ISSUE 1 • 2019

# ASH at work

Applications, Science, and Sustainability of Coal Ash

## CCP Beneficial Use—The Next 50 Years

Future Trends in Ash Harvesting, Demand, Testing, and Research

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## On the Cover

Industry experts offer their insights into what the next half-century holds for CCP beneficial use.


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# Change Is the Only Constant

*By Kenny Tapp, ACAA Chair*

I began my career with LG&E in 1977 in the coal and limestone handling department. I was later voluntold, in 1999, that I would be assuming CCP marketing responsibilities and was so green I thought they said "flash" instead of "fly ash." The company gave me only a week's notice to learn everything I could from the person I would be replacing, and he wasn't thrilled with spending his last days before retirement tutoring a newbie. Fortunately, I met several CCP marketers who took me under their wing and educated me about the industry. Joining the ACAA was the biggest help, as it put me in touch with many knowledgeable people and a wealth of information available on the website.

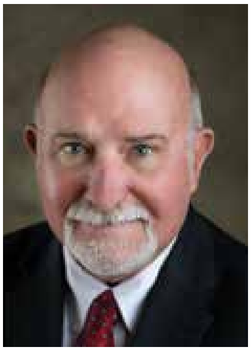
The industry has evolved significantly in the 20 years since, with some of the biggest changes being regulatory in nature. I am all for a clean environment, but in my opinion the minuscule environmental improvements that resulted from the regulatory changes of 2009-2017 did not warrant the billions of dollars that were spent to achieve them. Environmental Non-Governmental Organizations (ENGOs) have become more organized, better funded, and more aggressive in pressing their agenda with the Environmental Protection Agency and Congress—so much so that, at times, it seems the regulations could have been drafted by them. Fortunately, our industry has allies on Capitol Hill who we can work with to help craft laws and regulations that reach a sensible middle ground. We must continue to cultivate these relationships and educate our industry's allies and adversaries alike on the tremendous environmental value of coal ash beneficiation.

Another area in which the industry has evolved is in our use of technology. While new technologies have made some aspects of our jobs easier, they have also lengthened the workday. Where we once worked a fairly standard 8-10 hours each day, mobile communications have stretched our work responsibilities around the clock. Fielding telephone calls and answering emails and texts 24/7 is now the norm, and laptop computers are taken on vacation, much to the chagrin of family members. From the company perspective, operations are more efficient, and more work can be carried out with fewer employees. But much of this efficiency results from technologies that enable and encourage employees to work at any time.

Further changes are on the horizon, as I see our industry shifting from one that markets predominantly CCPs from fresh production to one focused on reclaimed pond and landfill materials. The driving force behind this is the continuing closure of coal-fueled power plants, which has had the effect of leaving downstream users in many regions of the country with shortages of CCPs for their products. Our industry has always responded quickly and favorably to adversity, and I believe we will effectively address these regional shortages. Our marketing and associate members will respond with research and development of new technologies and equipment to reclaim and process legacy ponds and landfills in a safe and environmentally responsible manner. Millions of tons of CCPs are waiting to be harvested, and I predict that reclaimed CCPs in the future will be more desirable than run-of-plant CCPs and be able to command a premium selling price due to their improved consistency. Much work still needs to be done on this front, but with collaborative efforts between utilities, marketers, associates, and academia, we will rise to meet this challenge.

As I looked around the room during the last ACAA board meeting, I realized that many of our directors are nearing the end of their careers. The recent announcements of the retirement of Fred Gustin and Laurie Cook are just two examples, and we owe them both a big debt of gratitude for their time and efforts in helping provide leadership to our association. As we look to turn the challenges that the industry faces into opportunities for our member companies, I am confident that many of the younger members of our association will be there to help us. A number of them have already shown a willingness to volunteer on our various committees, but we will soon need them to step up and accept leadership positions. I would encourage more of our younger members to consider joining and actively participating in our committees, events, and programs so that they too will be ready to become future leaders. The Educational Foundation scholarship program continues to identify and encourage young people to take an interest in our industry, and I would recommend the ACAA website as an excellent resource for our younger members who have an interest in furthering their knowledge of the ACAA and the CCP beneficial use industry that it serves.

In closing, let me say that I think the future is bright for our industry. Much hard work will be ahead of us, but with the high quality of the individuals we have within our organization, we will meet all challenges ahead of us.



# Starting Over……

*By Thomas H. Adams, ACAA Executive Director*

This past February, I marked my 10-year anniversary as Executive Director of the American Coal Ash Association (ACAA). As I reflected on my first decade with the ACAA, I recalled hours of discussion with Mark Bryant, Chair of the ACAA Board of Directors, and other Association leaders. I wanted to have a clear understanding of the expectations for the new executive director, and the Board of Directors wanted to be sure I was up to the task.

The to-do list was comprehensive. The main theme was to continue the pace of growth in the beneficial use of coal combustion products (CCPs) that marked the first eight years of the 21st century. The beneficial use rate had increased by 50% and the actual tonnage of beneficial use doubled. Some have called the period a "golden age" for the beneficial use of CCPs. ACAA leadership wanted the new executive director to maintain and grow relationships with major current and potential user groups.

Armed with the regulatory certainty of the "final determination" of 2000 by the U.S. EPA, investors had moved aggressively into CCP beneficial use markets. Then came the crown jewel of the expansion of beneficial use—the Coal Combustion Products Partnership, or $C^2P^2$. This public/private partnership was arguably one of the most successful of its kind. The future looked very bright for our industry.

What could possibly go wrong? Here is the list: economic collapse; a new president opposed to coal-fueled generation of electricity; Kingston; a new EPA administrator committed to reclassifying CCPs as a hazardous waste; ENGO attacks on beneficial use; cheap natural gas; new mercury control regulations for power plants; the Clean Power Plan; and renewable-mania. I am sure I have left out a few. For most of my first 10 years, I spent little time on those growth plans created in late 2008 and early 2009.

We have survived all that. However, our future is quite different. Investors have cautiously come back to our industry. Our future is shaped by many new factors: cheap natural gas for the foreseeable future; harvesting from ponds and landfills; CCP imports; plant retirements; material characteristic changes; user specification changes. And regulatory certainty is always a concern—here today, gone tomorrow depending on how the political winds blow.

I thought it might be time to take out that to-do list we had finalized in early 2009 and see what we could do with it. The playing field has changed a great deal and some of the initiatives on that list are no longer viable. But there are some things that continue to be important to our members. So, we will start over with this to-do list and modify it to fit the landscape of 2019. I look forward to working with our members and users in shaping our industry for the new realities of CCP production and use.


Sustain Ability

# Alternative Supplementary Cementitious Materials Availability - The Next 50 Years

*By Danny Gray*

Projecting how alternative supplementary cementitious materials (SCM) and market drivers will unfold over the next 50 years can be daunting. Certainly, a half-century ago no one would have predicted that we would arrive at the point where the industry currently finds itself. To have a shot at accuracy, one must focus on the "expected knowns"—dependable truisms such as: (1) global population will increase; (2) energy demand will increase, since it unlocks a door to better-quality lifestyles; (3) energy production will always seek the least-cost pathway; (4) renewable energy will find its role in an unsubsidized energy market; (5) concrete will remain an important construction material; (6) cement and other cementitious materials will remain in high demand as concrete volumes grow; and (7) technology and innovation will continue to improve energy production and efficiency. From these basics, one can start to map out where the coal combustion products (CCP) beneficial use industry will migrate.

The CCP industry has always been one of the best resource recovery stories that flies under the radar. Yet it continues to be the shining example that meets the very objectives outlined by Congress when the Resource Conservation and Recovery Act (RCRA) was enacted in 1976. Congress stated in RCRA:

"The objectives of this chapter are to … conserve valuable material and energy resources by … providing … for solid waste management plans … which promote … recovery of solid waste." RCRA further states that "… with respect to materials … the recovery and conservation of such materials can reduce the dependence … on foreign resources and reduce the deficit in its balance of payments."

While the recent historical trend has been for CCP generation to gradually decline and percentage usage to gradually increase, this trend will be impacted by the rapid changes underway in energy generation. Supply-side production of CCPs will see pressures as coal-fueled generation gives up market share to natural gas and renewables, a trend likely to continue until coal stabilizes at about 15-20% of total generation, as shown in the U.S. Energy Information Administration (EIA) data in Figure 1. On the demand side, however, beneficial use of CCPs is expected to continue the pattern of gradual increase as a percentage of current-generation volumes.

One of the most important barometers of CCP use involves its link to cement production. Fly ash usage is often tied directly to construction use of portland cement. During periods of strong economic performance, the U.S. cementitious market historically has seen approximately 80% of cement produced domestically, with the remaining 20% imported. In times of slower economic conditions, the 20% imported is scaled back in favor of domestic supply. "Homegrown fly ash" has always filled a strategic need within the cementitious market, replacing roughly 15-20% of cementitious materials, which in times of healthy economic conditions reduces the amount of cement imported. To the extent that domestic fly ash replaces and reduces imported cement, the goals outlined in RCRA are met precisely and the U.S. trade balance of payments is improved. While the past success of CCPs as a recovered resource is accepted and proven, the next 50 years will see dramatic change.

## Regulation Will Be the Primary Driver of Fly Ash Use in Construction

As is well known, the construction materials industry changes slowly. However, the pace will certainly pick up over the next few decades as alternative materials and methods are used to address the growing demand for cementitious products. Within the CCP industry, three factors influence the use of fly ash in construction products: specifications, supply/demand dynamics, and regulatory drivers. Each factor is intertwined with the others but, in today's market and as we move forward, the regulatory driver has become the largest factor impacting fly ash usage. Regulatory and legislative changes are usually caused by dramatic events. For example, RCRA was precipitated by the fast-rising environmental movement of the early '70s, and RCRA's CCR regulations were sparked by the Kingston impoundment failure of 2008. The impacts to the resource recovery CCP industry that result from EPA's regulations will be felt for decades to come.

EPA stated that its CCR rule was directed at disposal and exempted beneficial use. However, the exemption is not as clear and the impact tentacles are both direct and indirect as we move forward. On the disposal side, the CCR rule is intended to eliminate impoundments as a method for managing CCPs unless composite liner systems are retrofitted to existing facility units. The direct result is that impoundments are closing. Additionally, in many cases the cost to install wet-to-dry collection equipment and/or composite-lined management systems is prohibitive, and utilities are making the decision to prematurely close plants or generation units. The indirect impact on the CCP industry is that fly ash material sources are disappearing, and those that remain are either more distant from the customers or require mining old storage units and processing to replace the lost "as produced" fly ash. Alternative materials and alternative material processing are needed to replace the market voids.

As we move forward, the use of new and alternative materials will increase. In partial response to the regulatory-induced changes and loss of supply sources, ASTM is responding to the market need by developing standards to broaden access to materials that can be used for cementitious applications. For example, ASTM E3183-18 was recently adopted, which establishes guidelines for accessing and excavation of CCPs from impoundments and landfills. ASTM is also working on specifications and guidelines for natural pozzolans such as volcano ash, as well as blended ash products; refining the Class F and Class C fly ash definitions; and developing a standard for ground glass products that exhibit cementing characteristics. To enhance the availability of CCP cementitious materials, ASTM is reviewing the potential addition of a Class B definition for ground bottom ash. As fly ash has become a valued concrete component for mitigating problems such as aggregate-silica reactivity and the effects of modern de-icing strategies, state specifiers have also become more open to strategies involving blending of materials in order to obtain the needed volumes of supplementary cementitious materials.

Looking ahead, state departments of transportation (DOT) offices will need to amend their specifications to adjust to the changing materials markets. Each change in ASTM must be enabled by state DOT adoption and inclusion within their specification approaches. Over the next 50 years, the role that traditional fly ash serves in manufacturing superior concrete will be supplemented by fly ash recovered from landfills or impoundments, which is processed to make a new blended product that can provide the same technical improvements to the finished concrete. Low-permeability concrete with longer lifecycles will become the mainstay in concrete highways, and budget constraints will drive the use of alternative materials.

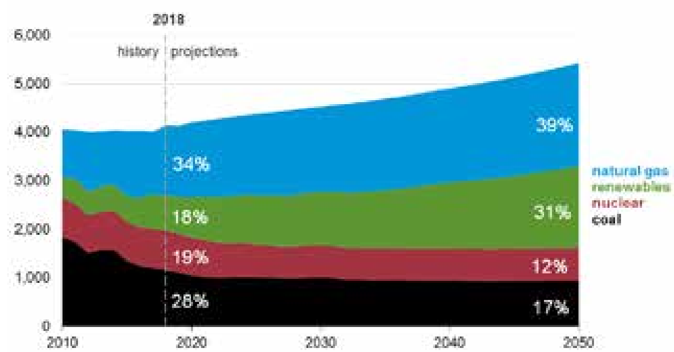



Figure 1. Electricity generation from selected fuels, in billions of kilowatt hours (EIA 2019 Reference case).

Ground granulated blast furnace slag (GGBFS) will be blended with recovered impoundment fly ash and/or natural pozzolans to make specialty products that enhance concrete and control federal and state highway expenditures.

In addition to ASTM's and state highway departments' adoption of alternative SCMs, geography will continue to play a key role in their market growth. Source locations for remaining coal-fueled power plants as well as new alternative SCMs will impact market utilization decisions, in much the same way as they currently impact fly ash utilization. In the eastern half of the U.S., where pond closures are accelerating due to CCR regulation, recovery and processing of pond ash will increase to fill voids where readily available current-production fly ash is unavailable. State legislative actions, in some cases, will also drive pond ash recovery and beneficiation. In other cases, utility funding related to closure timing will drive recovery projects.

In western states, where ash ponds are used less for CCP management, use of alternative SCMs will include more blends with natural pozzolans, GGBFS, ground glass, and possibly imported fly ash. While imported ash has been shown to be economical in a few cases, the key barriers to ash import growth include terminal capacity near port facilities and infrastructure needed to unload and store powdered products. Imports of "conditioned ash" for use in cement manufacture offer advantages with more readily available material-handling equipment at existing ports. To utilize imported fly ash in ready-mixed concrete, quality control programs will need to address the full supply chain to ensure that the landed product can be used in specification-grade concrete. Imported fly ash must also meet the import product chemical data reporting requirements under the Toxic Substances Control Act, among other federal import requirements.

## Despite Coal Plant Closures, CCP Production to Continue to Exceed Demand

While the supply of as-produced fly ash from traditional power plants will moderate as a result of plant closings, adequate levels of fly ash will continue to be available to meet market needs. In 2015, at the request of ACAA, the American Road and Transportation Builders Association (ARTBA) prepared a study on CCP utilization that assessed quantities of CCPs produced to meet market demand (see study projection in Figure 2). It is noteworthy that the 2015 study, which relied on the then-latest

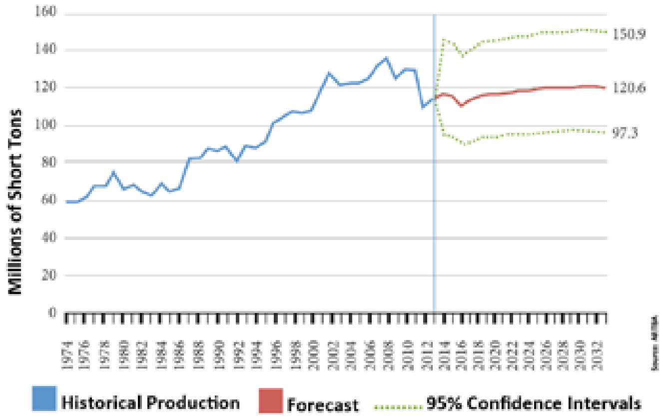



Figure 2. CCP production will increase 0.3% annually as coal demand for electric generation remains steady.

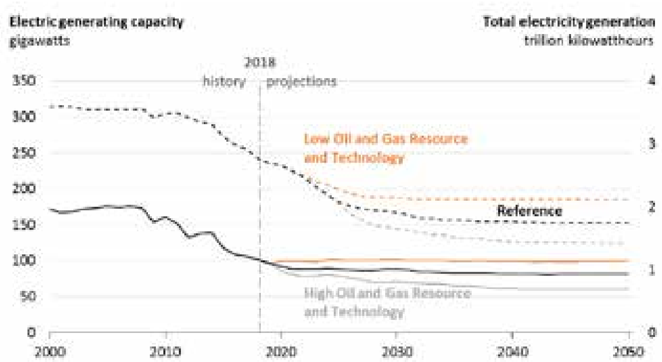



Figure 3. Coal-fueled generating capacity retires at a faster pace than generation in the Reference case.

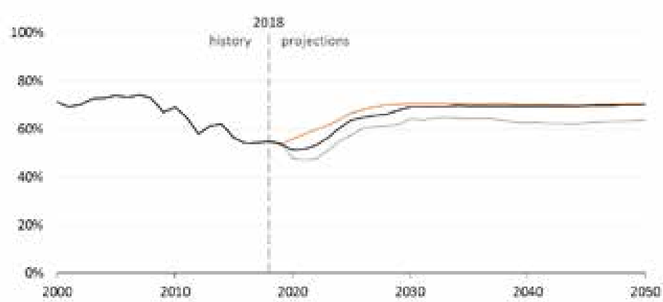



Figure 4. Capacity utilization rate - coal-fueled generation.

production data from 2013, showed a 2016 production estimate near 115 million tons, while 2016 actual production ended up at approximately 107 million tons. The 2015 ARTBA study concluded that "coal will continue to account for a significant percentage of U.S. electric generation during the next two decades … Even under alternative scenarios of accelerated coal-fueled electric generating unit retirements, CCP production is still expected to exceed overall demand."

In the recent EIA-published 2019 Annual Energy Outlook Report, it is estimated that electricity generation from coal will stabilize at about 18% of total electric generation by 2035, down from 28% in 2018. Figure 3 shows EIA's projection of how coal capacity and generation will decline over the next couple years, but stabilize after 2020.

Probably more crucial are the projections that coal plant capacity factors will dip to their lowest levels—to near 50%—by 2020 and, once the closures are complete, start to rise to the mid to upper 60% levels for the surviving coal fleet (see Figure 4). EIA assumes that tax credits phase out after 2023, causing wind capacity additions to continue at much lower levels, while solar installation costs continue to decrease. Coal retirements tend to remove the higher-cost plants, which improves the capacity rate for the more efficient units that remain. Based on the 2016 known CCP production and the slightly lower total coal generation projected by EIA, it is expected that sufficient CCPs will continue to be available in most regional markets, and recovered/beneficiated ash or alternative SCMs will address specific market shortfalls.

Today's energy landscape is dominated by abundant supply of competitively priced natural gas brought about by new technology developments in the exploration and production of oil and gas. However, the potential for the next generation of coal-fueled power plants is just one energy crisis away. The next generation of coal-fueled plant will be a high-efficiency, low-emissions (HELE) type that reduces the carbon emissions footprint and has partial or full carbon capture and storage or utilization (CCSU) added to the exhaust gas end. While the efficiency of coal units has historically been around 33% for U.S. plants, the newer HELE units are seeing efficiency closer to 38% in the U.S., while new Japanese units are above 40% with the ascent to 50% well underway. On the long-term horizon, step changes in coal-fueled generation technologies could emerge that increase these efficiencies.

As part of the current EPA efforts to continue the reduction of America's energy carbon footprint, the proposed Affordable Clean Energy rule would establish regulatory incentives to increase efficiency for existing units. While the regulatory change would be helpful, it is not expected that many utilities would take advantage of the rule to invest in efficiency gains at older units. Therefore, the supply-side impacts to unit-generated CCPs likely would not be affected.

## Market Forces Will Determine Energy Mix of the Future

Currently, we find ourselves in an energy market that subsidizes renewables and provides seemingly unlimited cheap natural gas to displace coal and nuclear generation. But history teaches us that if market conditions are "too good" for too long, markets get greedy and rebalance. Socializing the supply of electricity through excessive tax incentives cannot survive forever. Likewise, cheap natural gas for the U.S. will give way to offshore movements and depletion of reservoirs. Prices will adjust to supply/demand dynamics and economic norms will return. Technology advances in coal mining, boiler efficiency, and emissions control will also adjust to the market conditions, and once again coal will find its footing. Energy has led billions of people to a better-quality lifestyle, and the typical citizen will demand ever more energy to maintain that quality of life. In addition, billions more people will experience electrification for the first time in the future and their quality of life will improve, leading to longer life expectancies. Innovation will be called upon to deliver more energy while managing the impacts to the environment and economic conditions.

Looking out 50 years, the next generation of coal-fueled boilers could generate at higher efficiencies and less or no $CO_2$ emissions, while offering opportunities to generate improved CCPs. Since higher combustion efficiencies generally translate into lower unburned carbon levels, it is possible that with well-thought-out design, new-technology HELE power plants can mitigate the negative impacts to ash quality from chemical injections and isolate the higher-quality fly ash from downstream reagent injections. Upstream reagent injections may also include reagents that are concrete-friendly or minimized in volume to enhance the resulting fly ash quality. New design approaches and reagent packages will lead to new CCP materials at HELE plants.

Next-generation plants may also include the capability to extract other CCP-related resources that will be needed to manufacture many of tomorrow's advanced electronic products. Rare earth elements (REE) commonly found today at slightly enriched levels within CCPs will be mined from these materials as part of the pozzolan beneficiation. Alternatively, future boilers may be installed with capture systems to selectively collect and enrich the REEs between the combustion chamber and the exhaust gas treatment systems.

The decades ahead will see more beneficiation of recovered fly ash excavated from impoundments and landfills. Methods of beneficiation are discussed in "Digging Through the Past: Harvesting Legacy Ash Deposits to Meet Future Demand," by Rafic Minkara (see page 22). In the future, as fly ash prices approach cement prices in more markets, beneficiation opportunities will expand, driven by the marginal revenues introduced into the system. Governing bodies, and in some cases utilities, will mandate clean closure of sites to eliminate long-term liabilities.

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**Danny Gray** is Executive Vice President, Governmental and Environmental Affairs, at Charah Solutions Inc. He joined Charah in 2008 and has over 35 years' experience in the electric utility and coal ash management industries. Prior to joining Charah, Gray served as Vice President of Mineral Resource Technologies Inc., a CEMEX subsidiary, and in various senior management positions at ISG Resources and JTM Industries.

# Geosynthetic Solutions for Final Closure: A Decade of Performance

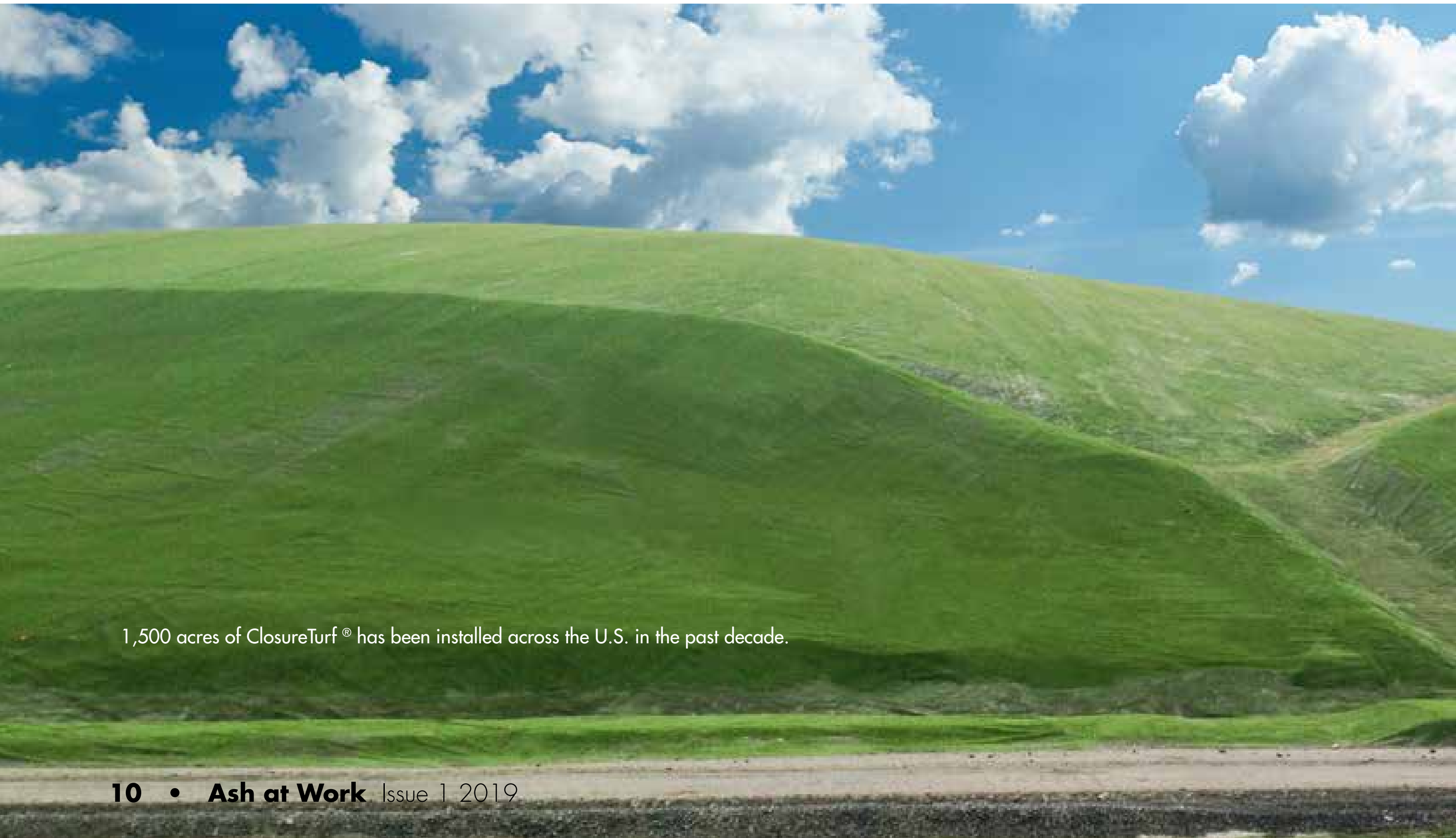
*By Mike Ayers*

Coal ash is the second-largest industrial waste stream in the United States, with approximately 130 million tons produced annually. Over the last several years, new technologies for final ash storage have been successfully implemented and are outperforming traditional vegetated closures in numerous categories. This year, Watershed Geo celebrates the 10-year anniversary of its first ClosureTurf® landfill installation and reflects on a decade of progress, noting the value of geosynthetics as a viable final closure solution for coal combustion residuals (CCRs).

