

ASH ISSUE 1 • 2016
at work

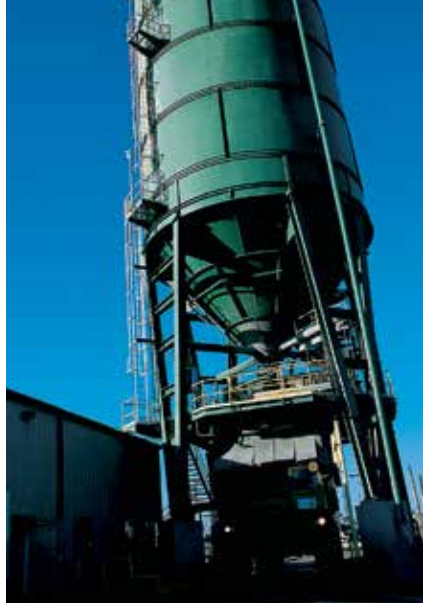
Applications, Science, and Sustainability of Coal Ash

Synthetic Gypsum:

Beneficial Uses for Construction and Agriculture

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38800 Country Club Drive
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Phone: 1-720-870-7897
Fax: 1-720-870-7889
www.acaa-usa.org
www.FGDProducts.org
www.WWCCP.org

Executive Director
Thomas Adams

Member Liaison
Alyssa Barto

Editor
John Ward

Advertising
Alyssa Barto

Creative Association Management
Publishing Services Manager
Barry M. Bergin

Editors
Carl R. Bischof (Senior Editor),
Tiesha Elam, Kaitlyn J. Hinman,
Kelli R. Slayden (Senior Editor)

Editorial Assistant
Angela R. Matthews

Graphic Designers
Gail L. Tatum (Senior Designer),
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On the Cover

Approximately half of the gypsum wall-board manufactured in the United States utilizes synthetic gypsum from coal-fueled power plants.



ASH **at work**

Applications, Science, and Sustainability of Coal Ash

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FINALLY, A RESPITE FROM PLAYING DEFENSE

By Hollis Walker, ACAA Chair

The theme of this edition of *Ash At Work* is beneficial use of flue gas desulfurization (FGD) gypsum. As some utilities chose to comply with initial sulfur dioxide regulations by fueling their plants with low-sulfur coals, others chose to build FGD scrubbers early on. Some of the scrubbers were designed to produce a calcium sulfate by-product, or better said, the design was to make a sulfur-removing technology that yielded a high-quality product that could be beneficially used. This first initial fleet of gypsum-producing scrubbers set the stage for creating a new commodity, a high-quality synthetic gypsum that did not have the same issues as historical synthetic gypsums (for example, the radioactivity seen in phosphogypsum). Through the early and mid-2000s, the production of FGD gypsum was steady at 11 to 12 million tons per year with a large percentage of it being beneficially used (70 to 80%). By 2008, as regulations became more stringent, another set of FGD gypsum scrubbers became commercial over the next several years and gypsum production has steadily increased, topping out at nearly 35 million tons in 2014. The beneficial use of this material has increased but not nearly as rapidly as the production (from just under 10 million tons in the early 2000s to just over 15 million tons in 2014); thus, the material has seen a use rate drop from nearly 80% down to 50%.

With this background on gypsum, one may be surprised to hear that there are gypsum shortages occurring. Similar to ash, the FGD gypsum market is experiencing shortages in locations that have historically used large amounts. These shortages are driven by less coal

being burned due to environmental regulation-driven retirements and displacement by cheaper natural gas. However, a shortage in a geographic region does not mean there is no material available—it just means the market must adjust to a new way of moving the material to the end user. This takes time and, in many circumstances, capital investment. This translates to a higher cost for the material, which also takes time for the market to accept. Our gypsum market is currently in this transition. Our association published a report last year that demonstrated there will be more gypsum produced over the next 20 years than the expected use rate would consume. I suspect that over the next couple of years, the market will have sufficiently adapted to the point that we don't hear much about gypsum shortages occurring.

As I reflect on the current state of our market (both ash and gypsum users seeing shortages of supply—regionally, albeit), I focus on the drivers and see two very different themes. One is market-driven, rooted in efficiency and innovation, causing electrical prices to go down, resulting in a higher standard of living for our citizenry. This foe to coal generation is natural gas and its associated fracking revolution that has caused natural gas production costs to drop 75% from what was thought to be its long-term stable price back in 2008. With the current price hovering around \$2/mmBtu, it has a devastating effect on coal generation; however, this price does seem to reflect a glut-in-supply price and is not sustainable for the long haul. I don't pretend that a sustainable price for natural gas (probably around \$4/mmBtu) will not still displace a lot of

coal, but that level will bring a lot of coal generation back into play.

The second theme is 180 degrees different. It is not rooted in market forces, but by the power of government and good intentions. Like many things rooted in good intentions, there is an initial good result; but then, instead of being satisfied with the resulting good, the momentum created usually only grows. The specific good intentions referred to here is making environmental regulations that clean up a problem; ash and gypsum owe their very existence to these. However, the never-ceasing crusade to “clean up the environment” runs out of real problems to solve and begins to create them. The fight over CCR regulations is one example. To have an environmental impact fight over a material as benign as coal ash and gypsum (relative to so many other materials, man-made and natural) defies common sense. But we've had it, and while we avoided the craziest outcome of a hazardous designation for this material, that resembles some dirt in nearly every constituent (you show me an ash and its metals and I'll find you a dirt that can match it), we are now dealing with costly regulations to store it. Related to this is the equally negligible environmental improvements from the ELG (Effluent Limitation Guidelines) regulations. The vast majority of water that touches ash cannot be discharged, no matter how clean, even if it meets drinking water standards. Just the fact that it “transported” ash makes it such a menace that any scientific metric used to demonstrate its purity fails convincing EPA of no negative environmental impact; thus, the water is prohibited by

the new regulation from discharging to a much dirtier river. This regulation actually prevents clean water from entering a river that would, admittedly on a small scale, improve the river by diluting its contaminants. Does that sound science-based and concerned over river pollution? These two regulations are examples of good-intentioned environmentalism morphing into a lumbering, environmentally inconsequential retarder of progress to the human condition. They drive up costs of coal-fired electrical generation without any real improvement to the environment. The nonsensical environmentalism has hit its pinnacle with EPA's endangerment finding for carbon dioxide. The power and momentum of today's environmentalism, once well-intended and needed, has resulted in the very air you exhale, and needed by vegetation to complete the circle of life, to be considered an endangerment to human health and the environment. And this finding done using a law that never intended this, and in complete contradiction

to the body of government that makes such laws (Congress voted down a carbon legislation in 2010).

Left to market forces, coal and gas will compete with each other to keep electrical costs low, reliability high with diversity in fuel, and provide the engine that increases prosperity for the American citizenry. Environmental extremism (defined as the religious zeal to stamp out man's footprint on the planet regardless of the relatively immeasurable environmental improvement) is the one man-caused distortion to the natural market forces that will derail the continual improvement to our society.

My plea to you: be engaged with the political process, understand where candidates are on the Clean Power Plan (CPP), and vote with common sense. It's time to pull back on the unwarranted and unscientific regulations on coal, especially as they only grow in scale and this one is rapidly moving coal toward regulatory critical mass.

Now, by the time you read this, I will have completed my 2-year term as Chair of our association. On June 8, at the conclusion of our summer meeting in Indianapolis, IN, I officially handed over the office to our new Chair, Charles Price. Charles has been serving this association for many years and brings a wealth of experience, history, and service to this role. I have great confidence in Charles and will be ensuring his transition is smooth as I'll still be around serving as Past Chair.

I want to say thank you to the many members who have supported me during this term, and a special thank you to those who have served this association in the many volunteer roles, from the officers, to the Board of Directors, to the Committee Chairs, and those who led special projects. And the warmest appreciation I give to Tom Adams, our Executive Director, and Alyssa Barto, our Member Liaison, for their hard work, dedication, and representation of our association. ♦

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OUR SECRET WEAPONS...

By Thomas H. Adams, ACAA Executive Director

As the lease of office space for the American Coal Ash Association was coming to an end in early 2012, our leadership had to make some decisions on the future of ACAA. Those decisions were much deeper than deciding whether to renew our lease and remain in the same Aurora, CO, location. Did we want to make a simple decision or was it time to look at another model for operating the association? After much discussion, three scenarios emerged.

1. Renew our lease and remain in the same building with the same structure;
2. Relocate the ACAA offices to another city and hire necessary staff and vendors; and
3. Hire a management provider to take over support operations allowing the executive director more time to focus on the ACAA mission.

Under the leadership of Mark Bryant, then Chair of the Board of Directors, the Executive Committee discussed and debated the merits of all three scenarios. The committee decided to see what a management proposal might look like. Requests for proposals were sent to potential vendors. Two very competitive yet different proposals rose to the top. A site visit was made by a search team of volunteers and a recommendation was prepared for the consideration of the Board of Directors.

In February of 2012, the American Coal Ash Association embarked on a relationship with Creative Association Management (CAM). CAM is a subsidiary of the American Concrete Institute (ACI) and provides association management services. Many of the services needed to operate ACAA were and are similar to those required by ACI—accounting, event planning, human resources, information technology,

Creative Association Management (CAM) provides support services to the American Coal Ash Association (ACAA) under an agreement initiated in 2012 and renewed in 2015. CAM's Chief Executive Officer is Ron Burg. Burg is the primary point of contact for ACAA and is responsible for all services provided to ACAA. The following is a roster of the individuals who work on behalf of ACAA and the specific service they provide.

MEMBER SERVICES

- Melinda Reynolds, Manager, Member Services: Provides daily oversight of services provided to ACAA by Alyssa Barto, Member Liaison.

FINANCIAL SERVICES

- Donna Halstead, Managing Director, Finance and Administration: Provides oversight of financial activities; secures financial services; recommends financial initiatives; secures annual financial audit services; and secures required insurance policies.
- Stacey Clement, Lead Accountant: Maintains financial records; processes accounts payable and receivable; tracks account aging; prepares financial statements; and prepares and files tax returns for both ACAA and the ACAA EF.
- Marie Fuller, Purchasing Coordinator: Provides purchasing services for products and services required by ACAA, including source identification; secures competitive bids; evaluates proposals; recommends vendors; executes purchase orders, fulfillment; and resolves disputes (if any).



Reynolds



Barto



Halstead



Clement



Fuller



Bergin

publishing/Internet, and purchasing. ACAA uses these services in a cafeteria-style arrangement taking only the services we need when we need them. To date, this relationship has proven to be a very wise decision.

To many of our members and the general public, the talented and dedicated staff at CAM is invisible. They are truly our secret weapons. Chances are the only persons ACAA members will ever meet in person are Alyssa Barto, Member Liaison, Vicki Rogers, Senior Event Planner, and me. However, there are 18 others who have regular direct involvement with ACAA. Nearby this message you will meet these individuals.

Ron Burg, Executive Vice President of ACI and CEO of CAM, recently commented on the ACAA/CAM relationship. "CAM is very pleased to have ACAA as a client. In fact,

we view them more as a partner than a client. ACI, CAM owner, benefits from the relationship, as it allows ACI to have a better understanding of the technical and political issues and concerns related to the coal ash industry and how they impact the effective use of fly ash in concrete. I believe that in addition to benefitting from the depth of administrative resources at CAM and ACI, ACAA benefits from accesses to ACI technical resources, ACI members, and ACI engineering staff."

In the interest of transparency, I have to make clear the fact that I worked for CAM as Executive Director of the American Shotcrete Association prior to joining ACAA in 2009. I knew all the key players and how CAM functioned. This history gave me a great deal of confidence that CAM could deliver the kind of support ACAA was seeking at a very reasonable cost. They have not disappointed. ♦

GRAPHIC DESIGN AND PRODUCTION

- Barry Bergin, Manager, Publishing Services: Provides oversight of *Ash at Work* production; consults on website design and content; and provides consultation on special ACAA documents and marketing initiatives.
- Ryan Jay, Graphic Designer: Provides primary design services for *Ash at Work*, including layout and content advisory; provides advisory and design services for the ACAA website; and provides special document design services as needed.
- Gail Tatum, Susan Esper, and Aimee Kahaian, Graphic Designers: Provide graphic support service for *Ash at Work*.
- Carl Bischof, Tiesha Elam, Kaitlyn Hinman, and Kelli Slayden, Editors: Provide editing services for *Ash at Work* content.

EVENT SERVICES

- Lauren Mentz, Manager, Event Services: Provides oversight of event management.
- Vicki Rogers, Senior Event Planner: Provides contracting services for ACAA membership meetings, including facility selection advice; hotel contract negotiations; design of meeting space; recommends food and beverage plans; arranges for speaker accommodations; arranges shipping of meeting materials; serves as liaison to the hotel before, during, and after the event; provides hotel signage; manages registration desk operations; secures audio/visual services on site; and reconciles hotel invoices after events.
- Ashley Mayra, Exhibit & Sponsorship Coordinator: Develops concepts for enhancing financial outcomes from association events and solicits support for association events via exhibit space sales, sponsorship sales, and other tools.

INFORMATION TECHNOLOGY

- Jason Pennington, Manager, Information Systems and Warehouse Operations: Provides information technology services for hardware and software as needed.
- Gabriel Bule, Systems Administrator: Troubleshoots IT issues as required.

HUMAN RESOURCES

- Lori Purdom, Manager, Human Resources: Provides human resource services to employees engaged in ACAA business.



Jay



Tatum



Esper



Kahaian



Bischof



Elam



Hinman



Slayden



Mentz



Rogers



Mayra



Pennington



Bule



Purdom

GRANULAR GYPSUM FOR AGRICULTURE:

Charah's SUL4R-PLUS® Fertilizer Develops International Distribution

By Danny Gray

Today, Louisville, KY-based Charah, Inc., is one of the largest providers of coal combustion product management and power plant support services for the coal-fired power generation industry, specializing in total ash management, including the recycling of by-products from coal combustion power plants. While always focused on expanding traditional beneficial uses for fly ash and bottom ash, the company recently has expanded its expertise to focus on all by-products with the goal of reducing volumes going into landfills and has invested in specialized technology to make this happen.

In partnership with Louisville Gas and Electric Company (LG&E) to recover thousands of tons of gypsum, Charah has developed a patent-pending technology and completed the first full-scale facility that merges the qualities of high-quality gypsum produced by the power plants with the growing sulfur deficiencies that are appearing in soils in many farm regions to

create a granular sulfur product to be sold to and distributed by agricultural companies. As part of the technology and the processing facility, Charah uses the calcium sulfate that results from the power plant exhaust gas sulfur removal process to manufacture SUL4R-PLUS® fertilizer, which can be used to replenish the sulfur and calcium to farm soils, turf, and specialty crops. This process essentially closes the cycle loop for the sulfur that once was returned to farm fields with rainfall, but now is removed by the power plant emissions control equipment before discharging the cleaned exhaust gases into the atmosphere.

The new facility, which began operations in 2013, is located at the LG&E Mill Creek Generating Station (Mill Creek), which has four generating units—all of which have forced oxidation wet scrubbers. Charah's technology allows sulfur captured from power plant exhaust gases to be converted into a granular calcium sulfate fertilizer product that returns vital nutrients to farm

Charah's SUL4R-PLUS® Manufacturing Facility at Mill Creek Generating Station began operations in 2013.



fields, replacing the sulfur that once was deposited as part of the normal rainfall cycle.

The electric utility industry has continued to change over the decades and today's coal-fired power plant is more efficient in converting coal fuel to electricity and is much cleaner in terms of emissions to the water, air, and land. The modern coal-fired power plant produces electricity that is reliable and economical for base load demand and helps drive industrial production in the United States to be competitive on a worldwide basis. In the air emissions segment, power plants have reduced SO₂ emissions by 80% between 1980 and 2014. The addition of sulfur removal systems at power plants has dramatically reduced emissions to the atmosphere. This dramatic reduction of emissions was accomplished by large investments by electric utilities. The reduction in sulfur emissions also caused an interesting impact on the American farming industry.

