Where will future ash supplies come from?

Ash Harvesting and Technologies Critical to Boosting SCM Supply

By Eric Effinger

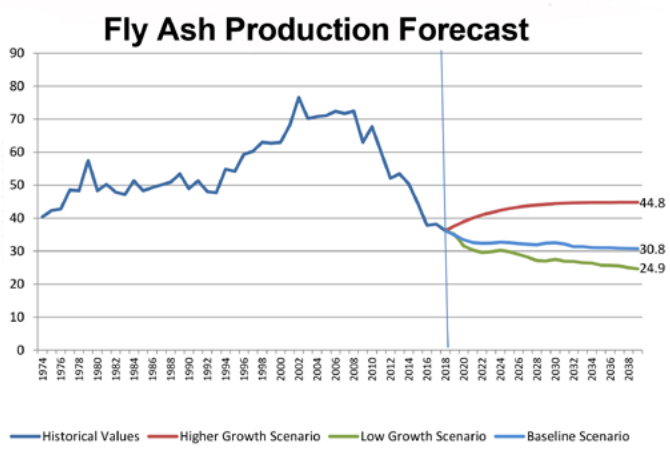
Since approximately 2008, the electric power industry has undergone a major shift away from coal-fueled electric power plants in favor of those using natural gas or passive power production. This change has resulted in a dramatic reduction in coal fly ash production, diminishing from a high of 72.5 million short tons in 2008 to 36.2 million short tons in 2018. Meanwhile, in 2018 the beneficial use of fly ash in concrete accounted for 12.5 million short tons of the material, which represented over 60 percent of its total beneficial use. Although the total tonnage of fly ash used in concrete has not increased significantly in the past 10 years, the concrete industry's demand for fly ash, as a percent of the material's total beneficial use, has increased by nearly 50 percent.

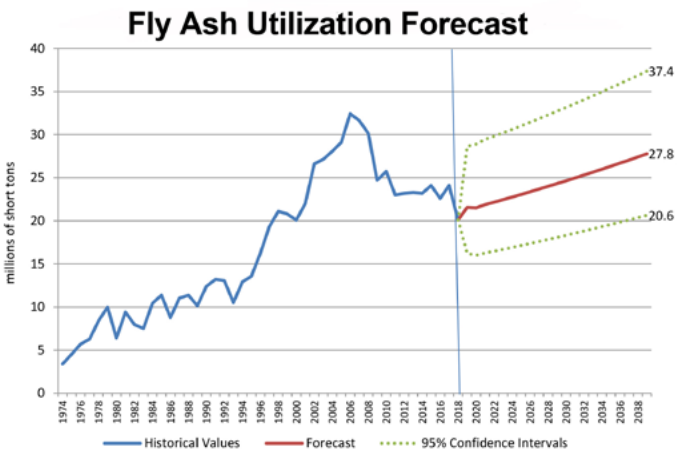
Looking ahead, the utilization of fly ash is expected to increase from 55 percent in 2018 to 90 percent in 2039, with the actual volume of fly ash utilized increasing from 20.1 million short tons to 27.8 million short tons at the end of these respective periods. The demand boost in North America comes from higher demand from the construction industry, increased road construction activities, and highway building; however, fly ash production will continue to fall over the same time frame. The American Coal Ash Association (ACAA) estimates that the average annual production of fly ash in the U.S. will be 32 million short tons by 2039, with the baseline forecast suggesting that fly ash production will fall from 36.2 million short tons in 2018 to 30.8 million short tons in 2039, decreasing at an annualized rate of 0.8 percent over the forecast period.

The falling production of fly ash will largely be driven by the continuing decline in the volume of coal-fueled electricity generation in the U.S. As a result, there will be a widening gap between supply and demand in the coming years, and prices for fly ash are expected to increase as demand outweighs supply. The global fly ash market is expected to grow from $8.5 billion in 2019 to $13.3 billion in 2027, at a compound annual growth rate of 5.8 percent, according to Fortune Business.

The growth in demand for fly ash is due to the increasing demand from the construction and infrastructure sectors as Class F is used as a substitute for portland cement in the production of concrete due to its inherent strengths, lower cost, and environmental benefits. This demand for fly ash will only grow once the recently passed $1.2 trillion infrastructure bill takes effect, which includes $110 billion to be used for the construction of roads and bridges.