ClosureTurf® is a final landfill closure system designed to address the environmental and performance failures of traditional soil/vegetated caps. To date, the engineered synthetic turf system spans approximately 1,500 acres of closure, safely and effectively reducing environmental and operational impacts of landfills, including ash impoundments, across the United States. It has also provided an innovative and stable solution for solar generation.

## CCR Regulations and Challenges

In 2015, the U.S. Environmental Protection Agency (EPA) published its final rule governing disposal of CCRs produced by electric utilities. The rule requires facilities to meet detailed location, design, operation, closure, and 30-year post-closure care requirements, including the maintenance of and repairs to final covers and other unit components, as well as the semiannual detection and assessment monitoring of groundwater.



1,500 acres of ClosureTurf ® has been installed across the U.S. in the past decade.

The federal CCR rule and individual state efforts to regulate this non-hazardous solid waste are furthering interest in new and emerging technologies. Industrywide, approximately 10% of the coal burned to make electricity makes its way into a CCR waste stream. Beneficial reuse is part of the solution, but the industry needs a long-term answer for CCR that is both cost effective and environmentally responsible. Final landfill closure solutions that include state-of-the-art engineered turf systems require less operation and maintenance expense over the life of the project and are environmentally friendly options that offer utilities more flexibility to meet the growing regulatory framework faced by utilities. Additionally, utilities are facing renewable energy mandates issued by individual states that vary widely, prompting the consideration of geosynthetic turf closures as an ideal surface on which to deploy and maximize the use of solar panels.

Designed to address the stringent requirements of CCR closure regulations, the synthetic turf system is proving to be an effective solution for utilities and industrial sites facing aggressive mandates. Currently being used on multiple large-scale CCR disposal projects, this innovative solution is fully compliant with the requirements of Subtitle D of the Resource Conservation and Recovery Act and offers meaningful advantages specific to CCR disposal challenges.

## Traditional Closure Design vs. Geosynthetic Closure

Prescriptive final cover designs for landfills have historically included a compacted soil liner, geomembrane liner, a drainage layer, and a vegetative soil cover. These traditional capping options involve large volumes of soil that many coal-fueled plants may not have available.

Because of challenges associated with prescriptive designs, and specifically the unique requirements for CCR surface impoundments and landfills, an engineered synthetic turf system was created as an alternative Subtitle D capping option and now has a decade of installed performance. In addition to eliminating the need for the intermediate soil cover and vegetative layer, these turf systems have many advantages over their traditional counterparts, including faster installation times, safer construction methods, improved storm water quality, and significantly reduced maintenance and post-closure costs. For surface impoundments, using an alternative capping design can also greatly reduce the amount of disturbance of the existing CCR material within the impoundment.

An engineered synthetic turf system is a three-component system comprising a structured geomembrane, an engineered turf, and a specified infill. The structured geomembrane provides both drainage and high interface friction for stability. It serves as the barrier layer to minimize infiltration through the cover system into the CCR. The engineered turf is made of synthetic grass blades tufted into two layers of geotextile backing. It is the protective layer that covers and protects the underlying geomembrane from ultraviolet (UV) degradation and wind uplift. The specified infill provides additional UV protection and allows the system to withstand traffic loads.

## Soil Construction Factors

Eliminating the need for a two-foot soil and vegetative cover layer improves safety while reducing the carbon footprint of the closure, as there is no need to transport soil to the site (see Figure 1). This means the removal of thousands of trucks from local roads, as geosynthetic turf closures eliminate the need for approximately 550 truck trips (275 round trips) per acre that would otherwise be needed to transport soil to and from a borrow site. Less equipment also means reducing the carbon footprint of the closure by approximately 80% compared to traditional soil/vegetative covers. The reduction in size, number, and duration of equipment further contributes to an overall increase in safety on both the project site and local roads, as well as the reduction of dust at the site, mud on the roads, and noise impacts to the surrounding community. Most traditional closures also require destruction of land for project soil sources, resulting in additional environmental impact and loss of future land use.

A geosynthetic turf system installs two to three times faster than a traditional soil cover and uses fewer and lighter pieces of equipment. The increase in project-completion efficiency means that owners, operators, and their design and construction teams can effectively cover more acreage per day. Additionally, the standardization of engineering and construction details associated with engineered turf systems reduces the burden on the regulatory review and approval process. The use of this system also makes it easy to install in smaller, incremental closures. The sooner full cells can be capped, the sooner leachate is reduced, providing significant savings for the owner.

Geosynthetics are lighter and improve the stability of CCR closures by eliminating the weight of the traditional soil and vegetative cover. This reduces the static load surcharge on the impoundment or landfill and the dewatering needed to stabilize

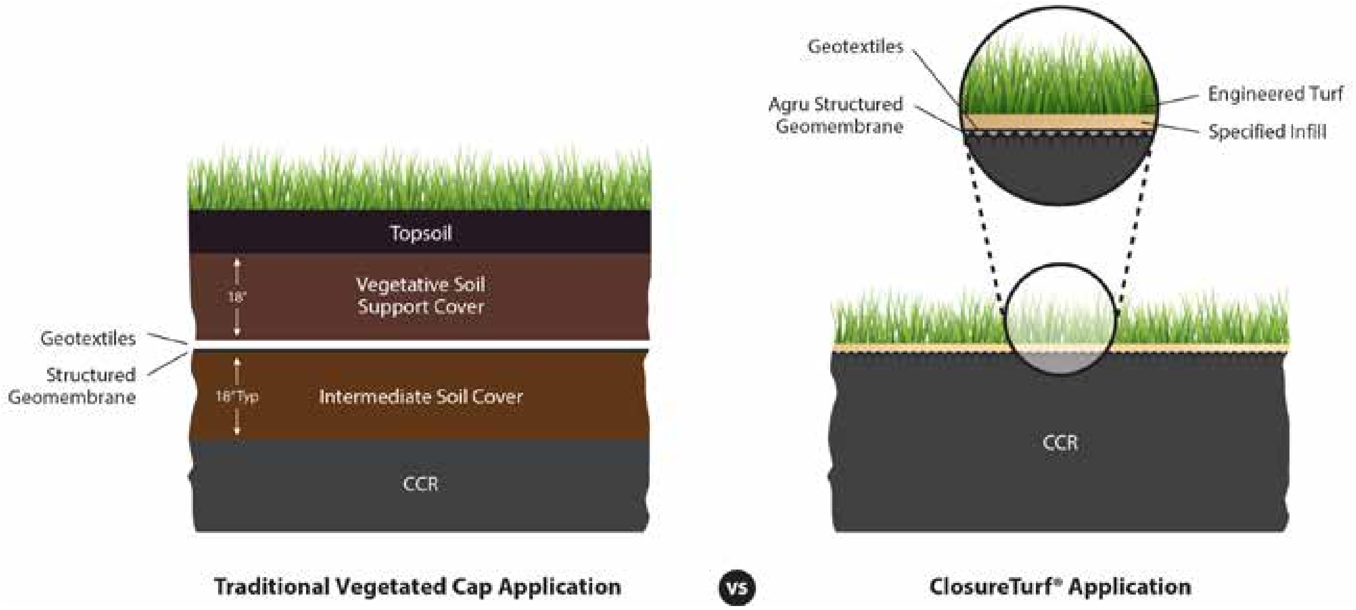



Figure 1. A comparison of a traditional vegetated system and geosynthetic turf system demonstrates the two-foot elimination of soil.

Engineered turf systems install at least 50% faster than traditional soil caps.

a CCR impoundment for final closure, which in turn can shorten the construction schedule. In the event that future access to the ash is needed, the geosynthetic system can be easily cut and resealed back together. A vegetated soil cap, in this instance, would require excavation, management of sediment runoff, and then complete reconstruction.

## Shear Strength and Slope Stability

Traditional soil covers are subject to veneer-type slope failure due to insufficient interface shear strength and the possibility of excess hydraulic head in the soil cover. By removing the burden of the heavy soil layers, final cover slope stability is significantly improved due to the highly durable interfaces of engineered turf. In fact, there are two interfaces in ClosureTurf®—the interface between the engineered turf and the structured geomembrane, and the interface between the structured geomembrane and the subgrade soil or waste.

Landfills settle as a result of CCR compression and the consolidation of foundation soils. The dewatering and consolidation of sludge, as well as differential settlement, can create depressions in the final cover, causing traditional soil covers to crack and ponding to occur on the cover surface. Engineered turf systems will tolerate a much larger differential settlement than soil covers due to the elongation of the geomembrane. The flexibility of the system conforms to the surface depressions without damaging the cover.

With the low load-bearing capacity of saturated ash, there are concerns that the additional geotechnical loading of a soil or clay cap and vegetated soil cover could produce excessive surcharge stresses, creating the geotechnical instability (i.e., sloughing) conditions often associated with very low California Bearing Ratio test value subgrades. What we have found through the successful deployment of geosynthetics is that it eliminates the possibility that these settlements will result in reversing the final grades of the cover due to the additional surcharge-type loading after the geomembrane installation.

## Design Life

If properly maintained, the engineered synthetic turf layer will have a 100+- year functional longevity. The results of 10 years of independent weathering data for the synthetic turf yarns tell us that the projected half-life of the engineered turf layer far exceeds 176 years. This longevity has been independently evaluated by multiple organizations that are experienced in the longevity performance of geosynthetics. The underlying geomembrane will last much longer because the engineered synthetic turf layer provides protection of the structured geomembrane so that it is not exposed to the environment. In fact, studies by the Geosynthetic Institute show that the geomembrane can last more than 400 years under covered conditions.

Wind tunnel testing was conducted at Georgia Tech Research Institute to evaluate the wind uplift of engineered turf. Wind actually created a downward force on the turf, and it resisted a hurricane-force wind of 120 mph without being lifted. Several project installations have experienced significant, if not historic, weather events, including hurricane-force winds and record-setting rainfall. A closure project in South Carolina endured a 1,000-year rain event when a hurricane swept through the area, and a Florida Panhandle project experienced a historic 500-year storm event in which 5.68 inches fell in a single hour (26 inches total in a 24-hour period). No damage to the system was incurred. Additionally, northern installations with an engineered turf system have provided opportunities to evaluate its performance in areas that encounter cold, high wind, and snowy conditions. Geosynthetics perform exceptionally well in each of these extreme-weather scenarios.

## Reduced Environmental Impacts

When considering a final cover system for a landfill or impoundment, it is important not only to keep water out of the waste, but also to ensure that nothing detrimental comes off the surface and lands in the water carried offsite. Considering the average size of CCR impoundments and landfills, opportunity exists for significant sediment pollution through erosion that is often an inherent part of traditional soil covers. Geosynthetic turf systems provide clean runoff with very low turbidity because they do not have a soil layer, except for the thin (0.5-inch thick) layer of sand infill. The sand acts as a natural filter as the water moves down the slope and channeling areas. As a result, sites have experienced a 90% reduction in turbidity, resulting in cleaner water. These systems also significantly reduce sediment loading to surrounding channels and sedimentation detention basins either onsite or offsite. This produces a positive impact on overall storm water quality, allowing effluent levels to meet (or be well below) the regulatory turbidity limits. Most importantly, they consistently provide repeatable water-quality results for every design storm event.

In areas of channelized flow (bench drains, down chutes, and perimeter channels), the geosynthetic turf system can be infilled with a fiber-reinforced, high-strength concrete matrix instead of sand. This specialized pozzolanic infill created specifically for storm water applications will flex and move with typical differential settlements that occur on permanent covers. It provides superior hydraulic performance capable of

Geosynthetics withstand erosive forces from extreme weather conditions.

Geosynthetics allow the direct attachment of new solar technology, maximizing the beneficial use of closed landfills.

handling high shear stress and large flows, resulting in very high velocities.

Geosynthetic systems also require very low post-closure maintenance compared to alternative soil systems. The cost of maintenance is estimated to be as much as 90% less as a result of reduction in maintenance activities, including the vegetation, mowing, fertilization, irrigation, re-vegetation, erosion repairs, and storm water pond cleaning associated with traditional soil covers. Common erosion, storm water, and siltation problems are prevented—even during severe weather events such as intense rainfall, hurricane force winds, and earthquakes. Further, they protect against driving forces and severe weather conditions such as drought and heat.

## Post-Closure Beneficial Use: Renewable Energy

With recent federal regulations likely forcing the closure of many power plants' coal ash impoundments, an engineered synthetic system provides an ideal foundation for utilities to deploy solar generation alongside active or retired coal-fueled plants. One of the biggest hurdles to utility-scale solar is finding suitable sites with grid infrastructure for interconnection. By nature, this problem is alleviated when solar is sited at an existing or retired power plant and the impoundments have been capped with engineered synthetic turf systems. Challenges to deploying solar panels on vegetated caps include fugitive dust, grass clippings, and potential damage from mowing equipment. Additionally, panel systems might move or break due to settling caused by erosion impacts to a vegetated cap.

Upright solar panels have been successfully deployed on numerous synthetic cap closure sites across the U.S. Recently, Watershed Geo demonstrated a unique approach to maximizing solar collection at landfills and impoundments. The solar system combines the most advanced, proven panel technology with a rackless, direct surface attachment system that can be used on the top decks and side slopes of a geosynthetic turf foundation. This new slope panel technology system increases the power output by as much as three times per unit area compared to traditional arrays.

## Looking Ahead

An engineered synthetic turf system is a proven technology that solves problems that have been plaguing the industry for decades. It addresses landfill stability and erosion problems by providing a long-lasting, geotechnically stable, and environmentally friendly final cover system that significantly reduces construction time and maintenance costs while providing an ideal foundation for solar panel deployment.

The volume of existing CCRs, in both landfills and impoundments, represents a staggering volume that will need to be closed, in some cases on very aggressive schedules. According to the EPA, there are over 310 active CCR landfills, with an average size of approximately 120 acres, and 735 active CCR surface impoundments, with an average size of roughly 50 acres.

The amount of coal ash likely destined for future disposal is expected to remain significant for years to come, leaving an ongoing disposal challenge that can greatly benefit from the use of new and emerging technologies such as geosynthetics.

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**Mike Ayers** is Chief Executive Officer of Watershed Geosynthetics LLC. He has over 25 years of professional experience in the design and development of heavy civil engineering projects, including the execution of all phases of land development, geotechnical evaluation, hydrology assessments, site selection, and management of the permitting process with state and federal agencies. A licensed professional engineer and general contractor in multiple states, Ayers has over 20 years of design experience using a variety of geosynthetics for stability, erosion control, and containment. He is actively involved in the Industrial Fabrics Association, Solid Waste Association of North America, and the International Geosynthetics Association.



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# Mining Coal Ash for Rare Earth Elements

*By John Simpson*

When China embargoed rare earth element (REE) shipments to Japan following a territorial dispute in September 2010, it served notice that it was willing to leverage its position as the world's near-monopoly supplier of these strategic materials. REE prices shot up roughly fourfold in a matter of weeks and continued surging the following year as China announced export restrictions that would curtail REE exports by roughly 35% to the world market.[1]

Beijing's official position was that its actions were taken to conserve a scarce natural resource and protect its environment. Ultimately, that defense was rejected in a ruling by the World Trade Organization, and China was forced to lift its export quotas.[2] Nonetheless, the incident laid bare the vulnerability of the U.S. and much of the rest of the world that relies on China for REEs to manufacture products ranging from electronics to renewable energy technologies to military hardware. Partly as a result, U.S. government and academic researchers began searching in earnest for alternative domestic supplies of rare earth elements—and a leading candidate became coal and coal by-products.[3]

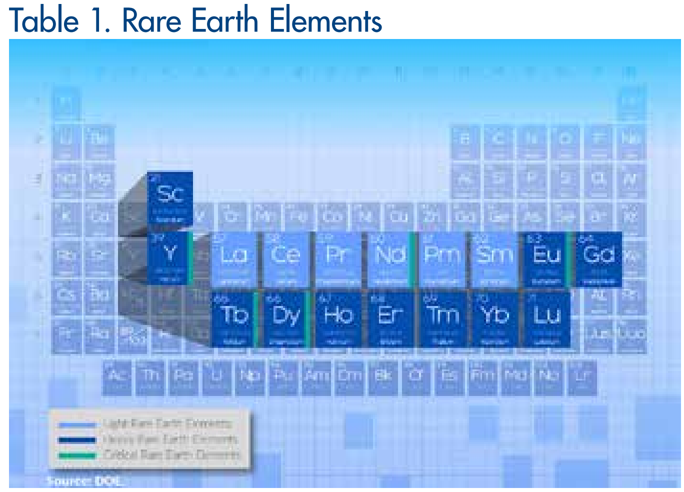
## REEs: Not So Rare After All

Rare earth elements are a group of 17 metals found within the Earth's crust. They comprise the 15 lanthanides—elements 57 through 71 on the period table—plus scandium (atomic number 21) and yttrium (atomic number 39)[4]; see Table 1. Despite their name, REEs are not particularly rare: a majority of them are more prevalent in the Earth than is lead, and all of them are found in greater abundance than is silver. However, they are generally not present in nature in large concentrations. Further, because of their chemical and physical characteristics—they all have the same ionic charge and are similar in size—separating rare earth elements can be extremely difficult.[5]

"Rare earth elements occur in ores in very small concentrations, a few thousand parts per million," notes Linda Wang, Professor of Chemical Engineering at Purdue University. Extensive mining, grinding, extraction, and purification are needed to transform the ores to the very high purity (approximately 99.9% minimum) required of rare earth metals for commercial applications. "Typically, old technologies from the 1950s are used for separation and purification," Wang adds. "They usually require 1,800 different extraction stages in series and in parallel for purification. Such processes can be hazardous, costly, and inefficient."[6]

Nevertheless, due to their unique magnetic, phosphorescent, and catalytic properties, demand for rare earth elements is increasing as their uses expand across a range of electronic, communications, and high-tech applications. For example, neodymium is integral to creating the strongest permanent magnets in existence, used in the generators and motors of wind turbines and electric vehicles as well as in computer hard disks and ear buds.

## Table 1. Rare Earth Elements



Clockwise from top center: rare earth elements praseodymium, cerium, lanthanum, neodymium, samarium, and gadolinium.

Europium's photoluminescence properties give it wide application as a red phosphor in television sets and fluorescent lamps. Lanthanum is used in the production of night-vision goggles and rechargeable nickel metal hydride (NiMH) batteries. Not the least, rare earth elements are used widely in defense applications, including the thermal coatings of jet engines, the control systems of guided weapons, ship and submarine SONAR systems, and the noise cancelling technologies used in stealth aircraft and helicopters.[7]

Global supplies of rare earth oxides are estimated to be in the vicinity of 110 million metric tons, with China, Russia, the United States, India, and Australia having the largest deposits.[8] From the 1960s, when rare earths first began to be mined in large volumes, through much of the 1980s, the U.S. was the world's largest REE producer. California's Mountain Pass mine was the source of most of the world's rare-earth elements during this period; however, tightening U.S. environmental regulations and increased supply competition from China saw the U.S. cede its position as the top REE producer in 1988.[9] China has reigned as the world's top supplier ever since, garnering roughly 90% of the market, and U.S. production has ceased altogether.

## Coal and Coal Ash Investigated as Potential REE Resource

In 2010, the Department of Energy (DOE) developed its first-ever Critical Materials Strategy, identifying yttrium, neodymium, europium, terbium, and dysprosium as "critical" REEs—reflecting both their importance to the clean energy economy and the potential risk of supply disruption (see Figure 1). The strategy aimed to diversify global supply chains to mitigate supply risk; develop material and technology substitutes; and promote recycling, reuse, and more efficient use to significantly lower global demand for critical materials.[10] As part of the strategy, DOE's National Energy Technology Laboratory (NETL) subsequently began exploring extraction of REEs from coal and coal by-products.[11] Congress then formally appropriated funding during fiscal year 2014 to identify the magnitude of the resource and develop the capabilities to economically recover rare earth elements in an environmentally responsible manner.

Subsequent research published in 2016 by Duke University and University of Kentucky scientists—and supported by the American Coal Ash Association—helped to characterize the content of a broad selection of U.S. coal ashes to rank their potential for REE recovery. Collecting ash from power plants that burn coal sourced from all over the country, including the three largest sources—the Appalachian Mountains, southern and western Illinois, and the Powder River Basin in Wyoming and Montana—researchers used hydrofluoric acid to test the samples for their rare earth content. Ash collected from Appalachian Mountains coal was found to contain the highest levels of rare earth elements at 591 parts per million (ppm), while ash from Illinois and the Powder River Basin contained 403 ppm and 337 ppm, respectively. The researchers then employed an industrial extraction technique using nitric acid to determine the recoverable portion of rare earth elements from each type of coal ash. Ash from the Powder River Basin gave the highest extraction percentage, and Appalachian Mountains ash the lowest.[12]

"One reason to pick coal ash from the Appalachian Mountains would be for its high rare earth element content, but you'd have to use a recovery method other than nitric acid," says Heileen Hsu-Kim, Associate Professor of Civil and Environmental Engineering at Duke. "For any future venture to begin an extraction program, the recovery method will need to be tailored to the specific chemistry of the coal ash being used."[13]

The researchers also tried "roasting" the coal ash with an alkali agent before dissolving it with nitric acid. Even though the process hadn't been optimized for recovery purposes, their tests showed a marked improvement in extraction efficiency. "The reagents we used are probably too expensive to use on an industrial scale, but there are many similar chemicals," says Hsu-Kim. "The trick will be exploring our options and developing technologies to drive the costs down. That way we can tap into this vast resource that is currently just sitting around in disposal ponds."[14]

DOE echoed as much in a 2017 report to Congress, noting that "opportunities to recover REEs from coal and coal byproducts appear possible, but require more information and technology development to create pathways toward both improved economics and environmental footprint."[15] Moreover, DOE noted, the co-production of REEs with other useful materials present in coal and coal byproducts offers the potential to enhance the economic viability of REE recovery from these sources. "The key to unlocking this potential reserve base for economic U.S. REE production from coal and coal byproducts is the improvement of separation technologies," DOE concluded.[16]

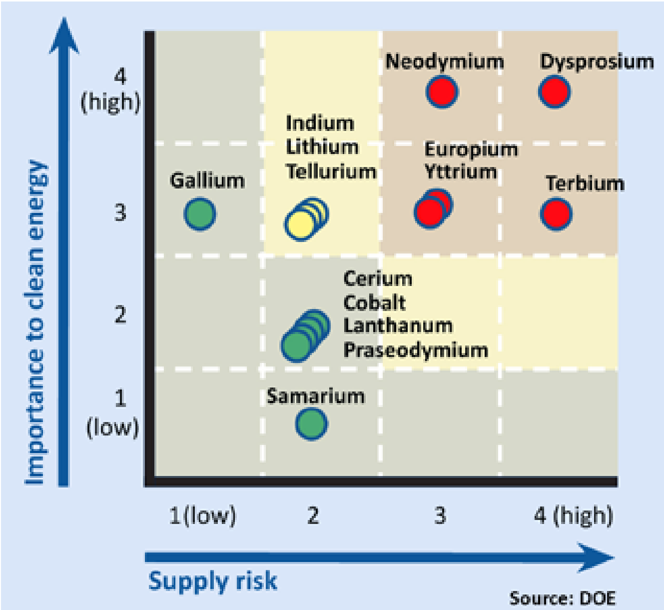



Figure 1. Criticality Matrix (2015-2025).