SUL4R-PLUS fertilizer, in its unique patent-pending granular form, is an in-demand granular calcium sulfate that is engineered to provide improved crop yield for growers. While synthetic gypsum has been used in agriculture applications in the past, Charah and its Agricultural Products division have a patent-pending process to create granules from the by-product, making sulfur and calcium application more efficient for the farmer in meeting the increasing demand for sulfur by the regional farming industry.

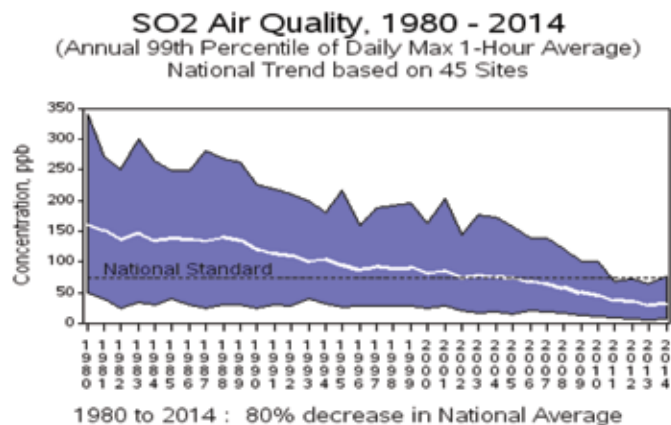
SUL4R-PLUS calcium sulfate is a highly soluble form of calcium and sulfur. In agriculture, it can aid in amending compacted soils and provide calcium and sulfur nutrition for a variety of crops, including corn, soybeans, wheat, alfalfa, peanuts, vegetables, rice, canola, and more. It separates into calcium and sulfate when it encounters moisture. When applied to soil, the sulfate attaches to excess magnesium on soil molecules. This process scrubs down the soil's composition. The calcium then replaces the magnesium on the soil molecule, allowing for improved soil structure.

"Because of its uniform granule size, SUL4R-PLUS calcium sulfate can be applied and blended with other dry inputs, making nitrogen, phosphorus, and potassium (NPK) much more efficient," said Scott Vanderventer, Director of Major Accounts and the East region for Charah Agricultural Products. "It spreads evenly for superior coverage, allowing farmers to make just one pass across their field. And because it is a sulfate form of sulfur, it is immediately available and starts working almost on contact. As an added bonus, the product contains calcium as well."

Today, Charah Agricultural Products focuses on innovative product development for the agricultural market, including SUL4R-PLUS fertilizer and the recently launched SUL4R-PLUS® BORON and SUL4R-PLUS® ZINC. Last year, Charah hired Peter DeQuattro as Executive Vice President, Agricultural Products. In this new position, he serves as the General Manager for Charah Agricultural Products and is responsible for production and sales of SUL4R-PLUS fertilizer, including the new Boron and Zinc options, and other products in the pipeline. DeQuattro has more than 25 years of experience in the energy industry, including

engineering, construction, operations, maintenance, project development, mining, asset management, and senior leadership.

According to DeQuattro, "We believe there is great opportunity in the recycling of gypsum, beyond wallboard and traditional channels, as the farming industry is continuing to acknowledge the importance of calcium sulfate in improving soil conditions and fertilizer uptake efficiency. In addition, the positive impact of gypsum in reducing negative impacts from fertilizer runoff



Sulfur reduction. This graph shows SO₂ air quality as a national trend from 1980 to 2014—an 80% decrease in the national average over that period.

Source: EPA

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SUL4R-PLUS® granular calcium sulfate.

Source: Charah Agricultural Products

to surface water quality is becoming more important as nutrient driven water quality episodes occur.”

The company continues to market the product throughout the Midwest and Canada, even having a segment on *American Farmer*, airing on RFD-TV. The episode explored the latest innovations and advancements in sulfur-fertilizer, focusing on how sulfur is increasingly becoming the fourth major crop nutrient of focus due to sulfur deficiency in crops.



Peter DeQuattro, Executive Vice President, Charah Agricultural Products.

Source: Charah Agricultural Products

In August 2015, Charah Agricultural Products completed its first international delivery of SUL4R-PLUS fertilizer to a customer in the Dominican Republic, who planned to use it in fertilizer blends on a variety of fruit and vegetables, including green peppers, sugarcane, and citrus to enhance yields and, in turn, profits. In addition, the product is being used directly for golf

courses as a soil amendment and to help green the grass.

According to DeQuattro, “This material underwent the ultimate stress test as it traveled from Louisville to Tampa on rail, sat in a rail yard for 5 weeks awaiting a vessel, and then traversed the Gulf of Mexico in 5 days under extremely humid conditions without clumping or dusting. The quality of SUL4R-PLUS calcium sulfate really exceeded our customer’s expectations.”

In addition, Charah Agricultural Products completed its first delivery to Ecuador in May 2016 for use in fertilizer blends for bananas and a variety of other fruit crops. Charah Agricultural Products is currently quoting additional orders to other countries throughout the region.

The SUL4R-PLUS Manufacturing Facility, a one-of-a-kind agricultural product development facility at the Mill Creek Generating Station, represents an innovative approach to the beneficial use of coal combustion by-products. In the future, Charah plans to develop and install custom manufacturing facilities around the country in strategic locations to meet the growing demand of sulfur fertilizers, and in partnership with power plants to generate a high-quality gypsum product.

For further information about the SUL4R-PLUS® Manufacturing Facility or SUL4R-PLUS® fertilizer, contact Charah Agricultural Products at (844) 822-8385 or at www.SUL4R-PLUS.com or www.charah.com. ♦

Danny Gray is Executive Vice President of Governmental and Environmental Affairs at Charah, Inc.



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EPRI RESEARCH ON USE OF FGD GYPSUM IN AGRICULTURAL APPLICATIONS

By Ken Ladwig

The Electric Power Research Institute (EPRI) maintains a robust research program on the use of flue gas desulfurization (FGD) gypsum in agricultural applications. The research is driven by the benefits gypsum can provide to soil health, crop yield, and water quality in nearby waterways. In addition, the quantity of FGD gypsum produced by the electric power industry has nearly tripled since 2006 as power plants remove more sulfur dioxide from the flue gas to meet new air emissions requirements, resulting in a large resource supply. EPRI research over the last 10 years shows that the application of FGD gypsum to farm fields as an alternative to mined gypsum does not result in significant environmental impacts, and that FGD gypsum can be an effective tool in controlling phosphorus runoff.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) mined from native rock sources has been used to improve soil quality and crop yields in the United States for more than two centuries (Table 1). In the 1990s, power plants began to produce FGD gypsum as plants installed wet FGD systems using forced oxidation technology. Forced oxidation changes calcium sulfite ($\text{CaSO}_3 \cdot 0.5\text{H}_2\text{O}$) initially produced in the scrubber to calcium sulfate (gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). These systems produce fine-grained gypsum with fewer mineral impurities than mined gypsum,¹ making it an attractive alternative to mined gypsum for many applications, such as wallboard and agriculture.

GYPSUM AGRICULTURAL NETWORK

In 2006, EPRI and The Ohio State University (OSU) initiated research on a network of sites across the United States to

evaluate use of FGD gypsum on field plots. Dr. Warren Dick led a research team that included the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) and several universities performing the field tests (Table 2). The primary purpose of the research was to evaluate the potential for environmental impacts to soil, water, and plant quality associated with the FGD gypsum application.

Network field sites were established in seven states, with each following similar protocols for consistency. The field tests used a randomized block design for statistical analyses. Seven treatments were used: FGD gypsum and commercially available mined gypsum products at three application rates each, and one control plot. Each treatment was replicated four times for a total of 28 plots. Agronomic application rates were used depending on the crop and soil types, ranging up to 5 tons per acre.

Samples were collected and analyzed during a 2-year period to evaluate changes to soil, water, and plant quality. Plant yield was also measured. For each site, the results were analyzed statistically to assess possible changes due to the treatments. Table 2 lists the locations, crop types, and final EPRI report number for each of the field studies.

Overall, the field studies found no evidence of significant environmental impacts to any media (such as soil, plant, and water) on the FGD gypsum-treated plots when compared to the plots treated with commercial gypsum products and the controls. These results are consistent with data on the composition of FGD gypsum, which has few mineral impurities and low levels of trace constituents.¹

The results with respect to crop yield were mixed. In many cases, the gypsum plot yields were similar to the controls. This likely reflects the fact that yield was a secondary consideration in the network research, and field sites were not selected to target specific soil and crop types that would benefit from gypsum application. Also, the short time over which the study was conducted (2 years) is often not long enough to see significant changes occur in soil quality that then impact crop yield. This suggests that soil and crop types should be carefully evaluated when considering gypsum amendments to maximize the yield benefit.

TABLE 1: KNOWN AGRICULTURAL BENEFITS OF GYPSUM APPLICATION

| |
|---|
| Improvement in soil health/soil quality |
| Reduced subsoil acidity |
| Plant nutrients (calcium and sulfate) |
| Improved water infiltration and soil aeration |
| Reduced phosphorus in runoff and drainage |
| Remediation of sodic soils |
| Improved crop yield and quality |

TABLE 2: GYPSUM AGRICULTURAL NETWORK SITES

| State | Crop | Local researchers | EPRI report |
|--------------|---------------|--------------------------|-------------------|
| North Dakota | Canola | North Dakota State Univ. | 1021794 (2011) |
| North Dakota | Wheat | North Dakota State Univ. | 1021817 (2011) |
| Ohio | Hay/corn | Ohio State Univ. | 1025354 (2012) |
| New Mexico | Alfalfa | New Mexico State Univ. | 1025355 (2012) |
| Wisconsin | Alfalfa | Univ. of Wisconsin | 3002001309 (2013) |
| Indiana | Corn/soybeans | USDA-ARS (Purdue Univ.) | 3002001236 (2013) |
| Arkansas | Cotton | Univ. of Arkansas | 3002001310 (2013) |
| Alabama | Cotton | USDA-ARS (Auburn Univ.) | 3002003265 (2014) |
| Alabama | Bermuda grass | USDA-ARS (Auburn Univ.) | 3002006090 (2015) |

EPRI reports can be downloaded from EPRI website (www.epri.com)

An earthworm study was also conducted as part of the network research to determine the environmental fate of metals in the FGD gypsum. Bioaccumulation factors, defined as the ratio of the concentration of an element in an earthworm living in a soil treated with gypsum to the concentration of the metal in the soil itself, were calculated. The values determined were found to be statistically similar or lower for the FGD gypsum treatments compared with the controls, suggesting no significant concentration impacts to earthworms at normal agronomic application rates.²

Additional EPRI studies were performed specifically to assess mercury due to its presence in FGD gypsum by Dr. Mae Gustin at the University of Nevada, Reno. Greenhouse studies with 66 tubs were set up with field soils, FGD gypsum and commercial gypsum products, and perennial rye grass. Mercury and methylmercury were measured in soil, water, plants, and flux to air. The use of FGD gypsum amendments did not significantly affect any media, including flux to air.³ The mercury and sulfur in the FGD gypsum also did not enhance methylmercury production under these test conditions.

MITIGATING PHOSPHORUS IN AGRICULTURAL RUNOFF

Runoff and tile drainage from agricultural fields represent non-point sources of nutrients (phosphorus and nitrogen) that can significantly degrade surface water quality. Phosphorus is a primary limiting nutrient for a variety of terrestrial plants and aquatic algae, and transport of excess phosphorus applied as fertilizer can lead to algal blooms in freshwater systems. The increasing frequency of algal blooms in the United States and elsewhere has made nutrient management in agriculture a high priority. High-profile incidents of algal blooms include the recent degradation of the City of Toledo, OH, drinking water on the western end of Lake Erie,⁴ and creation of ecologically “dead zones” (such as in the Gulf of Mexico and Green Bay, WI) due to the depletion of dissolved oxygen as the unusually large numbers of algae decompose.⁵

Several laboratory and plot-scale studies in the past few years have shown the potential for FGD gypsum to help mitigate loss of phosphorus from agricultural fields (for example, refer to Reference 6). These studies have generally suggested that a 40 to 70% reduction in phosphorus loading is possible using gypsum. EPRI has teamed with researchers at OSU and the University of Wisconsin (UW) to assess the phosphorus

mitigation benefits at a field scale and to create greater confidence around the best agricultural practices that can provide both water quality and crop yield (quality) benefits. This research is supported by several power companies located in the Midwest.

OHIO STUDY

Dr. Warren Dick is leading the research in the Maumee River Basin in Ohio on the west end of Lake Erie. The Maumee River has been shown to be a major contributor to phosphorus in Lake Erie.⁷ Field identification, management, and sampling are supported by Nester Ag LLC, Beneficial Reuse Management LLC (Gypsoil), and Greenleaf LLC.

Each field site consists of paired fields: one field receiving gypsum treatment while the other serves as a control (no gypsum). Eight sites were established in the Maumee River Watershed and have been monitored since 2012 or 2013. Water samples were manually collected at “edge-of-field” locations from drain tiles and tested for phosphorus (P) concentrations during or after rainfall events. From June 2012 to June 2015, soluble P concentrations were obtained for 87 sampling events. In addition, nearly 200 soil samples were collected and crop yield response was monitored. Most of the fields were planted in a corn-soybean rotation.

Mean soil P concentrations ranged from 20 to 200 mg/kg for the eight paired fields. Soluble P concentrations varied from below detection to 0.4 mg/L. Figure 1 shows the percent reduction in soluble P between the treated field and the control for each event. Positive percent reduction indicates that P concentration was lower on the gypsum-treated field than the control, and a negative percent reduction indicates the concentration was higher on the gypsum treated field than the control.

Below 0.1 mg/L, the data are randomly scattered, indicating no effect of the gypsum treatment. However, at higher concentrations, the gypsum benefit is clearly evident, with all but one sampling event yielding a P reduction; reductions ranged from 20 to 93%. The photo in Fig. 2 visually shows the difference in tile drainage from a treated field and control field. Annual sampling suggests the benefits of the gypsum decreases with time. Thus, a reapplication will probably be needed every other year or every third year to maintain water quality until soil levels decrease to a point where they no longer pose a threat to water quality.

In addition, field plot trials evaluating the interaction of nitrogen application rates and gypsum application rates on soil properties and corn productivity were established at two sites controlled by The Ohio Agricultural and Research Center (OARDC) operated by OSU. Results from these plots are expected to be available in 2016.

In 2016, the project team plans to collaborate with the USDA-ARS to perform automated monitoring at two to four USDA sites in northwestern Ohio. These sites also use an edge-of-field monitoring approach, but employ automated flow monitoring and sampling of both surface runoff and drain tiles.

WISCONSIN STUDY

In parallel with the Ohio study, UW's Dr. Francisco Arriaga is leading research in the Milwaukee River Basin in southeastern Wisconsin. Field identification, management, and sampling are supported by Sand County Foundation and Beneficial Reuse Management LLC (Gypsoil).

The Wisconsin study is also using an edge-of-field sampling approach on three paired sites. These three sites have surface runoff only (no drain tiles) and automated flow/sampling equipment is being used. In general, soil P concentrations were much lower than in the Ohio study. The initial FGD gypsum treatment was in 2014, but large rainfall events immediately after the treatments confounded the 2014 results. FGD gypsum was reapplied in late 2014 and monitoring has continued since then. Results are expected in early 2016.

