fired Power Plants	Virginia[b] Dominion Plants (8-VA and 1-WV)	North Carolina[c] 14 Duke Plants (7 active)
Year	2016	2013	2016
Current Coal Ash Beneficial Reuse Operational Details[d]	130% (9.26x10^5 tons)	29.6% (1.1x10^6 tons)	58% (6.96x10^5 tons)
Markets	-Cement (57%) -Concrete (31%) -Coal mine reclamation (39%)	- Concrete (4%)[e]-*halted* - Concrete Block (1%) - Unspecified (96%)	- Concrete - Cement - Structural fills - Agriculture
Current Beneficiation of Legacy Ash	4.01x10^5 tons in 2016 – Mining landfilled ash for cement production.	None Presently- No future utilization reported.	None Presently – Construction slated for 3 plants to reclaim 900,000 tons per year by 2019.
Cement Manufacturing Plants	2	1	0
Beneficiation Plants able to condition ash for concrete use	– Morgantown STAR Plant	0	1 – Roxboro, however Bellow Creek production ash meets spec.
Current Beneficiation for Concrete Application	221,668 tons	No known operational uses, CEC CBO shut down in 2014	Unknown

[a] Data provided by PPRP (2017)
[b] Data generated from Dominion (2014), Data from all Dominion owned generation
[c] Data generated from EPRI (2016)
[d] Values represent percentage of ash generated, as discussed previously, MD beneficially reuses more ash than the state currently generates
[e] The CBO at Chesapeake Energy Center closed when the plant switched fuel sources in 2014.

NATIONAL AND STATE REGULATION GOVERNING REUSE

The US Environmental Protection Agency signed a direct final rule on the disposal of coal combustion residuals (CCPs) from electric utilities on July 26, 2016 which became effective on October 4, 2016 (USEPA, 2015). The new rule encourages beneficial use by specifically distinguishing between disposal and beneficial use of CCPs. Disposal management options require substantial regulation, similar to disposal of municipal solid waste, where facilities must meet engineering and monitoring requirements. In contrast, CCPs that are beneficially used under EPA and state guidelines are exempt from future regulation under the Bevill amendment (the Bevill Amendment, section 3001(b)(3)(A) of the Resource Conservation and Recovery Act, exempted fossil fuel combustion waste from regulation under Subtitle C of RCRA until further study and assessment of risk could be performed). Additionally, there is further incentive to use CCPs in encapsulated products (such as in concrete or wallboard) because large non-roadway structural fill applications (un-encapsulated) must be appropriately demonstrated and monitored to not harm health or the environment and thus may represent a long-term liability.

Virginia Senate Bill 1398 was passed on April 5, 2017 requiring that all CCR surface impoundments located in the Chesapeake Bay Watershed to conduct an assessment regarding the closure of the unit by December 1, 2017. The VADEQ is addressing the safe closure of coal ash ponds through 2 permits: one regulating the treatment of wastewater discharge from the impoundments and the second requiring adequate solid waste management, closure and monitoring of the impoundments. This includes providing the public information and opportunities to comment and participate in the closure permitting. The four facilities specifically identified in the bill are the four plants that are the focus of this report.

The majority of beneficial uses are administered by the Virginia Solid Waste Management Regulations and implemented for highway construction by the Virginia Department of Transportation (VDOT). The VDOT has established specifications and used fly ash as structural fill in embankments, road subgrade base layers, as a substitute in Portland cement concrete, and as a filler in bituminous concrete since the 1980s (Hite and Dietrich, 2008).

Virginia regulations adopted the federal regulations which exempt fly ash, bottom ash, slag and FGD gypsum generated from coal fired power plants from being classified as hazardous waste. (9 VAC 20-60-261). Further exemption from regulation as a solid waste were also granted for encapsulated materials (i.e. concrete, paint, flowable fill, etc.) as well as un-encapsulated applications (structural fills, mine reclamation, roadway traction control, etc.) provided they were reused in a manner that was in accordance with state agency requirements. Specified terms and conditions were later promulgated in 1995 clarifying un-encapsulated land application requirements including environmental analysis, monitoring, reporting, and placement restrictions (USDOE, 2017)

BENEFICIATION TECHNOLOGIES FOR COAL FLY ASH BENEFICIAL USE IN CONCRETE

Beneficiation is often a critical step for the appropriate use of coal fly ash in the production of concrete. Coal ash must have the proper chemical and physical characteristics so that expected properties of the concrete are maintained and specifications are met. Because coal fly ash recovered directly from the flue or mined from legacy ponds often does not consistently meet these target specifications, a beneficiation step is commonly necessary to condition the ash so it is of acceptable quality for use in concrete.