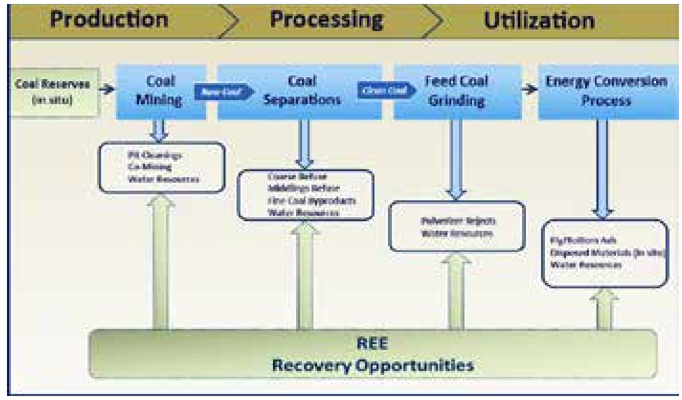



Figure 2. Schematic of the coal value chain as it relates to opportunities to recover REEs. SOURCE: DOE

## DOE Launches REE Program

To that end, since 2014 DOE's REE program has funded research into a wide variety of bench- and pilot-scale projects investigating technologies to separate REEs from coal and/or coal byproducts. The program's objective is to validate the technical and economic feasibility of prototype salable high-purity REE systems by 2020. Specifically, the projects are to achieve at least 2%—or 20,000 ppm—REE elemental concentration, which represents a significant enrichment from feedstocks that typically contain REEs at 300 ppm (0.03%).[17] The REE recovery percentage is critical for economically processing these elements on a commercial basis.

In August 2017, four such projects were selected to receive "Phase 2" DOE funding totaling $17.4 million, based on their having met "or greatly exceeded this goal," according to DOE.[18] Summaries of their work and achievements to date follow hereafter (see sidebar on page 20 for additional projects—both ongoing and completed—carried out under DOE's REE program).

- *High Yield and Economical Production of Rare Earth Elements from Coal Ash* (Physical Sciences Inc.). In Phase 1 of its project, PSI achieved 40% REE concentration at 15% REE recovery using post-combustion fly ash attained from burning Central Appalachian Basin coal.[19] In Phase 2, PSI, together with team members the University of Kentucky Center for Applied Energy Research and Winner Water Services, are developing and demonstrating a pilot-scale plant to economically produce salable REE-rich concentrates, including yttrium and scandium (REYSc) and commercially viable co-products from coal ash feedstock using environmentally safe and high-yield physical and chemical enrichment/recovery processes. The pilot plant will operate at the scale of approximately 0.4-1 tons per day (tpd) ash throughput for physical processing and about 0.5 tpd

### Purdue Researchers Patent Process That Could Be Used to Extract REEs from Coal Ash

Purdue University scientists have patented a process they say can be used to efficiently and inexpensively extract rare earth elements from coal ash that is available for licensing. Linda Wang, Purdue's Maxine Spencer Nichols Professor of Chemical Engineering, has developed chromatography separation techniques to separate rare earth elements first from other impurities and then from each other by using only a few chromatography units.

The processes involve ligand-assisted elution or displacement chromatography methods using robust, low-cost, inorganic sorbent titania or polymeric sorbents. According to Wang, the processes can effectively separate REEs with purities and yields greater than 95%.

"Using titania sorbents is what makes this innovation unique," Wang says. "They are robust and inexpensive, making the processes efficient and affordable. Additionally, the byproducts of our process include silica gel, aluminum oxide, and other metal oxides of commercial value, making the overall process profitable and economical."

Wang has demonstrated the feasibility of the technology at the laboratory scale and says it can be designed and scaled up for production. "We have had success in many challenging chromatographic separations, including the purification of medical isotopes, sugars, amino acids, chiral drugs, insulin, polymers, and many others. Thus, we are confident that we can produce high-purity REEs from coal ash."[29]

New efficient and inexpensive technologies being devleoped by Purdue University Professor Linda Wang could allow the extraction of rare earth elements critical to many electronics and green products from coal ash. Photo by Vincent Walter.

for chemical processing, producing at least 50g of dry REYSc nitrates concentrate containing more than 10% by weight of REYSc, and targeting 500g of dry REYSc nitrates concentrate containing more than 20% REYSc by weight. The ash feedstock will come from the Dale power plant in Ford, Ky., with at least 300 ppm of REYSc content, though more than 500 ppm is anticipated. The data obtained from the pilot plant operations will be used to enhance and validate the techno-economic analysis that was completed for both the physical and chemical processing plants at a scale of 600 tpd in Phase 1, and use it to design a commercial scale plant (hundreds of tpd throughput) with return on investment in less than seven years. Completion date: March 31, 2020.[20]

- *Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Minerals and Elements from Coal and Coal By-products Using Advanced Separation Technologies* (University of Kentucky Research Foundation). In Phase 1 of its project, UK achieved over 80% REE concentration at greater than 75% REE recovery using Central Appalachian Basin and Illinois Basin coal preparation plant refuse.[21] In Phase 2, UK is developing and testing a one-fourth-ton/hour pilot-scale plant for the extraction of REEs from Central Appalachian and Illinois Basin bituminous coal preparation plant refuse materials. The system will integrate both physical and chemical (ion exchange and solvent extraction) separation processes that are commercially available and environmentally acceptable. The innovative enabling technology utilized in the proposed system includes an advanced froth flotation process and a novel hydrophobic-hydrophilic separation process. Completion date: March 31, 2020.[22]
- *Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks* (University of North Dakota Energy and Environmental Research Center). In Phase 1 of its project, UNDEERC identified locations in North Dakota with coal-related feedstocks containing exceptionally high REE content and developed a method to concentrate the REEs in the lignite feedstocks using a technology that takes advantage of the unique properties of lignite. In lab experiments, the researchers achieved greater than 2% concentration of rare earths in the mixed rare earth concentrate, while recovering up to 35% of the rare earths from the incoming feedstock.[23] In Phase 2, the team is demonstrating the technology at a scale of 10-20 kilograms per hour feedstock throughput and evaluating the economics of a commercial-scale, rare-earths-concentrating facility in North Dakota. Completion date: December 31, 2019.[24]
- *Recovery of Rare Earth Elements from Coal Mine Drainage* (West Virginia University Research Corporation). In Phase 1 of the project, WVU achieved 5% REE concentration at greater than 90% REE recovery using acid mine drainage solids from the Northern Appalachian and Central Appalachian Basins.[25] In Phase 2 of the project, the research team is developing a process to recover REEs from solid residues (sludge) generated during treatment of acid coal mine drainage (AMD). This project is taking advantage of autogenous processes that occur in coal mines and associated tailings that liberate, then concentrate, REEs. Phase 1 findings showed elevated concentrations of REEs, particularly in low-pH AMD, and nearly all precipitating with more plentiful transition metals in the AMD sludge. REE extraction using hydrometallurgical methods produced a concentrate with 4.6% total REE content. A techno-economic analysis also found that REE extraction from AMD sludge is economically attractive, with a refining facility projected to generate positive cash flow within five years. During Phase 2, a continuously operating bench-scale unit is being constructed and operated yielding 3g/hr of REE concentrate. Completion date: June 30, 2019.[26]


## Economics Are at the Core of Successful Commercial REE Recovery

A priority of DOE's REE program is to determine, through cost-benefit analysis, whether rare earth elements can be separated and recovered from coal-based materials in an economically feasible fashion. To that end, the agency is applying techno-economic analysis models to evaluate the economics of commercially producing REEs from these separation and recovery processes. Although the projects selected for Phase 2 development have yet to be completed, DOE says the modeling has produced several insights into what it will take to develop commercially successful REE extraction from coal and coal byproducts:

- **Driving down operating expenses will have a bigger impact on reducing required revenues than lowering capital costs**. "Evaluation has indicated that operating costs far exceeded an annualized capital cost, on a per-ton-of-product-produced basis," DOE says. This emphasizes the need to make sound design decisions early in the development process, the agency adds.
- **Processing multiple products (i.e., non-rare earth minerals) in addition to REEs can greatly improve project economics**. This is particularly true for coal-based feedstocks due to their low REE concentrations, DOE says.[27]

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**John Simpson** is editor of *ASH at Work*.

## Additional DOE Coal Ash-Related REE-Recovery Research[28]

| Project Title | Primary Performer | DOE Project # | Completion Date |
|---|---|---|---|
| A Pollution Prevention and Economically Viable Technology for Separation of Rare Earth Elements from Powder River Basin Coal Ashes | University of Wyoming | FE0027069 | 8/31/2017 |
| Economical & Environmentally Benign Extraction of Rare Earth Elements from Coal & Coal Byproducts | Tusaar Corporation | FE0027155 | 12/31/2017 |
| Novel Membrane and Electrodeposition-Based Separation and Recovery of Rare Earth Elements from Coal Combustion Residues | Duke University | FE0026952 | 2/28/2018 |
| Concentrating Rare Earth Elements in Acid Mine Drainage Using Coal Combustion Products Through Abandoned Mine Land Reclamation | Ohio State University | FE0031566 | 4/30/2019 |
| Recovery of High Purity Rare Earth Elements from Coal Ash via a Novel Electrowinning Process | Battelle Memorial Institute | FE0031529 | 5/15/2019 |
| Economic Extraction and Recovery of REEs and Production of Clean Value-Added Products from Low-Rank Coal Fly Ash | University of North Dakota Energy and Environmental Research Center | FE0031490 | 5/15/2019 |
| Coupled Hydrothermal Extraction and Ligand-Associated Swellable Glass Media Recovery of Rare Earth Elements from Coal Fly Ash | Wayne State University | FE0031565 | 9/14/2019 |
| Sampling, Characterization and Round Robin Analyses of Domestic U.S. Coal Based Resources Containing High Rare Earth Element Concentrations | University of North Dakota Energy and Environmental Research Center | FE0029007 | 9/30/2019 |
| Application of Biosorption for REE Separation from Coal Byproducts | Lawrence Livermore National Laboratory | FWP-LLNL-18-FEW0239 | 2/28/2021 |

# Digging Through the Past: Harvesting Legacy Ash Deposits to Meet Future Demand

*By Rafic Minkara, Ph.D., P.E.*

A century ago this year, engineers for the first time successfully burned pulverized coal continuously and at high efficiency in steam boilers to produce electricity. The event took place November 11-15, 1919, at the Milwaukee Electric Railway & Light Company's Oneida Street Station, which has since been named to the National Register of Historic Places in recognition of this achievement. While development of this pioneering process was opposed by some at the time, the superior efficiency of this practice—which conserved fuel and reduced the cost of electrical power—soon made it the industry standard. It remains so today.

The process also produced what is sometimes referred to as pulverized fuel ash—a coal combustion product comprising the fine particles of ash that are expelled from coal-fueled boilers along with flue gases. With subsequent advances in the understanding of fly ash's pozzolanic properties—and the adoption of electrostatic precipitators to capture it—the foundation of the modern coal ash industry was born. Today, the usefulness of fly ash and other coal combustion products (CCPs) across a range of high-value applications is well known, and a growing percentage of U.S. fly ash production—64% in 2017—is beneficially used by industry (see Figure 1). As a result of this growing demand for CCPs, and declining production of coal ash from current-generation power plants, previously disposed ash is increasingly being examined as an option to help meet market requirements.


Oneida Street Station, in Milwaukee, where pulverized coal was first burned continuously and at high efficiency in steam boilers to produce electricity.

## A Potentially Vast Pozzolanic Reserve

Based on production and use surveys from the American Coal Ash Association, over 1.5 billion tons of previously disposed coal ash lies in landfills ("dry-stack" disposal) and surface impoundments (wet sluicing disposal) in the United States. Not all of this is likely to be beneficially used, as some materials in these deposits are typically of a heterogeneous nature. In addition to fly ash and bottom ash, some older surface impoundments (ponds) may contain, for example, coal mill wastes or byproducts from other emissions control processes. Or the coal ash may contain undesirable levels of coarser particles, making it less suited to beneficial use without further processing. In any case, in addition to careful testing of all materials excavated from landfills and impoundments for potential beneficial use to determine their physical and chemical characteristics, a cost-benefit analysis must be undertaken to assess whether the investment required to beneficiate the ash will leave room for a profit on the sold product.

The Environmental Protection Agency's issuance in 2015 of its Coal Combustion Residuals (CCR) rule, however, may improve the economics of beneficiating certain legacy ash deposits. In particular, the rule's requirements with respect to groundwater monitoring of surface impoundments make it a practical reality that many ponds will be excavated in the coming years and their contents transferred—either to alternative storage facilities or for purposes of beneficiation. Beneficiation of such ash deposits provides a potential avenue for recouping some of the expenses associated with such closures. Moreover, the rule's tightened requirements relating to existing landfills make these deposits increasingly candidates for harvesting as well.

As those in the industry well know, the basic criteria for qualifying fly ash as a cementitious pozzolan for use in concrete are established in the American Society of Testing and Materials (ASTM) C-618 specification. Among the criteria are standards for fineness, moisture, loss on ignition (LOI), and strength activity index (SAI). As with most current-production ash, that exhumed from a landfill or surface impoundment is unlikely to meet ASTM standards for cement or concrete production as-is and will typically require any of several processes to attain such quality. Helpfully, ASTM—as a result of the industry's increased interest in harvesting legacy ash deposits—recently published ASTM E3183 – 18, "Standard Guide for Harvesting Coal Combustion Products Stored in Active and Inactive Storage Areas for Beneficial Use." A cooperative effort, the guide was developed by a task group chaired by Boral Resources Director of Research Dr. Ivan Diaz Loya, with Hull & Associates Senior Project Manager Angie Gerdeman

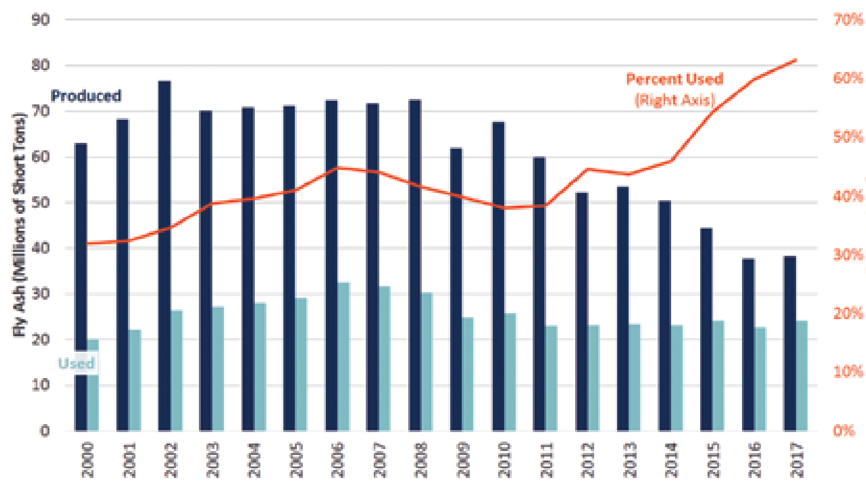


Figure 1. Fly ash production and use, with percent.

## Washingtonville Monofill Case Study

Boral Resources is harvesting and making available for beneficial use approximately 2 million tons of high-grade fly ash from its Washingtonville, Pennsylvania, monofill. The fly ash was produced by coal-fueled generating stations and infilled in the 1980s and 1990s. Comprehensive testing of the fly ash, which has been stored in a capped monofill on a 30-acre site above natural grade, determined it to be of consistent high quality, making it suitable for beneficial uses including high-strength/durability concrete applications. Washingtonville's on-site fly ash drying plant is being utilized to ready the fly ash for commercial applications.

In preparation for making the fly ash commercially available, Boral Resources sampled and tested the monofill materials comprehensively. Samples for testing were drawn from 12 boring locations at depths ranging from 15 to 50 feet and collected at five-foot intervals and evaluated using x-ray fluorescence to determine the consistency of their chemical properties. Carbon content, loss on ignition, particle size distribution and fineness, organic impurities (ASTM C40), foam index, and adsorption were also determined to ensure the quality and consistency of the material (see Table 1). Samples taken from all depths—0-5', 5-10', 10-15', 15-20', and 20-25'—tested negative for organic contaminants. Composites from borings and large (14-ton) excavated samples were used to assess the fly ash for concrete and durability testing per the requirements of ASTM C-618, as well as for compressive strength development, alkali-silica reaction (ASR) mitigation, and sulfate resistance.

Comparative analysis of the harvested fly ash samples against plant-produced fly ash across all phases—amorphous, quartz, hematite, magnetite, periclase, diopside, and mullite—determined that the harvested fly ash has retained the qualitative amorphous content and the quantitative composition of plant-produced fly ash. The reclaimed low-calcium fly ash retained its chemical and mineralogical characteristics, as well as the pozzolan performance attributes, of plant-produced fly ash, including its ability to react with $Ca(OH)_2$ to form additional hydrates, mitigate ASR, and contribute to strength gain in cementitious mixtures. The ash exceeds all the chemical and physical requirements of ASTM C-618 and AASHTO M295 specifications for the use of fly ash in concrete.

### Table 1. Comparison of ash reclaimed from Washingtonville monofill with current-production ash.

| | $SiO_2$+ $Al_2O_3$+ $Fe_2O_3$ | $SO_3$ | CaO | Moisture | LOI | Fineness | SAI 7 d | SAI 28 d | Water Req' |
|---|---|---|---|---|---|---|---|---|---|
| Current Generation | 81.99 | 2.55 | 9.38 | 0.21 | 8.80 | 28.65 | 79 | 80 | 101 |
| Reclaimed | 90.84 | 0.19 | 2.21 | 0.16 | 3.05 | 11.90 | 79 | 83 | 100 |
| ASTM C618 Class F | 70% min | 5% max | ** | 3% max | 6% max | 34% max | 75% min | 75% min | 105% max |

serving as the main drafter and reviewers from both the utility and coal ash industries. It provides harvesting guidance for CCPs, including evaluation of storage areas for harvesting; detailed characterization of CCP storage areas; planning and scoping of harvesting projects; detailed design and approval (as applicable) of CCP storage area harvesting; and implementation of harvesting. The guide is an essential tool to help inform decision-making as projects to beneficiate legacy ash deposits are considered.

## Reducing Residual Carbon in Fly Ash

One of the major attributes of some legacy ash deposits that, absent beneficiating, makes them unsuitable for use in high-value applications such as concrete is the presence of excessive levels of unburned carbon. ASTM C-618 specifies that LOI—a measurement of the unburned carbon (coal) remaining in fly ash—be below 6%. In practice, some specifiers typically require much lower LOI levels in fly ash. Frequently the result of using low-NOx burners pursuant to Clean Air Act requirements, the presence of activated carbon in fly ash can interfere with fresh concrete's ability to entrain the desired amount of air. As a result, fly ash containing undesirable levels of activated carbon must be treated prior to its sale to ready-mix concrete producers. Boral developed the original carbon passivation technology, which has recently been upgraded to address the more adsorptive, lower-concentration levels of activated carbon relative to unburned carbon. Boral's RestoreAir® process uses a liquid reagent to pretreat fly ash before delivery to customers to neutralize activated carbon's air entrainment. The technology's low dosage of liquid reagent passivates the carbon surfaces and reduces their ability to adsorb air entrainment agents in concrete (see Figure 2). Carbon is not removed, but its effect on air entrainment is neutralized. Boral has successfully demonstrated the technology on Class C and Class F ashes containing the most common powdered activated carbons and unburned carbons. The RestoreAir® processes have been deployed at numerous power plants with capacities to treat more than two million tons of ash annually.

For legacy fly ash deposits containing unacceptable levels of unburned carbon, Boral also offers Carbon Burn-Out (CBO), a technology in which residual carbon in fly ash is combusted to produce a consistent low-LOI and high-quality pozzolan. CBO is fueled by the residual carbon within the fly ash and can be used to beneficiate high-carbon fly ash either directly from the power plant or from ash that has been stored in landfills or

## 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
**Contact info:** Kevin Foody, 412-225-1110, kfoody@wm.com
**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.

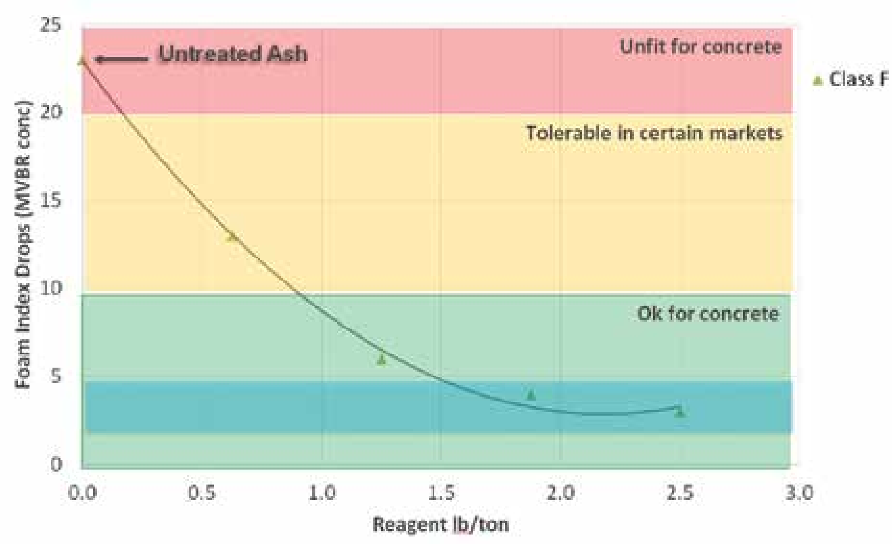


Figure 2. RestoreAir® (RA4.2) reagent: tamed dose response.

ponds. During the process, high-carbon raw ash is pneumatically conveyed from the dryer plant (if ponded or landfilled ash is being beneficiated) to the CBO silo. A forced-draft fan provides fluidization and combustion air to the CBO fluid bed combustor, while an induced-draft fan keeps the combustor freeboard pressure slightly sub-atmospheric. Feed ash is metered into the combustor, in which carbon burns on a continuous basis (see Figure 3). Excess heat from the CBO can be used to dry harvested ash, sent to a host power plant for energy recovery, or deployed for other beneficial use options.

Carbon burn-out can accommodate high-carbon contents (>20%). Typically, a

## Commercial Beneficiation Technologies cont.

**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
**Contact info:** Dr. Rafic Minkara, P.E., 770-330-0689, rminkara@boral.com
**Website:** www.flyash.com/products-and-technologies/carbon-burn-out

**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 yield ASTM C-618-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, 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
**Contact info:** Brad MacKenzie, 604-318-8077, brad@sonoash.com
**Website:** www.sonoash.com

**MP618™ Multi-Process Fly Ash Beneficiation**
**Vendor:** Charah Solutions
**Technology type:** Proprietary thermal fly 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:**
- Thermal process reduces LOI, ammonia, and moisture in both wet and dry fly ash
- Allows for the processing of kiln dust to remove mercury for emissions regulations compliance

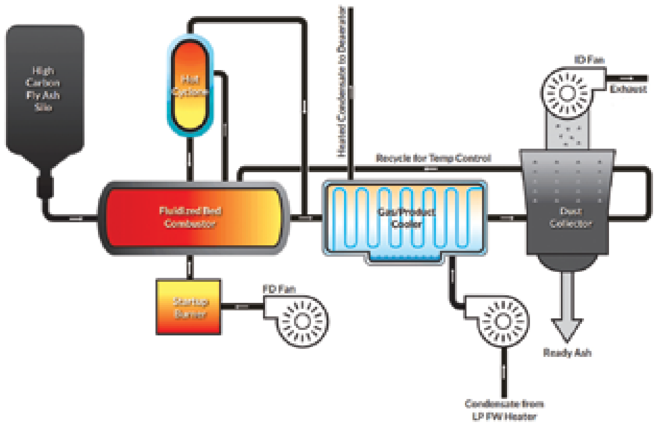


Figure 3. Carbon burn-out process.

minimum of 8% carbon is required for the conventional process to work solely via the fuel value of the fly ash. The CBO system can be designed to operate with 6% carbon in ash feed. For lower-carbon ash streams, support fuel such as natural gas may be needed. CBO-produced fly ash meets or exceeds ASTM Class F specifications. As an added benefit, the process simultaneously decomposes ammonia to nitrogen and water, yielding ash with no detectable ammonia residue.

