Results in Reclaiming and Recycling Coal Combustion Residuals for Encapsulated Beneficial Reuse

William Fedorka, P.E., Jimmy Knowles and John Castleman, P.E.

The SEFA Group, 217 Cedar Road, Lexington, SC 29073


ABSTRACT

The positive economic and technical benefits of utilizing fly ash as a replacement for cement in concrete are well established. However, as ever increasing environmental regulations on coal-fired plants negatively impact fly ash quality for use as supplementary cementitious material in concrete, increasing percentages of ash are disposed rather than used in concrete, and the supply of specification-grade fly ash has decreased dramatically. Industry and the environment would benefit from reclaiming fly ash from disposal sites, but previously-disposed fly ash does not meet industry’s expectations for quality.

The SEFA Group, a longtime leader in fly ash utilization, continues to develop state-of-the-art beneficiation technologies. The STAR® – Staged Turbulent Air Reactor – process is commonly used to manufacture a premium product on a commercial scale that can be applied across a wide variety of new markets, not previously open to coal combustion residuals.

In 2014 The SEFA Group decommissioned its CBO Plant at Santee Cooper’s Winyah Station and constructed a STAR® facility designed to operate with 100% reclaimed fly ash as its primary raw feed source. This new adaptation of a proven technology will eliminate future disposal, while also recycling material from nearby impoundments for beneficial reuse.

Since commercial operation in early 2015, the Winyah STAR® has reclaimed and processed over a quarter of a million tons of Coal Combustion Residuals from onsite ash impoundments and has consistently produced a product ash below 0.50% Loss on Ignition (LOI) while meeting all relevant specifications for use in Ready Mix Concrete as a replacement for Portland Cement.

This paper will discuss various aspects of the technology, operating experience, test results and product characterizations.

INTRODUCTION

Since its inception in 1976, The SEFA Group's core purpose has been to offer services and products to utilities, construction and related industries principally through maximizing the beneficial use of fly ash in environmentally sustainable ways. Over the years SEFA has also grown to provide related services in plant operations, transportation, construction and engineering, in its commitment to the highest level of service to customers. SEFA started the search for the optimal beneficiation method over 20 years ago to provide ready-mix concrete customers an uninterrupted supply of quality fly ash. The search led to development of SEFA's proprietary thermal beneficiation process, STAR® Technology. The stand-alone and cost-effective STAR® Process serves as the centerpiece of SEFA's emphasis on providing compelling value to our utility partners and customers.

Over the last 25 years our industry has learned valuable lessons and has made innovative advancements in coal ash beneficiation. Environmental regulations and power generation economics have resulted in drastic changes to coal ash characteristics and new requirements have dictated the processes used to alter coal ash if it were to be marketed for beneficial use. Through the years, SEFA has remained at the forefront of the coal ash marketing field, adapting and modifying the methods in an effort to meet the demand for specification-grade material. With more than two decades and over 6.5 million tons of experience in thermal beneficiation, the SEFA Group and its STAR® Technology offers a proven solution for coal ash marketing.

In addition to the beneficiation of conventional by-product, or production, fly ash the STAR® Technology is well suited for processing material previously stored in ponds and landfills. A process that simply dries reclaimed pond ash does not produce specification-grade fly ash. This is due to prolonged exposure to water, ponded coal ash undergoes chemical weathering, which reduces its strength-producing characteristics in concrete and other applications. Furthermore, pond ash differs from fly ash collected in a dry form in that it contains a significant amount of relatively coarser particles (greater than 45 µm and up to 150 µm). This loss of fines translates into reduced strengths when used in concrete.

However, pond ash processed with STAR® Technology meets all the requirements of the most stringent specifications for use in concrete and other applications. This means that utilities can eliminate long-term liability with 100 percent of the product stream designated for encapsulated beneficial use. This benefit has allowed utilities to re-evaluate their strategies for pond ash management, particularly given the 2015 US. Environmental Protection Agency (EPA) rules regulating Coal Combustion Residuals (CCR) commonly referred to as coal ash. The new rule regulates new and existing CCR landfills and surface impoundments (i.e. ponds) at electric-generating stations as non-hazardous solid waste units under Resource and Recovery Act (RCRA) Subtitle D. These new rules have specific requirements for using liners for all new CCR units. As such, they will increase costs related to disposal of coal ash moving forward, and extend the long-term liability associated with the risks of storing coal ash in landfills. STAR® Technology offers a permanent solution, eliminating coal ash, and a sustainable solution.
solution, resulting in high-quality, consistent fly ash that can be recycled for use in concrete.