There are a number of technologies that exist for separating or conditioning fly ash so that it meets national and state specs. These techniques include: thermal beneficiation, electrostatic separation, air classification, chemical passivation or controlling the power plant operational procedures. To date, thermal beneficiation is the only technology that is commercially available and actively processing legacy fly ash for the concrete market.

Thermal beneficiation technologies have been commercially deployed for over 15 years and produce more than a million tons of marketable fly ash per year (Oberlink, 2017). This technology involves the thermal conditioning of ash to reduce LOI, eliminate ammonia, and improve fineness and uniformity physical characteristic of ash so that it is suitable for use in concrete. Currently there are two commercially available thermal beneficiation processes that are operating in the United States. PMI’s carbon burnout (CBO) process has been in use since 1999 with the original plant opening at the Electric and Gas’s Waterlee Power Plant in South Carolina. Between 2002 and 2006, 3 more operations were opened including the Santee Cooper's Winyah Station (SC), Dominion Energy Brayton Point Station (MA), and Dominion

Virginia Power Chesapeake Energy Center (VA). During peak operation, the combined plants generated approximately 1 million tons/year for beneficial use in concrete production (PMI, 2017). Since that time, Brayton Point Station has closed (2017) and Chesapeake Energy Center switched fuel sources to Natural Gas (2017). The SEFA Group who operated the Santee Cooper CBO also switched the beneficiation technology to a STAR Facility in 2005.

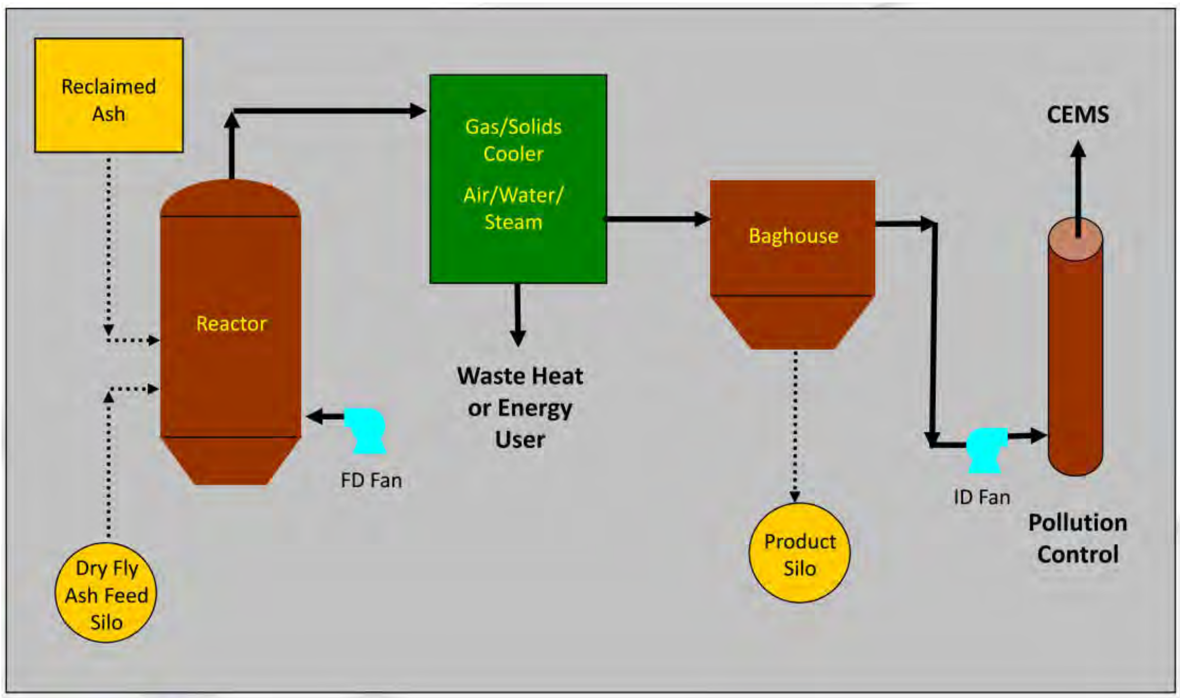

Figure 5 STAR Process Flow Diagram (Erwin, 2014)

The SEFA Group Inc.'s STAR plant is the second commercially available thermal beneficiation technology and the first technology able to commercially operate off 100% reclaimed ash (ash previously disposed in a landfill or impoundment). STAR stands for Staged Turbulent Air Reactor which is based upon entrained or dilute phase fluid bed technology as opposed to CBO which is based upon a dense phase "bubbling bed" technology (Figure 5; EPRI, 2016b; Erwin, 2014). More technical details of the technology are provided in other locations (Robl et al., 2017; EPRI, 2016b); however, the advancement in technology has allowed beneficiation of a far greater chemical and physical range of CCP feedstocks and can provide a wider range of beneficiated ash products to the market (Table 2).