## Sintered Lightweight Aggregate

Beyond dry powder fly ash, landfilled and ponded ash can now also be harvested for processing into a sintered lightweight aggregate (LWA), with the resulting product marketable in a variety of concrete and construction applications. The heart of the technology involves the use of a high-temperature/high-efficiency rotary kiln to dry the reclaimed materials, typically high-carbon fly ash but potentially comingled with bottom ash. The high-capacity kiln is supplied by a counter-current shaft drier requiring only a small amount of energy to dry the pelletized ash. The sintering operation is autothermal, with external fuel required only to initiate the process. Process heat is recovered (from flue gases up to 1,000° C), which is partly used for production purposes.

- Can be installed at both operating and non-operating power plants, whether the fly ash is current production or legacy ash stored in ponds or landfills
- Significantly lower cost profile versus competitive technologies
- Can be deployed in months versus years
- Efficient footprint with self-contained environmental controls
- Modular design and scalability allow for production of 50,000 tons to 300,000 tons per year, based on market demand

**Capital cost (range):** The Charah Solutions MP618™ Multi-Process 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:** Scott Ziegler, Vice President of Byproduct Sales, 502-322-0433 (m), sziegler@charah.com
**Website:** www.charah.com/byproduct-sales/mp618-multi-process-fly-ash-beneficiation-technology

**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
**Contact info:** Dr. Rafic Minkara, P.E., 770-330-0689, rminkara@boral.com
**Website:** www.flyash.com/products-and-technologies/restoreair

**STAR® Technology**
**Vendor:** SEFA Group
**Technology type:** Thermal beneficiation
**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, which provides a permanent solution to remove coal ash from the environment. 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. SEFA developed the first technology in the world to process coal ash from ponds on a commercial scale.
**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 three STAR® Plants today and will operate three more plants in North Carolina.
**Contact info:** Robb Erwin, P.E., CCP Business Development Manager, 803-767-2853 (m), 803-520-9103 (o), rerwin@sefa-group.com
**Website:** www.sefagroup.com

Surplus heat can be converted into central heating, hot water, or electricity and sold to generate revenue.

The process is automated, can be overseen by as few as four people, and allows for setup as a stand-alone operation at an existing landfill or pond (or it can be integrated with a power plant facility). The lightweight aggregate that results from the process is a ceramic, chemically neutral product with a wide range of uses in concrete manufacturing, building products, road construction, and geotechnical applications. Owing to its physical properties, it has potentially wider application than natural aggregates. Its advantages are in its weight and durability. Since 2014, a sintered LWA plant in Sowlany, Poland, has used landfilled coal ash as feed material to produce annual output of 40,000 metric tons of lightweight aggregate.


A pilot plant in Sowlany, Poland, produces 40,000 metric tons of lightweight aggregate annually.

While a variety of technologies now exist to beneficiate landfilled and ponded ash, the cost and complexity of doing so can be challenging. In any case, coal combustion products from landfills and ponds under consideration for excavation and beneficiation will need to undergo detailed characterization as to their physical and chemical characteristics—such as that Boral recently undertook at its Washingtonville monofill (see sidebar on page 23). A rigorous cost analysis will also be required to determine whether potential regulatory constraints (e.g., EPA's proposed five-year timeline for the closure and relocation of surface impoundments) and/or projected market price and demand leave room for a profit margin. Beneficiation processes can be as simple as using off-the-shelf equipment or as involved as developing customized solutions with high capex requirements. But in the end, they must be tailored to address material characteristics and market constraints.

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**Rafic Minkara**, Ph.D., P.E., is Vice President, Technology, at Boral CM Services. He has over 30 years of diverse professional experience including engineering design, construction management, and research and development in the environmental and utility industries. He received his BS, MS, and Ph.D. degrees in engineering and his MBA from the University of Toledo.

# EPRI and Georgia Power Team Up on Harvested Ash Use Research

*By Ben Gallagher, P.E., and Ken Ladwig*

Beneficial use of coal fly ash has ranged between 20 and 30 million tons annually over the last two decades. In the past four years, as coal-fueled plants have been retired, fly ash use as a percentage of that produced has increased from just under 50% to more than 60%. The previous issue of *ASH at Work* highlighted how collaboration between industry, academia, and government helps to research recycled materials and support ash utilization. Due to its unique properties as a cement replacement that improves concrete quality and lowers carbon intensity, fly ash use is expected to remain steady or increase. Ash is already being traded internationally to meet demand.

Today, the energy industry is transitioning away from coal-fueled generation due to economic drivers. The shift in power production has begun to pressure the supply of fly ash and other coal combustion products (CCPs) in the United States. Alternatives to production ash (freshly produced fly ash) supplies will be needed to maintain current markets and accommodate growth. At the same time, electric utilities are closing numerous CCP ponds and landfills in compliance with federal and state disposal regulations. The CCPs in many of these closing facilities are resources that will increase in value as production ash and mined resources become limited. Harvesting and responsible introduction of these CCPs into the market to complement the supply of production ash while maintaining market stability are essential for realizing the full value of these assets to benefit utilities and their customers. CCPs are already being harvested from a few ponds and landfills in the United States, and the expected increase in the number of harvesting sites will represent an attractive alternative as supplies of fresh CCPs decline.

However, harvesting CCPs from closing and closed facilities presents unique challenges. These are typically heterogeneous deposits, resulting in widely varying CCP quality from different horizontal and vertical locations in the facility (see Figure 1). Harvested CCPs are typically wetter than newly produced CCPs and may need some level of drying prior to use. In many cases, different types of CCPs—fly ash, bottom ash, and gypsum—are comingled in one facility. Non-CCP materials such as vegetation, mill rejects, concrete, and other debris may also be mixed with the CCPs. In addition, weathering of CCPs in a pond or landfill may alter particle surfaces, cause particles to agglomerate, or change chemical characteristics. Due to these factors, ponded or landfilled CCPs often will not meet specifications or performance standards for use in concrete and masonry.

> *"The Ash Beneficiation Center is a one-of-a-kind center that will utilize a collaboration and innovation model to maximize the value of coal combustion residuals at the lowest cost. The Center will provide the opportunity to cost effectively study technologies to efficiently and effectively develop additional high-value products and accelerate their availability in the marketplace."*
>
> *—Dr. Mark Berry, Vice President of Environmental and Natural Resources, Georgia Power*

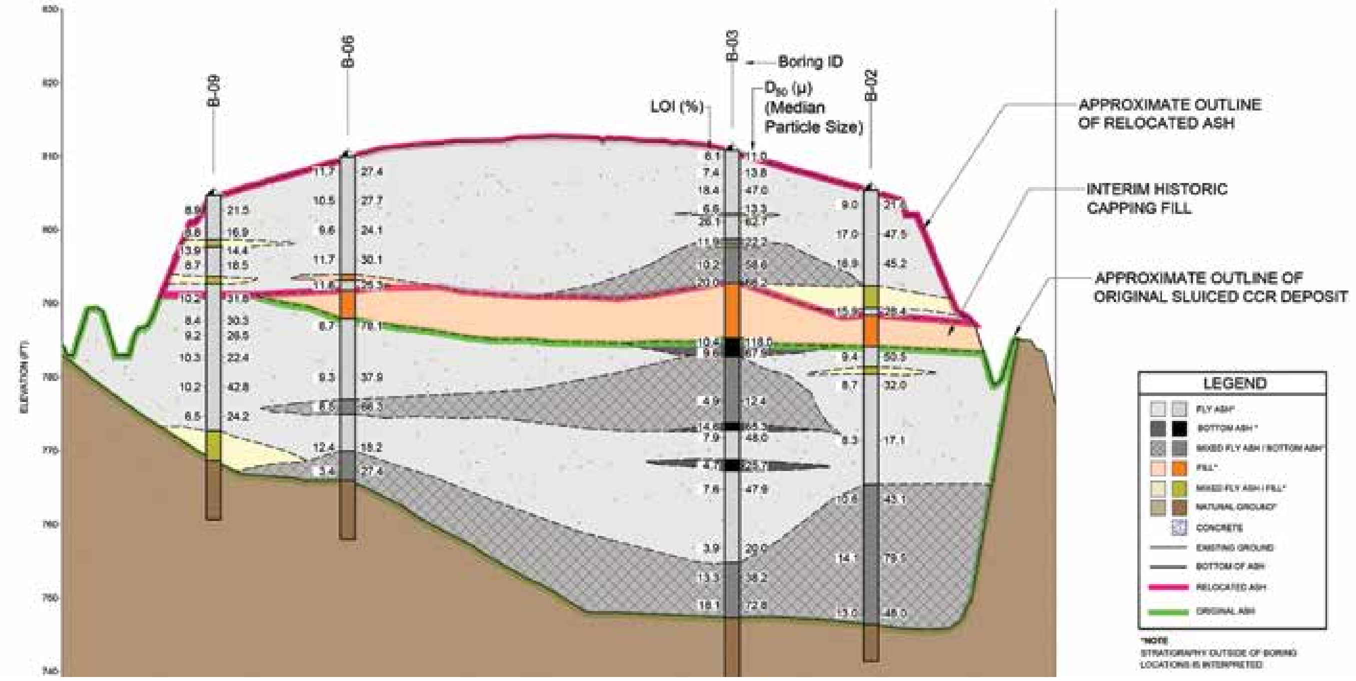


Figure 1. Complex deposits of CCPs and non-CCPs in a landfill underlain by a pond.

These challenges often require harvested pond or landfill CCPs to be processed before use in certain applications. Harvesting at a pond or landfill is reminiscent of the work carried out in a quarry or mine, with multiple operations that may include debris removal, drying, and size separation chained together to produce feedstock for use in concrete, masonry, and other value-added products. The investment in processing equipment is an opportunity to generate multiple products, maximize the value of the known reserve of material, and reduce waste from the harvesting operation.

"Beneficiation" is the broad term that describes improving CCPs to meet specifications as a feedstock for a particular use. Current commercially operating beneficiation technologies mainly focus on removing carbon from fly ash to enable use as a cement replacement. Several near-commercial processes focus on producing other construction materials such as aggregates, blocks, bricks, and tiles. Early-stage independent evaluations of these technologies, including feedstock specifications and operational experience, are important for understanding technical feasibility and cost. Verification of the finished products, showing that the materials meet relevant standards and perform as expected, is also vital to utilities, technology developers, and end users. Demonstrating performance often requires larger-scale pilot operations than can be achieved on a benchtop test scale.

Novel technologies for CCP beneficial use in new and diverse markets beyond construction materials are also emerging. As one example, a significant focus of recent research has been on extraction of minerals and metals from CCPs for use in industrial applications, as well as critical elements that have been identified as having strategic value to industry and U.S. security. This early-stage research on extraction and concentration technologies will need to be proven at benchtop and pilot scale. Testing at larger scales requires the ability to process and manage truckloads of material, which can be a significant barrier to researchers and technologies focused on chemical processes.

## The Beneficiation Center

In collaboration with Georgia Power and Southern Company, the Electric Power Research Institute (EPRI) is developing a research center to test beneficiation technologies and help development of emerging technologies. The Beneficiation Center will work with technology developers to provide third-party documentation of technologies and cost profiles, as well as impartially vet finished products. The Center will allow utilities, researchers, and vendors to collaborate and advance beneficiation technologies from benchtop to commercial operations, which will ultimately increase the value of harvested CCP assets to the benefit of utilities and utility customers.

The Beneficiation Center will include preprocessing technologies to supply CCPs of a required quality for various beneficial use technologies (see Figure 2). Preprocessing operations are expected to include debris removal, drying, size separation, size reduction, dry blending, and storage. Preprocessing may also include a wet process train with operations such as froth flotation, thickening, and filtration. Flexible configuration of the operations will enable production of a range of CCP qualities for use as feed to pilot processes. The total throughput of the preprocessing is envisioned to be about 100-150 tons per day. The Center will include all necessary environmental controls.

The Center will provide opportunities for testing at three different scales. The primary focus will be pilot-scale testing, on the order of 1-5 tons per day. Four to five outdoor test bays will be available for concurrent pilot testing of different technologies. At a larger scale, one demonstration-level test site (10 to 50 tons per day) will be available. Limited benchtop testing (pounds per day) also will be available for early-stage technologies. The Center will

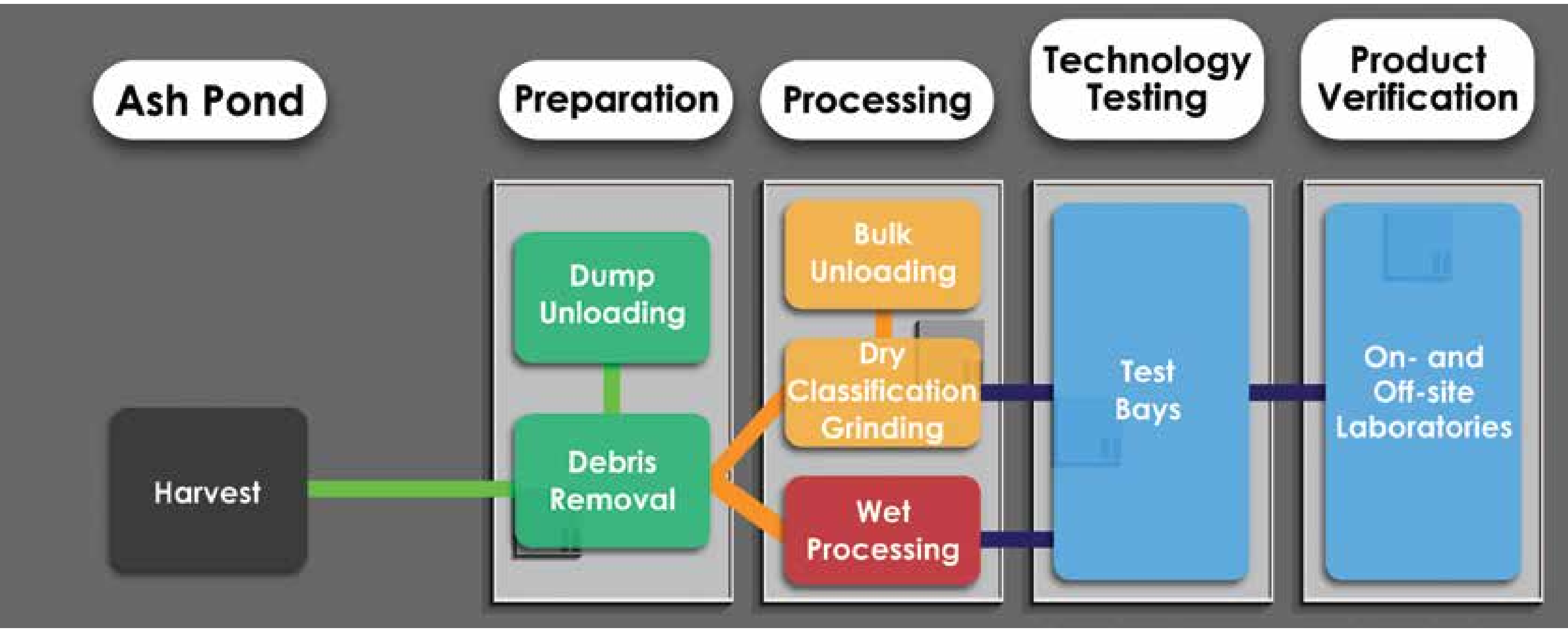


Figure 2. Diagram of the Beneficiation Center.

include monitoring of test bay inputs and outputs (CCP, energy, water, waste) as part of the technology evaluation.

Integral to the research is verification of finished products to ensure they meet relevant standards and market expectations. The Center will include limited on-site testing for products, including particle size and strength test equipment. Additional verification testing support will be provided by EPRI's laboratory facility in Charlotte, N.C., collaborating universities, and third-party testing facilities. Total costs for harvesting through final product will be estimated in collaboration with the technology developers.

"The Ash Beneficiation Center is a one-of-a-kind center that will utilize a collaboration and innovation model to maximize the value of coal combustion residuals at the lowest cost," says Dr. Mark Berry, Vice President of Environmental and Natural Resources for Georgia Power. "The Center will provide the opportunity to cost effectively study technologies to efficiently and effectively develop additional high-value products and accelerate their availability in the marketplace."

Planning and organization of the Beneficiation Center is currently underway, with a goal to begin operations in 2020. If you are interested in more information or possibly participating in research conducted at the Center, contact Ben Gallagher (bgallagher@epri.com, 650-338-8653) or Ken Ladwig (keladwig@epri.com, 262-385-7820).

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**Ben Gallagher** is Senior Technical Leader at the Electric Power Research Institute (EPRI). Prior to joining EPRI, he worked as an engineer for Southern Company for over 10 years, where he directed and completed geotechnical engineering studies for clean air improvements, CCP storage, and new generation sites. Gallagher holds a bachelor's degree in civil engineering from the University of Toldeo, a master's degree in geotechnical and geoenvironmental engineering from the University of Missouri–Rolla, and an MBA from the University of Alabama at Birmingham.

**Ken Ladwig** is a Technical Executive in the Environment Sector at the Electric Power Research Institute (EPRI), responsible for research in EPRI's CCP Environmental Effects Program and CCP Use Program. He has more than 25 years of experience in research pertaining to CCPs and environmental issues. Ladwig holds bachelor's and master's degrees in geological sciences from the University of Wisconsin–Milwaukee.


## Welcome, ACAA's Newest Members!

Tarmac International (Associate Member) is a manufacturer in the Kansas City area with plants centered on their Rotary Thermal Dryers. Tarmac can provide everything for drying and classifying of fly ash or bottom ash; screening; drying; classifying; and storage, including loadout and scales.
www.tarmacinc.com

SMI-PS Inc. (Associate Member) produces a chemical, marketed as SeleniumZero®, that removes selenate from coal ash ponds.
www.smiwater.com

P. Cassels Law PLLC (Associate Member) has over 15 years' experience providing legal transactional support to Progress Energy/Duke Energy for the excavation, transporting, beneficiation, sale, and beneficial reuse of CCPs. After retiring, Pam Cassels has opened her own practice with a continued focus on transactional work for coal and coal combustion products.
www.linkedin.com/in/pam-cassels-7b700b171/

# The Future of Coal Ash Beneficial Use: Research and Development Needs for Testing and Qualifying Fly Ash

*By Thomas L. Robl, Ph.D.*

Fly ash is in the process of changing its role from that of a useful byproduct to a strategic internationally traded commodity. The measurement of its quality and performance will bear increasing importance as the demand for greener concrete expands. One poorly kept secret is that the ASTM C-618 standard test[1] for strength activity index does not measure pozzolanic activity and is non-discriminatory, regularly producing false positives.[2] Any physically strong powdered material, such as milled quartz, brown sand, or milled limestone, will pass. This was not as serious an issue in the past but, with tighter supplies and higher valuations, the competition from natural pozzolans and other related materials will only increase. Our industry produces a premium product that needs defending. Specifically, our approaches to testing and certifying fly ash require the establishment of performance and test criteria that set a level playing field and clearly identify and reject non-performing materials.

## What Fly Ash Does

Fly ash impacts and improves the properties of concrete in three principal ways: enhanced rheology or flow, improved microaggregate gradation, and pozzolanic activity.

The initial impact is on the rheology of the wet concrete, or mortar, with the well-known "ball bearing" effect. The use of high-quality fly ash can easily increase concrete slump by 1 to 3 inches over a mix without it. Increased slump translates to reduced water and improved strength.

The second effect is improved particle packing. This is critical in contributing to the early strength of concrete. This effect is not as well known or as obvious. It is, however, very important as improved particle packing contributes substantially to the early strength of mortars.[3]

The third effect is pozzolanic activity. The hydration of the alite component (tricalcium silicate, or $C_3S$) of ordinary portland cement (OPC), and to a lesser extent belite (dicalcium silicate, or $C_2S$), produces $Ca(OH)_2$, or portlandite and calcium silicate hydrogel (CSH):

$$2[3CaO \cdot SiO_2] + 7H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 4H_2O + 3Ca(OH)_2$$

A material that chemically reacts with portlandite is defined as a pozzolan. Fly ash is important in this role: as it dissolves, it provides silica and alumina that react with portlandite to create additional calcium silicate and aluminosilicate hydrogel. This results in higher strength and density with improved resistance to alkali-silica reaction, carbonation, sulfation, and chlorination—and hence greatly improved durability.

## Measurement of Performance

Strength activity index is the performance-based standard for fly ash. A version appears in all national fly ash standards. It is typically measured as the compressive strength of a standard mortar mix with fly ash substituting at a defined level for portland cement. The standard control mortar mix in C-311 is 500g OPC and 1375g graded standard sand.[4] The ash test mixture is 400g portland cement, 100g fly ash, and 1375g graded standard sand for a substitution level of 20% by weight ash to OPC. The water content of the test mixtures and control is adjusted to a constant flow of ± 5 units on a standard flow table (see Figure 1). ASTM C-618 specifies that the water in the fly ash test mix be no more than 105% of control. In practice, however, the addition of fly ash almost always decreases the amount of water by several percent.

The mortars are molded into 50 mm (2 inch) cubes, tested at 7 days curing, and then compared as a percentage ratio to a mortar with all portland cement. The compressive strength of OPC-ash mortar is then divided by that of an OPC control mortar without fly ash. The ASTM limiting value for strength index is 75% of control or more at 7 or 28 days. If the 7-day criteria are met, no additional testing is required; if not, the tests can be run again at 28 days.

Strength activity index testing is a direct measure of ash performance. However, it is an indirect measure of pozzolanic reaction. It calculates a mechanical property, compressive strength, that is an expression of the contribution of several ash properties, including improvements in the rheology of the mortar, resulting in lower water; improved particle packing; and the actual pozzolanic activity of the ash.

Two issues are critical in the malperformance of the test. First, the graded sand as defined by ASTM C-778 has a very narrow size distribution.[5] There are practical reasons for this, as it allows packaging in large sacks without worries of particle segregation. However, the resulting packing of the mortar creates a very high void volume. Additives that are smaller or have broader size distribution improve compressive strength by enhancing the packing, i.e., filling in the holes. This effect is immediate, powerful, and critical in the initial stages of hydration. For example, at 7 days we have measured the difference between a C-778 mortar and a mortar with ideal packing to be as great as 6000 psi.[6] Second, by conducting everything on a constant-flow basis, the contribution to the rheology (i.e., ball bearing effect) of the ash is incorporated into the measurement, which is a physical rather than a chemical effect.

Our work has indicated that the pozzolanic reaction of a Class F fly ash, at least its measurable contribution to strength, is slow. The European standard EN-450 uses a fixed-water content, employs a standard sand with a broader size range, thus reducing the effects of both packing and rheology, and has an ash substitution level of 25%.[7] Figure 2 presents a plot of compressive strength of two Class F fly ash samples over time using EN-450 methods. The difference in strength between the test and control samples is the same at 7 days (12-15 MPa) as at 28 days. The gap in strength between the control and the fly ash samples does not begin to close until after 28 days.

Another way to measure pozzolanic reaction is by thermogravimetric analysis (TGA). This method has been in use for a long time and measures the reaction of portlandite directly.[8] Briefly, paste samples are prepared with cement only as a control and with fly ash mixed in. The amount of portlandite is compared on a per-gram-of-cement basis. The difference between the two represents the portlandite that is reacted. Figure 3 is an example of this kind of test, with the control on the left in each of the bar graphs. The data suggests that there is not a measurable pozzolanic reaction until at least 56 days.

