Reclaiming and Recycling Coal Fly Ash for Beneficial Reuse with the STAR^{TM} Process

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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 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^{TM} – 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 products.

In 2013 commercial-scale testing, 100% reclaimed material from landfills and impoundments was processed through a STAR^{TM} plant. In all cases the strength activity index of the final product met or exceeded ASTM requirements and closely approximated STAR^{TM} product from normal commercial operations.

In 2014 The SEFA Group decommissioned its CBO Plant at Santee Cooper's Winyah Generating Station and constructed a STAR^{TM} 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 thus allowing utilities to lessen its liability with long term storage of ponded ash.

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 transportation, construction and engineering which help to serve its primary goals. 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.

The SEFA Group began to search for the best method to refine coal ash in the mid 1990's. 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 5 million tons of experience in thermal beneficiation, the SEFA Group and its STAR technology offers a proven solution for coal ash marketing, and a unique strategy for pond ash management. Due to prolonged exposure to water, ponded coal ash undergoes chemical weathering, which reduces its strength-producing characteristics in concrete and other applications. Simply drying pond ash does not produce specification-grade fly ash. However, pond ash processed through STAR plants 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.

On April 17, 2015 the US. Environmental Protection Agency (EPA) published the final rule regulating Coal Combustion Residuals (CCR) commonly referred to as coal ash[1]. The new rule will regulate 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 are nearly identical to those for Municipal Solid Waste (MSW) landfills with their focus on protecting human health and the environment by addressing groundwater, structural integrity of impoundments, and specific requirements for using liners for all new CCR units. Groundwater monitoring is required for all CCR units as well as closure requirements which include a 30-year monitoring period[2]. These rules 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 on the utility's property.

BENEFITS OF THE STAR PROCESS

The STAR 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. The process reduces 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[3]. Once the ash is processed through STAR, the utility is free from the concerns of sediment and erosion of landfills, as well as groundwater monitoring and leachate system maintenance. Ash is simply gone and forgotten.

The STAR was designed for thermal beneficiation and is a self-sustaining process[4]. 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 30% moisture.

In addition, every STAR is a stand-alone facility, and can operate independently from the host utility[5]. 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.

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. 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.

To date the McMeekin STAR has processed over 600,000 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 typical LOIs at or below 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 SO_2, and a Continuous Emissions Monitoring System (CEMS) to confirm environmental compliance.