BENEFITS OF THE STAR PROCESS

STAR® Technology has proven to be a cost-effective solution by removing organics and contaminants from coal ash leaving 100% pure mineral matter with no solid waste stream. It was designed for thermal beneficiation and is a self-sustaining process. Which means the residual carbon in coal ash reacts and becomes the heat source for the process with no need for auxiliary fuel. In fact, the STAR process is exothermic, and as such has enough waste heat to handle 100% ponded material containing upwards of 25% moisture. Commercial operation removes all ammonia – through chemical decomposition into nitrogen and water vapor – and can also reduce other contaminants.

In addition, every STAR® Plant is a stand-alone facility, and can operate independently from the host utility. Criteria pollutants are handled internal to the process, with the exception of sulfur oxide (SOx) emissions which are typically controlled with a Flue Gas Desulphurization (FGD) process. The STAR plant has its own stack with integral Continual Emission Monitoring System (CEMS) to ensure compliance with permitting requirements. Both electricity and water can be obtained from 3rd parties completely severing the STAR® facility from the utility. In fact, the main driver for keeping the STAR® Plant onsite is to reduce transportation costs of the raw material.

The process provides an economical CCR management strategy, reducing cost by avoiding the handling and placing of coal ash in landfills. Also, in reducing the volume of coal ash disposal, the life expectancy of landfills is increased by postponing or altogether eliminating the need for new development or expansion. This has the added benefit of reducing the long-term liability associated with on-site storage.

As mentioned in the EPA CCR ruling, beneficial encapsulated use of coal ash meets EPA Guidelines as an approved method of ash usage. Once the ash is processed through a STAR® Plant, the utility is free from the concerns of sediment and erosion of landfills, as well as groundwater monitoring and leachate system maintenance.

The economic assessment that thermal beneficiation could present significant savings to landfilling was made in the 2015 “Ash at Work” feature article, “A New Solution for a Long-Standing Dilemma”. The article acknowledges that while each utility tailors its coal ash management program to its specific circumstances, and there is no single magic bullet to solve all problems, beneficiation can prevent coal ash from becoming or continuing to be a liability and expense as a landfill or pond waste product. Ash is eliminated and forgotten.

COMMERCIAL STAR PLANT EXPERIENCE

The first STAR® Plant was built at SCE&G’s McMeekin Station, which is located in Lexington, South Carolina. This facility was designed with a maximum heat input of 35 MM Btu/hr, and is permitted to process upwards of 140,000 tons per year of dry fly ash. Actual throughput is dependent upon the carbon content, or Loss on Ignition (LOI), of
the available feed material. Figure 1 below shows the relationship of material throughput of the STAR® at varying raw feed LOIs and design heat inputs.

The McMeekin STAR® began commercial operations in 2008 and to date has processed over 800,000 tons of high LOI fly ash originating from more than sixteen (16) different facilities with feed LOIs ranging from 5 to 25%. The final product is of premium quality with LOIs less than 1.0%.

The McMeekin facility is wholly owned and operated by The SEFA Group, and is permitted as a stand-alone facility. As such, the plant handles all emissions, and includes a wet scrubber for control of SO2, and a Continuous Emissions Monitoring System (CEMS) to confirm environmental compliance.

Lessons learned from the McMeekin “first-of-a-kind” STAR® Plant were incorporated into the design of the next generation STAR® facility, referred to as STAR® II. The first STAR® II Plant was located at NRG’s Morgantown Station and began commercial operations in 2012. The facility is owned by NRG, and is designed to process 100% of all fly ash generated at their Morgantown (1252 MW) and Chalk Point (728 MW) facilities. It should be noted that since the Morgantown STAR® has been in operation, NRG has been able to postpone all investments related to landfill development indefinitely. The swing in beneficial reuse versus disposal can be seen in Figure 1 below.

![Figure 1: Fly Ash Use vs Disposal: Morgantown Power Station, MD](image-url)
The STAR® II Plant was designed with a maximum heat input of 120 MM Btu/hr, and has a nominal processing capacity of 360,000 tons per year assuming a 9% Raw Feed LOI. The facility includes a concrete storage dome capable of holding more than 30,000 tons of finished product. To date the Morgantown STAR® plant has processed over 600,000 tons since startup. Even though the STAR® II plant is a three times scale-up of the McMeekin plant, the ash produced remains a premium quality product with typical LOIs still less than 1.0%. Typical throughput at varying Feed LOI can be seen in Figure 2 below.