Historically, this fly ash has been obtained directly from coal-fueled power plants around the country as it is being produced, but the accelerated rate of decommissioned coal plants is causing regional gaps in the production, supply, quality, and availability of fly ash around the nation. Fly ash from higher-production regions of the nation can be shipped by rail, truck,





and barge to high-demand regions that do not have supply—but it adds costs and time, and supply is not always reliable. Transporting fly ash long distances significantly increases its cost, and the price point of fly ash in most markets does not support these added transportation costs.

This higher demand has resulted in challenges regarding both the decrease in supply and quality of fly ash in some markets, which in turn has caused providers to consider a new source for the fly ash material that provides the performance attributes needed when used in the production of concrete: harvested fly ash. Harvested fly ash is ash that, owing to insufficient market demand at the time of production, was not used as it was produced, but instead was deposited in landfills or impoundments for disposal. Harvested fly ash is now becoming a principal source of fly ash that can provide the same product benefits as production ash to meet the increased demand by the concrete industry.

The Benefits of Ash Harvesting and How it Works

The benefits of ash harvesting are far-reaching and include:

- Capability to meet growing demand from concrete producers and others
- Lower costs versus using raw virgin materials
- Lower costs for logistics and delivery to markets
- Every ton of ash beneficially used in the production of portland cement saves 0.87 tons of CO2 from entering the atmosphere
- Beneficial use of fly ash provides concrete with higher strength, decreased permeability, increased durability,

Commercial Beneficiation Technologies

Ammonia Slip Mitigation
Vendor: Boral Resources
Technology type: Ammonia mitigation
Technology description: Boral's Ammonia Slip Mitigation (ASM) Technology is a low-capex solution specifically designed to mitigate the impact of ammonia slip resulting from SCR/SNCRs and other ammonia/urea injection systems at power plant systems. It is applicable to all phases (gas, liquid, and solid) containing ammonia. The gas-phase ASM is designed to treat ammonia in flue gas streams prior to deposition on ash to minimize air heater fouling. The liquid-phase ASM is applicable to power plants' wastewater streams, such as FGD scrubber blowdown, to reduce their ammonia concentrations prior to discharge or evaporative disposal in flue gas. The solid-phase ASM is meant to treat ammoniated fly ash for concrete use or disposal in landfill. The ASM chemical reagent treats the fly ash by converting the ammonia to harmless compounds, allowing its use in concrete applications and providing safer disposal operations.
Capital cost (range): The capital costs of ASM systems depend on the treatment phase and complexity of deployment at power plants, especially for the gas-phase system, which requires reagent injection in high-temperature flue gas. The capital cost for the solid-phase ASM to treat fly ash at the load-out silo ranges from $250,000 to $500,000.
 # Commercial units installed: 3
Contact info: Dr. Rafic Minkara, P.E., 770-330-0689, rminkara@boral.com
Website: www.flyash.com/products-and-technologies/ammonia-slip-mitigation

Carbon Blocker™
Vendor: Waste Management/Fly Ash Direct
Technology type: Carbon mitigation
Technology description: Carbon Blocker™ is a patented

chemical treatment process that mitigates the effects of excess carbon in fly ash when used as a constituent in a concrete mix. This is accomplished by satisfying the absorptive nature of the carbon. It is effective in mitigating natural and activated carbons. The Carbon Blocker™ chemical is applied to the fly ash as it is being loaded at the power plant. The process allows concrete admixtures such as air entraining agents, water reducers, etc. to perform uninhibited from the absorptive nature of carbon. Carbon Blocker™ has proven to be an effective carbon-mitigating solution for more than a decade.