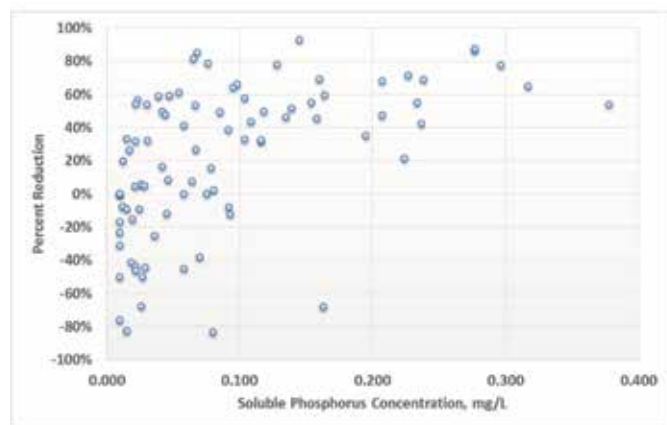


Fig. 1: Percent reduction in soluble P on the gypsum treated fields as a function of soluble concentration



Fig. 2: Tile drains at paired field and samples collected as part of this study

Laboratory incubation studies are also being performed by UW. Soil samples were spiked to obtain samples with low (≈ 45 mg/kg), medium (≈ 175 mg/kg) and high (≈ 380 mg/kg) soil P levels. Gypsum was then applied to the soils at application rates of 0.5 to 4.0 tons/acre. To date, soluble P reductions ranging from 21 to 67% have been observed relative to the controls. Percent reductions increased with increasing gypsum application rate. Importantly, plant available P was not affected by the gypsum treatments. The objective of the incubation study is to quantify the impact of gypsum application rates on soluble P concentrations, and eventually adjust the P index for sites that apply FGD gypsum.

SUMMARY

FGD gypsum is a valuable product for many agricultural applications, including improving soil properties, increasing crop yields, and mitigating P concentrations in runoff and tile drainage. Ten years of EPRI research has shown that the application of FGD gypsum to farm fields does not result in any significant environmental impacts to soil, water, and plant quality, and that FGD gypsum can be an effective tool in controlling soluble P contributions to surface waterways. During these 10 years, use of FGD gypsum in agriculture has increased by more than 10 times, a trend that is expected to continue. In 2015, USDA-Natural Resources Conservation Services (NRCS) established a national Practice Standard for use of gypsum,⁸ which will allow state NRCS programs to reimburse producers for use of gypsum as a Best Management Practice (BMP). State BMPs may also facilitate the use of FGD gypsum in nutrient water quality trading programs. ♦

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Ken Ladwig is a Senior Technical Executive for the Electric Power Research Institute, Palo Alto, CA.

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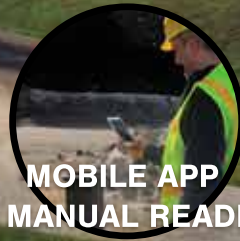
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GYPSUM USE BOASTS RICH HISTORY

Demand for FGD Gypsum Growing Even as Wallboard Consumption Declines

By Mundise Mortimer

Who could have known that technology that dates back to the 1850s would supply state-of-the-art gypsum board plants in the twenty-first century? The flue gas desulfurization (FGD) process to remove sulfur dioxide emissions from coal-fueled power plants, commonly known as “scrubbing”, can be traced back to 1850 in London, where early concepts for removing sulfur dioxide from flue gases were initially developed.

In 1929, the British government upheld a landowner’s claim against the Barton Electricity Works for damages related to sulfur dioxide emissions. Subsequent regulations followed and FGD operations were installed at three British power plants: in 1931 at Battersea Station in London; in 1935 at Swansea Power Station; and in 1938 at Fulham Power Station. All three were abandoned during World War II (Beychok 2012).

Commercial operations of large-scale FGD units did not reoccur until the 1970s and activity was concentrated in Japan and the United States (Beychok 2012). By this time, the technology had advanced. By scrubbing the sulfur dioxide emissions with a limestone slurry, followed by a dewatering process, the process produced calcium sulfate. This by-product is chemically identical to natural gypsum—the same material that has been used in construction over the past 3500 years, dating back to the ancient Egyptian pyramids. The terms synthetic gypsum, by-product gypsum, and FGD all refer to the same calcium sulfate by-product that results from the scrubbing process.

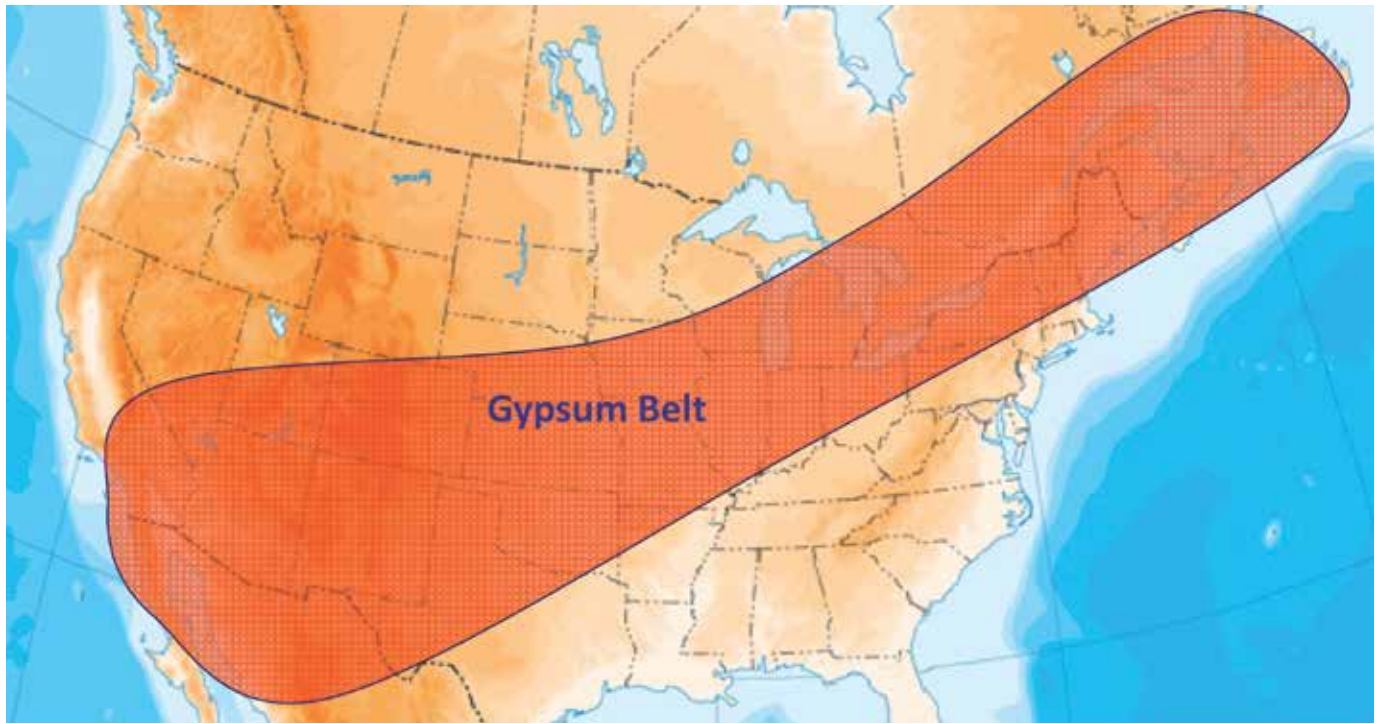
Gypsum board as a building material in the United States goes back to the late 1800s. Around 1890, Augustine Sackett and Fred L. Kane improved on a product Sackett invented in 1884 for the construction of packing crates. It was made of coal tar pitch sandwiched between straw paper. Attempts to use this product on walls and ceilings failed. Legend has it that Kane suggested using manila paper for the straw paper and plaster of Paris (gypsum) in lieu of pitch, and “plasterboard” was born. Sackett received a patent in 1894 and sold his plasterboard business to U.S. Gypsum Company in 1909. It is reported that Sackett produced 525 million ft² of his product annually prior to the sale of his company.

When it was first exhibited at the Chicago World’s Fair of 1933-34, sales of gypsum board—also known as wallboard or drywall—had not taken off. National Gypsum produced all the wallboard used at the Century of Progress Exposition (World’s Fair) in Chicago, which included buildings along a 6-mile parkway.

The market for gypsum board accelerated when World War II created both an urgent need for military structures and a shortage of labor and materials. Gypsum board eliminated the need for wood lath, multiple plaster coats, and days of drying time. To install gypsum board, 4 x 8 ft sheets were nailed up, nail holes filled, and joints taped and textured to disguise defects (Gellner 2003). The United States military was the perfect customer to appreciate the speed and ease of gypsum board versus the slow and labor-intensive process of lath and plaster.

After World War II, builders had become accustomed to the ease of drywall, and it became a popular material to meet the rising demand for homes during the post-war boom years. Prior to this time, American homes were plastered—a labor-intensive process that required nailing thousands of feet of wooden strips





known as lath to the ceilings and walls. The lath was covered with a layer of plaster known as a “scratch coat”. The wet plaster squeezed through the holes, locking it into the surface. Once it dried, days later, a second “brown coat” was applied to create a roughly flat surface. After several more days of drying, a “skim coat” of pure white plaster was applied to create the smooth, creamy, finished surface (Gellner 2003). The entire process could take days or weeks depending on the weather, and no other trades could work during the drying times. Prior to the war, a typical developer built about four houses a year. By the late 1940s, a developer like the legendary Bill Levitt built 17,000 homes at Long Island’s Levittown. Sold for \$7990 each, he made \$1000 of profit on each home (Gellner 2003). Drywall helped to make this type of mass production building a reality. The plaster trade was soon replaced by drywall contractors.

The demand for gypsum board mirrored both population growth and economic expansion in the United States. Gypsum plants were located within the Gypsum Belt (refer to the picture above) to access a mine or quarry or near a port where gypsum rock could be delivered by barge or ocean carrier. The gypsum belt in North America runs diagonally through the United States, beginning in southeastern Canada and continuing down through Mexico. Gypsum is mined in 17 states with the largest producing states (in descending order) being Texas, Oklahoma, Kansas, Nevada, Indiana, and California (Edwards 2015). The largest gypsum quarry in the world is the National Gypsum quarry in Nova Scotia, Canada.

The mandates to scrub power plant emissions in the United States were established to reduce pollution and improve air quality. At the time these mandates were put in place, it would have been difficult to foresee that a by-product from the flue gas desulfurization (FGD) process would revitalize another industry. The introduction of this low-cost, high-quality, readily available raw material brought the gypsum industry into a new era.

National Gypsum first encountered by-product gypsum in 1968 through a joint venture with private investors and Lafarge, a French gypsum board manufacturer, to build and operate a wall-board plant in Carpentras, France. A second plant was built north of Paris at Auneuil. With a Swiss partner, a third plant was built at Ottmarsheim on the French/German border.

The post-FGD era in the United States gypsum industry began in the 1990s with the introduction of high-speed plants located adjacent to or near coal-fired electric power plants to take advantage of the low-cost, high-quality by-product gypsum that eliminated the need for mined gypsum. This opened up geographical locations in metropolitan areas much closer to residential and commercial construction developments.

In 1994, National Gypsum's plant in Westwego, LA, began blending by-product gypsum with natural rock. In 1998, the company opened its first high-speed plant in Shippingport, PA, using 100% by-product gypsum. The by-product gypsum was conveyed directly from the power plant to the new gypsum plant located across the street. In 2001, a plant in Apollo Beach, FL, was opened adjacent to the local power plant. In 2007, a plant in Mount Holly, NC, was opened that is supplied by several coal-fired power plants in the area. Other plants have been able to incorporate by-product gypsum, thus further reducing the need for mined gypsum and diverting more waste from landfills.

The impact of by-product gypsum on the gypsum industry over the last two decades is illustrated in the Gypsum Association (GA) report on total gypsum ore consumption collected from the seven member companies (Fig. 1).

Correlating with the peak in housing, gypsum board production peaked in 2005 at 36.1 billion ft². The industry consumed 9.7 million short tons of FGD, which comprised 35% of all the gypsum ore used to make gypsum board products. In 2015, with housing still recovering, the industry produced 21 billion ft² of board, yet consumed 10 million short tons of FGD, which made up 45% of all ore consumed (Fig. 1).

Since the 2005 peak, the gypsum industry has reduced overall capacity by 2.5 billion ft² as a result of idling older capacity, yet the percentage of FGD use increased from 35 to 45%. This shift is largely due to the addition of new capacity supplied by by-product gypsum and illustrates the growing demand for FGD (Fig. 2).

The American Coal Ash Association (ACAA) conducts a survey of utility companies reporting generation of by-product materials. Recent reports breakout FGD gypsum by use, including gypsum board. As is the case each year, the survey reveals trends in coal combustion products (CCP) production and use. Some of the more significant 2014 findings included the following:

- Total CCP production was up from 2013;
- Production of FGD gypsum increased as more scrubbers became operational; and
- Use of FGD gypsum increased in both gypsum board manufacturing and agriculture.

Increases in the use of by-product gypsum produced by power plant emissions control equipment also helped to push the recycling rate for all types of coal combustion products to a record 48% (ACAA).

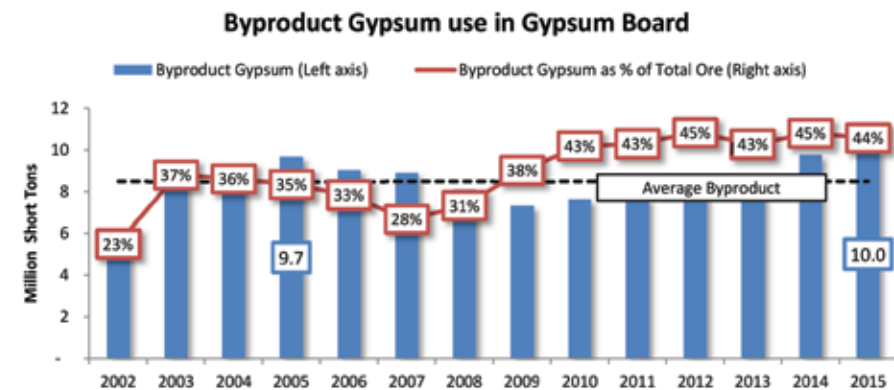


Fig. 1

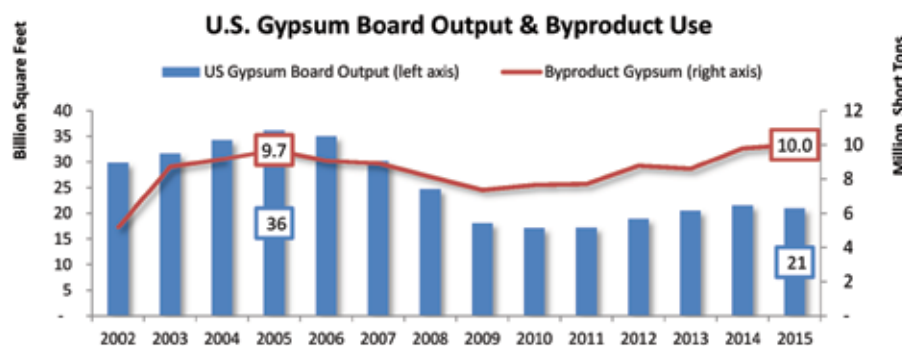


Fig. 2

Overall FGD production volume has increased over five times since 2002 and gypsum panel products consumption has also increased, though at a much lower rate. As a percentage of total FGD produced, gypsum board consumption has declined by almost half from 64 to 33% (Fig. 3). FGD is used for many applications, such as cement feed, mining, concrete, and structural fill, but gypsum board production continues to consume the majority of all FGD that is used (Fig. 4).

Overlaying the two reports offers interesting insights into trends in production, construction cycles, and shifts in the gypsum industry. Because the GA and ACAA data is collected from different sources using different collection methodologies, it is safe to assume some margin of error when comparing the two data sources. However, the results are certainly correlated and at least directionally correct over time.

By-product gypsum production in 2014 increased from 9.7 million to 34.1 million tons. Use of by-product

gypsum increased from 4.8 million to 16.8 million tons, driven by increased use in gypsum board manufacturing and agricultural applications.

There have been both environmental and economic benefits from power plants scrubbing emissions, and the gypsum industry has been a significant downstream beneficiary. The new gypsum plants that have come online during this time are faster, more efficient, and centrally located closer to end-use customers. Some of the benefits of by-product gypsum include:

- Power plants remove emissions from the air;
- By-product gypsum is diverted from landfills;
- By-product reduces demand for natural rock mining; and
- Reduces miles traveled for raw materials and finished products.