![STAR Throughput per Heat Input](http://www.flyash.info/)

**Figure 2 – STAR® Throughput based on Raw Feed LOI**

While the Morgantown STAR® Plant is owned by NRG, it was also permitted as a stand-alone facility, and can operate independently of the host utility. Similarly to the McMeekin STAR®, the STAR® II facility includes a wet scrubber for control of Sulfur Oxide (SOx) emissions, as well as a CEMS to ensure compliance with all criteria pollutants and permit restrictions.

In 2013 commercial-scale testing, 100% reclaimed material from landfills and impoundments was processed through the McMeekin plant. In all cases the strength activity index of the final product met or exceeded ASTM requirements and closely approximated the STAR® product from normal commercial operations.
Based on these results, in 2014 SEFA decommissioned its Carbon Burn-Out (CBO) beneficiation plant at Santee Cooper’s Winyah Generating Station and replaced it with a 120 MM Btu/hr STAR® Plant that could interchangeably beneficiate both freshly-produced fly ash and previously-disposed coal ash reclaimed from ponds. Similar to the McMeekin STAR® Plant, the Winyah STAR® Plant is owned and operated by SEFA. It was also permitted as a stand-alone facility. Because of this, the plant operates normally even when all the station units are off-line. In fact, even if any or all of the Winyah Generating Station units are decommissioned in the future, the plant could continue operating at full capacity for decades, limited only to processing the on-site pond ash.

The Winyah STAR® Plant, as shown below, began commercial operations in 2015. The plant routinely operates using 100% reclaimed coal ash from ponds, yet it is able to switch its feed source at a moment’s notice to process 100% dry fly ash as it is produced at the generating station. Since startup the plant has processed over 360,000 tons of reclaimed ash and over 150,000 tons of dry ash from the generating station.

The next STAR® Plants will be developed for two locations in North Carolina. Like the Winyah STAR® Plant, these facilities will reclaim and reprocess coal ash removed from containment ponds, transforming coal ash to a high-quality product that can be recycled in concrete. With nine years of technological advancements, proven market success,
and continued growth, SEFA has established STAR® Technology as one of the most advanced and environmentally-friendly options available for recycling coal ash.

STAR PRODUCT QUALITY

The enhanced quality of STAR® fly ash is a critical element of its compelling value proposition. In the context of production, a by-product is the “output from a joint production process that is minor in quality and/or net realizable value”\(^7\). However, the product from the STAR® Process can truly be considered a manufactured product whose properties are not only extremely consistent, but desirable for its intended use.

During typical commercial operation, the STAR® Plant processes bituminous coal fly ash. However, some sub-bituminous coal fly ash and various blends of bituminous and sub-bituminous coal fly ashes have been processed. Raw feed fly ashes from 16 different coal-fired power plants have been processed through the McMeekin STAR® Plant. As of the writing of this paper, the LOI of the raw feed fly ashes processed through the STAR® Plant have ranged from nearly 30% LOI to slightly over 5% LOI. Hourly samples of raw feed and STAR® processed fly ashes are collected and tested for LOI.

Current commercial STAR® Plant operations process Class F coal fly ash; however, during R&D activities, Class C (sub-bituminous) coal fly ash and blends of Class F and Class C fly ashes were successfully processed\(^8\). STAR® Plant operation can be varied to either reduce or remove all carbon from any of the fly ashes processed to date\(^9\).

Obviously, processing with STAR® Technology lowers the amount of residual unburned carbon, reducing the LOI well below the maximum LOI limit of all relevant concrete specifications. Typical STAR® processed fly ash is below 1% LOI. However, STAR® Plant operating conditions can be adjusted to change/control the LOI of the finished product to meet the expectations of the marketplace, including 0% LOI for applications intolerant of any organic matter.

A major objective for processing fly ash using STAR® Technology is to increase the quality and, therefore, the value of fly ash that is currently used in the commercial marketplace – for example, as supplementary cementitious material (SCM) in concrete. The STAR® Plant is easily able to accomplish this objective by removing and/or treating unburned carbon found in residual coal char particles\(^10\). STAR® Technology, therefore, decreases the heterogeneity of coal fly ash by increasing the polar nature of STAR® fly ash\(^11\). Further to this effect, STAR® Plant operation can be varied to create an oxidizing treatment of any remaining carbon to either partially or completely de-activate it so as to match the expected adsorptive characteristics/requirements of various manufacturing processes, such as air-entraining admixture dosage rates in concrete production\(^12\).