## Alternative Methods

The current approach to strength index testing using compressive strength is problematic. The 7-day results are not a reflection of the pozzolanic activity of a Class F ash, but rather they measure packing and rheologic contributions. The European approach using constant water and higher ash substitution levels may represent an improvement, but we have found that non-pozzolanic materials can still sneak past it.

One approach that we have been exploring over the past two years is the use of AASHTO resistivity measurements[9] on EN-196 prisms[10] (see Figure 4). Resistivity is a function of the interconnected pores of the prism. With time, resistivity increases as the fly ash reacts to form a more cementitious hydrogel. This property is more directly related to the pozzolanic reaction of the ash.

A plot of the resistivity of the prisms versus time is presented in Figure 5, which includes five compliant Class F fly ash samples along with an ultra-fine fly ash. The control prisms are plotted in blue in the figure. The resistivity remains remarkably constant over time, while the ash samples increase in resistivity. The trends are very much like those of the compressive strength and direct measurements but show a much higher degree of separation and sensitivity. The conductivity of the ash samples has resistivity values of 255% to 885% of control at 90 days versus 105% to 109% of control for compressive strength measurements.

In addition, the resistivity results appear to be highly discriminatory. The control sample remains constant over time, with almost no change over more than a year of measurements, as does the prism with limestone additions. Samples with fly ash show continued increases in resistively over at least a year's time,

Figure 1. Flow table used in strength activity testing to set water.

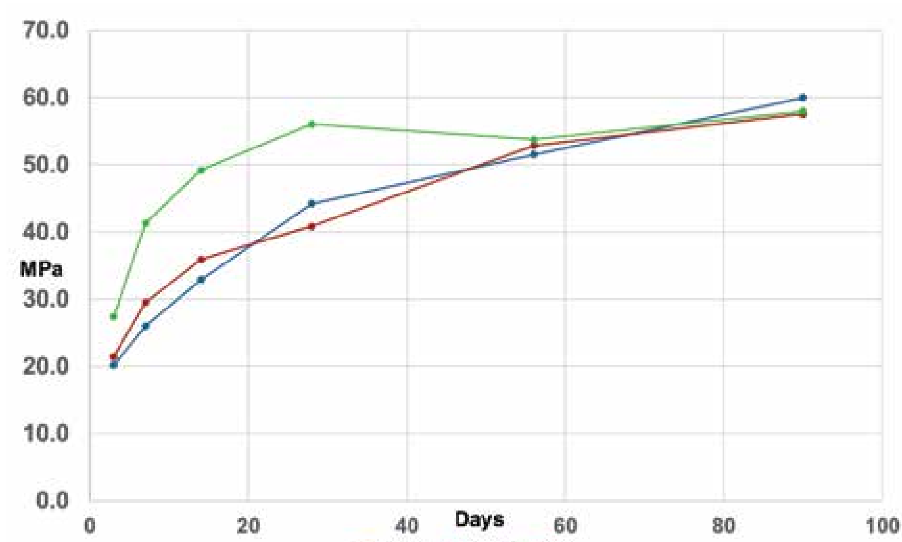


Figure 2. Plot of compressive strength data for fly ash and control with EN-450 methods.

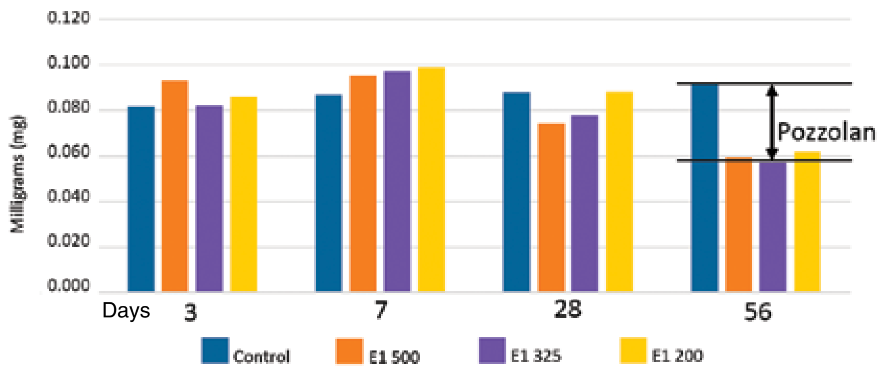


Figure 3. Portlandite content of past samples with control at various days measured by TGA/DTA.

Figure 4. Measurement of resistivity in EN-196 prisms using AASHTO methodology.

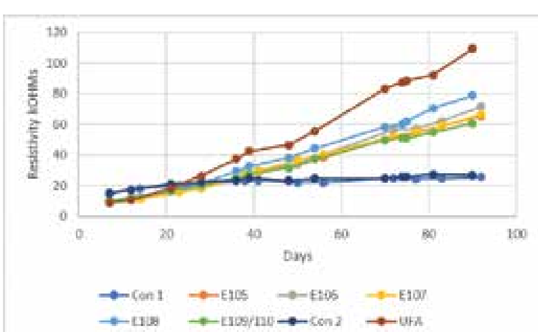


Figure 5. Plot of resistivity measurements for fly ash and control prisms over 90 days.

with measurements exceeding 400 kΩ/cm at 16 months of testing for a fly ash test prism.

The use of non-destructive testing using resistivity shows great promise, and further evaluations at the Center for Applied Energy Research are ongoing. This, of course, is not the only method that may have value in the assessment of fly ash performance, and other suggested approaches have merit.[11]

## Conclusions

Our current testing methodology is in need of reconsideration, augmentation with alternative methods, or even major overhaul. This will become more urgent as other materials enter the market, including ash harvested from landfills and ponds. In addition, the ability of non-pozzolanic materials to pass ASTM criteria puts the fly ash industry at a disadvantage to materials that provide only some of the short-term benefits.

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# A Future Outlook on Harvested Ash Utilization

*By Bill Fedorka, P.E., Robb Erwin, P.E., and Ross Gorman, P.E.*

The coal ash industry continuously evolves. From its inception, the industry has served an increasingly important role in solving market and environmental challenges for stakeholders. In recent years, two trends have dominated the industry. First, as coal-fueled generation has decreased, the availability of production ash for use in concrete has declined. Second, as infrastructure projects have grown in size and complexity, concrete producers have sought to use increasing amounts of coal combustion products (CCPs) in concrete mixes because, in many cases, they are specified to improve performance and offer a meaningful value proposition to the use of concrete in infrastructure projects.

The concrete industry's demand for quality fly ash is anticipated to remain strong. The American Coal Ash Association projects that demand for ready-mixed concrete will help drive CCP use, and forecasts growth in the overall utilization rate from 45% in 2013 to 63% in 2033.[1] In contrast, the supply of production fly ash shows signs of steady decline, with the closing of some coal-fueled plants, the conversion of others to natural gas, and the growth of renewable energy sources in the electricity generation fuel mix.

With concrete customers looking for solutions to the fly ash shortage, fly ash marketers are shifting focus to the vast resource of ash within coal ash impoundments. What changes are likely to emerge with respect to future regulations, the industry, and the environment as coal ash is increasingly harvested to fill the gap in the market?

- As harvested ash is processed to meet the standard specifications for coal fly ash for use in concrete—ASTM C-618 and AASHTO M295—the supply of ash material will no longer be seasonally dependent, and concrete producers will increase utilization of CCPs. The recent harmonization of the two standards may further increase acceptance by concrete producers. Higher utilization will primarily be linked to consistent loss on ignition (LOI), physical properties, and ready availability of material. Since opening its Winyah STAR® Plant, the SEFA Group has been a pioneer in processing harvested ash from ponds. The process produces premium-quality ash with a consistent LOI, allowing customers to increase cement replacement in mixes.
- The addition of ground bottom ash to ASTM C-618 will significantly impact the supply of harvested ash available for beneficiation.
- The new harvesting standard of ASTM E3183-18—Standard Guide for Harvesting Coal Combustion Products Stored in Active and Inactive Storage Areas for Beneficial Use—is a further game changer for the industry. As has been demonstrated, the quality of properly beneficiated, harvested material can be as good as production ash. This guideline for harvesting ash, and increased concrete industry acceptance of the harvested material that results, make the case for beneficial use of impounded ash even more compelling to utilities.
- Beneficial use of ash will surpass production at utility plants due to the beneficial use of harvested coal ash. As demonstrated by the Winyah STAR® Plant, a utility can operate and process harvested ash even when the generation facility is offline. Moreover, as demonstrated by SEFA's McMeekin STAR® Plant, where the host utility's coal units have been converted to natural gas, the facility can continue to provide environmental benefits by continuously processing ash from multiple off-site sources.
- With government regulation and legal pressure increasing to support removal of coal ash from ponds, there will be a lower tolerance of legacy ash remaining in the ground. A broader audience of stakeholders at the state and community levels will connect encapsulated beneficial use of coal ash with the reduction or elimination of environmental risk. Moreover, as technologies (e.g., SEFA's STAR® Technology) demonstrate their ability to process impounded material into commercially viable recycled material, concrete customers will drive increased

demand for materials to improve the strength and durability of their concrete products and the infrastructure that they create.
- The environmental implications go beyond processing and infrastructure and extend to transportation as well. The increasing use of modern fleets of tractors and pneumatic trailers to transport beneficiated ash products also provides benefits to the environment. For example, SEFA's 2019 tractors are greenhouse gas emission certified and designed to meet stringent requirements of the U.S. EPA and the California Air Resources Board that result in significantly reduced diesel emissions.

The foreseeable future for harvesting legacy ash—as well as for harvested ash utilization—looks like a win for utilities, concrete producers, the environment, and infrastructure alike. SEFA is actively working to provide solutions that keep pace with industry changes. Having processed over 1 million tons of harvested ash to date, SEFA expects to process upward of 1.5 million tons of harvested ash annually after 2020.

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SEFA Group's Winyah STAR® Plant can process harvested ash even when the generation facility is offline.

# 2020 to 2070 and Beyond: Transitioning from Production to Post-Production Coal Ash Use

*By Bruce Sifton, P. Eng., and Brad MacKenzie*

Over the last 50+ years, production coal ash has successfully transitioned from a "resisted use" product to a "required component" in cement mixtures to be used in infrastructure material. The next 50+ years will require an extension of that effort. It will necessitate the specification of coal ash to include the use of post-production coal ash from the vast reserves stored in impounded coal ash sites around the world. To initiate this transition, a new approach is needed to create a fungible market for this 21st century material supply.

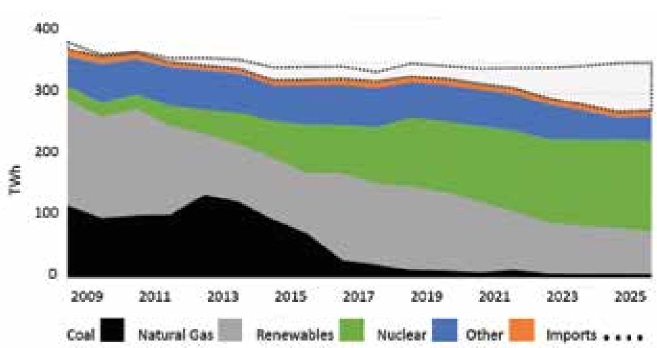



Figure 1. Historical and projected UK electricity generation by fuel type, 2008–2025 (TWh).
SOURCE: 2008–2016 actuals from BEIS; figures are approximated using BEIS' quarterly figures and National Grid data. 2018 forecast from BEIS, corrected to make historical and forecast data consistent.

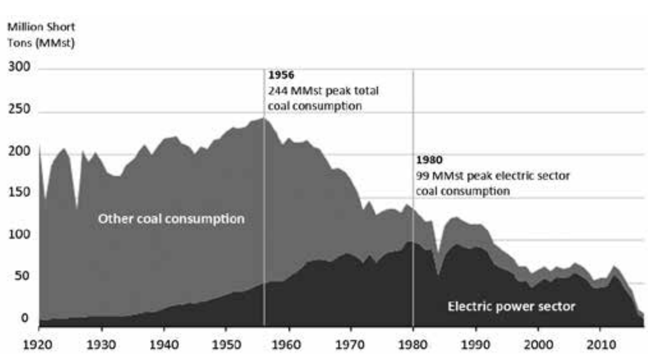



Figure 2. United Kingdom coal consumption, 1920–2017 (MMst).
SOURCE: U.S. Energy Information Administration.

## The Journey

The market is now witnessing the beginning of the end of one era and the genesis of a new economic reality. The "21st century commercial paradigm" of the construction and building products industry is already evident in regional production coal ash supply shortages around North America, the United Kingdom, and Europe. The results are longer transportation distances and the rising costs associated with moving the appropriate materials to address increasingly regional market demand. Additional demand is forecast over the next 20 years with the significant infrastructure upgrades required in most countries. Combined with new infrastructure requirements in fast-growing countries like China and India, this will create significant pressures on the collective coal ash market's future.

Nowhere is the problem more acute than in the United Kingdom. The UK leads the global charge toward zero-coal power generation, with plans to close all remaining coal plants by 2025 (see Figure 1). As recently as 2012, the UK generated 6 million tons of fly ash. Last year, that figure dropped to roughly 1.6 million tons[1] following further reductions in the use of coal. These trends portend a new era in the domestic cement market.

Gone are the days of readily available excess, compliant production coal ash. For Britain, the timing could not be worse. The additional complication for the UK, in the form of Brexit, creates cost uncertainty on materials exclusively imported from Europe. As a result, the domestic building products industry is now faced with a significant problem. Where will it source new EN-450 (European ATSM C-618 equivalent) compliant materials?

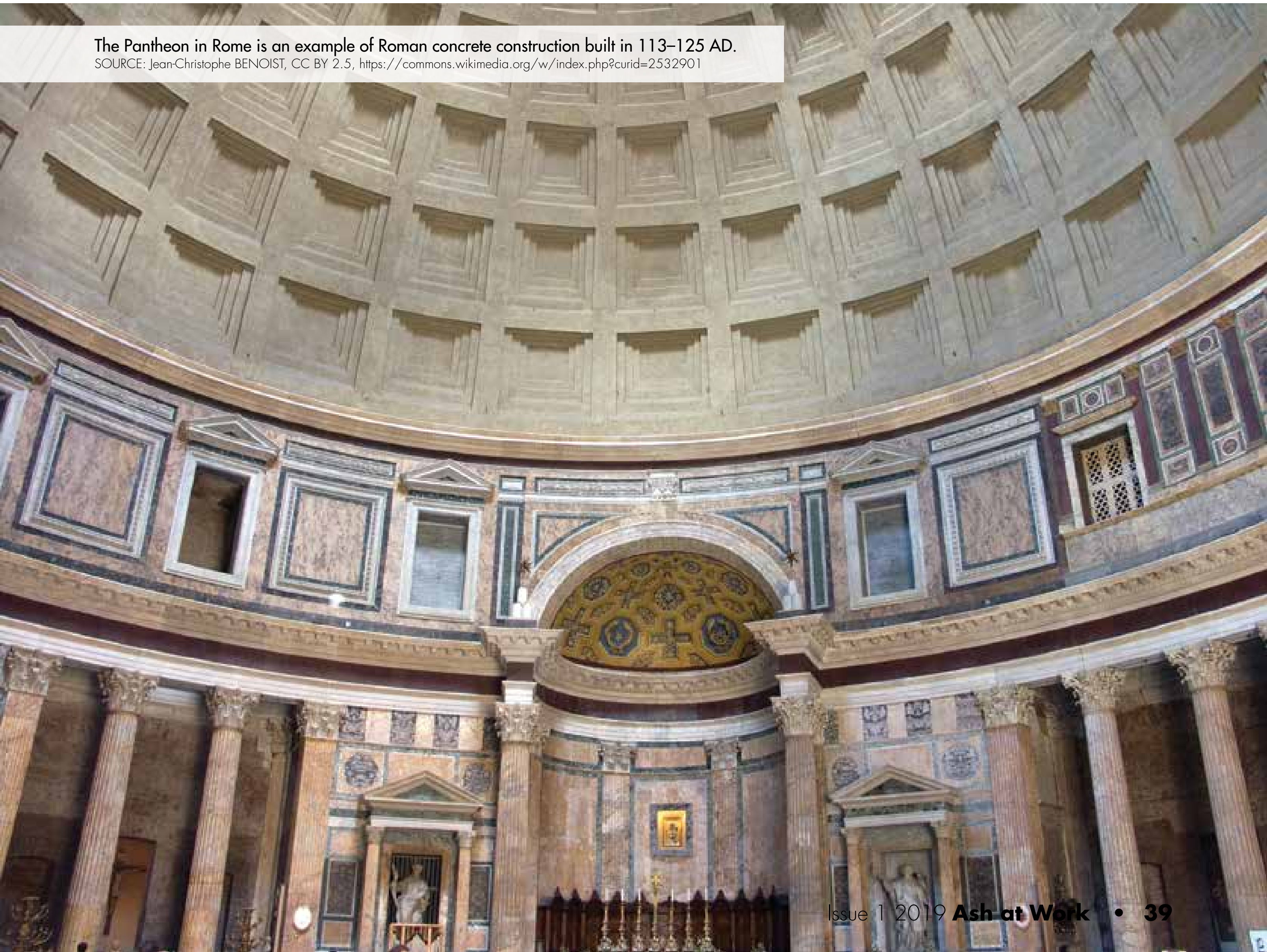
The answer is in the country's vast supplies of impounded and landfilled coal ash. The United Kingdom Quality Ash Association (UKQAA) has been studying this issue since 2014. UKQAA has stated that the country's stockpiled ash, estimated at 50 million tons,[2] should be designated as future "pozzolanic" reserves. However, this sort of initiative will require multi-level government support. In the meantime, the UK will have to continue to import its coal ash from the rest of Europe. While that might be a solution for the short term, Europe is also moving away from coal as a fuel. So whatever relief the industry can gain through those imports will only delay the inevitable.

The UK's situation represents the "canary in the coal mine" for the industry structure around the world. In all major markets, coal is being displaced in favor of lower-cost and less-carbon-emissions-intensive fuels. The UK and an increasing number of EU member states will eliminate coal by 2025 (see Figure 3), and Canada will follow by 2030. It is further evident that the U.S. will continue to see accelerated, ahead-of-schedule coal plant retirements. Even in emerging markets such as China, India, and other Asian countries, coal is falling out of favor. All these factors are compounding a worldwide supply shortage of compliant production coal ash.

Furthermore, many jurisdictions around the world are implementing some version of carbon pricing, either through a tax or cap-and-trade system. Carbon policies focused on coal power generation and the cement industry require a reduction of carbon emissions. The impact of these policies on power generation is reducing the use of coal as a fuel. The impacts on cement producers are process adjustments in current cement formulas.

As a result, what is old becomes new again. As with the formulas developed during the Roman Empire circa 312 BC


Figure 3. European countries phasing out coal power plants, 2015–2027.
SOURCE: Bloomberg New Energy Finance.



The Pantheon in Rome is an example of Roman concrete construction built in 113–125 AD.
SOURCE: Jean-Christophe BENOIST, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=2532901

to 500 AD—which used volcanic ash as a natural pozzolan in the construction of some of its most durable structures—new formulas will need to be considered in the search for a low-carbon reality for the 21st century's infrastructure build-out and refresh.

## Impounded Coal Ash Is Key to Looming Shortages

The easiest answer to the looming worldwide supply shortage exists in the billions of tons of "waste" coal ash in storage around the world. Collectively, the industry will need to embrace the concept of impounded coal ash as a viable ingredient when engineered to a certain specification. It has the potential to replace cement as the primary active cementitious ingredient.

John Ward, Chairman of the American Coal Ash Association's Government Relations Committee, stated in this very magazine (Issue 2, 2018): "However….if you want to invent the machine/pixie dust that eliminates performance variability among ash types and sources, that would be a true breakthrough—enabling the CCP world to shift from a series of local markets to a single fungible commodity market."

The authors agree completely with this statement; it is the key to unlocking the 21st century opportunity.

Applying this new 21st century thinking together with the appropriate innovative technology converts coal ash impoundments to resource-rich "above-ground ore bodies." The opportunity paradigm in this new reality is the additional high-value product matrix available in coal ash impoundments. This product matrix includes engineered pozzolanic material (high-performance cement), cenospheres, silica flour, rare earth elements, strategic metals, carbon offsets, and proppants.

The coal power industry and related associations have made excellent progress in quantifying and mitigating the perception of risk associated with production coal ash as a high-quality pozzolanic material. This can be seen in the dramatic rise in the use of production coal ash in North America, as the product application utilization rate has nearly doubled over the last decade to almost 45% even while the share of coal in the global energy mix has declined.

But the decline in coal use has reduced the volumes of reliable, uniform high-quality production coal ash available to the concrete and construction industries, as measured by consistent loss on ignition (LOI) and impurities (such as sulfur and nuisance heavy metals). Key concrete parameters like workability and ASTM C-618 (EN-450)-grade material particle size are often assumed to be consistent in the marketplace but are not. Both of these production coal ash components have highly empirical correlations with one another relating to high-performance and LEED-eligible applications, where reuse has significant value-add upside. Ensuring both workability and uniform particle size will be essential to making reclaimed coal ash a fungible market material in the 21st century marketplace and useful for future concrete applications.

## New Beneficiation Method

The "first mover" coal ash supply challenges facing the United Kingdom have been particularly interesting to SonoAsh. SonoAsh has developed a sustainable, modular, and patented solution for production and impounded coal ash. The technology creates new pathways to make impounded and production coal ash streams into a consistent manufactured product designed to meet regional and individual customer specifications.

The SonoAsh Sonicator reactor can process a broad range of coal ash samples. This manufactured coal ash meets ASTM C-618 (AASHTO M295 and European EN-450) requirements for high-value ordinary portland cement (OPC) displacement. The process creates <1% LOI from variable coal ash sources at more than 15% LOI at definable particle size specifications, typically 25-100 µm.

The SonoAsh outcome represents a genuine market opportunity, producing a scalable, regional, and economical OPC supplement with negligible greenhouse gas (GHG) emissions. This creates relevance from a risk mitigation and marketing perspective even where GHG/carbon discussions are unmeasured, untaxed, or not currently recognized. This is significant for a global market demanding major infrastructure expansion with challenging high-performance cement applications.

The world is transitioning to post-production ash realities at an accelerating rate. How the United Kingdom and Western European countries respond legislatively and in practice will become teaching moments for the industry in the rest of world.

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# Closure-by-Removal Strategies Facilitating Beneficial Use

*By Joe Laubenstein*

With apologies to Hamlet: To dispose or to beneficially use….that is *not* necessarily the question. As managers of coal combustion products plan for the coming decades, the old paradigm of choosing between disposal and beneficial use may no longer be valid. Instead, disposal and beneficial use might be better viewed as two sides of the same coin.

Beneficial use markets are demanding increasing volumes of ash from a steadily diminishing supply of newly produced ash. To meet the demand, marketers are beginning to turn to harvesting ash that was previously disposed. But regulatory requirements are forcing closure of landfills and wet impoundments at a pace that far outstrips the ability of markets to absorb it. What is needed is an integrated strategy that marries compliance and current disposal regulations with an eye toward future beneficial use opportunities.

## Demand Drives the Equation

Once upon a time, coal ash was viewed purely as solid waste, and its disposal was carried out with no particular view that it would ever be excavated or put to beneficial use. As its potential economic and environmental value became better understood to industry, coal ash became known as a "byproduct" of coal-fueled electricity generation and later a "product." Today, demand for our industry's product is stronger than ever from specifiers in the construction, transportation, agricultural, and other sectors, who well recognize coal combustion products' (CCPs) ability to enhance the performance and sustainability characteristics of their own products.

While this turnaround is welcome news for the coal ash industry, we have now entered a period of declining coal-fueled electricity production—and an accompanying diminishment in the production of CCPs from the coal fleet. According to the Energy Information Administration (EIA), U.S. coal consumption has fallen approximately 44% from 2007, driven primarily by declines in coal use in the electric power sector. EIA forecasts that coal's share of the electricity generation fuel mix will decline from 27% in 2018 to 25% this year and 23% in 2020. Contrast this with CCP utilization—which reached a record high of 71.8 million tons in 2017 (the latest year for which data are available)—and it is clear that legacy ash deposits will increasingly have to be relied upon to meet industry's growing need for CCPs.