Since 2002, the gypsum industry consumed 117 million tons of by-product gypsum that would have otherwise come out of a gypsum mine or quarry. This is enough gypsum ore to produce 100% of the industry's gypsum board production from 2012 to 2014. This by-product gypsum would otherwise have been landfilled by the power companies. Instead, it was used to manufacture a building material that helped construct the places we call home, work, school, and many other structures inhabited every day. Yet it's safe to imagine that the decision to scrub emissions gave little consideration to the long-term benefits it would have on the gypsum industry and the local economies where power plants are scrubbing emissions.

The gypsum industry existed and thrived prior to the availability of by-product gypsum and will continue to manufacture gypsum board with both natural rock and by-product gypsum. However, it's remarkable to note how two seemingly unrelated industries mutually benefit from technology that was first introduced in the 1850s. It's a classic example of technology advancement intersecting with a market need or what is often referred to as innovation or simply a great idea whose time has come. ♦

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Mundise Mortimer is Director of Strategic Planning at National Gypsum Company. Mortimer has been with National Gypsum for over 10 years. Previous roles included architectural marketing and demand management. In addition, she leads the National Gypsum Sustainability Committee.

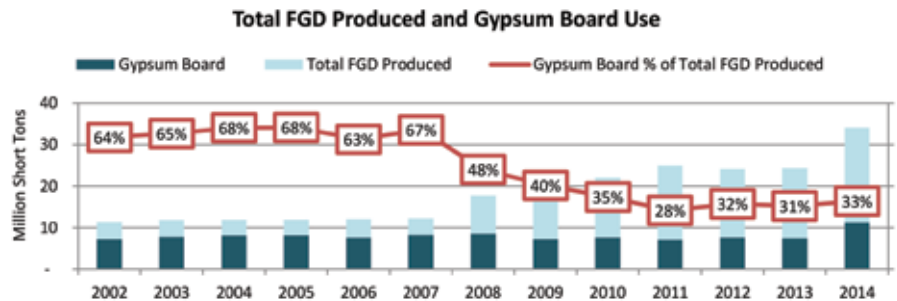


Fig. 3

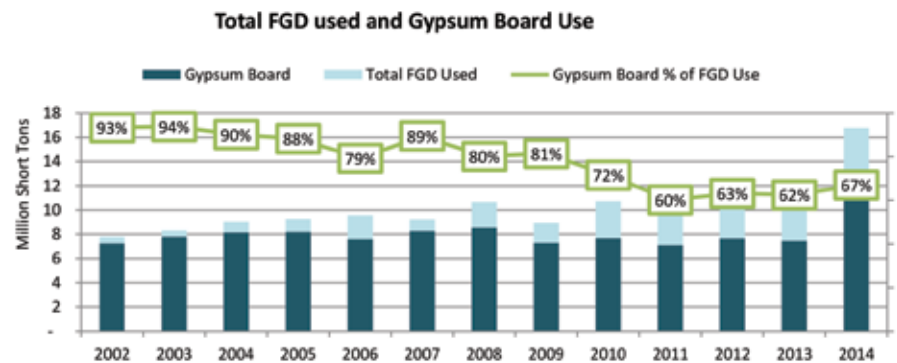


Fig. 4

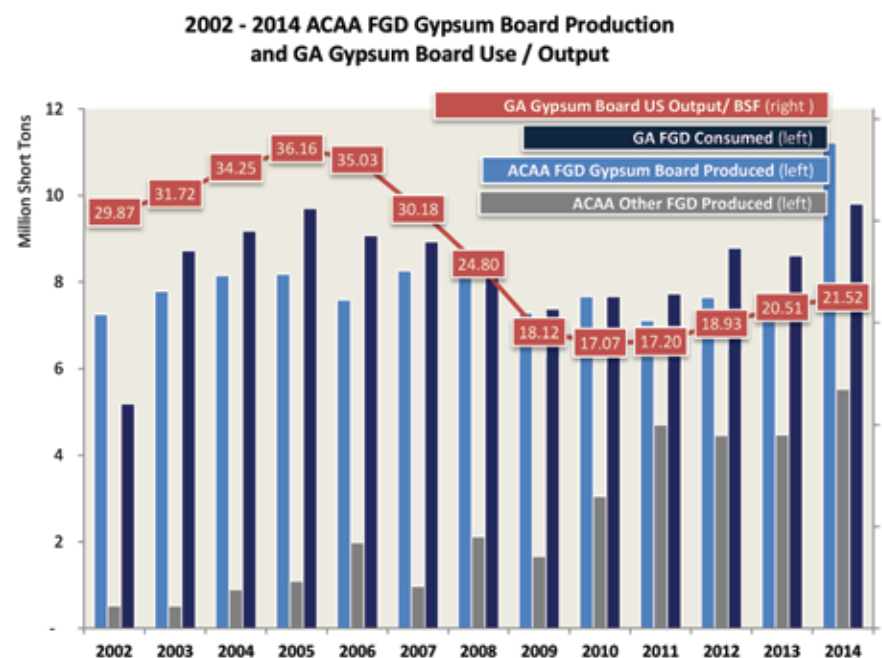


Fig. 5

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GYPSUM MOVES FRONT AND CENTER AS SOIL IMPROVEMENT TOOL

By Karen Bernick

Agronomist Gary Pennell likes to spread colorful field maps across a table when describing why he recommends gypsum. The maps show zones in customer farm fields where added calcium from gypsum applications has helped improve crop productivity.

“Where percent base saturation for calcium is high, we almost always see the highest yield locations in the field, too,” says Pennell, referring to a common soil test measurement to pinpoint the relative levels of various crop nutrients.

“We are raising better crops and using less (traditional) fertilizers like potash and phosphorus,” adds Pennell, who oversees the agronomy department at Farmers Elevator in New Bavaria, OH, about 45 miles southwest of Toledo.

“It happens in field, after field, after field,” Pennell says.

Soil scientists have demonstrated that gypsum can help farmers in a variety of ways and is even referred to by one researcher as the Swiss Army knife of soil amendments. Research shows that gypsum helps manage water infiltration and runoff, reduce nutrient and soil loss, protect water quality, mitigate aluminum toxicity that thwarts roots, repair salt-damaged soils, and

replace deficient nutrients. (See related story on pioneers in gypsum research.)

Armed with scientific evidence of gypsum’s agronomic benefits, plus expanded access to gypsum in locations where crop growers need it, more and more agronomists like Pennell are urging farmers to incorporate it into their farming practices and then witnessing many positive results.

FGD BRINGS WIDER AVAILABILITY

Gypsum isn’t completely new to farming. Mined gypsum, or “land plaster,” was once widely used by Colonial farmers, including Benjamin Franklin and George Washington, as a rich fertilizer. But because gypsum was expensive to transport, its past use was mostly limited to areas with natural gypsum deposits, except for certain specialty crops.

The availability of flue gas desulfurization (FGD) gypsum is changing that. FGD gypsum is a synthetic form of gypsum produced at coal-fired utilities using scrubbing technology to clean sulfur dioxide emissions. It has the same basic chemistry (calcium sulfate dihydrate) as mined gypsum and is virtually free of impurities.

According to the latest industry survey by the American Coal Ash Association, U.S. agriculture’s use of FGD gypsum grew 56% between 2013 and 2014. But the 1.3 million tons applied by farmers is still just a fraction of the 34 million tons of by-product gypsum produced by U.S. utilities in 2014.

One of the pioneers in expanding the use of agricultural gypsum is Beneficial Reuse Management (BRM), the Chicago-based recycling company and marketer of GYPSOIL™ brand gypsum. BRM works with utilities and other synthetic gypsum producers to source high-quality material for land application, assists with permitting, and supports research and education to help demonstrate the impact of gypsum use on agricultural soils.

Since it entered the gypsum market in 2009, BRM has grown its agricultural distribution network from a handful of dealers in three states to more than 500 active dealers in 21 states. BRM also recently built a plant in Winona, MN, to process FGD gypsum into pelletized form that can be mixed with other pelleted fertilizers.



Gary Pennell (right), lead agronomist Farmer's Elevator in New Bavaria, OH, and his associate, Cory Badenhop (left), frequently recommends gypsum for farmer clients to raise calcium levels and improve soil structure.

“Despite a weak agricultural economy and reduced spending on almost all crop inputs, we saw double-digit growth in our sales of bulk gypsum in 2015,” says Robert Spoerri, BRM’s Chief Executive Officer. “We expect continued growth of our bulk gypsum for

growers interested in gypsum’s tremendous soil amendment benefits. The addition of pelletized gypsum to our product offerings will enable us to deliver a cost-effective and high-quality alternative to ammonium sulfate and other higher-cost fertility products.”

NEW FEDERAL PRACTICE STANDARD OPENS DOOR FOR FINANCIAL ASSISTANCE FOR GROWERS WHO USE GYPSUM IN CONSERVATION

The National Resources Conservation Service (NRCS) is the arm of the United States Department of Agriculture that provides technical and financial incentives for farmers adopting conservation practices. Last year, the NRCS reviewed the body of scientific research evaluating gypsum’s impact on soil and water quality and developed a national practice standard for using gypsum as a conservation tool on America’s farms.

The national practice standard, called Code 333, provides technical guidelines for conservationists who make recommendations to farmers, and in some locations, paves the way for cost-sharing incentives for farmers that want to incorporate gypsum in their on-farm conservation initiatives.

Code 333 designates four basic conservation purposes for gypsum applications, including:

- Improve soil health by improving physical/chemical properties and increasing infiltration of the soil.
- Improve surface water quality by reducing dissolved phosphorus concentrations in surface runoff and subsurface drainage.
- Improve soil health by ameliorating subsoil aluminum toxicity.
- Improve water quality by reducing the potential for pathogens and other contaminants transported from areas of manure and biosolids application.

Flue gas desulfurization (FGD) gypsum that is produced by forced-oxidation wet systems after the removal of fly ash is acceptable for these uses. The Code stipulates any materials applied, as part of the program must have chemical analysis documentation with the calcium and sulfur content and content of heavy metals and all other potential contaminants listed in the table. Concentrations of potential contaminants cannot exceed maximum allowable concentrations listed in the table. In addition, the radium-226 concentration in the gypsum-derived product cannot exceed 10 picocuries per gram (pCi/g).

Financial incentives are available through various state programs and grants in at-risk watersheds. One location where financial incentives have been available is the Western Lake Erie Basin, where concerns about water quality came to a head in 2014 when 500,000 residents in Toledo were without drinking water for 3 days.

Prompted by positive water quality research from Ohio State University, Indiana, and Ohio, NRCS adopted gypsum interim programs to help address these concerns in 2015 prior to the national standard. Wisconsin and Michigan NRCS have approved limited gypsum programs in certain watersheds for 2016.

Greg Lake, a farmer in Woodburn, IN, and District Director for the Allen County Soil and Water Conservation District, has used gypsum for approximately 11 years to improve the high-clay soils that are common in the Western Lake Erie Basin and to eliminate crusting and sealing. “We are trying to improve water movement as well as soil quality,” says Lake, who helps area farmers implement conservation strategies, including gypsum applications.

According to Lake, Indiana’s interim gypsum standard is used to guide growers applying for financial incentives available through USDA’s Environmental Quality Incentives Program (EQIP) and the Tri-State Western Lake Erie Basin Phosphorus Reduction Initiative (WLEBPRI) grant. The multi-year program is a designed project to protect the western basin of Lake Erie by reducing phosphorus and sediment loading to decrease harmful algal blooms.

For more information about using gypsum as part of on-farm conservation programs, visit www.gypsoil.com/conservation.

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Screening values for elements in gypsum-derived products for use as a soil amendment.

| Symbol (Element) | Units gram (g) kilogram (kg) milligram (mg) | Screening Value for Gypsum-Derived Products | Comment |
|--------------------|--|---|--|
| Ag (Silver) | mg kg ⁻¹ | | No limit required |
| Al (Aluminum) | g kg ⁻¹ | | No limit required |
| As (Arsenic) | mg kg ⁻¹ | 13.1 | ... |
| B* (Boron) | mg kg ⁻¹ | 200.* | |
| Ba (Barium) | mg kg ⁻¹ | 1000. | |
| Be (Beryllium) | mg kg ⁻¹ | 2.5 | |
| Ca (Calcium) | g kg ⁻¹ | | Ca fertilizer; no limit required |
| Cd* (Cadmium) | mg kg ⁻¹ | 1.0 | |
| Co (Cobalt) | mg kg ⁻¹ | 20. | |
| Cr(III) (Chromium) | mg kg ⁻¹ | 100. | |
| Cu (Copper) | mg kg ⁻¹ | 95. | |
| Fe (Iron) | g kg ⁻¹ | | No limit required |
| Hg (Mercury) | mg kg ⁻¹ | 2.5 | |
| Mg (Magnesium) | g kg ⁻¹ | | Mg fertilizer; no limit required |
| Mn (Manganese) | mg kg ⁻¹ | 1500. | |
| Mo (Molybdenum) | mg kg ⁻¹ | 10. | |
| Ni (Nickel) | mg kg ⁻¹ | 100. | |
| Pb (Lead) | mg kg ⁻¹ | 30. | |
| S* (Sulfur) | g kg ⁻¹ | 220. | S fertilizer; *limit access to ruminants |
| Sb (Antimony) | mg kg ⁻¹ | 1.5 | |
| Se (Selenium) | mg kg ⁻¹ | 50. | |
| Sn (Tin) | mg kg ⁻¹ | | No limit required |
| Tl (Thallium) | mg kg ⁻¹ | 1.0 | |
| V (Vanadium) | mg kg ⁻¹ | 136. | |
| Zn (Zinc) | mg kg ⁻¹ | 125. | |

* Should not apply greater than 0.9 lb. hot water soluble B/acre with gypsum amendment application rate.

* Cd is 1% of Zn limit to restrict food-chain risks of soil Cd.

* Prevent ruminant livestock from ingesting gypsum from storage piles; prevent grazing on amended pastures until one rainfall (or irrigation) event to wash forage.

From USDA Document CPS-1 Code 333. NRCS, NHP June 2015.

“Crop growers are looking for ways to get the most out of their spending on crop inputs and be more sustainable, too,” Spoerri says. “One of the highest value resources in farming is soil and farmers are paying attention to ways to improve it.”

An annual reader survey by *No Till Farmer*, a farm magazine geared to growers that practice no-till or conservation tillage, indicates that gypsum use has tripled among its readers since 2008.

AGRONOMISTS TOUT GYPSUM'S IMPACT

Joe Nester, an independent agronomist and owner of Nester Ag, based in Bryan, OH, was first impressed with gypsum's potential impact as a soil amendment at a farm field day back in 2002. Many of Nester Ag's clients operate in the Western Lake Erie Basin where tight, clay-based soils are prone to runoff, ponding, and soil particle loss during rain events if not properly managed.

At the 2002 field day, USDA researcher Darrell Norton used a rainfall simulator to demonstrate that gypsum-treated soils behaved differently than untreated soils, even with similar tillage. Treated soils absorbed more water and lost less soil sediment when rain was set to replicate a typical Midwest rainfall event.

“A light bulb turned on in my head,” says Nester. “When water runs through soils, it pulls air into the soil with it. That's the magical part that creates the soil life.”

Nester recommends gypsum to deliver calcium to tight clay soils that are high in magnesium. He suggests his clients amend soils to aim for soil test values of 12 to 15% base saturation for magnesium and at least 65 to 70% calcium, particularly for heavier soil with some clay content. Nester says when test numbers move closer to those levels, soil physical properties begin to improve. Nester is careful to point out that gypsum is neutral in pH so it does not replace agricultural lime used to change soil pH.

“For farmers to know if gypsum would be a correct tool to use on their farms to improve soil quality or water infiltration,

first they are going to need a good representative soil test,” says Nester. “If they have clay soils, they need to look at their calcium and magnesium relationships because the gypsum can be used to alter that so that water infiltrates better, minimizing crop stress and the duration of that stress.”

Nester does not sell gypsum or other crop inputs. Instead, he and his four employees, who take advanced training through the American Society of Agronomy (ASA) to become Certified Crop Advisers (CCAs), are hired by crop growers to review cropping practices, soil tests, yield, and other data and then make soil management recommendations.