Capital cost (range): $400,000 - $600,000

 # Commercial units installed: 9

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Website: www.flyashdirect.com

Carbon Burn-Out

Vendor: Boral Resources

Technology type: Carbon mitigation

Technology description: Boral's Carbon Burn-Out (CBO) is a technology and process in which residual carbon in fly ash is combusted to produce a consistent low-carbon, low loss-on-ignition (LOI), high-quality pozzolan. This fluidized bed thermal treatment process can also remove ammonia from fly ash. The CBO system is available in two configurations: (1) a custom-designed system for integration into an operating power plant to handle all its ash production and reclaim the heating value of the residual carbon in the ash, and (2) a modular stand-alone system consisting of prefabricated unit processes that are designed to beneficiate harvested fly ash. As such, the modular CBO system may be used to beneficiate high-carbon fly ash either directly from the power plant or from fly ash that has been stored in landfills or ponds. The modular CBO system is less expensive and faster to deploy than the traditional customized thermal beneficiation processes. The production capacity of a CBO system can be greatly enhanced by coupling it with RestoreAir® to treat higher residual carbon levels in the ash product.

Capital cost (range): The capital cost of thermal technologies depends on the design production capacity, feedstock carbon content, and the desired final carbon contents, as well as site development constraints. The modular configuration is significantly less expensive than the customized systems. RestoreAir® add-on can further significantly improve the cost effectiveness of thermal processes.

 # Commercial units installed: 4

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Website: www.flyash.com/products-and-technologies/carbon-burn-out

Coomtech Kinetic Turbulent Air Dryer

Vendor: Coomtech Ltd.

Technology type: Low energy materials drying

Technology description: The Coomtech technology dries powders and granules using managed turbulent airflow, instead of heat, to shear surface moisture from the material. This results in up to 75% less energy consumption than thermal drying. The technology is modular, scaling in multiples of a base unit of 4-6 tph capacity. Feed and receiving stages use off-the-shelf components for reliability and serviceability.

reduced alkali-silica reactivity, lower heat of hydration, and increased sulfate resistance

Ash harvesting typically falls into two categories:

Ready-to-Use Ash (Unprocessed Ash)—In many cases, ash that was previously deposited in landfills or impoundments is good-quality ash. If the ash in these existing impoundments is tested and meets American Society of Testing and Materials (ASTM) C-618 and regulatory specifications, it can be excavated and sold to concrete producers or other manufacturers as-is for beneficial use.

Beneficiated Ash (Processed Ash)—Ash contained in some landfills and impoundments does not currently meet ASTM and regulatory specifications to be directly used in concrete production. Reasons can include its having a loss on ignition (LOI) above 6 percent; minimum concentration of alumina, iron, and silica; or high moisture and high ammonia content. This ash must first be processed or beneficiated to meet specs before it can be beneficially used in the concrete/construction market.

What Makes for a Good Harvesting Site

The condition of the ash and potential for reuse in each case is determined through material sampling, physical testing (microscopy, particle size analysis, carbon content, magnetic content, X-ray fluorescence, atomic absorption), chemical analysis, and analysis of the results. Based upon these tests and the analysis, it can be determined whether the previously deposited ash: (1) is good-quality ash that can be sold and reused unprocessed as-is; (2) must first be processed/beneficiated prior to reuse; or (3) is simply not economical for beneficial use due to its chemical makeup or physical location within the landfill or impoundment. This includes assessing the costs of harvesting the ash to pull it from the landfill or impoundment, the costs for processing/beneficiating, if needed, as well as the logistical costs for transporting the ash to concrete producers via truck, rail, or barge.

Charah Solutions EnviroSource™ Fly Ash Beneficiation to Meet Market Demand

It is now apparent that meeting the growing demand for fly ash—as well as concrete producers' requirements for cost-effective, high-quality product—will require the beneficiation of ash stored in existing landfills and impoundments. Charah Solutions' patented EnviroSource™ fly ash beneficiation technology provides the ash harvesting solution to meet market demand at a significantly lower-cost profile and a much more efficient footprint than other beneficiation/processing technologies. EnviroSource™ technology is a proven thermal process that reduces LOI, ammonia, activated carbon, and environmental controls facilitates deployment within months, not years, at a significantly lower-cost profile than competitive technologies. Capable of handling both current fly ash production or harvested coal ash from a pond or landfill, EnviroSource™ technology is a proven beneficiation process that creates marketable product in support of coal ash initiatives in an environmentally responsible manner.