SEFA currently has 3 STAR plants in operation, including the Santee Cooper Winyah Generating Station which is the first thermal beneficiation plant capable of processing ash solely from reclaimed ash feedstocks. SEFA's first plant was opened at SCE&G's McMeeken Station in Lexington, SC in 2008. Today the facility processes high-LOI fly ash originating from more than 16 facilities including dry production ash, reclaimed landfilled ash, and reclaimed pond ash. The facility can process 140,000 tons of ash annually. Their second plant was opened at the NRG Morgantown Facility in Newberg, MD in 2012. This facility currently process 360,000 tons per year of ash from Morgantown and Chalk Point power plants and has storage capabilities of up to 30,000 tons of product. The most recent plant to open was the Santee Cooper Winyah Generating Station in Georgetown, SC. SEFA decommissioned their CBO plant and opened the

STAR facility in 2015. The Winyah Station is similar in size to the Morgantown Station and has a nominal processing of 400,000 tons per year. The plant was specifically designed to have wide operational capacity in order to routinely switch between 100% legacy ash and 100% production ash. This requires the processing of feeds with wide ranging chemistries and physical characteristics into a high-quality specification grade material. Feed ash ranges in LOI from 5% to over 25%; moisture contents range from under 20% up to 30%. This increased processing capability not only allows for the removal of ash from impoundments, it also supplies the concrete industry with a consistent supply of material. Uninterrupted supply and consistent quality boost the markets confidence and in turn increases demand (ACAA, 2015).

Table 2. STAR technology process characteristics.

Self-Contained Process	STAR facilities are self-sustained and independent operating facilities.
Energy	No auxiliary supplemental heat is required during normal operation as all energy is generated from combustion of residual carbon in coal ash feed when LOI is above 6%. Startup fuel is supplied via 3rd party vendors (i.e. natural gas/propane)
Emissions	Facilities are independently permitted. Air monitoring can be by a Continual Emissions Monitoring System if required. Most criteria air contaminants are controlled internally through the process (NOx and CO). SOx is as exception which is treated via Flue Gas Desulphurization.
Nominal Feed Rate	>350,000 tons per year (wet)
Physical and Chemical Ranges for CCP Feed Stock	The STAR process is able to process a wide range of sources in minimal timeframes. The Winyah Plant routinely switches between reclaimed ash to process ash when WGS required.
Ash Sources	100% production ash to 100% reclaimed ash
Water Content	Up to 30% moisture content. Generally under 20 to 25%.
LOI	5 to 25% LOI (*dry mass*)
Class	Class F and blends of Class C&F[b]
Characteristic of SCM fly ash product for concrete applications	Processing a consistent supply of legacy ash allows STAR facilities to provide a consistent source of specification-grade coal fly ash to the concrete industry. The process is able to provide a consistent product regardless of source feed.
LOI	Processing can be tailored to control the residual carbon. Regardless of the source feed, LOI can be consistently controlled to as low as 0.1% LOI.
Fineness	Processing can be tailored to control the particle size of mineral matter.

[a]Sources: ACAA (2015); Fedorka et al. (2015); Erwin (2014; Knowles (2014)
[b]Not Conducted at full commercial scale

The group is also currently contracted to open 3 additional STAR facilities in North Carolina the next 2 years. These locations include; The Buck Steam Station near Salisbury, NC where over 5.3 million tons of ash are currently impounded in surface ponds; the HF Lee plant in Goldsboro, NC which will process 6 million tons of impounded ash; and the Cape Fear Plant in Moncure, NC which will process the 5.7 million tons of impounded ash (Duke Energy, 2016a&b, Duke Energy, 2017a&b). These additional facilities are estimated to process a combined 900,000 tons of legacy fly ash annually. The evidence from these experiences indicates that this technology is mature, cost-effective, and able to produce a valuable product for the market at a price that allows these operations to be sustained and profitable. There are no known impediments to implementation of one or more STAR plants at one or more of the four Dominion Energy facilities in Virginia, although site-specific considerations are important to consider. It is possible that the most cost-effective solution is for one STAR plant to serve multiple fly ash storage locations.