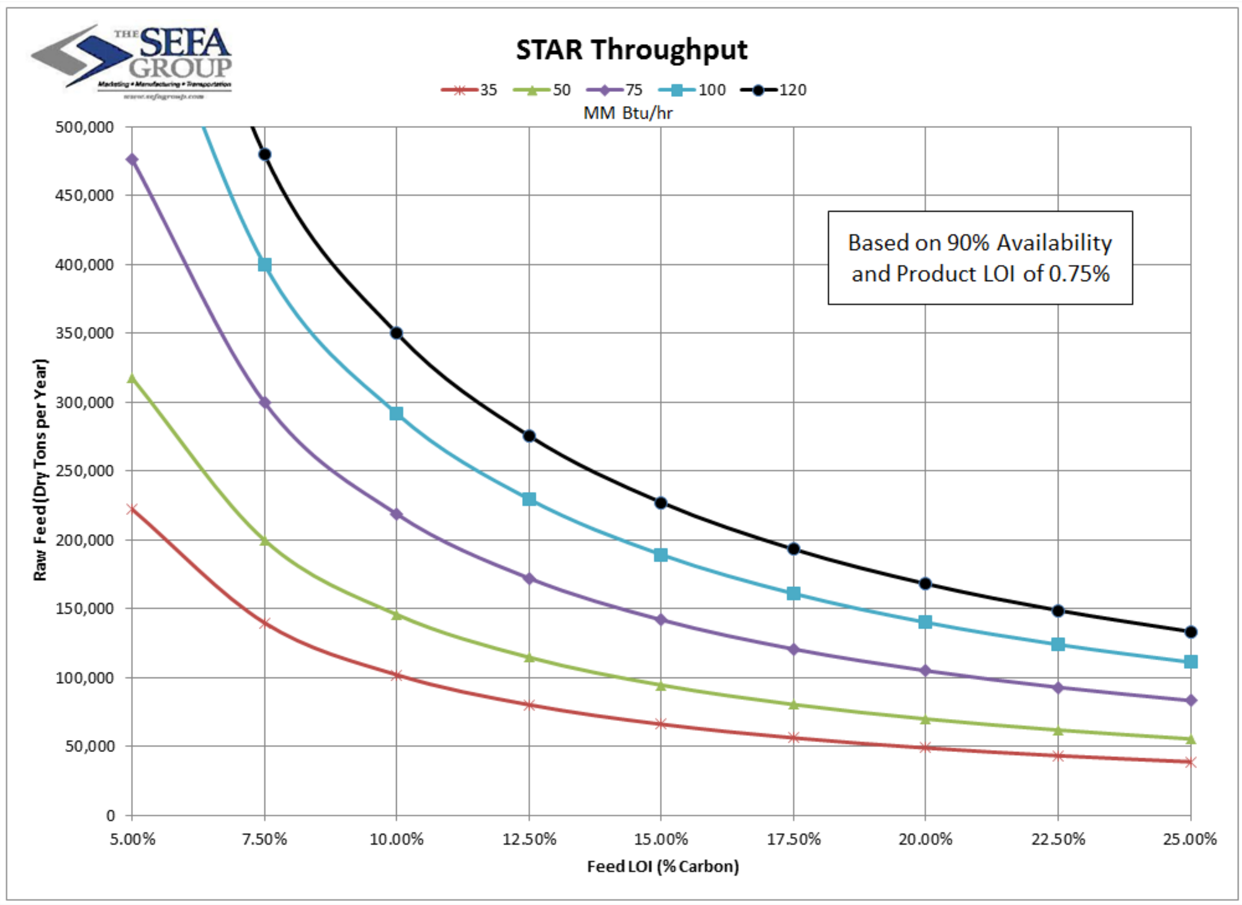

Figure 1 – STAR Throughput based on Raw Feed LOI

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 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 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.

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

(SO_X) 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 a STAR 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.

In 2014 The SEFA Group decommissioned its CBO Plant at Santee Cooper's Winyah Generating Station and constructed a STAR facility designed to operate with 100% reclaimed fly ash as its primary raw feed source supplied from local impoundments and ponds. The facility was deemed commercial on April 1, 2015 (see picture below).

Figure 2 – Winyah STAR facility in Georgetown, SC

STAR PRODUCT QUALITY

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.

Commercial operation removes all ammonia – through chemical decomposition into nitrogen and water vapor – and can also reduce other contaminants. Obviously, STAR processing 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. It is even possible to operate the process in such a way to achieve 0% LOI product.

Current commercial STAR Plant operation processes 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. STAR Plant operation can be varied to either reduce or remove all carbon from any of the fly ashes processed to date.

LANDFILL COSTS VERSUS BENEFICIATION

The landfill industry is highly regulated and growing environmental regulations have made it more and more costly to own and operate landfills. It requires large amounts of capital to permit, construct, operate and monitor sites. New CCR regulations are intended to mirror non-hazardous Municipal Solid Waste (MSW) landfill rules and standards (RCRA Subtitle D). It can cost more than $1 million per acre to permit, construct, operate, close and monitor a landfill in compliance with these regulations[6]. Permits today require 30 years of environmental monitoring after a landfill closes. This is a major financial commitment that needs to be planned out well in advance.