WATER QUALITY AID

Three years ago, Nester was also tapped by soil scientists at Ohio State University to coordinate on-farm sampling in a multiyear study to measure impacts of gypsum applications on water quality. The ongoing study has shown gypsum decreases concentrations of soluble reactive phosphorus (SRP) in tile water by 30 to 60%. This demonstrates gypsum's potential as an effective tool to help reduce the amount of phosphorus running off farm fields into sensitive waterways. The OSU findings, as well as other studies at land grant universities and the USDA, were instrumental in a new conservation practice standard adopted by the Natural Resources Conservation Service (NRCS) in 2015. (See sidebar.)

Greg Kneubuhler is an independent agronomist and owner of G & K Concepts, Inc., based in Harlan, IN, with clients in northern Indiana and northwest Ohio. “We see more interest in gypsum now more than ever,” says Kneubuhler, who is also a CCA. “There is a lot of value in managing the calcium and the calcium-magnesium relationship, particularly related to soil structure.”

“If we keep phosphorus in the fields by managing soil structure, it improves our environment and crop yields,” adds Kneubuhler.

“With gypsum, phosphorus attaches to the calcium and forms calcium phosphate so it is not leaching away,” observes Gary Pennell. “It is tremendous for water quality and the crops respond, which translates into yield and into dollars.”



Spoerri



Nester



Kneubuhler



Polenske

SULFUR REPLACEMENT

In Wisconsin, agronomist Jeff Polenske, who heads Tiltch Agronomy Group based in Appleton and was named ASA's International CCA of the Year in 2015, started recommending gypsum years ago as a "cheap source of sulfur" for alfalfa and other crops grown by his clients.

Sulfur helps plants form amino acids that build protein and it also helps nitrogen-fixing legumes, such as alfalfa and soybeans, use and store nitrogen. At 13 to 17% sulfur in the sulfate form, Polenske says gypsum is an excellent source of sulfur, which is often deficient today due in part to less acid rain.

"Getting as much sulfur on the crop as possible is always a goal," Polenske says. "Growers usually get their money back from gypsum on just the sulfur."

Beyond sulfur, Polenske says he's also noticed soil structure improvements when gypsum is applied to soils that are slow to drain and highly compactable. "We see less ponding and runoff," he says.

Soil health has certainly become a focal point in agriculture. The Food and Drug Organization of the United Nations declared 2015 as the International Year of the Soils. The Natural Resources Conservation Service created a major public service initiative as well—"Unlock the Secrets in the Soil"—to call attention to soil improvement. Soil health and ways to improve it are frequent topics in farm magazines and at industry events and tradeshows.

"The soil is a living thing," says Nester. "As land values, crop values, and input values all increase and water quality becomes more important, soil health becomes even more important."

With its tremendous potential to amend soil quality, agricultural gypsum seems poised and ready to make an important impact in advancing productive and earth-friendly farming practices. ♦

Karen Bernick is a freelance writer and communications consultant based in Iowa.



GYPSUM WEBINARS REACH WIDE AUDIENCES

Interest in agricultural gypsum has recently prompted various continuing education opportunities for crop consultants and other professionals involved in agronomy.

In January, the American Society of Agronomy (ASA), a scientific organization made up of soil and crop scientists, crop consultants, and other professional agronomists, staged its first gypsum-related webinar as continuing education for ASA members plus others. The event, sponsored by Beneficial Reuse Management/GYPSOIL, drew a large audience, with over 1350 registered participants.

The webinar was designed to respond to the growing interest in gypsum and related new conservation practice standards according to webinar facilitator Dr. Clay Robinson, ASA's Agronomy and Soil Science Education Manager. Featured speakers included soil scientist Dr. H. Allen Torbert, United States Department of Agriculture-Agricultural Research Service, Auburn, AL; soil scientist Dr. Warren Dick of Ohio State University (OSU); and Ron Chamberlain, lead agronomist and director of research from Beneficial Reuse Management/GYPSOIL.

"We had several questions from CCAs about using gypsum, and in 2015, the USDA-NRCS published its new amendment standards that apply to gypsum," says Dr. Robinson. For more information about ASA webinars, including registration for on-demand viewing of the gypsum webinar, visit www.agronomy.org.

"It is important to realize gypsum has different uses as a soil amendment, and to identify which of those uses is appropriate for a site-specific use," Dr. Robinson adds.

This past December, another crop industry group, the IPM Institute of North America, Inc., sponsored a similar webinar, "Building Profitability and Protecting Water Quality through Gypsum," via the Partnership for Ag Resource Management. OSU's Dr. Warren Dick and Cory Schurman of GYPSOIL were featured speakers.

With 270 registered and 179 live participants, mostly agricultural retailers and certified crop advisers, IPM Institute organizers reported the gypsum event doubled attendance compared to all previous webinars. A replay of the IPM webinar can be viewed at <http://partnershipfarm.org/webinars/>.

CULTIVATING PUBLIC POLICY SUPPORT FOR AGRICULTURAL GYPSUM

By Nancy Pals and Joshua More

The recent Federal attention to flue gas desulfurization (FGD) gypsum and its use in agriculture has created a focus on issues facing the interstate use of gypsum within the agricultural industry. Currently, over 20 states have approved FGD gypsum for use in agriculture. However, each state has developed—or is developing—its own regulatory systems, guidelines, and regulations for CCPs and the use of FGD gypsum in agriculture. This has resulted in some confusion and frustration for in-state, as well as interstate, marketers and end users of this product. The lack of consistency among states regarding use, registration, oversight, and testing requirements has created uncertainty and, as a result, can be prohibitive to widespread acceptance and use. In an era of tightening budgets and increasing regulatory oversight, gone are the days when FGD gypsum was sold out the back door of the landfill. Navigating the labyrinth of red tape and add-on costs can become time-consuming, so it is critical to identify and communicate with the policy makers in the states in which you wish to market gypsum.

So, who are the policy makers? To answer that question, one must first know how the state categorizes FGD gypsum being used in agriculture. Some states may require chemical analysis (including TCLP and/or total metals analysis); some classify it as a solid waste, fertilizer, or soil amendment; and still others have no laws regarding its use for agriculture. Generators may also have concerns about the viability of such use and the benefits versus liability if they allow their product to be used in such a manner, and may require education about the benefits to agriculture and soil health.

Using a grassroots approach to working with local farming groups has proven helpful in expanding the acceptance of FGD gypsum use.

Expanding the acceptance of FGD gypsum use in modern agriculture requires that the marketer have a full understanding of the opportunities as well as the challenges facing the FGD gypsum market before approaching state policymakers and customers. If a state registers FGD gypsum as a fertilizer, typically the State Department of Agriculture, the State Chemist, or both, will drive policy. If a state considers FGD gypsum a solid or industrial waste, the state environmental agency usually will drive policy. If you are unsure of the regulatory status of FGD gypsum in your state, the best place to start is with the state environmental agency.

Having said that, there are several positive factors driving the expansion of the agricultural gypsum market in the United States. In 2015, the USDA's Natural Resources Conservation Service (NRCS) released a federal conservation practices standard for gypsum use. In these new guidelines, FGD gypsum is specifically mentioned as beneficial to agriculture and is included in the standard. The release of the NRCS Conservation Practice Standard 333 paves the way for state NRCS offices to request that FGD gypsum use be included in USDA federal cost-share programs for conservation. This factor will help drive broader acceptance of agricultural FGD gypsum use. FGD gypsum used in combination with other approved practices is already helping states address water quality concerns, including the problem of excess phosphorus in bodies of water.

Using a grassroots approach to working with local farming groups has proven helpful in expanding the acceptance of FGD gypsum use. In addition, building relationships with local Soil and Water Conservation Districts and Farm Bureaus is also an excellent way to begin educating stakeholders (including policy makers, regulators, generators, distributors, and end-users) about the benefits of FGD gypsum use in agriculture.

CASE STUDY: GYPSUM POLICY IN ILLINOIS

Prior to the signing of Public Act 099-0020 in the summer of 2015, using gypsum in Illinois was, to put it mildly, a nightmare. Illinois classified FGD gypsum as a waste sludge and, as such, it was subject to unreasonably strict guidelines for land application. In addition to requiring an Illinois Environmental Protection Agency (IEPA) permit, the State imposed restrictive use guidelines, a buffer and a requirement to notify every landowner that was adjacent to a field on which FGD gypsum was applied. The State also required townships and counties to be notified of each application in each individual field. Indeed, every ton which was applied had to be recorded and turned in as a monthly usage report to the IEPA. The requirements were restrictive and prohibitive. The farmers wanting to use gypsum were leery of excessive bureaucratic interference on their farms and the paperwork was a nightmare for the marketing companies. Moreover, the fertilizer dealers wanted nothing to do with gypsum.

Notwithstanding these overly burdensome restrictions, gypsum was needed in a state where over a million acres were sodium and sodic or brine damaged. Gypsum provides valuable agricultural benefits, such as improvement to soil health, sulfur, and phosphorus reduction.

In an effort to address this regulatory impasse, in the spring of 2015, Headwaters Resources met with the local United States Department of Agriculture offices and the St. Clair Farm Bureau to discuss how to move FGD gypsum out of the sludge permit program. Those meetings then transitioned into a grassroots plan to develop support from the agricultural and environmental stakeholders. Headwaters then partnered with Beneficial Reuse Management and engaged Schiff Hardin LLP to pursue a fix. The first step was meeting with IEPA Director

Lisa Bonnett and her senior staff, who all agreed that FGD gypsum should not be regulated as a waste sludge and were willing to partner with us to pursue a fix. IEPA determined that the cleanest fix would be through legislation to change the Illinois Environmental Protection Act and reclassify FGD gypsum as a coal combustion byproduct.

The coalition secured the sponsorship of Senator John Sullivan and Representative Jerry Costello for their legislative initiative, Senate Bill 543. They drafted a one-page summary of the proposal for their sponsors and more in depth talking points for them to use for floor debate. The coalition also secured the support of several environmental and industry agencies and organizations, such as IEPA, the Illinois Department of Agriculture (IDA), Illinois Environmental Regulatory Group, Illinois Fertilizer and Chemical Association, and the Illinois Farm Bureau. All of this groundwork paid off, as Senate Bill 543 passed unopposed in both chambers of the General Assembly and was sent to the Governor with much support and no opposition.

The coalition also lobbied Governor Rauner's staff to convey the agricultural and business benefits of making this statutory change. Governor Rauner's team was enthusiastic about the change and Senate Bill 543 was among the first group of bills the Governor signed into law. Public Act 099-0020 has completely changed the regulation of FGD gypsum in Illinois. Gypsum is no longer regulated by IEPA as a waste sludge, but rather by the IDA as a fertilizer or amendment. As a result, the gypsum market in Illinois is now open to benefit the power plants which manufacture the material, the marketers who sell the material, and more importantly, the farmers who can apply the material.

A coalition of farmers can have a positive effect on both policy-makers and promoting widespread use of gypsum in agriculture. An example of this occurred last year in a state that regulated FGD gypsum as a waste sludge. The regulations were restrictive and hampered the use of gypsum in agriculture. A coalition was formed by the state's farm bureau and local farmers. That coalition then approached the state's legislature and drafted a bill to change the regulation. The FGD gypsum marketing companies in the state were part of the process, but did not bring the issue to the legislature; the local farmers worked with the state department of agriculture, environmental protection agency, and other participants to change the law in a manner that expanded gypsum use in the state. Marketing companies played a key role by bringing together the stakeholders to explain the issues facing gypsum use in the state, the benefits to natural resources, and the benefits to farmers. The companies provided detailed technical support and played a role in facilitating the various participants and their roles. The local farmers, led by the Farm Bureau, took the information and used it to bring about much-needed change. This approach worked in a state where previous business-led efforts to change the regulations for FGD gypsum had failed.

Stakeholder involvement is crucial in cultivating support for FGD gypsum use in agriculture.

Having stakeholder involvement is crucial in cultivating support for FGD gypsum use in agriculture. Without it, marketing efforts will fall on deaf ears. Education and involvement at a local, county, and state level is vitally important in helping all parties recognize and understand the value provided by the resource. ♦

Nancy Pals is a Gypsum Marketing Specialist with Headwaters Resources based in Illinois.

Joshua R. More is a partner in Schiff Hardin's Environmental Group with broad experience counseling clients on air, water, and waste enforcement and permitting and compliance issues. He frequently presents on coal ash issues around the United States.

FGD GYPSUM MARKETING APPLICATIONS AND EXPERIENCES:

Boral Material Technologies

By G. Craig Plunk

Boral Material Technologies LLC (BMT) is a principal marketer of coal combustion products (CCP) in the United States. In addition to fly ash marketing, BMT also provides coal-fired power generating plants with complete on-site CCP handling and management, environmental, construction, technical, and engineering services. BMT began marketing CCPs including flue gas desulphurization (FGD) products in 1978.

BMT is a division of Boral Industries based in Alpharetta, GA. As well as CCP management, Boral's United States-based businesses include Boral Bricks Inc., a leading manufacturer of brick in the United States; Boral Roofing LLC, a manufacturer of clay and concrete roof tiles; Boral Stone Products LLC, manufacturer of Cultured Stone® and Boral Versetta Stone®, the leading brand of mortarless manufactured stone veneer panels; and Boral Composites Inc., manufacturer of Boral TruExterior® Siding and Trim, pioneer of the innovative poly-ash category of exterior building products.

FGD is the residue remaining after flue gas undergoes sulfur removal (desulfurization). At coal-fired electrical generating stations, this desulfurization process is designed to remove sulfur dioxide (SO_2) from exhaust flue gases by injecting CaCO_3 (limestone) into the hot flue gases. The calcium carbonate reacts with the sulfur in the flue gas, producing CaSO_3 (calcium sulfite).

Depending on the specific equipment design, the CaSO_3 can be further oxidized to yield calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) by using forced oxidation. History and experience has shown that calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) normally commands a higher value and provides for additional marketing opportunities. ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is more commonly referred to as synthetic gypsum. The quantity of FGD, both CaSO_3 and ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), that has been produced and is available to market has certainly trended upwards over the last several years. This increase is due to both increased regulatory requirements affecting emissions and the economic advantages to the generators available by using higher sulfur fuels in conjunction with FGD equipment.

The quality and purity of the FGD residue produced at coal stations can vary widely depending on the specific facilities' process design, collection method, and fuel composition. The chemical composition, purity, and quality of the FGD will in most cases determine the specific application best suited for the material. The purity of CaSO_4 or FGD synthetic gypsum in most cases (>95%) exceeds that of natural rock gypsum mined from the earth. The purity of mined gypsum varies from 75 to 95% depending on natural geological variations within the mine. Making use of FGD gypsum is an excellent form of recycling and sustainability by saving landfill space as well as conserving natural rock gypsum.

FGD gypsum can be used in a variety of applications such as portland cement manufacturing, wallboard manufacturing, agricultural uses, waste stabilization, and mine reclamation. In a 2014 survey, FGD gypsum production increased from 9.7 million to 34.1 million tons as emission-control devices were added and operated at coal-fired power stations. The use of FGD gypsum in 2014 increased from 4.8 million to 16.8 million tons. This was mainly driven by increased use by cement manufacturers, wallboard manufacturers, and agriculture usage.

PORTLAND CEMENT

In the production of raw portland cement, the heating of a homogeneous mixture of raw materials, mainly limestone and various clays, will produce clinker. The clinker consists of various calcium silicates, tricalcium aluminate, and calcium aluminoferrite. Once the clinker lumps have cooled, approximately 5% gypsum is added and then the combined materials are ground



Synthetic gypsum



into a fine powder. The gypsum plays a very important role during the cement manufacturing process. The introduction of FGD gypsum into the cement is used to control the set time of the cement. If not added, the cement will set immediately after mixing of water leaving no time for concrete placing.

Boral has been marketing FGD gypsum to the cement industry for over 20 years now. One of the advantages that FGD gypsum has over natural rock gypsum is that because of its high purity, cement plants can use less FGD gypsum than natural rock gypsum to achieve the desired portland cement chemistry. A disadvantage to using FGD gypsum in the past was its high moisture content, which made it difficult to feed properly. Today, through more innovative feed system designs, cement plants are better equipped to handle and therefore use more FGD gypsum.