Table 3. Location and status of SEFA Plants[a]

Current Facilities					
Facility	Location	Station	Status	Nominal Processing	Feed Ash Quality
McMeekin STAR Plant	Lexington, SC	16 different facilities	Opened in 2008	140,000 tons/yr	Dry Production Ash
Morgantown STAR Plant	Newburg, MD	Morgantown and Chalk Point Generation Stations	Opened in 2012	300,000 tons/yr	Dry Production Ash
Winyah STAR Plant	Georgetown, SC	Santee Cooper	Opened in 2015	400,000 tons/yr	100% reclaimed ash previously landfilled or impounded in a surface pond. Can also operate with production ash.
Contracted Future Facilities					
Facility	Location	Station	Status	Nominal Processing	Impounded Ash Volumes
STAR Plant IV	Salisbury, NC	Buck Steam Station	Scheduled to break ground for construction in 2018	900,000 tons/yr[1]	6.4million tons
STAR Plant V	Goldsboro, NC	H.F. Lee Plant	Scheduled to break ground for construction in 2018		6.2 million tons
STAR Plant VI	Moncure, NC	Cape Fear Plant	Scheduled to break ground for construction in 2019		5.7 million tons

[a]Sources: Fedorka et al. (2015); Duke Energy (2016a,b & 2017a,b)

ECONOMICS OF BENEFICIATION

An economic case study comparing thermal beneficiation management of ash to traditional landfilling was compared in Fedorka et al., 2015. In the analysis associated expenses for $50 million STAR facility with a processing capacity of 320,000 TPY was compared to installation and operation of an onsite RCRA Subtitle D landfill to manage CCP disposal (using Duffy, 2005) over a 20-year operational lifespan. The analysis found that the beneficiation option yielded a savings of $15 million (in present day dollars); this did not include the 30-year post-closure monitoring expenses of the landfilling option or associated benefits of the STAR facility operating beyond the 20-year operation period. While the exact expense of existing STAR facilities is variable depending upon size, ash feed quality and site characteristics, estimates of the future North Carolina facilities are around $50 million per facility. SEFA officials were not able to share exact costs, but commented that the estimate represented the high end of the price range for thermal facilities at large coal-fired power plants (Southeast Energy News, 2016).

SITE-SPECIFIC CONSIDERATIONS FOR DOMINION ENERGY'S IMPOUNDMENTS

As evidenced by the experiences in Maryland, South Carolina, and future installations in North Carolina, thermal beneficiation technologies are commercially available and are viable alternatives for processing large volumes of legacy ash. These approaches allow the sale and use of the ash in encapsulated form in concrete which is an environmentally preferred management option that eliminates long-term liability associated with managing coal ash materials.

There are site-specific considerations that will influence the feasibility and cost of managing the ash from the current storage locations of Dominion Energy. Details of the sites and consideration of the optimum number and location of STAR or similar facilities is beyond the scope of this report. However, major factors include the following:

- Access to barge and rail transport. These facilities all transported and handled large volumes of coal throughout their operation, so generally should be suitable for handling the transfer of ash between facilities and sale of bulk ash products. All facilities are located adjacent and connected by heavy rail. Additionally, in 2007 the Chesapeake Energy Center also constructed a pier to receive 1.6 million tons of foreign coal per year (The Virginian-Pilot, 2007).
- Available areas on site for a new facility. Similar to the transportation consideration, these are large facilities that historically handled large volumes of coal (ash typically represents approximately 10% of the original coal material). These facilities have space for large ash ponds (e.g. up to 100 acres each), so would be expected to reasonably able to accommodate a STAR facility, as has been done at facilities in neighboring states.

Table 4 provides known site-specific legacy ash details at the Dominion facilities including estimated volumes, areas, status, condition and risk ratings. Additionally, site descriptions and aerial imagery is provided for each of the facilities.

Table 4. Dominion Energy Legacy Ash Locations and Details

Impoundment	Size[a,b] *acre*	Amount of Ash[a]	Status[a]	Price of Closure[a]	Hazard[b]	Condition[b]	Liner Present[d]
Bremo							
North Pond	96	6.1 million tons[c]	Accumulating – ash is actively being filled from E. Pond	$21 million	Significant	Fair	No
West Pond	17		Empty – ash has been transferred to N Pond		Significant	Fair	No
East Pond	NA		Removing - CCR actively being transferred to N Pond		NA	NA	NA
Chesapeake							
Impoundments and Landfilled Ash	NA	3.4 million tons[e]	Idle – no ash added	NA	Significant	Poor	No
Chesterfield							
Upper Pond	49	14.4 million tons[c]	Accumulating- cells 3&4 actively being filled	$29.4 million	Low	Satisfactory	No
Lower Pond	100	2.3 million tons[c]	Idle – preparing for closure	$79.7 million	Significant	Fair	No
Possum Point							
ABC Pond	18	3.6 million tons[c]	Empty – ash has been transferred to Pond D	$92.9 million	NA	NA	NA
D Pond	64		Idle – no ash added		Significant	Satisfactory	NA
E Pond	38		Empty – ash has been transferred to Pond D		Significant	Fair	NA