Capital cost (range): The Charah Solutions EnviroSource™ Fly Ash Beneficiation system runs $10 million - $45 million depending upon the number of units needed and scale of project.

 # Commercial units installed: 1 (Sulphur, Louisiana)

Contact info: Adam Piacentino, Vice President of Business Development – Sales, 704-650-6727, apiacentino@charah.com

Website: www.charah.com

Harvested Ash Processing and Beneficiation

Vendor: Boral Resources

Technology type: Harvested ash processing and beneficiation

Technology description: Ash harvesting and beneficiation generally consist of deploying environmentally responsible practices to excavate the ash deposit, then upgrading the material quality using screening, drying, or advanced material processing units to convert the harvested ash into a quality pozzolan for commercial use in concrete. Advanced material processing such as classification, grinding, RestoreAir®, and Carbon Burn-Out can be bolted on to enhance the quality as needed for quality challenging deposits. The ash harvesting/beneficiation system must ensure consistent quality to

The drying cartridges themselves have no moving parts, using high-velocity air knives to dry the material. Operating temperature is low at an average 85 degrees Celsius.

Capital cost (range): Dependent on capacity, but as an example a 30 tph system would be in the $5m region. Local factors such as the availability of waste heat will affect capex cost and opex savings.

 # Commercial units installed: One demonstration unit has been operating for approximately 2 years. Two commercial units are in production for installation in Australia and the UK.