WALLBOARD

Boral has marketed synthetic FGD gypsum to the wallboard industry for over 20 years. Synthetic FGD gypsum is now used in over 40% of domestically manufactured wallboard. Chemically, the synthetic FGD gypsum contains fewer impurities than gypsum extracted from gypsum mines. Synthetic FGD gypsum is normally blended with natural rock gypsum for wallboard manufacture as a means to control production cost and quality. Wallboard manufacturers in the 1990s recognized they could lower manufacturing costs by using synthetic FGD gypsum and have been successful in leveraging the environmental benefits of recycling.

Controlling the moisture content and the chloride content of synthetic FGD gypsum are critical to maintain high levels of quality control in synthetic FGD gypsum for wallboard manufacture. The control of moisture content in synthetic FGD gypsum is essential to wallboard manufacturers. Typically, wallboard manufacturers specify that the synthetic gypsum moisture content not exceed 15%. The higher the moisture content in the synthetic FGD gypsum, the more energy must be expended to dry the material, with the end result being higher manufacturing cost. Additionally, higher-moisture-content gypsum can present more challenges when transporting and feeding the manufacturing process.



Portland cement

| Chemical tests | Source A | Source B |
|---|----------|----------|
| Silicon dioxide (SiO ₂), % | 0.08 | 2.32 |
| Aluminum oxide (Al ₂ O ₃), % | 1.02 | 1.76 |
| Iron oxide (Fe ₂ O ₃), % | 0.36 | 0.77 |
| Sum of SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃ , % | 1.46 | 4.85 |
| Calcium oxide (CaO), % | 34.61 | 40.35 |
| Magnesium oxide (MgO), % | 0.00 | 0.43 |
| Sulfur trioxide (SO ₃), % | 42.81 | 53.62 |
| Sodium oxide (Na ₂ O), % | 0.08 | 0.34 |
| Potassium oxide (K ₂ O), % | 0.01 | 0.04 |
| Total alkalis (as Na ₂ O), % | 0.09 | 0.37 |
| Physical tests | | |
| Moisture, % | 15.30 | 20.77 |
| Loss on ignition, % | 20.99 | |

| Source | Chloride content, ppm |
|--------|-----------------------|
| A | 151.7 |
| B | 87.9 |
| C | 5.38 |
| D | 4.43 |

The chloride content of synthetic FGD gypsum must also be monitored and controlled when used in wallboard manufacture. High chloride levels can interfere with the wallboard paper adhering to the gypsum board. It is recommended that the chloride content not exceed 100 ppm. Typically, the chloride content is determined by the individual power plant process design and is dependent on the chloride content of the source water and the degree to which the water is recirculated.

AGRICULTURE

There are a number of beneficial uses of gypsum in agriculture. As a soil amendment/conditioner, gypsum improves soil structure, is a soil aerator in clay and compacted soils, decreases the bulk density of soil, decreases dust erosion, improves the ability

of soil to drain, and improves water-use efficiency. By improving soil structure, gypsum improves the growth medium in plants, vegetables, lawns, hay production, and peanuts.

Boral has marketed FGD gypsum for agricultural use since the early 1990s. Since then, the largest agricultural market has been its use in peanut production. Calcium and sulfur are two important nutrients in peanut production. Calcium is by far the most critical nutrient for achieving high yields and grades. Low levels of calcium may cause several serious production problems, including unfilled pods, pod rot disease, poor grades, darkened spots in the seed and poor germination. FGD gypsum also provides low-cost sulfur for soils deficient in this mineral.

There have been many challenges in marketing FGD gypsum from coal-fired power plants over the years. Being able to meet those challenges are important because the product has so many beneficial uses across many markets, not to mention its positive effects on environmental sustainability. ♦

G. Craig Plunk, PE, is Director Technical Services for Boral Material Technologies LLC. He is a member of ACI Committees 211, Proportioning Concrete Mixtures, and 232, Fly Ash in Concrete; and ASTM Committee C09, Concrete and Concrete Aggregates. He is a licensed professional engineer in multiple states since 1986.



FGD synthetic gypsum in agricultural application



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COAL COMBUSTION PRODUCTS IN THE FABRICATION OF CALCIUM SULFOALUMINATE CEMENT— A New Low-Carbon Alternative to Ordinary Portland Cement

By Tristiana Y. Duvallet and Thomas L. Robl

The principal ingredients of ordinary portland cement (OPC) are limestone and clay, which are milled, mixed, and heated to a temperature typically between 1400 and 1450°C in a rotary kiln. The chemistry of the cement meal is formulated to create the phase responsible for most of the strength development in OPC, “alite” or tricalcium silicate (C_3S), from belite, or dicalcium silicate (C_2S). This reaction requires a liquid phase to occur, which is provided by both phases tricalcium aluminate (C_3A) and ferrite (C_4AF) (an iron-rich calcium aluminate).

OPC is the world’s most widely used construction material, with an annual production of more than 3.6 billion tons.¹ The amount of carbon dioxide released, originating from both the calcination of limestone and the combustion of the fuels, varies from about 0.7 to 1.0 tons of CO_2 per ton of cement produced, which represents around 5% of the anthropomorphic global CO_2 emissions.²

One way to reduce carbon emissions from OPC is through supplementary cementitious materials (SCMs), of which coal combustion fly ash is the most important. ACAA estimated that in 2014, 32.8% of fly ash produced was used in concrete and cement products.³ This presents a cost savings and a major reduction of carbon emissions through direct substitution for OPC, as well as improved concrete durability and strength, resulting in longer service life.⁴

CALCIUM SULFOALUMINATE CEMENT (CSA) AND COAL PRODUCTS

Practical low-carbon alternatives to OPC are difficult to come by. OPC can be fabricated from common materials and natural

resources, such as limestone and shale that are found almost everywhere. One cement that is showing some potential as an alternative are calcium sulfoaluminate (CSA) cements. CSA can be produced from gypsum or anhydrite and bauxite, which are common and abundant materials, although not as inexpensive or widely available geographically as limestone and shale.

The first version of CSA was produced and used as shrinkage-compensating admixtures to OPC. Large-scale applications of CSA cement were first developed in China in the 1970s in response to the energy crisis at the time. The production of CSA in China has grown to about 1 million tons per year.

In CSA cement, the principal phase responsible for strength development is $C_4A_3\$$, or Klein’s compound, named after Alexander Klein of the University of California, Berkeley, who worked on these materials in the 1960s. The mineral name for this phase that is also used is Ye’elimite. Upon hydration, Klein’s compound hydrates to ettringite, which is responsible for the early strength development: CSA cements can gain 75 to 80% of their strength within 1 day—much faster than OPC—presenting a useful performance advantage.

CSA cements can be used in specialized applications: small/medium precast concrete shapes, heavy prestressed concrete elements, construction engineering (especially in winter), mass and impermeable concrete, and various applications.⁵ CSA is also compatible with OPC and an important application is increasing the rate of strength development of OPC-CSA concrete, as well as improving bonding properties.

CSA cements can have a broad range of composition ranging from nearly pure Klein’s compound, to Klein’s compound with other phases. Three general types of CSA cements include CSA – belite cement, abbreviated CSA/B; calcium sulfoferroaluminate cement (CSFA); and calcium sulfoferroaluminate – belite cement (CSFA/B).

Because of this, CSA can be fabricated from a wide variety of materials such as fluidized bed combustion spent bed materials, bauxite processing muds (red mud), fly ash, bottom ash, and

CEMENT NOTATION:

| OPC = ordinary portland cement | CSA = calcium sulfoaluminate |
|--------------------------------|------------------------------|
| C = CaO | F = Fe_2O_3 |
| S = SiO_2 | $\$$ = SO_3 |
| A = Al_2O_3 | H = H_2O |

in particular, flue gas desulfurization (FGD) gypsum. In CSA cements, 10 to 35% FGD gypsum can be used for the production of the CSA clinker⁶⁻⁹; and an additional 15 to 30% FGD gypsum to produce the CSA cement (necessary to form ettringite when cement is mixed with water).^{10,11}

In contrast OPC, the maximum content of SO_3 is allowed under ASTM standards is no more than 4.5%.¹²

CSA AND CARBON REDUCTION

Another advantage of CSA cements over OPC are the CO_2 emissions released during their production. As it can be seen in Fig. 1, C_3S and $\text{C}_4\text{A}_3\text{S}$ are the most abundant phases (up to 75 wt.%) in OPC and CSA cements, respectively, and the carbon dioxide released from the production of these phases differs significantly; the production of 1 g of $\text{C}_4\text{A}_3\text{S}$ releases 0.216 g of CO_2 , while the production of 1 g of alite (C_3S) releases 0.578 g of CO_2 .

The difference in the firing temperatures necessary to form $\text{C}_4\text{A}_3\text{S}$ and C_3S is significant: C_3S is formed at firing temperatures close to 1450 to 1500°C, while $\text{C}_4\text{A}_3\text{S}$ can easily be formed at 1200 to 1250°C, representing a significant energy saving in fuel consumption.

Production of CSA cements can easily be performed in current OPC plants, using rotary kilns, and thus no additional expenses are necessary in purchasing special kilns, representing enormous savings for companies willing to switch from OPC to CSA cement production. In regard to cost and energy savings, grinding CSA clinker requires less energy compared to OPC clinker due to the presence of $\text{C}_4\text{A}_3\text{S}$ in CSA cement, which is easier to grind than alite (C_3S).

An important obstacle in the industrial development of CSA cements are the material costs and the fact that OPC has now been used for over a century, with a well-established research background. The alumina source needed for the production of CSA cements comes from bauxite, which is an expensive material. Yet, their high-early-strength development, even in cold temperatures, can be perceived as an advantage over the price, reducing the length of construction time and projects.

CAER AND CSA RESEARCH

The University of Kentucky Center for Applied Energy Research (CAER) has been studying CSA cements for over 15 years. The reason for this attraction is that CSA cements can be produced using very high levels of coal combustion by-products as discussed previously. Their work has focused on two areas: the use of coal combustion products and other industrial by-products in its fabrication, and improving its performance. The overall goal has been to reduce its cost and increase its environmental performance. Current CSA cement research projects at CAER include:

Production of CSA cements from coal combustion products¹⁴

One area of focus has been the use of fluidized bed combustion (FBC) spent bed as a raw ingredient. FBC spent bed contains both calcium sulfate and a large amount of raw lime. Its use

further reduces carbon emissions, as well as cost. A wide variety of formulations were tested in bench scale equipment. Two formulations were fabricated using a research rotary kiln similar to the ones used to produce portland cement. These CSA cement formulations, referred to herein as CSAB#4 and CSFAB#3, were fabricated from approximately 45 to 50 wt.% limestone, 20 to 25 wt.% spent ash, and 30% bauxite. Additional FGD gypsum was added to the CSA clinkers in the order of approximately 25 wt.% and was added to the clinker as well.

Mortar cubes of these two compositions, CSAB#4 and CSFAB#3, were produced and compared to OPC Type I and a commercial available CSA cements, which are two commercially available cements, by following ASTM C305¹⁵ and ASTM C109.¹⁶ Compressive strengths after 1, 7, 28, and 56 days were measured and are shown in Fig. 2. The commercial CSA demonstrates high early compressive strength of 30 MPa compared to 14 MPa for OPC after 1 day. However, after 56 days, both cements exhibit a compressive strength of around 40 MPa. Both research cements created at CAER exhibited higher strengths than the commercial cements. CSFAB#3 had similar strength compared to OPC after 1 day, but was stronger than OPC after 56 days. For the case of CSAB#4, it demonstrated similar strength to the commercial CSA after 1 day, but almost doubled the strength after 56 days.

This project, in collaboration with the U.S. Department of Energy and the National Energy Technology Laboratory (NETL), successfully demonstrated that CSA cements produced from coal combustion by-products can present higher mechanical properties compared to commercially available OPC and CSA cements.

Production of hybrid “Alite-CSA” cement

CAER began collaborating with Professor Yongmin Zhou of Nanjing University in 2009 on the development of a practical CSA-alite cement or CSA/A. The belite in CSA cement, as well as in OPC, has little contribution to the strength development. It generally exists as a phase that helps to tie up excess silica. Mineralizers and fluxing agents were used to lower the formation temperature of alite (usually close to 1400°C) to that compatible with Klein’s compound—that is, 1250 to 1275°C.

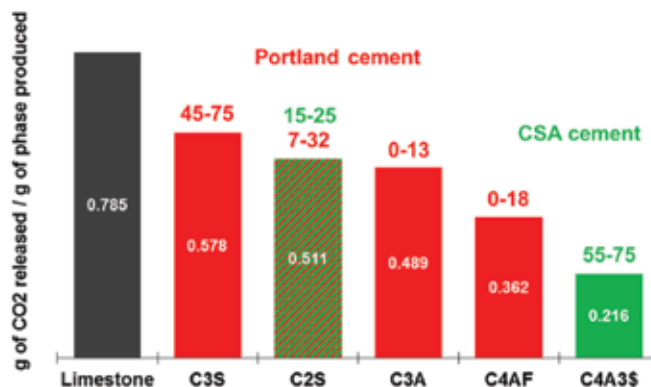


Figure 1. Graph illustrating the amount of carbon dioxide released for the production of clinker phases in OPC and CSA cements during the calcination process.¹³ Above the bars are values representing the contents by mass of each clinker phase in OPC and CSA cements.



Figure 2. Images of: The rotary kiln used at CAER (left), pellets being fired in the rotary kiln (upper right); and clinker pellets following the firing process (lower right)

A critical part of this effort also included the development of modulus values needed to predict phase compositions in this system. A U.S. patent was eventually awarded to CAER for this effort in 2015.¹⁷

This hybrid cement is a combination of both C_3S and C_4A , which are the phases responsible for most of strength development in OPC and CSA cements, respectively. This ongoing research project demonstrates the feasibility of producing this material and is now focusing on its durability properties.

CONCLUSIONS

Calcium sulfoaluminate cements are low-energy and low- CO_2 emission materials, and represent a viable alternative to portland cement. These materials represent a potential for coal combustion product use that greatly exceed that for OPC.

ACKNOWLEDGMENTS

Special thanks to the contributing authors Robert B. Jewell and Anne E. Oberlink, for helping in the writing of this article. ♦

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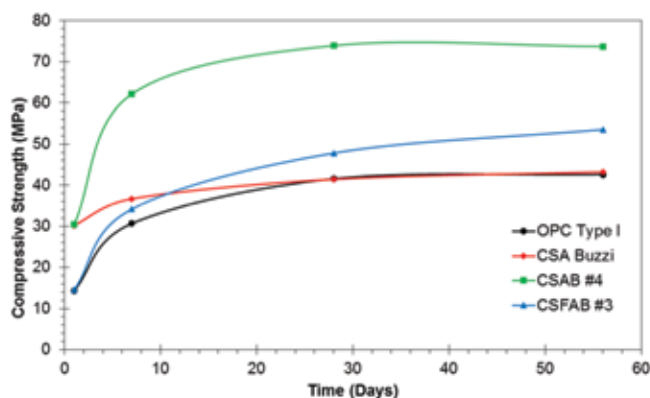


Figure 3. Compressive strength development of mortar cubes from commercially OPC and CSA cements compared with research-made CSA cements from coal combustion by-products produced at CAER

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Tristiana Y. Duvallet is a Research Engineer Senior in the Environmental and Coal Technologies (ECT) Group at the University of Kentucky Center for Applied Energy Research (CAER), with experience in formulating and developing novel and low-energy, low- CO_2 cements. She received an engineering diploma in materials science from the Ecole Supérieure d'Ingénieurs de Recherche en Matériaux et Informatique (ESIREM) at Dijon in France in 2008, and a PhD in Materials Science and Engineering from the University of Kentucky in 2014.

Thomas L. Robl is the Associate Director for the Environmental and Coal Technologies (ECT) group at the University of Kentucky Center for Applied Energy Research. He is a member of the University of Kentucky Graduate Faculty and is a Director of the American Coal Association and Co-Chairman of the World of Coal Ash International Symposium. He received his PhD from the University of Kentucky in 1977 in geology.