And while total volumes of newly produced ash are expected to continue to be significant in the near future—2017 coal ash production volume actually increased 4% over year-earlier totals (see Figure 1)—regional disruptions of ash supply are already being felt. Of more immediate importance, promulgation of the Environmental Protection Agency's (EPA) Coal Combustion Residuals (CCR) rule—which sets costly new requirements on the operation and monitoring of landfills and impoundments—will force many owners and operators of such sites to reconsider how they will manage their previously disposed coal combustion products. Closure-by-removal strategies are one designated option offering the potential to offset a portion of the costs associated with regulatory compliance via the harvesting, beneficiation, and sale of previously disposed ash.

## Ash Harvesting: No One-Size-Fits-All

Harvesting previously disposed ash is not a one-size-fits-all proposition. Ash that has been stored in a surface impoundment (pond) will inevitably require different beneficiation processes than will ash that has been landfilled. CCP characteristics may vary widely even within a given pond or landfill depending on a range of factors, including the period during which the ash was deposited and the source or sources of the coal that was originally combusted. In any case, thorough testing and analysis must be carried out to determine whether and what amount of ash can be harvested and the specific beneficiation processes that will be required to ensure the ash meets standards—pertaining to moisture content, unburned carbon, particle size, strength activity index, and other criteria—to be suitable as a supplementary cementitious material.

A new ASTM international standard published in December 2018—ASTM E3183–18, "Standard Guide for Harvesting Coal Combustion Products Stored in Active and Inactive Storage Areas for Beneficial Use"—is helpful in this regard. Aimed at utilities, CCP marketers, regulators, and environmental professionals, the standard offers guidance related to harvesting CCPs for beneficial use, including planning and scoping of projects, as well as detailed characterization and design guidance for both active and inactive storage areas.

To be sure, there are a lot of previously disposed coal combustion products already out there. Based on its annual CCP Production and Use Survey results, the American Coal Ash Association estimates that more than 1.5 billion tons of CCPs have cumulatively been disposed in the United States. Other parties have added to that estimate volumes from before the ACAA survey commenced to reach a figure of greater than 2 billion tons. More recently, data analytics company FirmoGraphs LLC analyzed public reports by U.S. utilities to conclude that a maximum of 3.4 billion cubic yards of material exists in 752 operating units nationwide (see Table 1 on the next page). Note that these are estimated maximum volumes assuming that all reported capacity is full and that each site may contain multiple units.

While all of this material is not suitable for beneficial use under today's market conditions, it is worth noting that market conditions two decades or more into the future will certainly be different than they are today. Because of advances in technology and increases in the value of coal combustion products, there are many ashes currently being beneficially used that would have been considered "unusable" just a decade or two ago. As such, any "future-looking" consideration of coal ash beneficial use must take into account the potential of previously disposed materials.

## Regulatory Compliance Does Not Sync with Markets

However, environmental regulations do not anticipate leaving coal ash landfills and surface impoundments open indefinitely while they wait for beneficial use markets to absorb the material. Instead, most compliance programs require closure within 10- to 15-year timeframes.

Furthermore, regulatory bodies are increasingly compelling utilities to employ "closure by removal" strategies, rather than simply capping disposal sites in place. Recent decisions by legislators and regulators in Virginia and North Carolina are just two examples of a trend that will force many utilities to move materials to new disposal sites when conducting closure activities.

For utilities interested in long-term solutions that maximize beneficial use potential, this requirement could come with a silver lining.

## The Case for a Qualified Strategic Landfill Partner

Partnering with an experienced landfill constructor and operator offers a number of advantages when closure by removal is undertaken, including the ability to maximize the potential for eventual beneficial use. These advantages include:

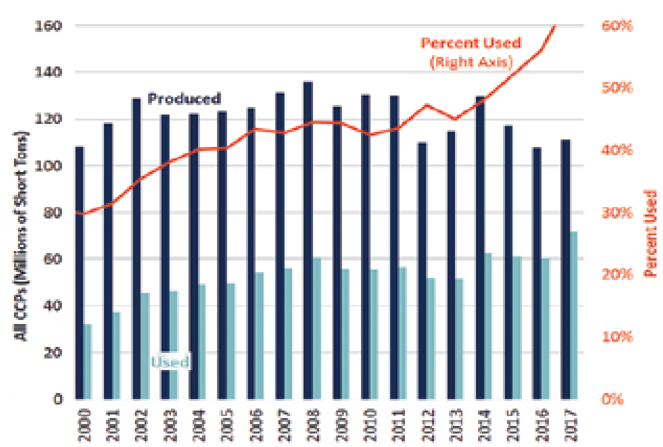


Figure 1. All CCPs Production and Use, 2000 - 2017, with percent.

## Table 1. Estimated Number and Volume of Coal Ash Disposal Sites in the U.S.

| Type CCR Unit | Sites* | Units | Area, Acres | Volume, maximum cyd |
|---|---|---|---|---|
| Inactive Surface Impoundments | 61 | 99 | 2,230 | 53,310,000 |
| Landfills | 201 | 238 | 17,820 | 2,259,280,000 |
| Surface Impoundments | 196 | 415 | 21,500 | 1,108,870,000 |
| **Totals** | **297** | **752** | **41,540** | **3,421,470,000** |

SOURCE: FirmoGraphs Analysis, March 2019. *Note that each site may contain multiple units.

- *Landfill Construction Expertise*—One practical outcome of the EPA's CCR rule is that many surface impoundments are likely to close and their contents excavated and transferred to an existing or bespoke landfill. Waste Connections has decades of landfill management experience and the ability to build a Subtitle D landfill on the customer's site and install dry ash handling systems to meet the new effluent limit guidelines. This includes constructing dedicated cells to segregate materials, optimizing their storage for potential future harvesting for beneficial use.
- *Financial Stability*—Closure-by-removal projects are significant and long-term undertakings that carry financial risks, from cost overruns to insolvency. Waste Connections is the third-largest solid waste services company in the United States, operating 93 MSW, non-MSW, and industrial landfills across 41 states that produce annual revenues of almost $5 billion. Our financial foundation and track record of contract fulfillment have led to consistent year-over-year income and revenue growth.
- *Rail Access*—The ability to move ash by rail significantly increases safety and reduces other undesirable community impacts that can be created in closure-by-removal activities. Waste Connections provides intermodal rail services for the transport of CCPs to the beneficial use site or other final disposition. We also handle the dewatering of on-site impoundments necessary for transportation and the completion of the paint filter test for landfill storage and/or disposal.
- *Materials Characterization Advantages*—One of the major barriers to harvesting ash directly from existing disposal sites is the difficulty of characterizing the quality of ash that was disposed under varying conditions over long periods of time. The ability to sample and characterize materials as they are deposited in new landfills will create roadmaps for future harvesting activities—allowing selection of the most appropriate and economical technologies and strategies available at the time harvesting activities commence.
- *Unparalleled Safety Record*—Perceived and actual lapses in operational safety can undermine public confidence in closure-by-removal projects, add regulatory scrutiny, and boost costs. Waste Connections has consistently led the industry in safety performance, with some of the lowest total recordable incident rates (TRIRs), experience modification rates (EMRs), and accident frequency rates. Our commitment to safe, sustainable service yields performance and reputational dividends to our company and our customers.

Coal combustion products today are just that—products that are valued for the positive performance and environmental benefits they supply when used in a variety of construction materials. As utilities work to comply with ash disposal regulations today, they will be helping future generations if they recognize that the materials they are handling are not waste, but rather the valued products of tomorrow.

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**Joe Laubenstein** has 38 years' service in the solid waste industry, where he has managed over 250 projects beneficially using a variety of different industrial waste streams. When the federal CCR rule was promulgated, he assumed the position of Director of CCR Management for Waste Connections, the third-largest waste services provider in the United States, where his responsibilities include all aspects of developing environmentally sound and economically viable programs for the management of CCR materials from coal-fueled power plants. Laubenstein holds a degree in soil chemistry from Cornell University.

Editor's Note: "Six Questions for…" is a regular *ASH at Work* feature in which leaders with unique insight affecting the coal ash beneficial use industry are asked to answer six questions.

Lawrence L. Sutter, Ph.D., P.E. is a Professor in the Materials Science & Engineering Department at Michigan Technological University. He also serves as the Director of the Michigan DOT Transportation Materials Research Center at Michigan Tech. He has an extensive background in materials characterization and concrete durability and has carried out research on various recycled and secondary materials, including fly ash, blast furnace slag, and municipal solid waste incinerator ash, as well as conventional construction materials, such as cement, aggregates, and concrete. Recent projects have included intensive study of the effects of alternative deicers on concrete pavements. Other past projects include research for the Federal Highway Administration, the National Cooperative Highway Research Program, and the Michigan, South Dakota, and Wisconsin DOTs investigating concrete pavement durability and performance.

**Ash at Work (AW)**: Professor Sutter, you have been researching supplementary cementitious materials (SCMs) for quite some time. What got you interested and involved in this topic?

**Dr. Lawrence Sutter (LS)**: First, I'm a materials engineer and have always been fascinated by understanding and manipulating material properties. Second, given my general interest in materials, I cannot stand seeing any material wasted, and reuse has always been a personal interest. Whether it is wood, masonry, metals, or plastics, my garage at home is full of materials just waiting for that chance to be beneficially used! These interests gave me the perfect background for involvement with fly ash. Professionally, as a materials engineer, I examine the internal structure of materials and relate that structure to the material's properties. My first exposure to fly ash was examining a sample using a scanning electron microscope. I have seen literally thousands of different material structures, both man-made and natural, but I have never seen anything as extraordinary as the internal structure of a fly ash particle! Literally, no two are alike and the structure defies simple description. I immediately became immersed in the grand challenge of "characterizing" fly ash. This led me to concrete and the study of cementitious systems, and before long I was deeply involved in construction materials of all kinds. I found my niche in this industry trying to solve the problem of how to characterize materials, in particular recycled materials for beneficial use. This led to involvement with ASTM and understanding the needs of the industry for testing and specifying SCMs, and I have continued with this involvement to this day. I have also been very involved in the improvement of concrete durability, and SCMs are central to that effort.

**AW**: What are some of the most significant developments you have seen over the years?

**LS**: Had you asked me that question a couple years ago, I would have quickly said "none." In 1977, ASTM approved the addition of Class C to Standard Specification C-618 and, until recently, any additional changes were incremental at best. Over that same time period, research activities around the world significantly improved our understanding of SCM properties and how to most effectively utilize these materials, but that knowledge was largely not being adopted in construction practices. However, in the past few years, the availability of fly ash has become more unpredictable, and in some local cases fly ash is temporarily unavailable. This has caused the industry to re-examine materials that once may have been rejected for use such as natural pozzolans, alternative SCMs, and recovered fly ash. The focus now is much more on understanding what improvements in concrete performance can be expected from a material, and not how it aligns with a classification system. This has rekindled the grand challenge of materials characterization and leads to very practical questions of performance in concrete.

**AW**: There are many initiatives being considered by ASTM International to change existing specifications and create new specifications. One of the primary reasons for these initiatives is to increase the availability of supplementary cementitious materials needed to produce durable concrete. What do you view as the most significant of the ideas under consideration?

**LS**: As I said previously, ASTM had been static for many years—but not anymore. All stakeholders want to see changes in test methods and specifications that lead to increased utilization, increased availability of all SCMs, better prediction of performance in concrete, and maybe most importantly more consistency in performance. There are a variety of activities that will impact the SCM market once enacted. First, we will be balloting an addition to C-618 to establish a class for ground bottom ash (i.e., Class B). Once passed, this will provide a new source of materials in many markets. Also relative to fly ash, we are balloting to standardize the foam index test, and we will begin looking at other tests to measure the adsorption properties of fly ash to supplement measurement of LOI. Natural pozzolans are also gaining popularity in some markets, primarily in the western U.S. Interestingly, the natural pozzolan specification has not changed since 1968. There is a desire to put in place test methods to measure the pozzolanic properties of a proposed natural pozzolan, and this is still being discussed. A separate task group is examining a suite of tests that have come out of a RILEM research project, and those tests will be balloted in the near future. Regarding other materials, ASTM has been developing a new standard specification for ground glass pozzolan. This new standard is very close to completion. Another initiative is to develop a performance-based specification that will allow alternative SCMs to be qualified for use in concrete, and that activity is just getting underway. All told, ASTM is very far from static and it is an exciting time to be involved.

**AW**: You are leading an effort to harmonize the ASTM C-618 specification for fly ash with the M295 specification of the American Association of State Highway and Transportation Officials (AASHTO). How is this going?

**LS**: The harmonization process has been going great! AASHTO and ASTM started the harmonization process with standards for portland cement and blended hydraulic cements, and we have learned much from that experience. Therefore, when the SCM groups started meeting, we hit the ground running and made immediate progress. The most recent development is that AASHTO has adopted the recent change in ASTM C-618 that established criteria for Class C and Class F ash based on the calcium oxide content, rather than the sum of the oxides, as has been the case since the early days of fly ash specifications (1954). The group continues to meet, and we will be discussing a number of changes to achieve harmonization.

**AW**: There is a sense of urgency that comes out when discussing durability of concrete pavements and bridge structures. Alkali-silica reactivity (ASR) and aggressive use of deicer materials are best mitigated with pozzolanic materials. Is this urgency real?

**LS**: It is absolutely urgent. As the nation turns its attention to renewal of our transportation infrastructure, durability is a key consideration. More and more, we see design-life requirements of 50, 75, or 100 years or more. And when everyone thinks of durability and long life, they think of concrete. So the spotlight is clearly shining on the concrete industry to produce a durable product. When it comes to most durability challenges, SCMs are one of the most effective ways to achieve durability. And the most accepted and widely specified SCM is fly ash—making a stable, high-quality fly ash supply more important. For ASR, the concrete industry is being challenged by diminishing supplies of high-quality aggregates, and increasingly lower-quality aggregates once rejected are now being used. Therefore, the demand for SCMs, and in particular fly ash, will only increase. Deicer attack is a slightly more complicated issue, as deicers are used to ensure the safety of the traveling public. Therefore, the use of deicers will not diminish. The concrete industry has had challenges adapting concrete mixtures to resist these chemicals, but through research we now have solutions. And again, like all solutions for durability issues, fly ash is the centerpiece. It cannot be overstressed—the need for a consistent supply of high-quality fly ash—and this comes back to our previous conversation about standard specifications and test methods. The concrete industry is counting on the SCM industry to do its part in making concrete the most durable material it can possibly be.

**AW**: Michigan Tech is located in Houghton, Michigan, in the Upper Peninsula. What do you tell people are the most interesting and attractive attributes of life in the UP?

**LS**: Well, we are approaching 300" of snowfall for this season, so I'm not sure I can sell you on the weather! Summertime in the Keweenaw Peninsula, however, is the finest climate you will ever experience. For me, the most significant attribute of the area is its people. Maybe it's because we all share the same rite of passage every winter, and that bonds us together. Whatever the reason, the people here are the finest and friendliest you will ever meet. And if you like anything outdoors, there is no better place. Whether it is golf, biking, hunting, fishing, or just a day hike, the opportunities and experiences in the Upper Peninsula are second to none. A very special attribute of the Keweenaw Peninsula, where Houghton is located, is that: (a) we are not on the way to anywhere, so you don't get a lot of traffic just passing through, and (b) we are just far enough from the metropolitan areas of Detroit and Chicago that most travelers stop in the southern UP and don't take the extra two to five hours needed to get to Houghton. Consequently, those who visit do not do so accidentally, and they generally appreciate the area as much as those who live here.

**AW**: Thank you, Professor Sutter.

## Ad Index

# Ash Allies: National Coal Council

By Janet Gellici

In the fall of 1984, U.S. Secretary of Energy Don Hodel announced the establishment of the National Coal Council (NCC), stating, "the Reagan Administration believes the time has come to give coal—our most abundant fossil fuel—the same voice within the federal government that has existed for petroleum for nearly four decades."

The Secretary named 23 individuals to serve on the Council, noting that these initial appointments indicated that "the Department intends to have a diverse spectrum of the highest caliber of individuals who are committed to improving the role coal can play in both our nation's and the world's energy future." Throughout its 35-year history, the NCC has retained its original charge to represent a diversity of perspectives through its varied membership.

The NCC is a non-profit advisory group to the U.S. Secretary of Energy, chartered under the Federal Advisory Committee Act (FACA). The NCC provides advice and recommendations to the Secretary on general policy and technology matters relating to coal and the coal industry. The Council's primary activities include providing the Secretary with advice on:

- Federal policy that affects, directly or indirectly, the production, marketing, and use of coal;
- Plans, priorities, and strategies to address more effectively the technological, regulatory, and social impact of issues relating to coal production and use;
- The appropriate balance between various elements of federal coal-related programs;
- Scientific and engineering aspects of coal technologies, including emerging coal conversion, utilization, or environmental control concepts; and
- The progress of coal research and development.

The Council's mission is purely advisory. While NCC does not engage in lobbying, it supports the use of coal and is a proponent for the use of our nation's domestic coal resources.

The principal activity of the NCC is to prepare reports for the Secretary of Energy. To date, the Council has prepared more than 35 reports for the Secretary, at no cost to the Department of Energy. Recent reports have included:

- *Fossil Forward—Revitalizing CCS: Bringing Scale & Speed to CCS Deployment*
- *Leveling the Playing Field: Policy Parity for CCS Technologies*
- *$CO_2$ Building Blocks: Assessing $CO_2$ Utilization Options*
- *Power Reset: Optimizing the Existing Coal Fleet to Ensure a Reliable and Resilient Grid*

NCC's reports—which are available for viewing and download at www.NationalCoalCouncil.org—reflect the balanced perspective of its members. FACA requires that committee memberships be "fairly balanced in terms of the points of view represented and the functions to be performed." In balancing FACA committee membership, agencies are expected to consider a cross-section of those directly affected, interested, and qualified in the subject area.

Membership in the Council is limited to 150 individuals. Members, appointed on an individual rather than corporate basis, have an extensive breadth and depth of knowledge about coal production, coal use, coal transportation, and coal technology. This level of expertise and diversity allows NCC to provide the Secretary with a well-balanced perspective on critical energy issues.

The Council meets twice a year—in the spring and fall—usually in Washington, D.C. Advance notice of meetings is published in the *Federal Register* and meetings are open to the public.

The NCC is a totally self-sustaining organization that receives no funds from the federal government. Its activities and operations are funded solely from member contributions and sponsors, including the support of members in the NCC Chair's Leadership Council (CLC). The CLC provides strategic guidance to NCC, helping to chart the strategic agenda for the Council's work with DOE.

The Council was founded based on the conviction that an industry advisory council on coal could make a vital contribution to America's energy security. NCC's founders believed that providing expert information could help shape policies relevant to the use of coal in an environmentally sound manner. It was expected that this could, in turn, lead to decreased dependence on other less abundant, more costly, and less secure sources of energy. These principles continue to guide and inform the Council's activities.

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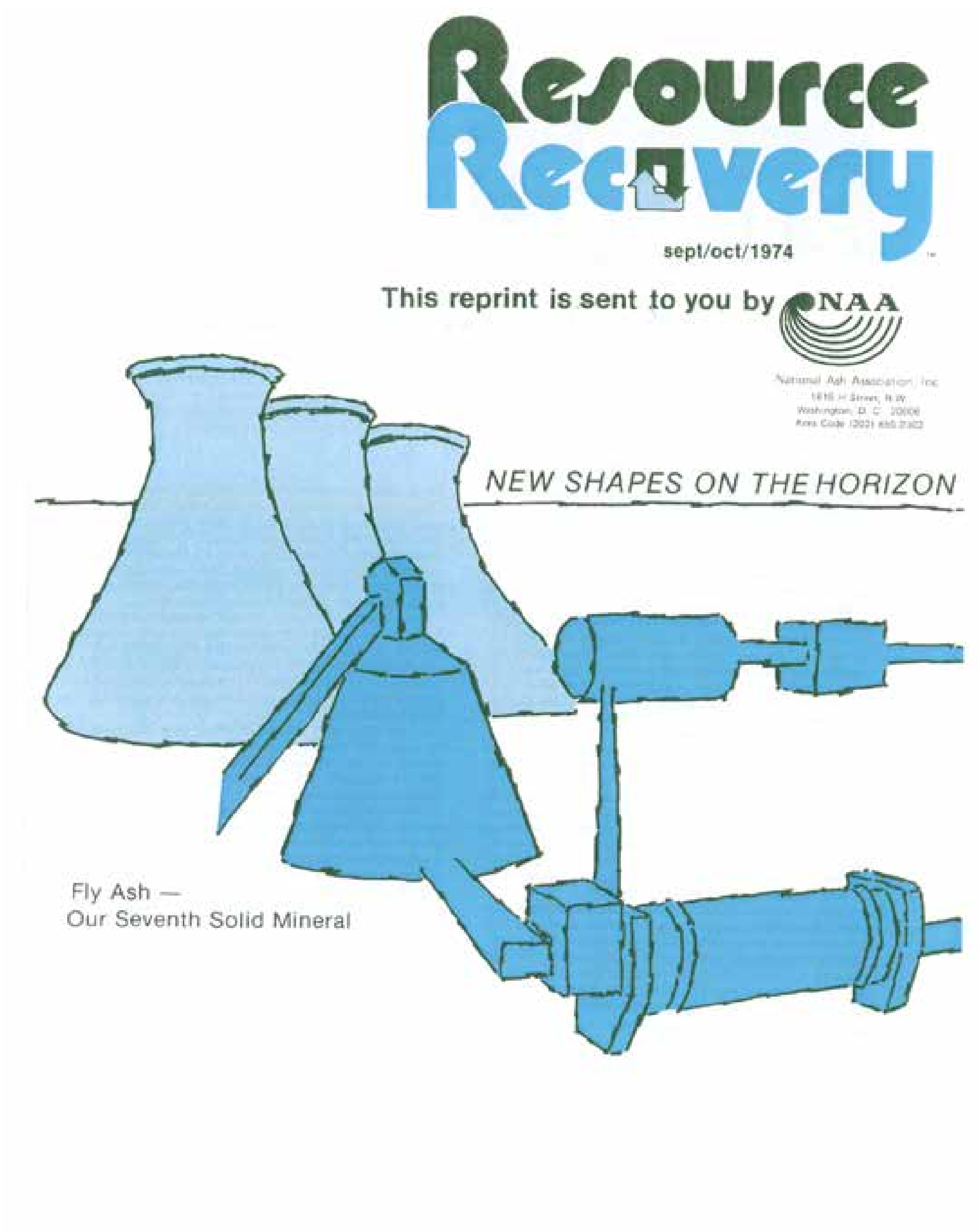
**Janet Gellici**, CAE is Chief Executive Officer of the National Coal Council. She has worked in the coal industry for approximately 35 years, variously serving as Chief Executive Officer of the American Coal Council, Executive Director of the Coal Trading Association, and Communications Director of the Colorado School of Mines' Management Institute. Gellici earned her MBA from Regis University and is a graduate of the University of Iowa with a degree in journalism and business administration.

# ASH Classics

## Growing Acceptance of Coal Ash as a Mineral Resource

*"ASH Classics" is a recurring feature of* **ASH at Work** *that examines the early years of the American Coal Ash Association and its predecessor National Ash Association (NAA), focusing on issues and events that were part of the beneficial use industry's defining years.*

*The early 1970s were a time of eco-consciousness and, as a result of the oil crisis, growing focus on the development of domestic mineral resources for national security purposes. This ASH Classic, from 1974, highlights coal ash's emergence as a resource with environmentally useful applications ranging from soil amendment to cement replacement.*




*Fly ash is a smoke stack residue captured by pollution control equipment in the Nation's power plants. Fifty million tons were produced last year alone, and when coal replaces scarce and costly oil in more utility plants, this tonnage will increase dramatically. But, instead of a burdensome, wasted byproduct, fly ash has tremendous potential as a resource — for building materials, soils stabilizers, and a host of other profitable applications. In this article, two prominent ash industry executives report on current programs making fly ash a mineral resource that can help build America's future.*

# FLY ASH — JOINING THE RANKS OF NATURAL RESOURCES

*By John H. Faber, P.E., Executive Vice President, National Ash Association, and Allan W. Babcock, Ash Consultant, Monongahela Power Company*

A fuller utilization of all our waste resources can be ecologically and economically rewarding for the entire country. In fact, the seriousness of the energy crisis dictates that we move in this direction.

The nation eased into what might best be termed an "Era of Recyclability" at the beginning of the decade following a wave of "ecomania" that now appears to have subsided and given rise to a more realistic and practical approach to solving the problem.

Significant progress has already been achieved and it has been clearly demonstrated that many of the nation's pollution problems can be profitably resolved through recycling. Likewise, the drain on our natural resources can be slowed by converting many so-called industrial wastes into construction components.