NA – Not Available

[a] Dominion Closure and Annual Inspection Reports (available: https://www.dominionenergy.com/ccr)

[b] Dominion (2014)

[c] Assumed 1 ton per CY equivalent for ash

[d] USEPA (2012)

[e] E.D.Va (2013)

Figure 6 Bremo Power Station (Image: Google Earth © Google Google Landstat/Copernicus)

Bremo Power Station is an active 227megawatt power plant that currently generates electricity from natural gas. It is located on the banks of the James River in Fluvanna County approximately 50 miles west of Richmond, VA. The plant actively burned coal between 1931 and 2014 and leaves a legacy of 3 ash impoundments on the property including North Pond, which is approximately 96 acres. Dominion has submitted closure plans to transfer all ash from East and West ponds to North Pond and cap the ash in place. The estimated price is $16.5 million for closure and $4.5 million for post-closure monitoring (Dominion, 2016a).

Figure 7 Chesapeake Energy Center (Image Google Earth © Google Data LDEO-Columbia, NSF,NOAA Data SIO, NOAA, US Navy, NGA,GEBCO)

Chesapeake Energy Center (CEC) was a 660megawatt power plant powered by coal that now operates two small combustion turbines powered by light fuel oil. It is located on the banks of the Elizabeth River approximately 10 miles south of the center of Norfolk, VA. The plant actively burned coal up from the 1980s to 2014 and leaves a legacy 23-acre coal ash landfill and a 4.2-acre bottom ash pond. These fills were constructed on top of a portion of a large historic ash pond whose footprint encompasses both the bottom ash pond and landfill. Dominion is currently working to cap and close both the landfill and ash pond in place. The estimated cost of this project was not determined.

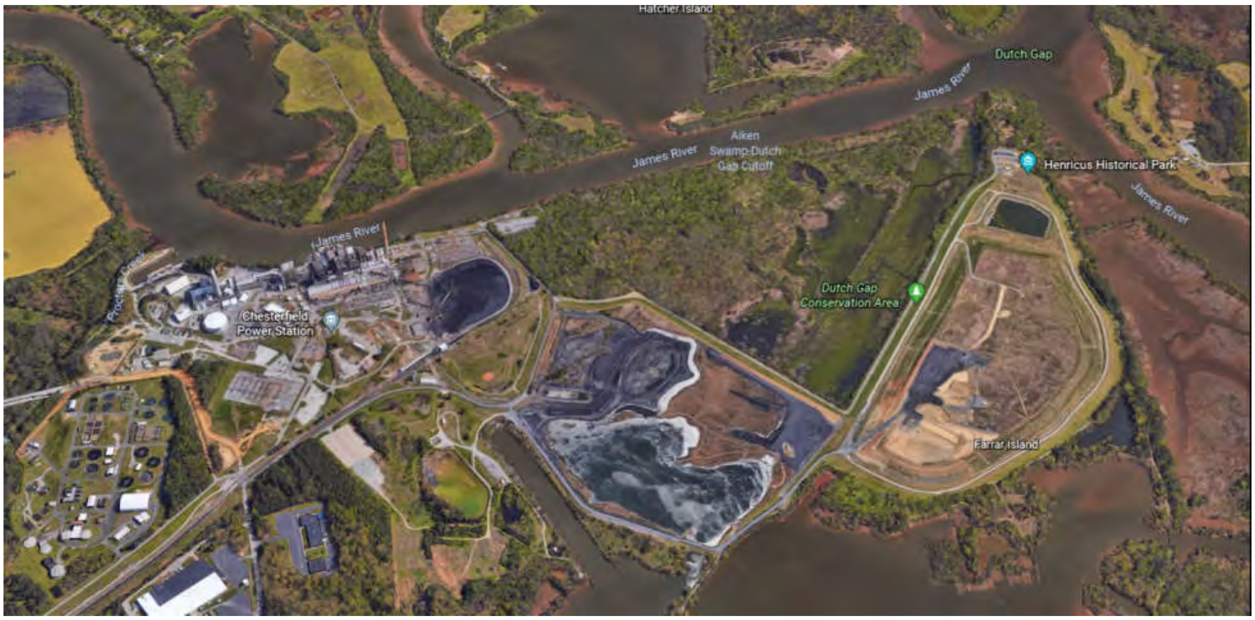

Figure 8 Chesterfield Power Station (Image Google Earth © Google; Data © Google)

Chesterfield Power Plant is an active 1,600megawatt coal fired power plant located on the banks of the James river in Chesterfield County approximately 15 miles south of Richmond, VA. The plant has been active since 1952 and leaves a legacy of 2 historic ash ponds. The Upper (East) Pond is approximately 49-acres and the Lower Pond is approximately 100-acres. Dominion has submitted closure plans to cap both impoundment in place. The estimated price for closure is $100 million with an undetermined monitoring cost (Dominion, 2016b).