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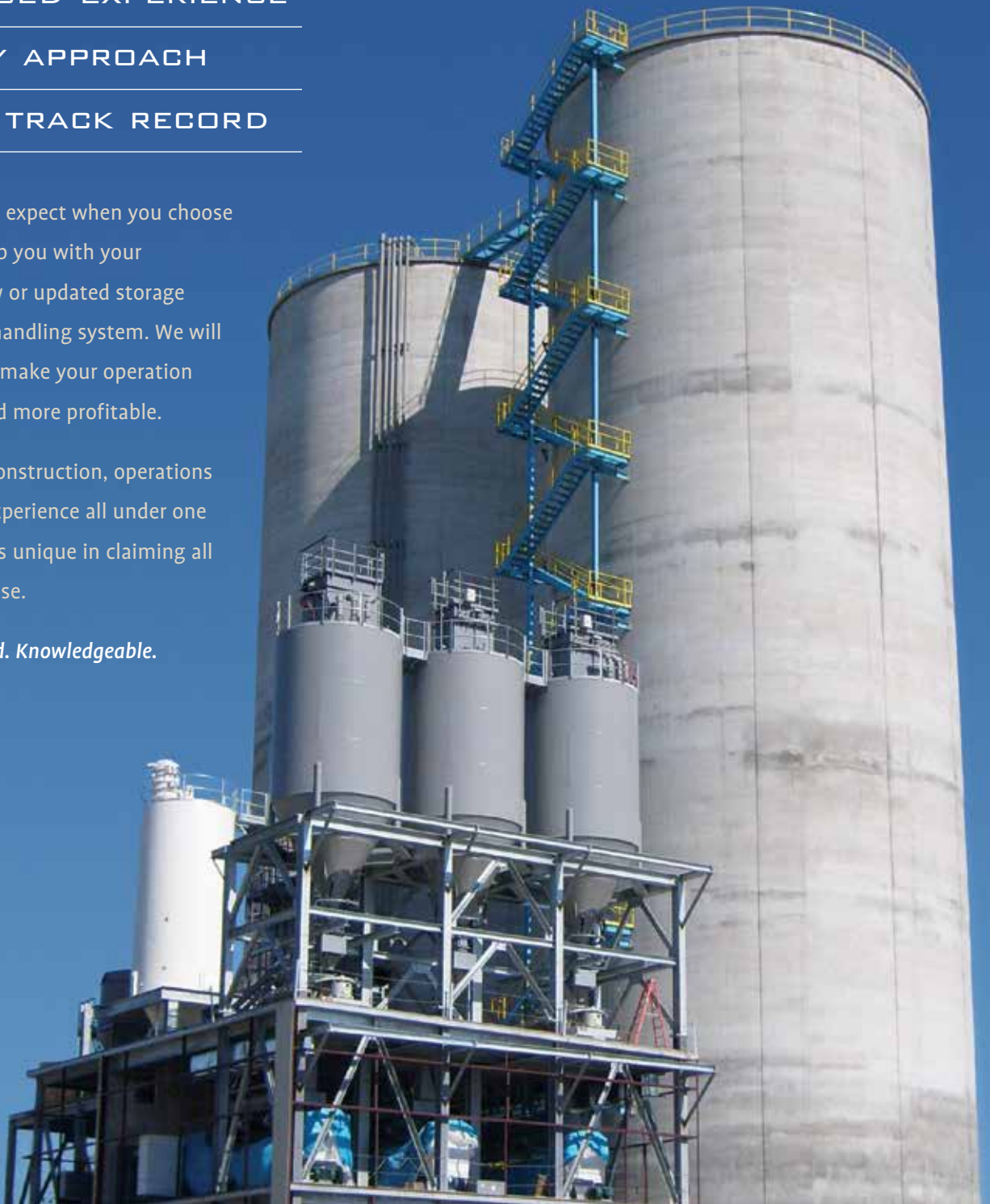
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FGD GYPSUM—PURE AS THE DRIVEN SNOW?

No Significant Difference in Trace Metals Found in Mined and Synthetic Gypsum

By Lisa J.N. Bradley

Gypsum, like many other materials, is all around our everyday life and a necessary ingredient to materials that make the quality of our lives better. The gypsum that we are all familiar with as a component of wallboard is a hydrated form of calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). There are many uses for gypsum in addition to wallboard: the Gypsum Association notes that it can be used as a soil additive to improve crops, it is used in surgical casts, it is used in brewing beer to control the tartness and clarity of the beer, and it is a primary ingredient in toothpaste. Our houses, roads, and bridges are made of concrete, which is made possible by the use of gypsum as a control agent in cement. The U.S. Geological Survey (USGS) Minerals Yearbook (2013) notes that “Miscellaneous uses, such as athletic field markings, accounted for less than 1% of gypsum consumption.” Most of us have slid into home plate and come away with a gypsum mark on our uniforms. But probably the most unusual and most fun is the use of gypsum to simulate snow storms in movies and TV programs!

There are two major sources of gypsum: it can be mined and is referred to as mined or crude gypsum, and it is also produced at coal-fueled power plants as part of air emissions control systems, which is referred to as synthetic or flue gas desulfurization (FGD) gypsum. As noted by the USGS in their 2005 Minerals Yearbook:

“In the United States, the most common source of synthetic gypsum is FGD systems used to reduce sulfur dioxide emissions from coal-fired electric power plants. These FGD systems not only keep the air clean but they also can provide a sustainable, ecologically sound source of very pure gypsum.”

Synthetic gypsum is used as a replacement for mined gypsum for wallboard, cement, and agricultural applications, in descending order of tonnage according to the American Coal Ash Association (ACAA) 2014 Production and Use Survey.

So is there anything else in gypsum, either mined or synthetic, than the calcium sulfate? To answer this question, we gathered readily available information on mined and synthetic gypsum, as shown in Table 1. These are data for major and trace elements, listed alphabetically. Trace elements are so called because they are present in such low concentrations (in the milligrams per kilogram [mg/kg] or part per million [ppm] range). Together, the trace elements generally make up less than 1% of the total mass of soils, and this is also the case for the gypsums. The data for both of these forms of gypsum are from reports published by the Electric Power Research Institute (EPRI); detailed references are in the footnotes to the

table. Data are provided for the minimum, median, 95th percentile, and maximum concentration for each element for each type of gypsum. Looking at the median results for both types of gypsum, as expected, the major elements calcium and sulfur (of the CaSO_4) make up 55% and 44%, respectively, of the total material.

For context, because context is always important, data for these elements are also provided, where available, for background soils (mainly from USGS sources). As noted previously, gypsum plays an important role in agriculture as a soil amendment, therefore data are also provided for fertilizers used in the United States. These data are from EPRI and from North Carolina State University.

Finally, we provide a risk-based context for these data by comparing them to screening levels developed by the U.S. Environmental Protection Agency (USEPA) for a child’s exposure to residential soils. USEPA considers it to be safe for children to be exposed to these concentrations of each of these trace elements in soils on a daily basis, throughout their lifetime. What this tells us is that by developing these residential soil screening levels, USEPA considers the presence of these levels of these elements in soils to be safe for humans, even for exposure on a daily basis. The yellow highlighting in the table indicates what concentrations in each of the materials is above a risk-based screening level for residential soil. As can be seen, all of the concentrations for all of the materials are above the risk-based screening level all of the concentration for arsenic for all—even background soils! However, with the exception of the maximum detected concentrations of arsenic in fertilizers, all of the remaining concentrations of arsenic are below the 90th percentile background concentration in U.S. soils.

So when we take a close look at mined and synthetic gypsum, we see that there really is no significant difference between the two, and concentrations are below risk-based screening levels. Thus, synthetic gypsum can be used safely for its important commercial uses in wallboard, cement products, and for agricultural applications. ♦

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Table 1
Comparison of Synthetic and Mined Gypsum and Similar Materials to Risk-Based Screening Levels

| Constituent | Risk-Based Screening Level Residential Soil (a) (mg/kg) | Background Soil (b) | | Synthetic Gypsum (c) | | | | Mined Gypsum (c) | | | | Fertilizer (d) | | Fertilizer (e) | |
|-------------|--|-----------------------|--|----------------------|-------------------|-------------------------------|--------------------|--------------------|-------------------|-------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| | | Background (mg/kg) | Background 90th percentile (mg/kg) | Minimum (mg/kg) | Median (mg/kg) | 95th Percentile (mg/kg) | Maximum (mg/kg) | Minimum (mg/kg) | Median (mg/kg) | 95th Percentile (mg/kg) | Maximum (mg/kg) | Minimum (mg/kg) | Maximum (mg/kg) | Minimum (mg/kg) | Maximum (mg/kg) |
| Aluminum | 77,000 | 15,000 | (f) 100,000 | 61.1 | 209 | 1,120 | 1,610 | 143 | 1,330 | 2,290 | 2,420 | NA | NA | NA | NA |
| Antimony | 31 | BDL | (f) 1.3 | 0.051 | 0.151 | 1.44 | 4.97 | 0.20 | 0.44 | 1.18 | 1.19 | < 0.1 | 12.2 | NA | NA |
| Arsenic | 0.67 | 2 | (f) 12 | 1.98 | 2.86 | 8.57 | 11.1 | BDL | 2.04 | 2.50 | 2.58 | < 2 | 4,600 | 2.7 | 120 (h) |
| Barium | 15,000 | 200 | (f) 1,000 | 0.91 | 6.38 | 29.5 | 55.2 | 2.22 | 12.2 | 28.1 | 31.0 | < 2 | 704 | NA | NA |
| Boron | 16,000 | BDL | (f) 70 | 2.67 | 13.2 | 123 | 387 | 4.19 | 7.96 | 20.3 | 25.7 | < 15 | 123,644 | NA | NA |
| Cadmium | 70 | BDL | (g) 0.5 | 0.006 | 0.066 | 0.234 | 0.369 | BDL | 0.040 | 0.161 | 0.214 | < 0.02 | 201 | 0.06 | 8.5 |
| Calcium | EN | 1,500 | (f) 62,000 | 199,000 | 237,000 | 264,000 | 268,000 | 173,000 | 213,000 | 261,000 | 265,000 | NA | NA | NA | NA |
| Chromium | 120,000 | 15 | (f) 100 | 0.45 | 2.19 | 8.64 | 14.8 | 0.27 | 1.75 | 2.88 | 3.19 | < 0.5 | 840 | 1.0 | 134 |
| Copper | 3,100 | 5 | (f) 50 | 0.25 | 1.16 | 2.61 | 3.17 | 0.69 | 1.87 | 4.39 | 4.67 | < 1.5 | 3,620 | 1 | 138 |
| Iron | 55,000 | 7,000 | (f) 50,000 | 130 | 811 | 1,740 | 1,820 | 58.7 | 924 | 2,769 | 3,770 | NA | NA | NA | NA |
| Magnesium | EN | 1,000 | (f) 15,000 | 50.3 | 1,090 | 2,960 | 5,860 | 500 | 2,990 | 15,400 | 15,600 | NA | NA | NA | NA |
| Manganese | 1,800 | 100 | (f) 1,000 | 0.83 | 9.18 | 62.4 | 129 | 10 | 35 | 175 | 241 | < 2.5 | 9,641 | NA | NA |
| Mercury | 23 | 0.02 | (f) 0.19 | 0.007 | 0.194 | 0.917 | 1.41 | 0.00030 | 0.00072 | 0.0126 | 0.0151 | < 0.003 | 2.91 | 0.4 | 3.2 |
| Molybdenum | 390 | BDL | (f) BDL | 0.044 | 0.560 | 2.24 | 4.00 | 0.34 | 0.74 | 1.24 | 1.30 | < 0.04 | 39 | NA | NA |
| Nickel | 1,500 | 5 | (f) 30 | BDL | 1.11 | 2.41 | 2.86 | BDL | 1.68 | 2.22 | 2.33 | < 0.15 | 517 | 7.0 | 44 |
| Potassium | EN | 4,500 | (f) 25,000 | 29.0 | 197 | 540 | 744 | 96 | 760 | 1,180 | 1,230 | NA | NA | NA | NA |
| Selenium | 390 | BDL | (f) 0.8 | 1.44 | 5.24 | 26.8 | 32.0 | BDL | 0.12 | 0.29 | 0.35 | < 1 | 44 | 0 | 13.2 |
| Silicon | NA | 230,000 | (f) 390,000 | 69.0 | 252 | 589 | 1,050 | 100 | 167 | 207 | 209 | NA | NA | NA | NA |
| Sodium | EN | 1,000 | (f) 20,000 | 10.2 | 24.0 | 720 | 1,300 | 29 | 113 | 388 | 419 | NA | NA | NA | NA |
| Sulfur | NA | 840 | (f) 1,500 | 156,000 | 188,000 | 206,000 | 208,000 | 119,000 | 167,000 | 210,000 | 211,000 | NA | NA | NA | NA |
| Thallium | 0.78 | 0.2 | (g) 0.7 | BDL | 0.011 | 0.035 | 0.062 | BDL | 0.011 | 0.158 | 0.200 | < 0.15 | 3.9 | NA | NA |
| Vanadium | 390 | 20 | (f) 150 | 0.32 | 1.61 | 5.87 | 8.57 | 0.32 | 2.97 | 7.34 | 9.17 | < 1 | 949 | NA | NA |
| Zinc | 23,000 | 22 | (f) 99 | 1.76 | 5.84 | 17.0 | 23.3 | 1.4 | 6.2 | 19.7 | 23.5 | < 5 | 460,564 | 1 | 235 |

Notes:
 < - Not Detected Below Value Reported.
 BDL - Below Detection Limit.
 EN - Essential Nutrient.
 NA - Not Available.
 RSL - Regional Screening Level.
 USEPA - United States Environmental Protection Agency.
 (a) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. January 2015. Values for residential soil.
 Values based on a target risk level of 1E-6 and a target hazard quotient (HQ) of 1.
 (b) - Coal Ash: Characteristics, Management and Environmental Issues. Electric Power Research Institute (EPRI), September 2009. Range (10th percentile - 90th percentile) in soil in US. EPRI compiled the data from source (d), with the exception of cadmium and thallium, from source (e).
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 (i) - This number is also above the 90th percentile background value.
 > RSL.
 > RSL and > 90th percentile background.

Lisa J.N. Bradley, PhD, DABT, is Senior Toxicologist and Senior Client Leader with Haley & Aldrich. She received her PhD in toxicology from the Massachusetts Institute of Technology, and is certified by the American Board of Toxicology. She was appointed to the National Coal Council by the Secretary of Energy, and is the Secretary/Treasurer of the ACAA. She has 25 years of experience in risk assessment and toxicology consulting.

PIONEERS OF AGRICULTURAL GYPSUM

Growth in the use of synthetic gypsum in agriculture did not happen overnight. At the foundation of this expanding market stands years of dedicated research by scientists across the country.

The American Coal Ash Association recognized some of these scientists in 2015 when it conferred the organization's fourth

ever Champion Award on the U.S. Department of Agriculture's Agricultural Research Service for its work in advancing the use of synthetic gypsum from coal-fueled power plant scrubbers as soil amendments (refer to *ASH at Work* 2015 Issue 2).

Today, *ASH at Work* magazine salutes other individual scientists for their work as pioneers of agricultural gypsum.



RAY B. BRYANT
Research Soil Scientist
USDA-ARS-Pasture System
and Watershed Management
Research Unit

Dr. Ray Bryant is a Research Soil Scientist for the U.S. Department of Agriculture Pasture Systems and Watershed Management Research Unit, located on the Penn State University campus at University Park, PA. He leads ARS research project "Management and conservation practices to improve water quality in agroecosystems of the northeastern US," which has a strong focus on water quality in the Chesapeake Bay. The project addresses nutrient management with emphasis on manure management, drainage ditch management, cover crops, riparian area use and conservation, and manure treatment technology.