The technology has not been fully marshalled to launch an all-out attack in every area of resource recovery, but more allies are joining the fight every day. In addition, inflationary trends are making it economically more attractive. However, product acceptance remains the number one obstacle to widespread use of these new materials. A re-evaluation of specifications is now emerging, which in itself is a favorable sign.

Congress has under consideration two measures that will give recycled materials the same tax breaks and freight rates that natural aggregates now enjoy. In April, another group of lawmakers — The Maryland General Assembly — recognized the importance of these materials by passing legislation classifying "pozzolans" as a natural resource and providing for the material to be stockpiled so it can be fully recovered. Thus, for the first time, power plant fly ash has equal status with sand, gravel, limestone, or other natural aggregates in that state.

Pozzolans (volcanic ash) have enjoyed a cherished position in the resource recovery field for many centuries. The Romans were among the first to practice the art by recycling volcanic ash for building construction. The ash industry is trying to build and expand that base even today. And we have been joined by glass, steel, paper, aluminum, timber, rubber, plastics, and other industries.

## ALL-TIME HIGH PRODUCTION

Coal burning electric utilities are the principal producers of ash now reaching the market place. Last year ash collection reached an all-time high of nearly 50 million ton and this will be exceeded by 1980.

Although available in much smaller quantities, ash from oil burning stations is also playing a vital role in the industry's resource recovery program. Further recycling of this ash yields a valuable source of vanadium.

Current production tonnages have vaulted coal ash into seventh position among solid minerals. The U.S. Department of Interior's totals rank ash behind sand-gravel, stone, coal, iron, Portland cement and clays.

Ash has been described in many ways, but one of the most appropriate phrases terms it simply "the fallout from the energy production cycle." The material is generally available in two categories: (1) fly ash which is the powdery particulate collected from flue gases in the stacks, and (2) bottom ash or boiler slag which drops to the furnace floor during the burning process.

Not all ash is the same. Variances in equipment, burning techniques, and coal are the major factors responsible for the physical and chemical makeup of the ash. The blending of high sulphur coals with lignite and/or low sulphur fuels and the types of processes employed to collect $SO^2$ stack gases tends to alter ash from existing coal burning stations.

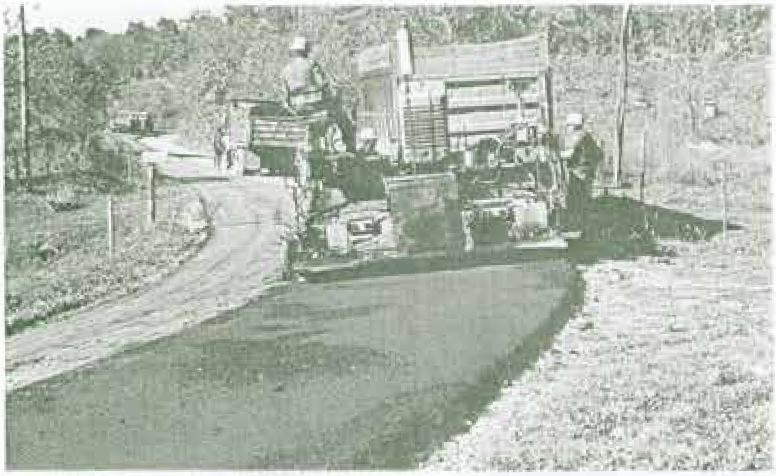
It is still too early to tell if refuse-to-fuel concepts, now moving from the pilot plant stage to commercial sized operations, will have a deleterious effect on coal ash. The ratio of refuse to coal in the boiler charge will ultimately determine ash composition.

Union Electric Company reports no adverse or significant changes in the composition of the ash from its Merremac Station where processed refuse is being burned in suspension as a supplement to fossil fuel. An evaluation of that operation is expected in the near future.

By the end of 1974, Union Carbide hopes to have a good handle on the efficiency of its 200 ton oxygen-based gasification plant in South Charleston, West Virginia. Here refuse is being utilized to produce a low BTU gas that can be a supplementary fuel in virtually any type boiler or with refinements as a pipeline-quality gas. (See *Resource Recovery*, Apr/May/Jun/1974.)

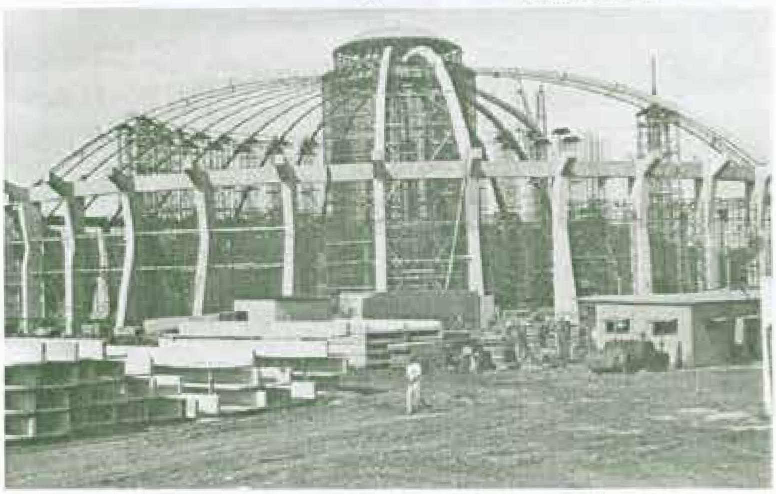
Getting back to the recycling aspects of present ash supplies, it is noteworthy that in the not-too-distant future fly ash may be an important raw material source for the industrial production of artificial magnetite and alumina oxide. Methods of extracting both minerals have been perfected, but the economics of existing processes and present market conditions are not compatible in this country. The program is, however, being utilized in Poland.

Full cycle reclamation is the optimum goal of the ash industry, particularly among the electric utilities who are being plagued with almost unconscionable delays on proposed new generating stations, ever-increasing fuel costs, and multi-million dollar expenditures to meet conflicting



Cold mix "Ashphalt" being placed on farm-to-market road.

Insulation made from power plant ash.



Sintered fly ash used in concrete beams for coliseum in Morgantown, W. Va.

Federal and State environmental standards. Reductions in ash disposal expenses are reflected in the cost of fossil fuel burned by the utility — a most significant factor in cost of energy.

A possible forerunner of future standard operating procedures was recently attained in the Midwest where a utility coal contract called for the fuel supplier to be responsible for disposal of the resultant ash. It is expected much of this ash will end up in the coal pits where it was mined in sort of a back-to-the earth form of reclamation.

## NEW USES TESTED

New uses and applications of these coal byproducts are being tested and developed with increasing regularity. The storehouse for this technology currently rests with the National Ash Association in Washington, D.C. The NAA, formed in 1968, collects and disseminates data on all aspects of ash production, sales, utilization and research.

As one might expect, more emphasis is being placed on beneficial environmental applications of fly ash itself or in combinations with other waste resources. The well-informed now view ash utilization as an opportunity and not a problem.

One program has been the use of fly ash as a soil conditioner in mined land reclamation and the revegetation of coal refuse banks. The ash tends to raise the pH of these acid spoils to tolerant levels, to improve water retention capability of the soil, and to aid in establishment of a vegetative cover. It is not a substitute for fertilizer or other plant nutrients. Much has been accomplished since the Morgantown Energy Research Center of the U.S. Bureau of Mines set out their first experimental plots nine years ago, but much remains to be done to upgrade known technology.

The coal industry has found fly ash valuable in treating subsidence problems, as a fire control media both inside the mine and on outside refuse piles, and a stabilizing agent in slurry impoundments.

Additionally, both fly ash and bottom ash have been successfully used in sanitary landfill operations as a cover and compaction media. Research has demonstrated that fly ash is particularly effective in accelerating decomposition of household refuse. The acceptance and use of ash could become a valuable asset for landfill operators in areas where cover material is in short supply or simply not available.

Some advantages to be gained from using ash in these areas are:

1. Percolation through fill is reduced due to compactability of fly ash thus reducing leacheate to ground and surface waters;

2. Ash is more inert than other readily available materials, having been fired through a temperature of 1,000 F. ± shortly before delivery;

3. Moisture content of fly ash can be varied and controlled to suit operators needs;

4. Ash is available 365 days a year while, because of freezing or wet conditions, soil or other cover material may be unusable.

Fly ash concrete used in cooling towers and stacks.

Fly ash is also playing a role in sewage treatment. The use of fly ash as a coagulant aid causes better flocculating conditions, clearer treated water, and denser sludge.

## NEED SPECIFICATION CHANGES

Growing aggregate and cement shortages along with escalating fuel, equipment, and labor costs are making the use of these materials more attractive in the highway construction field. But, long-standing practices and specifications, plus natural tendencies to shy away from new products and procedures, have slowed acceptance. Modifications of existing specifications must be encouraged to permit full use. Research discloses that better performance and greater economy have been achieved with ash mixtures that do not meet existing specs.

For example, bottom ash can be mixed with emulsified asphalt to provide a stable basemix, but often has to be blended with other aggregates to meet highway specifications. Fly ash and cement can be blended to provide a strong and durable base, but is not widely used. Coal mine refuse-lime-fly ash is another basemix that has possibilities, but does not meet current published specifications.

The Federal Highway Administration recently recognized the situation and issued a memorandum (N 5080.4) which directed field office personnel and State Highway officials to encourage substitution of fly ash for cement whenever possible and as an agent for the stabilization of soils, subbases, and bases.

Additionally, the Federal Aviation Administration adopted a new item for its airport spec book (P-305-1.1) to permit the construction of a base course by mixing, spreading, shaping, and compacting mineral aggregate-lime-fly ash, and water.

In addition, fly ash can be effectively utilized as a structural fill in embankments, particularly when they have to be constructed over poor ground such as alluvial clay or silt where excessive weight could not only produce intolerable settlement but even a complete failure of the subsoil. Ash is also used as a load bearing structural fill on building sites because of its lightweight and self-hardening properties.

Highway engineers are taking a serious look at the use of coal wastes as a fill material for embankments. Tests are being conducted combining the refuse with fly ash to improve the stability of such applications.

The increased use of ash by the building industry is also hampered by specification restrictions. For example, the use of pozzolan ash in concrete and concrete byproducts is limited by fineness qualities although the utility and coal industries have successfully utilized non-specification fly ash for years. However, a modification of American Society for Testing Materials standards in this area appears imminent.

Many building components are available on the market that incorporate the use of recycled ash in the form of lightweight aggregate as well as concrete blocks, brick and tile. A new lightweight fire-proof material has been developed by researchers from cenospheres — tiny hollow spheres found in some fly ashes — that can be substituted for plastics in the manufacture of ceiling and wall tile, door cores, insulation, trim and moldings.

The technology for new sources of energy production such as geothermal, magnetohydrodynamic systems, breeder reactors, and solar energy systems do not appear likely before the turn of the century. Therefore, the ash from coal-fired generating stations will continue to be an available resource for a long time to come. It's a resource that should be used wherever economically feasible.

# ASH at work

**Applications, Science, and Sustainability of Coal Ash**



## The ONLY magazine dedicated to coal ash

*ASH at Work* magazine has long served as a trusted voice in the coal combustion products (CCPs) industry. Featuring a timely mix of news, technical information, and insights into the world of coal ash beneficial use, our international readership of utility personnel, ash marketers, technology providers, scientists, engineers, and academics look forward to each new edition of the magazine.

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# Behind the Scenes

WOCA

# 8 Things You Never Knew

## We put the "world" in World of Coal Ash

With more than 1,000 attendees from 22 countries across 5 continents, WOCA is the most inclusive coal ash conference across the globe.

## The Exhibit Hall, though

If a company is involved in coal combustion products and service, you can find them at WOCA. With more than 100 exhibitors and vendors, the WOCA Exhibit Hall is the best in show.

## They say content is king

WOCA 2019 is at the head of the coal ash roundtable and will feature up to nine parallel sessions at one time – a new WOCA record and proof that we are committed to bringing the very best content to our attendees.

## Top scientific journal

The Coal Combustion and Gasification Products Journal is a free, global publication that was born out of WOCA and its content.

## Mixing Science with Social

At WOCA 2019, you can, easily, interact with presenters, industry leaders, and global research experts at both technical sessions and over food and beverages.

## Student Engagement

Student engagement remains an important part of WOCA. If you want to find your next hire or learn about new techniques and emerging technologies, come and engage with the next generation of coal ash leaders.

## A Poster Session Happy Hour?

Yep, we have that.

## It's the people

WOCA attracts the best and brightest from industry, government, and higher education. And they all care about this industry and its future. Who wouldn't want to be part of that?

# # of Attendees

| 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 |
|---|---|---|---|---|---|---|
| 518 | 522 | 520 | 524 | 591 | 882 | 1018 |

# # of Exhibitors

| 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 |
|---|---|---|---|---|---|---|
| 40 | 41 | 50 | 84 | 62 | 81 | 89 |

# # of Sponsors

| 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 |
|---|---|---|---|---|---|---|
| 16 | 25 | 29 | 25 | 23 | 22 | 27 |

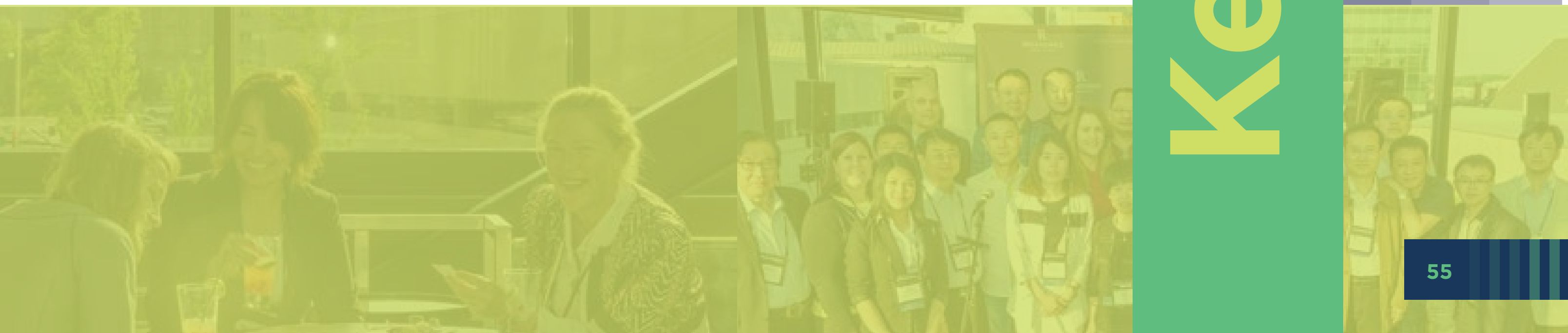
# Countries Represented

| 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 |
|---|---|---|---|---|---|---|
| 24 | 26 | 23 | 22 | 18 | 19 | 19 |

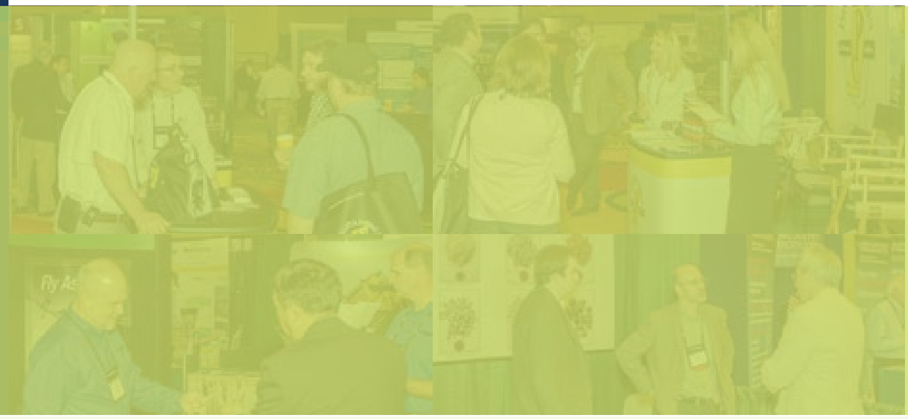
# Keep on Growing

**Cities Visited**

*Covington, KY; Denver, CO; Lexington, KY; Nashville, TN; St. Louis, MO*



# Come *Visit Our* Exhibitors



| Booth | Company |
|---|---|
| 1 | Domtec International |
| 2 | Envirocon, Inc. |
| 3 | Kansas City Fly Ash |
| 4 | Atarfil |
| 5 | Cascade Drilling |
| 6 | DeWind On Pass Trenching, LLC |
| 7 | Survey Equipment Services |
| 8 | Atlantic Lining Co. |
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| 30 | TenCate Geosynthetics |
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| 32/52 | Chesapeake Containment Systems |
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| 64 | AECOM |
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| 71/72 | Xylem Dewatering |
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| 97 | Synthetex, LLC |
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# Beneficial Use **Case Study**

## San Francisco-Oakland Bay Bridge Eastern Span

### Coal Combustion Product Type
Class F Fly Ash

### Project Location
San Francisco and Oakland, California

### Project Participants
Headwaters Resources (now Boral Resources), Pacific Cement, RMC Lone Star, CTLGroup, California Department of Transportation, T.Y. Lin International/ Moffat & Nichol (joint venture), Kiewit/FCI Mansion (joint venture), Parsons Transportation Group, Schwager Davis Inc., American Bridge/Fluor (joint venture)

### Project Completion Date
2013

### Project Summary
The San Francisco-Oakland Bay Bridge is a series of spans carrying Interstate 80 approximately 4.5 miles, via Yerba Buena Island, between the two aforementioned cities. A section of the original bridge's eastern span, which runs 1.9 miles between Yerba Buena Island and Oakland, collapsed in the 1989 Loma Prieta earthquake. Rather than upgrading the span to bolster its seismic resistance, the California Department of Transportation (Caltrans) opted to rebuild it to exacting new standards.

### Project Description
Construction of the new eastern span—which actually comprises several distinct sections, including the Self-Anchored Suspension Span (SAS) and the Oakland Touchdown—began in 2002 with its longest segment, the so-called Skyway. Initial designs considered both steel and concrete structures, with the latter winning out as the more cost-effective solution. The 1.2-mile elevated section of roadway, designed for a 150-year service life, would eventually incorporate over 12 million cubic feet of concrete and 452 precast concrete sections weighing 300 to 800 tons apiece.

Credit: California Department of Transportation.

Since 1997, Caltrans has stipulated the use of at least 25% fly ash replacement for portland cement in structural concrete mix designs to combat alkali-silica reactivity. Concrete mixes of up to 50% fly ash were used in the footings, the high salt zones, and other mass concrete components. Use of the fly ash, supplied by Headwaters Resources (now Boral Resources) prevented the cracking of the cement when it hardened, a common problem in a salt-water environment. It also helped in the concrete's placement, as the fly ash particles' round shape acts like ball bearings to improve flow and workability in the mix. Moreover, concrete containing fly ash is denser and stronger, making it better able to carry loads as well as prevent salt from entering the hardened product.

At the western edge of the eastern span, the SAS—the world's longest self-anchored suspension span, at a half-mile-long—ends at a pier bent supported by four columns resting on massive concrete anchor blocks. To help achieve the stringent corrosion and thermal standards required, the concrete contained 40% fly ash. The concrete's compressive strengths attained 9000 psi at 90 days. At the east end of the eastern span, the Oakland Touchdown's concrete footings incorporate a 50% fly ash mix for thermal control. The average measured compressive strengths of the footing pile caps were 4630 psi and 5630 psi at 28 days and 56 days, respectively.

Other notable facts from the project, one of the largest public works projects in California's history, include:

- Approximately 60,000 tons of fly ash used
- 30 different concrete mix designs employed
- World's widest bridge, according to Guinness World Records
- Skyway decks comprise the world's largest pre-cast concrete segments
- Projected lifespan is twice that of a concrete bridge built without fly ash
- Won the Environmental Protection Agency's $C^2P^2$ Innovation Award

Credit: California Department of Transportation.

# Beneficial Use Case Study

## Brickhaven #2 Mine Remediation and Structural Fill

### Coal Combustion Product Type
Fly Ash, Bottom Ash

### Project Location
Moncure, Chatham County, North Carolina

### Project Participants
Charah Solutions Inc. and a major utility

### Project Completion Date
Estimated closure completion: 2021

### Project Summary
To execute two large closure-by-removal (CBR) impoundment projects for a major utility in North Carolina, Charah Solutions needed a custom "out of the box" solution. Charah Solutions purchased an active, centrally located 300-acre clay mine to serve as an offsite facility and provided rail delivery and unloading infrastructure capable of relocating up to 300,000 tons of ash per month. Cell construction, mine reclamation, and leachate management were all owned and financed by Charah Solutions.

### Project Description
To meet changing regulatory requirements, a major utility decided in 2014 to excavate or close many of its coal ash basins but needed an innovative solution to complete the clean closure of ash ponds at multiple generating stations in central and eastern North Carolina that had been retired in 2013.


Credit: Charah Solutions.

In order to execute such major CBR impoundment projects and meet complex engineering and regulatory challenges, Charah Solutions developed a custom, turnkey solution and deployed massive material handling capabilities and innovative logistics coordination. It first purchased Brickhaven, an active, centrally located 300-acre clay mine previously used by the brick industry in Chatham County, N.C., which was then repurposed using an existing reclamation permit for this site.

Next, Charah Solutions designed and constructed a Subtitle D equivalent engineered fill site for placement of coal ash. As part of this unique high-volume material handling project, Charah Solutions provided all siting, design, permitting, construction, engineering, QA/QC, and operations. Approximately 6.725 million square feet of HDPE liner and cap was utilized for the engineered fill, and three 500,000-gallon leachate storage tanks were installed for leachate collection in the constructed cells. The construction activities were financed by Charah Solutions on a per-ton basis.

To support this large-scale logistics operation, Charah Solutions recognized that rail would be the most efficient and safest way to move ash from both sites with the least environmental impact. The project uniquely involved the use of rail to relocate up to 300,000 tons of ash per month, coupled with the potential beneficial use of the removed pond ash. Charah Solutions installed approximately two miles of rail spurs at Brickhaven to connect with CSX rail systems and employed five 85-car unit trains to support the rail delivery and unloading infrastructure.

As part of this state-of-the-art system, Charah Solutions specifically modified its railcars with locking fiberglass covers to eliminate fugitive dust and employed elevated excavators to straddle the railcars so as to unload approximately 9,000 tons of ash in under 12 hours. On average, one dedicated unit train with 85 cars was unloaded at the Brickhaven site each day.

Upon completion of coal combustion products (CCP) relocation in 2019, the site will enter 18 to 24 months of closure activities and be permanently capped and closed according to regulatory requirements with site management and groundwater monitoring in place for 30 years. The original design for clay mine reclamation and structural refill was for storage of up to 12 million tons of CCPs. This includes the more than 5 million tons excavated and transported from one plant and 2 million tons from another already in place. Four railcar storage and switching spurs, an 880' long rail unloading "subway," and over 300 acres of previously unusable land will now be available for future industrial development.

# Beneficial Use **Case Study**

## Oroville Dam Spillway Recovery

### Coal Combustion Product Type
Class F Fly Ash

### Project Location
Oroville, Butte County, Calif.

### Project Participants
Kiewit Infrastructure West Co., California Department of Water Resources, Salt River Materials Group, Mathews Readymix

### Project Completion Date
Phase 1: 2018

### Project Summary
Oroville Dam is an earth-filled embankment dam on the Feather River near Oroville, California, in the foothills of the Sierra Nevada Mountains east of the Sacramento Valley. The dam forms Lake Oroville, California's second-largest man-made reservoir, with a capacity of over 3.5 million acre feet. Built in the 1960s for flood control, water supply, and hydroelectricity generation, the dam, amid heavy rainfalls in February 2017, sustained damage to its main spillway that, upon inspection, revealed a large area of concrete and foundation erosion.

Dam engineers continued to operate the damaged spillway, attempting to lower the rising reservoir levels sufficiently and avoid use of a second, earthen emergency spillway. On February 11, 2017, after discharge was reduced to the main spillway, the emergency spillway carried water for the first time in its history. Before reservoir levels had been brought under control, debris from the crater in the main spillway had been carried downstream, and the emergency spillway had sustained erosion.

Credit: Salt River Materials Group.

Credit: Salt River Materials Group.