Figure 9 Possum Point Power Station (Image Google Earth © Google; Data SIO, NOAA, US Navy, NGA,GEBCO Google Landstat/ Copernicus)

Possum Point Power Plant is an active 1,661megawatt plant that currently generates electricity from natural gas and oil. It is located on the Potomac River approximately thirty miles south of Washington, D.C. where Quantico Creek flows into the Potomac. The plant actively burned coal up until 2003 when units 3 and 4 were converted to natural gas. This historic activity leaves behind 5 ash ponds which cover approximately 120-acres combined. Dominion has submitted closure plans to transfer as from the 4 smaller ponds to Pond D, which they propose to cap and close in place. The estimated price is $92.8 million for closure and $11.6 million for post-closure monitoring (Dominion, 2016c).

CURRENT AND FUTURE AVAILABILITY OF CCPS

The availability of less expensive natural gas and the implementation of more strict emissions requirements has combined to significantly reduce the US and mid-Atlantic electricity production reliance on coal. The production of electricity by coal has dropped by approximately 50% between 2000 and 2016 in VA, which correlates with a 50% reduction in production of CCPs. With a steady demand for concrete, there is a clearly increasing market availability for legacy ash as a cost-effective substitute for Portland Cement.

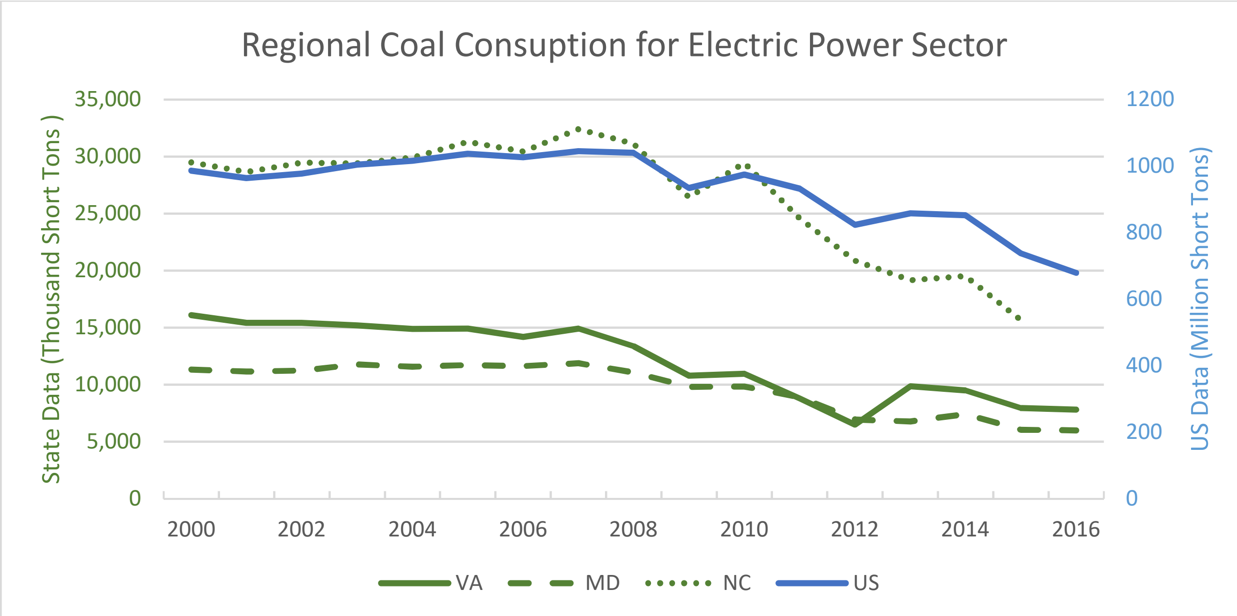

Figure 10 Decline in US, VA and MD Coal Consumption (EIA, 2017)

SUMMARY

This report demonstrates that beneficial reuse of ash contained at the four Dominion Energy Virginia sites is technically, logistically, and economically feasible. There is a strong demand in the market for high quality coal fly ash and there are technologies commercially available and operating in the region that currently are producing high quality ash for the concrete market from landfilled or ponded ash. Representatives from the concrete industry have stated the need for high quality ash sources in the Virginia region and have indicated a willingness to set up long-term contracts for ash suppliers. Success in the mining and beneficiation of legacy ash in South Carolina has spurred the planning and planned groundbreaking for multiple new beneficiation plants in North Carolina in 2018, demonstrating economic viability. This combination of available technology, vendors with experience, a strong market and economic feasibility together make clear that beneficial use of legacy ash from the Dominion Energy sites is possible, feasible, and given the environmental benefits of this approach, an overall preferred approach compared with long-term disposal options.