Contact info: Richard Atkinson, VP Americas, Tel: +1 647 581-2128

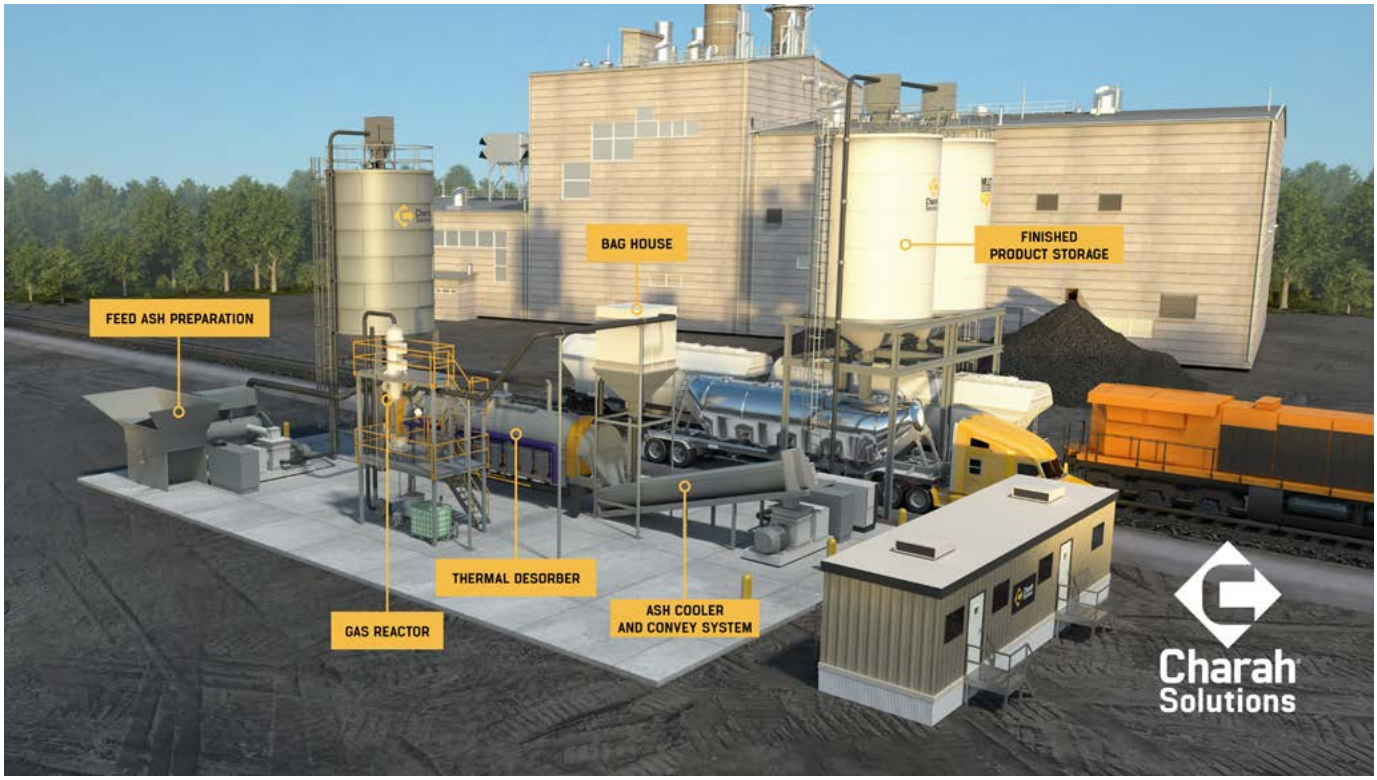
Website: https://coomtech.com

EnviroSource™ Fly Ash Beneficiation

Vendor: Charah Solutions

Technology type: Proprietary harvested ash processing and thermal ash beneficiation technology for residual carbon mitigation, ammonia mitigation, and mercury mitigation to generate a low loss-on-ignition (LOI), high-quality fly ash.

Technology description: Charah Solutions' EnviroSource™ thermal beneficiation technology reduces loss-on-ignition (LOI), moisture, ammonia, and particle size in coal ash. The process produces consistent ASTM C618-quality fly ash for beneficial recycling into ready-mix concrete and other industrial applications. The patented EnviroSource™ technology is a modular system that can be scaled for productions ranging from 50,000 to 300,000 tons per year, which allows flexibility to design the process based on utility expectations and market demands. An efficient footprint with self-contained



EnviroSource beneficiation technology - how it works

yield ASTM C618-quality fly ash suitable for beneficial use in ready-mix concrete and other durable/high-strength applications.

Capital cost (range): The capital cost to harvest and beneficiate fly ash is very site specific and highly dependent on the condition and quality of the in-situ deposit as well as other project parameters and constraints. Existing material storage and load facilities can reduce the cost of the project. Site reclamation regulatory timeline, if applicable, and access to landfill for disposal of encountered waste material can also influence the capital cost of the harvesting and beneficiation project.

 # Commercial units installed: 1

Contact info: Dr. Rafic Minkara, P.E., 770-330-0689, rminkara@boral.com

Website: www.flyash.com/services/disposed-ash-harvesting-for-beneficial-use

Low-Frequency Sonication

Vendor: SonoAsh LLC/SonoAsh Engineered Materiels Ltd.

Technology type: Carbon reduction, particle size adjustment, calcium reduction, ammonia reduction, sulfur adjustment

Technology description: SonoAsh leverages patented low-frequency sound technology to fracture the carbon component from impounded ash and at the same time adjust the particle size and reduce calcium/sulfur/ammonia present to create the desired uniform "manufactured ash" specification. The high carbon component encapsulates a recoverable fraction of the metals present, creating a new condensed ore body for further recovery. SonoAsh partners with utilities and other strategic stakeholders to develop output channel partnerships.

Capital cost (range): $6 million - $25 million will process between 10,000 and 50,000 tpy.

 # Commercial units installed: 3

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Website: www.sonoash.com

RAM™ (Reclaimed Ash Management)

Vendor: Ashcor USA Inc.

Technology type: Harvested, comingled ash processing and beneficiation

Technology description: As an industry leader in fly ash marketing for over 20 years, Ashcor has engineered a commercial solution that transforms the way fly ash is sourced. Our patent-pending Reclaimed Ash Management (RAM™) technology processes previously stored coal ashes (including fly ash comingled with bottom ash) into a high-grade pozzolan for use in concrete. Ashcor can process the entire ash deposit without an ash waste stream and can also address contaminants such as salts and gypsum. Using our RAM™ technology, we are the first ash marketer to manufacture a material from harvested bottom ash and fly ash that meets and exceeds ASTM C618 and CSA A3000 specifications. RAM™ ash offers a consistent average fineness compared to live fly ash sources.