The cost to dispose of MSW at a landfill is commonly known as a “tip fee” or “gate fee”. In Sept. 2012, the average national spot market price to dispose of one ton of waste in a U.S. landfill was roughly $45, up 3.5% over 2011[7]. This compares to average national tip fees of approximately $32 in 1998 and $8 in 1985[8]. Between 1985 and 1995, the national average tip fee increased by 293%. In the subsequent 10 year period the national average tip fee increased by 7% per year.

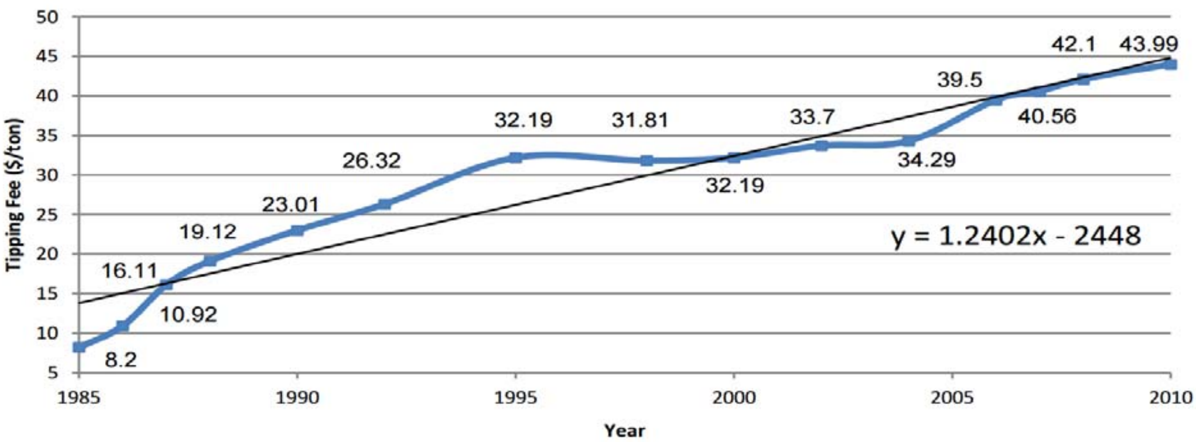

Figure 3 – MSW Landfill Tipping Fees[9]

In June of 2014, the EPA published an Economic Impact Analysis (EIA) for MSW Landfills to study the impact of proposed amendments to the Standards of Performance[10]. As discussed previously the new CCR regulations for the most part mirror those for MSW landfills as both are controlled under RCRA Subtitle D. The EIA presents a model originally published in 2005 to help estimate costs for a hypothetical landfill based on known market conditions and cost data.

Landfill costs fall into the following categories: site development, construction, equipment purchases, operation, closure and post-closure. Site development includes site surveys, engineering and design studies, and permitting fees. Construction costs encompass building the landfill cells as well as development of permanent on-site structures needed to operate the landfill. Evacuation of the landfill site comprises a notable portion of the construction costs. Installation of a liner can also vary greatly in cost depending on the site's geology.

Table 1: Typical Costs Per Acre for Components of Landfill Construction (Duffy, 2005)

Task	Low End	High End
Clear and Grub	$1,000	$3,000
Site Survey	$5,000	$8,000
Excavation	$100,000	$330,000
Perimeter Berm	$10,000	$16,000
Clay Liner	$32,000	$162,000
Geomembrane	$24,000	$35,000
Geocomposite	$33,000	$44,000
Granular Soil	$48,000	$64,000
Leachate System	$8,000	$102,000
QA/QC	$75,000	$100,000
TOTAL	$336,000	$774,000

Operating costs are relatively small when compared to the capital costs and include staffing, equipment, leachate treatment, and facilities and general maintenance[10].

The most straightforward means of evaluating the economic benefits of STAR is to perform a cost analysis on two (2) options – (1) The "Do-Nothing", or 100% landfilled options vs (2) investment in STAR and removing material offsite through sales of Thermal Beneficiated ash.