### Project Description
While it was clear that the main spillway would have to be rebuilt, the immediate need was to stabilize the hillside and minimize any erosion that could threaten the spillways and cities below. Chad Christie, Plant Manager at Mathews Readymix, was called on to supply more than 20,000 yards of concrete to the unlined hillside below the emergency spillway. After emergency action was taken, the California Department of Water Resources and its contractors began a two-year project to rebuild the main and emergency spillways and splash pad.

Ultimately, over 100,000 tons of Class F fly ash would be consumed during Phase 1 of the project, primarily for the one million cubic yards of roller-compacted concrete (RCC) batched at the larger of two on-site plants. Structural and leveling (slabs) required an additional 75,000 cubic yards of fly ash concrete, which was delivered in conventional mixer trucks and placed with concrete pumps.

This phase of the project—completed in 2018—was similar to many RCC projects but with higher volumes of fly ash. The target for the RCC mix was over 50% fly ash by weight of cementitious material. This ensured less thermal cracking and lower heat of hydration during the placement. Dump trucks were utilized to deliver the RCC, which was distributed with bulldozers and compacted with vibratory rollers and plates.

# Beneficial Use **Case Study**

ACAA

## DFW Connector

### Coal Combustion Product Type
Class F Fly Ash

### Project Location
Dallas, Texas

### Project Participants
NorthGate Constructors (a joint venture of Kiewit Texas Construction L.P. and Zachry Construction Corporation), PB Americas Inc., Texas Department of Transportation, Parsons Brinckerhoff, Cemex, Bexar Concrete Works

### Project Completion Date
2014

### Project Summary
Phase one of the Dallas-Fort Worth (DFW) Connector Project was conceived by the Texas Department of Transportation (TxDOT) as a way to reduce congestion at the junction of two of the region's most heavily trafficked highways—SH 114 and SH 121—and improve access to the world's fourth-busiest airport. The 8.4-mile $1 billion project rebuilt portions of four highways, two major interchanges, and five intersection bridges—doubling the capacity of the original highway corridor around the north entrance of DFW International Airport. The largest project funded in a single contract in TxDOT's 94-year history to that point, it was also one of the most challenging, as much of the concrete paving had to be performed on weeknights and weekends to minimize disruption to the traveling public.

### Project Description
In March 2009, TxDOT selected NorthGate Constructors—a joint venture of Kiewit Texas Construction L.P. and Zachry Construction Corporation—to develop, design, build, and maintain the project. Safety, efficiency, and quality of work were the top priorities, and so the team used a design-build process that allowed for construction to begin in areas where designs were complete while plans were simultaneously under development for other segments of the project.

Credit: Texas Department of Transportation.

Traditionally, TxDOT designs project plans before granting them to contractors, but due to the DFW Connector's size and four-year time constraint, the agency required bidders to present designs for approval. Cement and fly ash supplier Cemex helped NorthGate with its proposal by showing them how locally available materials could be used to carry out concrete paving in the most efficient manner. Ultimately, Cemex—the project's sole supplier of both fly ash and cement—would furnish the project's contractors with 26,000 tons of Class F fly ash.

TxDOT consumes approximately 150,000 to 200,000 tons of fly ash annually. The agency has traditionally relied heavily on fly ash to improve the workability, temperature control, economics, and durability (mitigating against ASR and sulfate attack) during concrete placement. For the DFW Connector Project, concrete with 25% Class F fly ash replacement was used to help produce, among other things, the longest bridge girders in TxDOT history. Bexar Concrete Works delivered precast/prestressed concrete beams measuring up to 166 feet long for the SH 114/SH 121 interchange, attaining 8200 psi strength and up to 6500 psi release strength within 16 hours.

Concrete paving operations ultimately produced 155 lane miles of new concrete pavement on main lanes, toll-managed lanes, frontage roads, and intersections. Despite the accelerated time schedule—the project was substantially completed within 45 months—more than 267,000 man-hours of paving operations were carried out during the project without recordable injury. Moreover, the project was completed without rework and the pavement achieved an average International Roughness Index score of 62—well below TxDOT's criterion of 75. In 2015, the DFW Connector Project earned a Gold Award from the American Concrete Pavement Association's Excellence in Concrete Pavements awards.

Credit: Texas Department of Transportation.

# Beneficial Use Case Study

## FGD Gypsum Field Application to Reduce Phosphorus Runoff

### Coal Combustion Product Type
Flue Gas Desulfurization (FGD) Gypsum

### Project Location
Maumee River Watershed, Ohio

### Project Participants
The Ohio State University, Electric Power Research Institute, Greenleaf Advisors LLC, U.S. Department of Agriculture, Nester Ag, Beneficial Reuse Management LLC (Gypsoil), Ohio Coal Development Office

### Project Completion Date
2015

### Project Summary
Fertilizers and animal manure are important sources of nutrients, such as phosphorus and nitrogen, that help crops to grow more productively. But they can be a significant source of pollution if excessive amounts of such chemicals drain into lakes and rivers. Recent decades have seen a dramatic growth in the incidence of runoff-induced algal "blooms" in U.S. water basins that harm wildlife and pollute drinking supplies. Now, field testing has attempted to demonstrate that spreading flue gas desulfurization (FGD) gypsum on affected farmland can reduce concentrations of soluble reactive phosphorus draining from farm fields to improve the quality of these affected aquatic resources.

### Project Description
In a three-year study led by Dr. Warren Dick, professor of soil and environmental chemistry at the Ohio State University, and supported by the Electric Power Research Institute, researchers applied FGD gypsum directly to eight corn and soybean fields in the Maumee River Basin on the west end of Lake Erie. The test sites selected were actively farmed fields of between 6 and 35.6 acres in size containing high phosphorous levels in the soil. Each site also paired a control field that that received no FGD gypsum treatment for comparison.

Application of FGD gypsum to agricultural fields can reduce phosphorus runoff. Credit: Ohio State University.

Water samples were collected during or after rainfall at the edge of each field from drain tiles installed to remove excess water from below the surface of the soil and tested for phosphorus concentrations. Over the three-year period of the study, soluble phosphorus concentrations were collected and analyzed for 87 rain events. The reduction in phosphorus concentrations for specific gypsum-treated areas varied from 0% to 93%, with reductions across all gypsum-treated fields combined averaging 54%. Results further showed that phosphorus reductions in tile drainage water persist at least 20 months after gypsum treatment, after which new application is required.

The science behind FGD gypsum's utility in this application is that, when spread on a field, it binds in the soil with phosphorus to make calcium phosphate—a far less soluble form of phosphorus. This makes it less able to run off in water. "Not only that, but FGD gypsum, which is a synthetic form of gypsum, can improve both the soil and the crops," Dick added. "Naturally occurring, mined gypsum has a long history as a soil amendment and fertilizer for farming." According to Dick, gypsum is an excellent source of sulfur nutrition for plants for improving crop yields, as it interacts with nitrogen to make it more efficient.

Shortly after this research emerged, in 2015, the USDA Natural Resources Conservation Services (NRCS) established a national Practice Standard that allows state NRCS programs to reimburse agricultural producers for the use of gypsum as a best-management practice to improve soil health and water quality.

Algal bloom in Lake Erie as captured from space. Credit: NASA.

ACAA

# Beneficial Use **Case Study**

## Gautrain

### Coal Combustion Product Type
DuraPozz Pro Fly Ash

### Project Location
Gauteng, South Africa

### Project Participants
Ash Resources, Bombardier Transportation, Bouygues Travaux Publics, Murray & Roberts, Strategic Partners Group, RATP Group, J&J Group, Farrells, Jaco Groenewald and GAJV, Martinez Architects, Atkins - Urban Edge Architects JV

### Project Completion Date
2012

### Project Summary
Gautrain is a 50-mile-long, high-speed commuter rail line in Gauteng, a northeastern province of South Africa that is home to Johannesburg, the country's largest city, and Pretoria, its administrative capital. It was constructed to help reduce vehicle congestion between those two cities as well as to provide rail service to Tambo International Airport. Construction of the system took over five years and involved significant tunneling and bridge/viaduct building over portions of terrain that boast sinkhole-prone dolomitic conditions.

### Project Description
One of the largest rail construction projects globally in recent years, Gautrain required approximately 28 million cubic feet of concrete with durability stipulated for a 100-year lifespan. The above-ground portions of the rail line necessitated construction of approximately 50 bridges and 16 viaducts, much of which were formed from precast concrete. The main contractor, Bombela Civils Joint Venture (BCJV), specified Lethabong-based Ash Resources' DuraPozz Pro fly ash in virtually all of the project's concrete mix designs.

Credit: Manuguf - Wikimedia.

Credit: NJR ZA - Wikipedia.

Credit: NJR ZA - Wikimedia.

To create the required forms, BCJV created the largest precast yard in the Southern Hemisphere at Midrand, in suburban Johannesburg. The yard produced a wide variety of castings, including M-beams for bridges, parapets, viaduct segments, noise barriers, and tunnel walkway sections. The largest of the concrete castings were huge viaduct segments weighing between 45 and 65 tons apiece.

In many instances, a high-production precast yard would utilize CEM I portland cement of Class 42.5R or 52.5. However, after extensive trials, engineers Murray & Roberts settled on a concrete mix incorporating 30-35% DuraPozz Pro fly ash, which they deemed to be less expensive, more environmentally friendly, and higher strength than a pure-cement mix. Moreover, supplier Ash Resources was able to ensure the availability of the fly ash, which was sourced from the nearby Lethabo Power Station. Optimizing with other materials, an accelerated mix was attained that allowed the casting molds to be turned around within 12 to 18 hours, eliminating the need for steam curing. Compressive strength achieved exceeded 4000 psi within 24 hours and averaged 10,700 psi after 28 days.

The above-ground route to Pretoria crossed over unstable dolomitic limestone landscape. Meeting the challenge to create stable foundations, engineers utilized over 3.5 million cubic feet of grouting incorporating a fly ash/CEM I cement mix for good pumpability together with bentonite.

# Beneficial Use **Case Study**

## Niagara Region Wind Farm

### Coal Combustion Product Type
Fly Ash

### Project Location
Regional Municipality of Niagara, Ontario

### Project Participants
Lafarge Canada Inc., Rankin Construction, Boralex Inc., Enercon Canada Inc., WSP Canada Inc., Borea Construction, Pumpcrete Corporation, Mammoet, Degrandis Pumping, Salit Steel

### Project Completion Date
2016

### Project Summary
The Niagara Region Wind Farm comprises 77 wind turbines spread out over a 170-square-mile area in south-east Ontario. Collectively, the turbines, each 425 feet high, utilized 2.6 million cubic feet of ready-mix concrete and 1.3 million cubic feet of precast concrete. Challenges included an aggressive time schedule—the turbines were installed in only 16 months—and the placement of concrete during winter months, which complicated curing operations.

### Project Description
Niagara Region Wind Farm is the first in the province of Ontario to be built with concrete towers. Concrete was selected over steel for a variety of reasons. It allows for taller tower heights, which translates into additional wind power generation. Prestressed concrete also has higher material damping properties than competing materials, boasts elevated fire resistance, and is less susceptible to fatigue or dynamic failure. Finally, the energy required to manufacture a precast concrete tower, factoring in end-of-life recycling, is significantly lower than that of a steel tower.

The compressed timeframe within which the project needed to be completed meant placing one cast-in-place concrete base per day during times when pouring operations were being carried out. Each base required approximately 34,000 cubic feet of concrete, which was placed continuously. The bases had to meet 28-day strength requirements while controlling for heat of hydration to prevent thermal cracking during mass concrete placements.

To control the heat of hydration and lower mix costs, materials supplier Lafarge Canada and general contractor Borea Construction chose a 50-50 fly ash/general-use (GU) portland cement mix. A more traditional slag approach was rejected given fly ash's superior heat reduction capabilities. Lafarge also opted for a combination of ice and chillers (cooling tap water to 37-39° F rather than the 59-64° F used under normal conditions) in place of a more expensive liquid nitrogen procedure, saving an estimated $100,000.

Lafarge teamed with Rankin Construction to provide two mobile ready-mix plants that met volume and scheduling requirements. One plant was supplied for the concrete bases and the other for the precast segments. Locally based plants provided supplementary volume and loads as needed. To ensure proper temperature for the curing of the concrete segments during the cold winter months, project developer Enercon Canada constructed a heated tent onsite and enlisted the use of a specialty crane to enable the safe transport of concrete segments.

Over the course of roughly five months, Borea Construction placed a volume of concrete twice that of Toronto's famed CN Tower (which reigned as the tallest free-standing structure on land for over 30 years). Shortly after meeting the 16-month construction schedule, the Niagara Region Wind Farm was commissioned in November 2016. It subsequently earned recognition as one of 10 exceptional projects at the 2017 Ontario Concrete Awards.

Credit: CNW Group-Boralex Inc.

# Beneficial Use **Case Study**

## Saluda Dam

### Coal Combustion Product Type
Fly Ash

### Project Location
Columbia, South Carolina

### Project Participants
South Carolina Electric & Gas, Paul C. Rizzo Associates, Barnard Construction Company, Griffin Dewatering Southeast, Kleinfelder, H.B. Mellott Estate, Hayward-Baker/Nicholson (joint venture)

### Project Completion Date
2005

### Project Summary
At the time of its construction in 1930, Saluda Dam was the world's largest earthen dam, creating the then-largest man-made reservoir in the world, Lake Murray, 10 miles upstream from Columbia, South Carolina. With improved understanding of the area's susceptibility to earthquakes—and the potential for a catastrophic flood in the case of a major seismic event—dam owner South Carolina Electric & Gas (SCE&G) developed a remediation plan to mitigate against that worst-case scenario. The design challenges were many: as a functioning hydroelectric dam, source of drinking water and cooling water for SCE&G's McMeekin Steam Electric plant, and region-wide recreational resource, the reservoir's water levels needed to be roughly maintained. Moreover, any excavation work required to build a supporting structure near the dam could risk breaching it.

### Project Description
To bring the dam up to compliance with federal regulations, engineers considered a range of alternatives, eventually focusing on two potential solutions: a rockfill berm on the downstream slope of the existing dam and a new roller compacted concrete (RCC) gravity dam downstream of the dam. They eventually settled on a hybrid of the two, constructing an RCC dam around the existing powerhouse flanked on each side by zoned earth/rockfill embankments. The structure would serve as a backup dam in the event that the original dam were to fail.

While it incorporates the same materials as conventional concrete, RCC is a drier mix that has almost no slump. The concrete is delivered by conveyor or truck and placed in a fashion similar to paving, with the material spread by bulldozers or modified asphalt pavers and then compacted by rollers. Compaction gives the concrete its strength, density, and smoothness. The surface of RCC can be walked or even driven upon immediately after compaction—allowing concrete layers to be placed in quick succession.

Fly ash is essential to RCC mixes, as it improves the workability of the lower-moisture concrete and helps control the heat of hydration. Due to the particularity of RCC mixes, as well as the proposed use of reclaimed fly ash from on-site ponds, design engineer and construction manager Rizzo Associates undertook a rigorous testing and analysis of potential RCC mixes over a two-year period prior to the start of construction. Testing involved the production of lab trial mixes and an eventual 4,500-cubic-yard field test placement to ensure optimal performance characteristics had been achieved. Ultimately, engineers settled on a 50/50 fly ash-to-cement mix that incorporated 150 lbs. of fly ash per cubic yard. Physical and chemical analyses were performed on the ash reclaimed from SCE&G's McMeekin ponds—which were required to be excavated and moved prior to the start of construction, as they were situated in the design footprint of the planned remediation dam—to ensure it would meet ASTM standards and dam design criteria.

At the time of its construction, the Saluda remediation dam was the third-largest RCC dam in the U.S., incorporating 1.3 million cubic yards of concrete and 97,500 tons of recovered fly ash. The project also set a North American record for placing 18,590 cubic yards of RCC in a single day. Despite the efficiency with which the work was carried out, construction of the remediation dam nonetheless required great care to ensure that the required excavation work would not disturb the existing berm nearby. To that end, hundreds of wells—shallow, deep, and eductor—were dug to dewater and improve the stability of the excavation slope. For the benefit of close-by residents, crews installed a sprinkler system to lessen the dust generated by the batching plants.

The innovative methods used to complete the dam earned it several awards, including the Outstanding Civil Engineering Achievement from the American Society of Civil Engineers. Moreover, it helped prove the ability to use ponded ash as a major component in RCC to build strong, durable critical-infrastructure projects.

ACAA

# Beneficial Use **Case Study**

## Wilshire Grand Center

### Coal Combustion Product Type
Class F Fly Ash

### Project Location
Los Angeles, California

### Project Participants
Headwaters Resources (now Boral Resources), California Portland Concrete, AC Martin Partners, Thomas Properties Group LLC, Brandow & Johnston Inc., Thornton Tomasetti, Turner Construction

### Project Completion Date
2016

### Project Summary
Wilshire Grand Center, which opened in 2017, sits on the site of the former Hotel Statler on Wilshire Boulevard in downtown Los Angeles. Redevelopment of the site started with a deconstruction, rather than demolition, of the original hotel and the recycling of considerable volumes of both concrete and steel. Development of the 3.5-acre site involved construction of an 1100-foot-high, 73-story skyscraper—the tallest west of the Mississippi River—to house the 890-room InterContinental Los Angeles hotel, 265,000 square feet of Class A office space, and 45,000 square feet of restaurant and commercial space.

### Project Description
Given the height of the building and its location within an active earthquake zone, engineers wanted to ensure the highest levels of structural support. To that end, they stipulated a continuous placement of concrete for the building's foundation with a 25% substitution of Class F fly ash in place of portland cement. Headwaters Resources (now Boral) supplied 1800 tons of fly ash to California Portland Concrete from its Pomona, California, distribution terminal that originated from power plants in Utah and Arizona. The mix was designed to achieve a compressive strength of 6000 psi in 90 days.

On the day, crews placed 21,200 cubic yards of concrete for the building's foundation—the largest concrete placement in world history to that point, as attested by Guinness World Records. The feat required a fleet of more than 200 trucks, which made 2120 trips over 19 hours to place the concrete. To mark the occasion, the USC marching band escorted the first truck to the building site. Eight batch plants—two of them ready-mix and all within 20 miles of the job site—were utilized to ensure continuity of operations. On site, 13 pumps were used to convey concrete from the trucks to the pit where the foundation was being placed.

Credit: Wilshire Grand Center.

Credit: Wilshire Grand Center.

Although the placement was carried out in the middle of February, given the size of the placement—roughly 82 million lbs. of concrete was placed to create a 17.5-foot-thick foundation—heat of hydration was a concern. While the use of 25% fly ash helped to mitigate the heat gain, engineers achieved further thermal control by pumping chilled water through 0.5-inch-diameter plastic piping for two weeks following the placement. In addition to controlling the overall heat gain of the concrete, engineers added thermal insulation to the top of the mat to keep the temperature difference between the foundation's core and its exterior to a maximum of 35 degrees.

# In & Around ACAA

**Houston, TX**

ACAA bids a fond farewell to two long-time leaders, Laurie Cook and Fred Gustin. Cook, who is the Membership Subcommittee Chair, will retire from her position as Principal Market Engineer, CCPs, at DTE Energy later this year. Gustin, who served as Communications and Membership Committee Chairman, retired in April from his position as Manager, CCPs & Additives, at Evergy.

**Houston, TX**

The ACAA Board met during the Association's Winter Meeting at the Marriott Marquis in Houston to elect several new Directors and Committee Chairs to fill open seats (see News Roundup on page 68 for details).

**Houston, TX**

The ACAA Women's Leadership Forum convened during the Association's Winter Meeting in Houston in January. Caryl Pfeiffer, Director, Corporate Fuels and By-Products at LG&E and KU Services Company, was the guest speaker. The forum was launched in 2010 as a vehicle by which to foster professional dialogue, development, and camaraderie among women in the industry.


**Houston, TX**

Michael J. Nasi, partner at Jackson Walker LLP, is shown updating ACAA members on what to expect next regarding the EPA's Coal Combustion Residuals rule. Despite the Winter Meeting's concurrence with a "polar vortex" that forced the cancellation of thousands of flights around the country, attendance throughout the General Session was strong.

## New ACAA Leaders Selected

Three American Coal Ash Association members were elected to open seats on the ACAA Board of Directors at the Association's Winter Meeting in Houston, Texas, January 30, 2019. Elected to serve three-year terms on the Board were:

- Utility—Tara Masterson, Tennessee Valley Authority
- Marketer—Danny Gray, Charah Solutions
- Associate—Mike Schantz, Lhoist

Earlier in January, Amanda Udicious, Manager of Coal, Transportation, and CCRs at NRG Energy, was selected by the ACAA Board to fill a vacant utility seat. Tom Flexon of NRG, who held the utility seat for the 2018-2020 term on the ACAA Board, recently resigned because he has accepted a new position within his company.

Two new committee chairs were also announced at the Winter Meeting. Travis Collins, National Minerals Corporation, has been appointed as Communications and Membership Committee Chairman, replacing longtime Chairman Fred Gustin, who retired from his employer, Evergy, in April. Peggy Rennick, SCB International, was selected to assume the Membership Subcommittee Chair, replacing Laurie Cook, who is retiring from DTE Energy later this year.


Tara Masterson


Danny Gray


Mike Schantz


Amanda Udicious


Travis Collins


Peggy Rennick

## DC Court: Compliance Deadlines on Ash Ponds Can Stand While EPA Revisits CCR Rule

The U.S. Court of Appeals for the District of Columbia on March 13, 2019, granted the U.S. Environmental Protection Agency's request to allow the agency to re-examine deadlines for compliance with parts of its 2015 coal ash disposal regulation, refusing a bid by environmental groups to throw out extensions that were granted earlier by the EPA. The 2015 rule required "certain wastewater surface impoundments to take steps toward closure within six months of specified triggering events." A July 2018 update to the rule extended closure deadlines to October 31, 2020. But shortly after that rule update was issued, the DC Court overturned portions of the original regulation, forcing EPA into a new round of rulemaking.

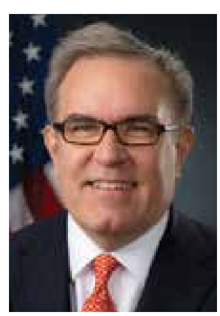
In allowing EPA's extended deadlines to stand, the court agreed with EPA that rolling the deadlines back would be disruptive. "We are confident that EPA will, as represented, expedite its rulemaking proceedings on remand to the fullest extent possible," the court said. EPA has not indicated when the next round of revisions to the coal ash regulation will be proposed.

## No Action Required to Address Historical CCR Structural Fill Applications, EPA Determines

The U.S. Environmental Protection Agency's Office of Resource Conservation and Recovery (ORCR) has determined that no further EPA action is warranted to address historical coal ash structural fill applications. This activity was a follow-up to a 2011 EPA Office of Inspector General report that led to the dissolution of the Coal Combustion Products Partnership (C$^2$P$^2$) program. That report required EPA to develop a beneficial use risk evaluation methodology (which was completed in 2016) and evaluate whether "large volumes of unencapsulated coal ash reportedly used for structural fill beneficial use applications may represent a large universe of inappropriate disposal applications with unknown potential for adverse environmental and human health impacts."

EPA has now published a previously unpublished report entitled "Information Assessment of Historical Structural Fill Applications." The document details considerable efforts by the ORCR, including reviews of the following: (1) comments on the CCR Disposal Rule proposed in calendar year 2010, (2) the known damage cases from the CCR rulemaking, (3) communications with the EPA's regional offices and states, (4) relevant literature, and (5) Superfund National Priority List sites. Based on this document, EPA has now concluded "that no further action to address historical CCR structural fill applications as a general issue is warranted at this time" and "that existing statutory authorities are available to address environmental concerns that may arise at a historical CCR structural fill site."

## EPA Administrator Recognizes Coal Ash Beneficial Use


EPA Administrator Andrew Wheeler

Coal ash received a shout-out at a major international energy event recently when U.S. EPA Administrator Andrew Wheeler included in his keynote address to the CERA Week conference an endorsement of the beneficial use of coal combustion products. "…We are currently developing new ways to assist states in expanding the beneficial reuse of coal ash," Wheeler told attendees of the conference, which bills itself as the "World's Premier Energy Event." He added, "We already issued a proposal to give states more flexibility in managing coal ash, and now we are exploring ways to increase productive reuse. One common reuse for coal ash is as an additive to concrete. What better way to support President Trump's energy and infrastructure goals than through roads and bridges built from the byproduct of American coal production. So we are working to remove regulatory obstacles while also ensuring environmental protections are in place for such uses."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