The STAR® Plant can simultaneously produce multiple streams of processed product, each of which may have very different chemical and/or physical characteristics. For example, coal ash can be processed to produce high-quality SCM while, at the same
time, producing a separate stream of size-classified fly ash, tailored it to the expectations and/or requirements of a different market sector, such as mineral filler for plastic or rubber composites\textsuperscript{13}. Alternatively, the STAR\textsuperscript{®} Plant can operate to reduce or remove targeted “contaminants” (e.g., mercury), further enhancing its value in certain consumer products and some manufacturing processes – especially high-temperature processes\textsuperscript{14}. If there is no need to separate these product streams, all of the STAR\textsuperscript{®} processed coal ash is comingled with the main product stream.

Whenever the main product stream captures higher concentrations of targeted contaminants, the STAR\textsuperscript{®} processed fly ash from this stream is used in products, such as concrete, that do not restrict the presence of these contaminants and which will serve to reduce their potential toxicity and/or sequester them, as in the case of mercury, for example, through entombment in the cementitious paste matrix of concrete products\textsuperscript{15}.

**FUTURE AVAILABILITY AND USE OF FLY ASH**

Historically, coal was the dominant supply of electricity in the United States, coal fired units were base loaded and fly ash was plentiful year round. In today’s environment, coal has taken a back seat to natural gas and as a result, many coal plants have been retired and those still in operation sit idle during the milder weather seasons of spring and fall. This conflicts with the peak periods of construction and especially the pouring of concrete.

Coal plant retirements in recent years continue as utilities move away from coal to burn cheaper natural gas and increase their renewable capacity. The latest data from Energy Information Administration’s (EIA) September Monthly Electric Generator Inventory shows that in 2015 alone, utilities retired power plants generating 22.2 gigawatts of electricity\textsuperscript{16}. The old adage that larger coal fired units that had been retrofitted with all recent environmental controls would run for years to come is no longer the case. Even newer units such as JEA and FP&L’s 1252 MW St. John’s River Power Park in Jacksonville, FL is scheduled to be shut down in early 2018. The two utilities noted that St. John’s was producing half as much energy as it did a decade ago\textsuperscript{17}.

Today, coal-fired electricity accounts for 25% of operating electricity generating capacity in the United States and generated about 30% of U.S. electricity in 2016. Most coal-fired capacity (88%) was built between 1950 and 1990, and the capacity-weighted average age of operating coal facilities is 39 years\textsuperscript{18}. 

![Figure 4: Electricity Net Generation (Billion KilowattHours)](image)
As natural gas and renewables have increased their market shares of electricity generation over the past decade, coal generation has decreased. Average annual net generation from coal-fired units reached an annual high of 2.0 billion kilowatthours in 2007 and has since fallen to 1.2 billion kilowatthours in 2016 (its lowest levels since the early 1980’s – see Figure 4). In addition, the variability of coal generation on a month to month basis due to seasonality, over the 2014 through 2016 year period, has increased by nearly a factor of three when compared to generation from 2003 through 2005 (Figure 5)\textsuperscript{19}.

In 2016, the American Association of State Highway and Transportation Officials (AASHTO), convened a Task Force at their Subcommittee on Materials meeting for the purpose of documenting issues facing the coal industry and their impact on the production of fly ash, especially as related to use in the structural and paving concrete by State DOTs. The Task Force’s efforts included a survey that was sent to all State DOTs, as well as the Federal Aviation Administration (FAA)’s Pavement Group, the Federal Department of Defense (U.S. Army Corp of Engineers) among others. The survey had 52 respondents including 46 States\textsuperscript{20}.

The survey results indicate that the concern with fly ash supply is not a minimal or regional issue. Many agencies anticipate the use of Supplementary Cementitious Materials (SCMs) to increase due to Alkali-Silica-Reactivity (ASR) concerns and the
desire for durability and sustainability. Over 80% of those that responded to the survey identified recent supply issues with fly ash over the last four years and some reported that they have already approved the use of foreign sources of fly ash due to local shortages. Slag was also noted as an option that was being chosen as a replacement for fly ash in a number of responses. In addition, some agencies noted that they are actively looking at alternatives to fly ash, including sponsoring research in this area.