REFERENCES

ACAA. (2015). A New Solution for a Long-Standing Dilemma. *Ash at Work*. Retieved from https://www.acaa-usa.org/Publications/AshatWork.aspx

ACAA. (2016a). Beneficial use of coal combustion products: an American recycling success story. Retrieved from https://www.acaa-usa.org/Portals/9/Files/PDFs/ACAA-Brochure-Web.pdf

ACAA. (2016b). Best Coal Ash Management Practices: Integrating Strategies for SDisposal and Beneficial Use. *Ash at Work*. Retrieved from https://www.acaa-usa.org/publications/ashatwork.aspx

Aggarwal, V., Gupta, S. M., & Sachdeva, S. N. (2010). Concrete durability through high volume fly ash concrete (HVFC) a literature review. *International Journal of Engineering Science and Technology*, *2*(9), 4473–4477.

ARTBA. (2011). *The Economic Impacts of Prohibiting Coal Fly Ash Use in Transportation Infrastructure Construction*. Retrieved from: https://www.artba.org/wp-content/uploads/2017/06/study2011flyash.pdf

Dominion. (2014). *Coal Ash Management Report*. Dominion Energy. Retrieved from https://www.dominionenergy.com/library/domcom/pdfs/corporate/environment/coal-ash-report-2014.pdf

Dominion. (2016a). Bremo Bluff Closure Plan. Retrieved from http://www.deq.virginia.gov/Portals/0/DEQ/Land/Bremo/DominionResp/RevisedClosurePlan.pdf

Dominion. (2016b). Chesterfield Closure Plan. Retrieved from https://www.dominionenergy.com/library/ad317bacb7ff49b3bdd785292dc7c471.ashx

Dominion. (2016c). Possum Point Closure Plans. Retrieved from https://www.dominionenergy.com/library/1abe15287013438bb536a3e93ec537c7.ashx

Duffy, D. (2005). Landfill Economics Part 1,2&3: Getting Down to Business. Retrieved from:https://foresternetwork.com/daily/waste/landfill-management/landfill-economics-part-ii-getting-down-to-business-part-i/

Duke Energy. (2016a). Duke Energy to recycle coal ash at Buck Steam Station in Salisbury. Retrieved November 20, 2017, from https://news.duke-energy.com/releases/duke-energy-to-recycle-coal-ash-at-buck-ste

Duke Energy. (2016b). Duke Energy to recycle coal ash at H.F. Lee Plant in Goldsboro. Retrieved November 20, 2017, from https://news.duke-energy.com/releases/duke-energy-to-recycle-coal-ash-at-h-f-lee-plant-in-goldsboro

Duke Energy. (2017). Duke Energy is building a smarter energy future by recycling even more coal ash. Retrieved November 20, 2017, from https://news.duke-energy.com/releases/duke-energy-is-building-a-smarter-energy-future-by-recycling-even-more-coal-ash

Duke Energy. (2017b). Duke Energy Coal Plants and Ash Management. Retrieved from: https://www.duke-energy.com/_/media/pdfs/our-company/ash-management/duke-energy-ash-metrics.pdf?la=en

EIA. (2017). Table CT-8 Electric Power Sector Consumption Rates, 1960-2015, United States Retrived from: https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_use/eu/use_eu_US.html&sid=US

E.D.Va. (2013). *Sierra Club v. Va. Elec. & Power Co.*, 247 F.Supp.3d 753, 757

EPRI. (2016a). Phase I: Market Summary Summary Retrieved from: https://ncdenr.s3.amazonaws.com/s3fs-public/Environmental%20Management%20Commission/EMC%20Meetings/2016/November2016/GWWMC/2016%20Duke%20Energy%20-%20EPRI%20Re-Use%20Technologies%20Report.pdf

EPRI. (2016b). Phase II: Beneficiation Technologies Study Summary Retrieved from: https://ncdenr.s3.amazonaws.com/s3fs-public/Environmental%20Management%20Commission/EMC%20Meetings/2016/November2016/GWWMC/2016%20Duke%20Energy%20-%20EPRI%20Re-Use%20Technologies%20Report.pdf

EPRI. (2016c). Duke Energy Coal Ash Beneficial Reuse Technologies Study. Presented to the GWWMC.Retrieved from:

Erbe, M., et al. (2013). Commercial Use of CCBs: Changes, Challenges, and Opportunities. *2013 World of Coal Ash Conference Proceedings*. Retrieved from: https://www.flyash.info/