Capital cost (range): The capital cost of a RAM™ facility is site specific and highly correlated to desired throughput volume. Additionally, a variety of other factors to be considered include quality of the ash deposit, site characteristics and features (i.e., storage and load-out facilities) and associated regulatory and permitting requirements. RAM™ facilities can be customized to accommodate a wide range of ash deposits, offering a flexible and competitive solution to address ponded and landfilled ash.

 # Commercial units installed: 1

moisture in fly ash, giving utilities the best option for harvesting ash contained in landfills and impoundments that needs to be processed to meet ASTM and regulatory specifications.

Charah Solutions' EnviroSource technology's benefits include:

- Increases supply of available fly ash to the market
- Reduces LOI, ammonia, activated carbon, mercury, and other contaminants
- Significantly lower-cost profile than competing beneficiation technologies
- Efficient footprint with self-contained environmental controls
- Can be deployed in months versus years
- Modular design and scalability allow for production of 40,000 to 200,000 tons per year
- Delivered as a portable or stationary system depending on client requirements
- Separates and isolates heavy metals such as mercury
- Reduces utilities' need for landfills, ponds, and other disposal methods
- Cost-effective installation and operation
- Can be installed at operating power plants, non-operating power plants, or off-site

With EnviroSource technology, there is no impact on the power plant operation. The technology can be either fully independent or integrated with the operation of the power plant. The process delivers a marketable concrete-grade or cement kiln-friendly product from existing coal fly ash streams.

EnviroSource technology is a four-step process:

1. Exposes high-LOI fly ash to indirect heat in the thermal desorber
2. Separates off-gassed contaminants from solids in a gas reactor

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Website: ashcor.atco.com

RestoreAir®
Vendor: Boral Resources
Technology type: Carbon passivation
Technology description: RestoreAir® uses a liquid reagent to treat fly ash at the power plant silo, before delivery to customers, to neutralize the impact of powder activated carbons (PACs) or un-burned carbon (UBC) on air entrainment in concrete. The technology uses a low dosage of liquid reagent to passivate the carbon active surfaces and reduce their ability to adsorb air entrainment agents in concrete. Carbon is not removed, but its effect on air entrainment is neutralized. The technology has been successfully demonstrated on Class C and F ashes containing the most common PACs and UBCs. Ash treated by RestoreAir® has been widely accepted by state DOT and concrete producers. The deployment of the technology is complemented by advanced patented analytical tools, such as SorbSensor®, to gain a thorough understanding of adsorption kinetics of PACs and fly ashes.
Capital cost (range): RestoreAir® installations at power plants and fly ash terminals are relatively simple. Systems installation costs can range from $250,000 to $500,000 depending on existing load-out silo space availability and integration complexity.
 # Commercial units installed: 20
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Website: www.flyash.com/products-and-technologies/restoreair

STAR® Technology
Vendor: The SEFA Group
Technology type: Thermal beneficiation resulting in:
• Carbon reduction and mitigation
• Ammonia removal
• Mercury sequestration
• Harvested coal ash drying
• Production and impounded coal ash processing
Technology description: STAR® Technology is The SEFA Group's patented thermal beneficiation process that transforms coal ash into a consistent, high-quality product for recycling into concrete and other industrial applications, providing a permanent solution to remove coal ash from the environment. It was the first technology in the world to process coal ash from ponds on a commercial scale. With a decade 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.
Capital cost (range): The capital cost of a STAR® facility varies significantly based on its production capacity, the extent to which it may tie into a host generating facility, site development characteristics, local construction costs, and a variety of other factors. In SEFA's experience, the capital cost is often favorable in comparison to the long-term costs of landfilling ash as a waste product.
 # Commercial units installed: SEFA operates and maintains six STAR® plants today. Four of those process harvested fly ash.
Contact info: Walt LeMaire, CCP Services Business Development, Executive Director, 281-702-6757 (m), wlemaire@sefagroup.com
Website: www.sefagroup.com