Florida and Texas are two states in particular that have ongoing research looking at new sources of pozzolanic materials in concrete. During a recent study, Texas found that six out of the eight pozzolans tested were found to be viable alternatives for Class F fly ash. Texas is also experiencing a situation where power plants that historically supply a Class F fly ash are switching coal sources and will soon be supplying a Class C fly ash. Texas Department of Transportation’s (TxDOT) primary approach to ASR mitigation is the use of Class F fly ash, so any reduction in supply is seen as a huge impact to their strategy.

Current shortages, combined with questions on future availability will have an impact on this strategy. TxDOT states in their ‘Construction and Materials Tips’ newsletter published in April 2012, that while current short-term fly ash shortages are an inconvenience, the more concerning issue is the long-term uncertainty of fly ash availability\(^{21}\). With the potential for the state’s fly ash resources to dwindle, TxDOT has been forced to take a hard look at how fly ash, particularly Class F fly ash, is being specified and used in its projects. For instance, specifying Class F fly ash in concrete pavements during summer months has become common in several large urban districts. While this specification is important to the long-term performance of concrete pavements, it consumes a large quantity of Class F fly ash, and the same performance can be achieved through other means. During shortages they are considering diverting Class F fly ash to concrete structures (bridge decks, columns and precast bridge beams) where TxDOT has historically encountered alkali-silica reaction (ASR)\(^{21}\).

These type of supply issues are not only found regionally and can be expected to increase moving forward. The American Road & Transportation Builder Association’s (ARTBA) June 2015 report entitled “Production and Use of Coal Combustion Products in the U.S.”, forecasts CCP utilization to increase from 51.6 million short tons in 2013 to 76.5 million short tons in 2033. Specifically fly ash utilization is forecast to increase 53 percent over the next 20 years. Expanding use of fly ash in high volume applications, new concrete mixtures and future growth in the ready-mixed concrete market will drive increased utilization\(^{22}\).

Historically, the production of ready-mixed concrete in the United States has grown at an average annual rate of three percent. Because it cannot travel for long distances before hardening, local demand for ready-mixed concrete is highly dependent on the dynamics of the local construction market, and can fluctuate from year to year. About half of all concrete is purchased by state and local governments\(^{23}\). If future growth continued along the historical trend, total ready-mixed concrete production would
increase from 300.8 million cubic yards to over 543.3 million cubic yards in 2033 (+80%).

New concrete mixtures with higher volumes of fly ash have significant potential to reduce costs, reduce energy content and improve long term performance when used for highway and bridge construction\textsuperscript{24}. Some studies have shown that mixtures where 50 percent or more cement is replaced with fly ash have produced “sustainable, high performance concrete mixtures that show higher workability, higher ultimate strength and high durability”\textsuperscript{25}.

SUMMARY

For over 40 years, The SEFA Group has been a leader in the beneficial use of fly ash in environmentally sustainable ways. And for the past two decades, SEFA has been at the forefront of development and commercialization of thermal beneficiation technologies. SEFA’s STAR\textsuperscript{®} Technology not only returns the low grade ash to specification standards but improves the quality of the ash far beyond previous levels. The self-sustaining STAR\textsuperscript{®} Process removes all organics and contaminants from the ash leaving 100% pure mineral matter with no solid waste stream.

SEFA has successfully demonstrated the viability of STAR\textsuperscript{®} Technology through commercialization at three STAR\textsuperscript{®} facilities. The most recent STAR\textsuperscript{®} Plant at the Winyah Power Station has the ability to process 100% ash reclaimed from ponds. The waste heat generated from the STAR\textsuperscript{®} Process is used to dry the pond ash thus making the entire plant a self-sustaining closed loop system. Further, the plant can switch at a moment’s notice from the reclaimed ash to 100% dry ash produced at the power plant, or any blend of both. This flexibility allows full load operation at all times without any dependence on operation of the power generation plant now or in the future. This unique independence is particularly important as the supply of fly ash for the construction industry continues to dwindle as more coal fired generation is taken off line. At the same time the market for high quality fly ash continues to grow. Utilizing reclaimed ash from ponds and landfills will provided continuous feed material and ensures uninterrupted supply for customers.

Coal ash pond closure with excavation and beneficiation offers a permanent solution where 100% of coal ash is transformed into a new, environmentally-responsible material. STAR\textsuperscript{®} Technology is a stand-alone solution that is cost-effective and eliminates long-term liability. This is a unique environmental success story.
REFERENCES


16. EIA Reference....