Erwin, R. (2014). STAR Beneficiation Process By-Products Utilization. Solid Waste Association of North America Presentation. Retrieved from: http://www.scswana.org/Resources/Documents/2014%20STAR%20Beneficiation%20Process%20By-Products%20Utilization%20-%20Erwin.pdf

Fedorka et al. (2015). Reclaiming and Recycling Coal Fly Ash for Beneficial Reuse with the STAR Process. *World of Coal Ash Conference. Nashville, TN. May 5-7*. Retrieved from: http://www.flyash.info/2015/168-fedorka-2015.pdf

FHWA. (2003). Fly Ash Facts for Highway Engineers. Retrieved from https://www.fhwa.dot.gov/pavement/recycling/fach00.cfm

FHWA. (2008) Federal Highway Administration Highway Statistics 2008, Table HM-12

Hite, S. and Dietrich, R. (2008) Beneficial Use of Industrial Materials in Virginia Roadway Consruction. Retrieved from http://infohouse.p2ric.org/ref/50/49255.pdf

Knowles, J. (2014) Comparison of Fly Ash Beneficiation Technologies. The SEFA Group Inc.

Lee. R., et al. (2015). Transforming CCBs in Maryland to Enhance Beneficial Use. *World of Coal Ash Conference Proceedings*. *Nashville, TN. May 5-7*. Retrieved from: https://www.flyash.info/

Leming, M. (2017) Fly Ash in Concrete, An Overview of Benefits and Quantities Needed for Use in Portland Cement Concrete in Noth Carolina, South Carolina and Virgina. Retrieved from: http://www.crmca.com/wp-content/uploads/2017/06/FlyAshStudyFullwithUpdate.pdf

Oberlink, A., Robl, T., Jewell, B., Ladwig, K., Hebeler, G., & Yeboah, N. (2017). Coal Ash Use Study for Duke Energy , North Carolina. *World of Coal Ash Conference. Lexington, KY. May 9-11*. Retrieved from http://www.flyash.info/2017/123-Oberlink-woca2017p.pdf

Power Engineering. (2011). Dominion installs FGD at Chesterfiled. Retrieved from: http://www.power-eng.com/articles/2011/06/dominion-installs-fgd-at-chesterfield.html

PMI. (2017). Carbon Burn-Out Precess Information. Retrieved from: http://www.pmiash.com/carbonburnout.asp

PPRP. (2017). Summary Charts - CCB Generation and Use in Maryland 2016.

Robl, T. (2017). University of Kentucky, Lexington, KY, United States. *Coal Combustion Products (CCPs): Characteristics, Utilization and Beneficiation*, 217.

Southeast Energy News. (2016). How North Carolina Law could make it harder to recycle coal ash. Retrieved from: http://southeastenergynews.com/2016/11/07/how-north-carolina-law-could-make-it-harder-to-recycle-coal-ash/

USDOE (2017) Current Regulations Governing Coal Combustion Byproducts. national Energy Technology Laboratory. Retrieved from https://www.netl.doe.gov/research/coal/crosscutting/environmental-control/solid-waste/state-regulations/virginia

USEPA. (1992). *EPA Guideline for Purchasing Cement and Concrete Containing Fly Ash. EPA report number EPA/530-SW-91-086.*

USEPA. (2005). Using Coal Ash in Highway Construction: A Guide to Benefits and Impacts.

USEPA. (2012). Database of caol combustion waste surface impoundments. Retrieved from: https://earthjustice.org/sites/default/files/Coal-Plant-CCW-Disposal-Units-from-ICR.pdfUSEPA. (2005). Municipal Solid Waste Landfills: Economic Impact Analysis for the Proposed New Subpart of the New Source Performance Standards. Retrieved from: https://www3.epa.gov/ttnecas1/regdata/EIAs/LandfillsNSPSProposalEIA.pdf

USEPA. (2015). Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities. Retrieved from https://www.federalregister.gov/d/2015-00257

USGS. (2016) Iron and Steel Slag Mineral Commodity Summaries. Retrieved from: https://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_slag/mcs-2016-fesla.pdf

USGS. (2017). Coal Combustion Products Statistics [through 2015; last modified January 19, 2017]. Retrieved from https://minerals.usgs.gov/minerals/pubs/historical-statistics/

VADEQ. (2017). Coal Ash Mangement in Virginia. Retrieved November 20, 2017, from http://www.deq.virginia.gov/ConnectWithDEQ/EnvironmentalInformation/CoalAshPermits.aspx

Virginian-Pilot. (2007). Area getting two facilities for incoming coal. Retrieved from: https://pilotonline.com/business/area-getting-two-facilities-for-incoming-coal/article_f99727a4-cecd-55cc-8775-cced5c583def.html