ENVIROSOURCE TECHNOLOGY RESULTS

Reduction of LOI/Carbon			
Parameter	**Coal Fly Ash unprocessed** result units	**Coal Fly Ash processed with EnviroSource** result units	**Percent reduction** result
Loss on Ignition	16.20 %	1.18 %	92.72 %
Loss on Ignition	15.50 %	.84 %	94.58 %
Loss on Ignition	14.70 %	2.50 %	82.99 %
Loss on Ignition	14.53 %	2.10 %	85.55 %
Loss on Ignition	9.91 %	1.10 %	88.90 %
Loss on Ignition	8.30 %	2.20 %	73.49 %
Loss on Ignition	7.25 %	.15 %	97.93 %
Loss on Ignition	6.93 %	.30 %	95.64 %
Loss on Ignition	6.05 %	.43 %	92.89 %
Loss on Ignition	5.94 %	.17 %	97.14 %
Loss on Ignition	3.58 %	1.23 %	65.64 %
Loss on Ignition	1.77 %	.28 %	84.18 %
Average of above samples Loss on Ignition	**9.22 %**	**1.04 %**	**88.72 %**

Reduction of Ammonia			
Parameter	**Coal Fly Ash unprocessed** result units	**Coal Fly Ash processed with EnviroSource** result units	**Percent reduction** result
Nitrogen (Ammonia)	353 ppm	32 ppm	90.93 %
Nitrogen (Ammonia)	431 ppm	37 ppm	91.42 %
Nitrogen (Ammonia)	435 ppm	44 ppm	89.89 %
Nitrogen (Ammonia)	385 ppm	51 ppm	86.75 %
Average of above samples Nitrogen (Ammonia)	**401 ppm**	**41 ppm**	**89.78 %**

Reduction of Mercury			
Parameter	**Coal Fly Ash unprocessed** result units	**Coal Fly Ash processed with EnviroSource** result units	**Percent reduction** result
Mercury	40200 ppb	<100 ppb	99.75 %
Mercury	3870 ppb	<100 ppb	97.42 %
Mercury	4140 ppb	<100 ppb	97.58 %
Mercury	1380 ppb	<100 ppb	92.75 %
Mercury	1310 ppb	<100 ppb	92.75 %
Mercury	1184 ppb	<100 ppb	91.55 %
Mercury	815 ppb	<100 ppb	87.73 %
Average of above samples Mercury	**7557 ppb**	**<100 ppb**	**98.68 %**

3. Removes carbon, ammonia, chlorides, and mercury to generate low-LOI fly ash

4. Removes metals, ammonia, chlorides, and the products of the combustion from the gas stream using its proprietary gas reactor. This process generates a minimal amount of precipitate (less than 30 tons generated for every 200,000 tons of fly ash processed), and the precipitate is returned to the finished product so there is no waste stream.

EnviroSource Technology Results

Results provide a consistent LOI reduction over a wide range of fly ash inputs, reducing the LOI, ammonia, activated carbon, mercury, and other contaminants to meet ASTM and regulatory specifications for sale into the market. The process reduces LOI concentrations by as much as 95 percent and consistently achieves LOI levels below 1 percent for most ash. The technology can also remove 90 percent of the ammonia in the ash.

Ash Harvesting Benefits the Entire Industry and the Environment

In order to meet future demand, ash harvesting is certain to become standard practice across the industry as less production ash is available due to the decline in coal-fueled electricity generation in the U.S. The Environmental Protection Agency's issuance in 2015 of the Coal Combustion Residuals (CCR) rule, as well as state and local legislation, will also help drive demand for ash harvesting and beneficiation, as much of this legislation dictates the amount of ash that must be beneficiated in closure projects. Ash harvesting will benefit the entire industry by increasing the supply of marketable ash while meeting the price and supply demands of concrete producers across the nation.

Ash harvesting and ash beneficiation also benefit the environment as they conserve our natural resources, including water, decrease landfill disposal, and reduce greenhouses gases—as every ton of ash beneficially used in the production of portland cement saves 0.87 tons of CO2 from entering the atmosphere. Moreover, ash beneficiation plays a vital role at the utility level as utilities work to meet their emissions reduction timeline goals and drive economic and environmental benefits to local communities.

Eric Effinger *is Vice President of Operations at Charah Solutions Inc. A registered professional engineer and certified project management professional, he has over 15 years of experience executing and managing large-scale heavy civil construction and utility-related projects throughout the United States. Effinger earned a Bachelor of Science in Civil Engineering Technology from the University of Southern Indiana.*