To estimate the Net Present Value (NPV) of a new landfill development project for CCR's, it was assumed that the Site Development costs, which include all engineering and permitting, would total a fixed $1 million. An average value of $423,000 (adjusted from $350,000 in 2005 dollars) per acre was used for the Landfill Construction costs (see Table 1) in accordance with the Duffy model[11]. Likewise the costs for installation of a cap and post-closure care were estimated to be $80,000 and $50,100 per acre respectively[12]. This brings the total landfill development, construction and closure costs to $560,000 per acre.

For the purpose of the model a 1500 MW facility with an effective heat rate of 9600 Btu/kWhr and a Capacity Factor of 75% was assumed to burn bituminous coal with a heat value of 12,500 Btu/lb, containing 10% ash. Fly ash was assumed to be 85% of the total ash generated resulting in 321,667 tons per year (TPY). In the model this ash was mixed with 23% moisture to achieve proper compaction, and was placed in the fill where one ton of ash was assumed equal to one cubic yard of air space. To estimate the Operating Costs of the landfill, it was assumed that each cell to be built in 33 acre cells, at a height of 60 feet with 3:1 slopes. In addition, a value of $2.00 per ton was assumed for hauling, and $3.50 per ton to place and compact the material.

For the "Do-Nothing", or 100% disposal case, five (5) 33 acre cells would need to be developed over the 20-year period to handle the 7.9 cubic yards of fly ash disposal. The NPV of all costs was determined to be $82 million dollars assuming a 10% discount rate and inflation of 2.5%. This represents an equivalent, "all-in" disposal cost of $27.55 per ton average over the 20-year period.

Nearly 6.5 million tons of ash were disposed of on-site, and the utility, or landfill owner, still has to deal with the 30-year Post-Closure period and all its associated costs, not to mention the perpetual liability of all that material buried underground.

If 85% of the available fly ash could be beneficiated and taken offsite, only one cell would be need to be developed with a life of nearly 40 years. Beneficiation would eliminate the liability and 30-year Post-Closure costs on 5.5 million tons of fly ash. At the end of the 20-year period the Beneficiation facility would be paid for, with plenty of years of productivity ahead as Life Extension costs are paid through the O&M of the facility. And even if the power plant went dark, or was moth-balled, the STAR could still reclaim material from disposal sites and use as raw feed.

For the 85% Beneficiation option, the NPV of disposal costs would reduce to $17 million. Assuming a capital cost for a STAR facility in the $50 million range, the total investment for the beneficiation plus disposal option would be $67 million ($17 million disposal NPV plus $50 million beneficiation investment). This represents a savings of **$15 million** in today's dollars. If a Discount Rate of 8% is used in the analysis, the NPV of 100% disposal costs would be $97 million in today's dollars, and the economic benefit grows to **$30 million**.

In addition, the beneficiation option would avoid disposal of 6.7 million cubic yards of material, and avoid all Post-Closure Landfill costs which according to new regulations will extend 30 years after closure. The sales of ash from the beneficiation facility will cover all O&M associated with the beneficiation facility, and includes capital for life extension that will allow the plant to operate well past the 20 year period included in the analysis.

SUMMARY

The SEFA Group has nearly two decades of experience with thermal beneficiation, and has developed its own proprietary process for refining fly ash – Staged Turbulent Air Reactor. The STAR Process generates a superior product that not only commands premium pricing from the ready mix concrete market, but it has opened the door for ash to be used in other high-value filler markets. The first facility located at SCE&G's McMeekin Station began commercial operations in 2008, the second, or STAR II facility located at NRG's Morgantown Generating Station in Southern Maryland began commercial operations in September of 2012. In 2014 SEFA de-commissioned its CBO facility in Georgetown, SC and erected a new STAR facility with the ability to run on 100% reclaimed material from ash impoundments / ponds. Based on estimated costs for new landfills to comply with the latest EPA rules for CCR disposal, it can be shown that a STAR Beneficiation facility can save millions over the life of the plant, while reducing the long-term liability associated with disposal.

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