Dr. Bryant's personal research program focuses on strategies to address legacy sources of nutrients from agricultural soils and landscapes that have historically received excess nutrients and now act as source areas that negatively impact water quality. He uses knowledge of soil and landscape processes to devise strategies, such as chemical- and bio-filtration, for preventing the movement of nutrients from agricultural fields to drainage waters that eventually flow to the Chesapeake Bay. He recently co-lead development of a Natural Resources Conservation Service (NRCS) National Practice Standard for surface application of gypsum products, calling on expertise from more than 70 scientists from the international community. National Conservation Practice Standard Code 333 was officially adopted by NRCS in June 2015. It provides the first conservation practice for controlling dissolved phosphorus losses in runoff and leachate. The standard sets purity criteria that allow use of clean flue gas desulfurization (FGD) gypsum produced by modern forced-oxidation wet systems after the removal of fly ash.

Most of Dr. Bryant's research is conducted in partnership with faculty and students at Penn State and the University of Maryland Eastern Shore (UMES), an 1890s university located in Princess Anne, MD. In Pennsylvania, he is working toward a liquid dairy manure treatment technology capable of removing phosphorus while leaving nitrogen available for use on farms. In Maryland, research projects seek to sustain a viable poultry

industry by minimizing environmental impacts and protecting water quality. Collaborative research with UMES scientists seeks to identify terrestrial sources of urea, an emerging contaminant that is implicated in a globally observed increased frequency and toxicity of algae blooms.



WARREN DICK
Professor of Soil and Environmental
Chemistry
The Ohio State University

Dr. Warren Dick grew up on a diversified farm in North Dakota. He graduated from Wheaton College (BS, 1975) and Iowa State University (MS and PhD, soil science). Dr. Dick studies enzymatic and biological nutrient cycling in soil under various management systems, microbial ecology, and beneficial uses of agricultural and industrial byproducts, especially flue gas desulfurization (FGD) gypsum.

Dr. Dick has mentored more than 35 graduate students, 12 undergraduate interns, 8 post-docs, and 27 visiting scholars. He has published 31 papers that have been cited more than 100 times. He is active professionally and has served as Editor-in-Chief of both the Soil Science Society of America and the American Society of Agronomy.

Dr. Dick was involved in developing "Conservation Practice Standards for Amending Soil Properties with Gypsum Products." He also was involved in developing similar standards for the states of Ohio, Michigan, and Indiana. His work on beneficial uses of coal combustion products—especially FGD gypsum—to improve agricultural and environmental quality has been internationally recognized. This has led to collaborations with other researchers in China, Brazil, and Israel.

Dr. Dick headed up a major national network of research sites evaluating the agricultural and environmental impacts of land application of gypsum. This work and other similar projects has led to numerous publications and presentations. The bulletin "Gypsum as an Agricultural Amendment" published by The Ohio State University Extension Service has been widely circulated in the United States as well as other countries in the world.



RUFUS L. CHANEY
Senior Research Agronomist
USDA-ARS Crop Systems and
Global Change Laboratory

During his career, Dr. Rufus Chaney has conducted research on food chain transfer of trace elements in soils and soil amendments. This work began when biosolids were unregulated materials, before the Clean Water Act Section 503 Rule was developed. Biosolids

from some cities were too contaminated to be acceptable in agriculture to protect both soil fertility and food quality. He worked in a team that developed the 503 rule by quantifying transfer coefficients from soils to plants and plants to livestock and humans.

These understandings were used to assist the U.S. Environmental Protection Agency in developing a Risk Assessment for Spent Foundry Sand and were applied to other by-products and composts. This information assisted the risk assessment for FGD gypsum, which clarified that fluidized bed ash often contains too high boron, arsenic, and some other elements to be acceptable in agriculture. The industry learned that it could limit trace elements in FGD gypsum by removing fly ash before capturing the SO₂ in FGD gypsum. Beneficial uses of the “new” FGD have been identified and commercial uses are increasing as this knowledge is recognized.

Dr. Chaney’s research is based in Beltsville, MD.



MALCOLM EDWARD SUMNER
International Soil Consultant

A native of South Africa, in 1970, Dr. Sumner was the first to use gypsum as a strategy to tackle subsoil acidity. He showed that by being a neutral salt, which does not interact with soil surfaces to increase pH and consequently negative charge, and because it is much more soluble than lime (170 times), gypsum readily moves down the soil profile, where it precipitates toxic Al³⁺. Consequently, roots can grow into hostile zones to access water that was previously beyond their reach and thus increase yields.

After immigrating to the United States in the late 1970s, Dr. Sumner’s work resumed at the University of Georgia, where substantial economic yield increases (10 to 80%) to surface-applied gypsum (5 to 10 t/ha) were obtained in many crops (corn, soybeans, cotton, alfalfa, clover, sorghum, and sunn hemp). Experiments were conducted from 1978 to 2000 on a variety of acid soils in Georgia, culminating in the discovery that the beneficial effect of single large application of gypsum (5-10 T/ha) could last for up to 15 to 20 years, which makes this strategy highly economic as the cost can be amortized over many years.

Initially, mined gypsum was used but more recently, phosphogypsum, a by-product of phosphate fertilizer manufacture and flue gas desulfurization (FGD) gypsum (a by-product of the removal of sulfur dioxide from stack gases in electric power plants), have become the main sources because of their strategic location. In

the case of both these materials, Sumner immediately saw their potential uses and together with his team garnered in excess of \$2 million for research to demonstrate their benefits. Subsequent to the research phase, which ended in 2000, he has been promoting the use of gypsum throughout the southeastern United States by means of on-farm demonstration trials involving paired comparisons of gypsum with a control. The results of these demonstration plots have overwhelmingly confirmed the benefits to be derived from gypsum use on acid soils at the farm level while at the same time promoting the use of by-product materials.

Dr. Sumner’s pioneering research spread to other regions of the United States and across the world. Although Dr. Sumner does not claim to be responsible for increases in the use of FGD gypsum, he was the key player in opening the field for many new uses and continues to promote the use of these products in agriculture throughout the world. The recipient of numerous honors and awards, he is the author of two books, 50 monograph chapters, and over 300 journal articles.



L. DARRELL NORTON
Former Director and Research
Soil Scientist
USDA-ARS National Soil
Erosion Research Laboratory

Dr. L. Darrell Norton received his BSc in 1975 and MSc in 1976 from Purdue University and his PhD in 1981 from The Ohio State University. He is a former Director and Research Soil Scientist

for the USDA-Agricultural Research Service (ARS) National Soil Erosion Research Laboratory (NSERL), located on the campus of Purdue University, West Lafayette, IN, where he is Emeritus Adjunct Professor in the Departments of Agronomy and an Adjunct Professor in the Department of Agricultural and Biological Engineering. He was at the NSERL from 1982 to 2012, conducting research on various aspects of soil erosion related to physio-chemical and biogeochemical interactions between soil and rainwater.

The last 24 years at NSERL, he was leading research to evaluate various industrial by-product materials (synthetic gypsum) for use in controlling erosion and managing water in agricultural production systems. Much of his research has focused on relatively clean, high-calcium- and sulfur-containing materials from air purification systems from coal-fueled power plants.

Dr. Norton and co-authors—including many of his MSc, PhD students, post-docs, and collaborators—have published more than 270 scientific articles and technical reports and has been widely invited to present results of his research at scientific congresses all over the world. He has conducted projects and cooperative research with many agencies in the United States and many international research institutions such as CSIRO, Australia; EMBRAPA, Brazil; UN-FAO, India; CAS, China; US-AID, Africa; BARD, Israel; and many university and institutes in the United States, Mexico, Brazil, and Europe. He was recently a Visiting Professor at the Federal University of Lavras, Lavras, Brazil, on

various projects including the using Synchrotron X-Ray micro-fluorescence to understand nutrient movement in plants.



H. ALLEN TORBERT

Research Leader
USDA-ARS National Soil
Dynamics Laboratory

Dr. H. Allen Torbert grew up on a cotton farm in central Alabama. He received his BS in 1983 and his MS in 1985 from Auburn University's Agronomy and Soils Department. Shortly thereafter, he attended the University of Illinois, where he received

his PhD in 1989 from the Agronomy and Soils Department. From 1989 to 1992, Dr. Torbert was a Research Associate with the USDA Agriculture Research Service (ARS) in Auburn, AL. In 1992, he moved to Temple, TX, where he worked as a Soil Scientist at the USDA-ARS Grassland Soil and Water Research Laboratory. In 2001, Dr. Torbert returned to Auburn as a Soil Scientist and was appointed Research Leader in 2005 for the USDA-ARS National Soil Dynamics Laboratory. He is also an affiliate faculty member of Auburn University and Texas A&M University and serves on several graduate student committees. Dr. Torbert's program focuses mainly on soil fertilizer practices to develop cropping systems that optimally integrate animal manure into sustainable agriculture while safeguarding environmental integrity. His principal scientific contribution is in the area of soil chemistry, with emphasis on soil fertility, crop residues, tillage requirements, and animal waste management.

Dr. Torbert began studying gypsum as a soil amendment while working as a Soil Scientist in Texas, where losses of phosphorus (P) in runoff from dairy farms into surface waters was of great concern. In greenhouse studies, he demonstrated that runoff losses of P could be reduced with the use of gypsum as a soil amendment. After moving to Alabama, the focus shifted to reducing P losses from poultry litter application and field studies with gypsum were conducted. He was instrumental in the development of a cooperative effort (which he now leads) between USDA-ARS scientist from the Southeast, which began research in 2007, to evaluate the benefits and safety of FGD gypsum. Experiments in Alabama, Georgia, and Mississippi demonstrated that losses of P and microorganisms in runoff following poultry litter applications could be reduced with applications of FGD gypsum. Data collected across locations has proven valuable during the commenting process for the EPA "Standards for the Management of Coal Combustion Residuals Generated by Commercial Electric Power Producers" and the ongoing process of developing an EPA risk assessment for FGD gypsum use in agriculture.

Growing scientific interest led Dr. Torbert to becoming a founding member of a "By-product Gypsum Uses in Agriculture Community of Interest" within the American Society of Agronomy. Dr. Torbert served on a committee working with NRCS to develop a new National Conservation Practice Standard for use of gypsum products entitled "Amending Soil Properties with Gypsum Products Code 333" (finalized in June 2015). Dr. Torbert has given many talks on the use FGD gypsum in manure management, has published several articles in peer-reviewed journals, and looks forward to continued research in this field for many years to come.



DEXTER B. WATTS

Research Scientist
USDA-ARS National Soil
Dynamics Laboratory

Dr. Dexter B. Watts is a Research Soil Scientist for the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) at the National Soil Dynamics Laboratory (NSDL) in Auburn, AL. As a soil scientist, Dr. Watts' research focuses

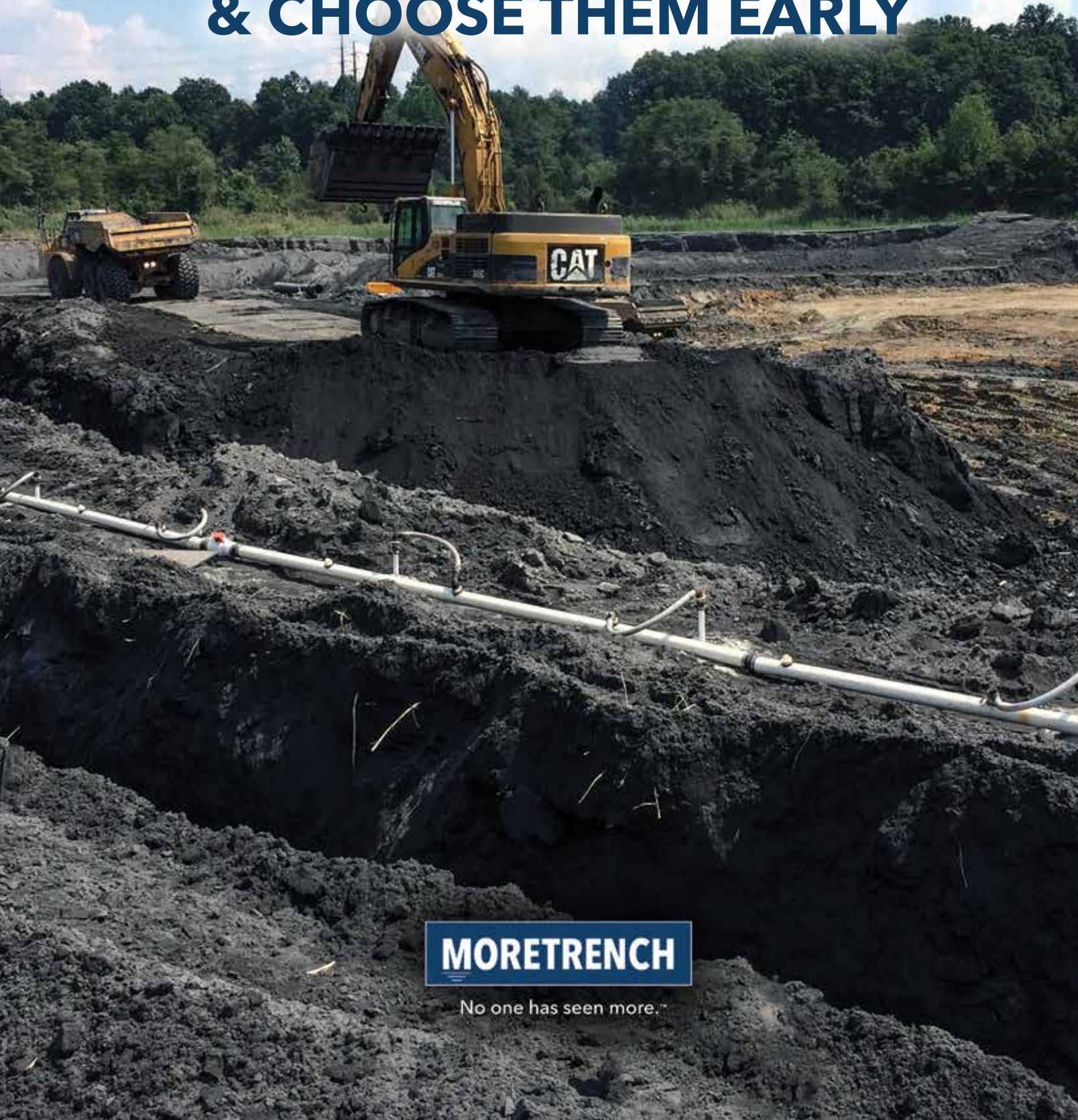
on sustainable soil management practices and crop production systems with the dual goal of improving farmer profitability and lessening their impact on the environment. Specifically, Dr. Watts works with a multi-disciplinary team of researchers investigating animal waste management strategies for reducing greenhouse gas emissions in conservation tillage systems; using industrial by-products to improve crop production systems and environmental quality; conservation systems research for improving environmental quality and producer profitability; determining manure impacts on microbial transformations and soil ecology; and developing best management practices (BMPs) that will minimize and mitigate nutrient loss from agricultural systems.

Dr. Watts received his BA in chemistry in 2000 from Talladega College, his MS in plant and soil science in 2003 from Alabama A&M University, and his PhD in agronomy and soils from Auburn University in 2007. After receiving his PhD, Dr. Watts did a post-doctorate with USDA-ARS National Soil dynamics from 2007 to 2008. Since becoming a Research Soil Scientist with ARS in 2007, Dr. Watts has authored or co-authored 32 referred publications, one patent, two book chapters, four technical papers, and 13 proceeding articles. Dr. Watts' greatest accomplishments and recognition has come from his research contributions on the use of FGD gypsum as a soil amendment for reducing agriculture's influence to water quality and the use of microbial inoculants (U.S. Patent 9,266,786) as an abatement tool for reducing greenhouse gas emissions while improving plant growth promotion. These accomplishments have contributed to Dr. Watts receiving the Early-Career Award in Agronomic Research from the Southern Regional Branch American Society of Agronomy in 2012; Employee Recognition for the Presidential Early-Career Scientist and Engineers for the Mid-South Area in 2013; American Society of Agronomy Environmental Quality Young and Inspiring Scientist Award in 2013; one of the recipients of the USDA-ARS Southeast Area Technology Transfer Award for "By-Product Gypsum (Calcium Sulfate Dihydrate) Use in Agricultural Systems to Improve Soil Physical and/or Chemical Properties, Reduce Runoff Pollution and Improve Water Quality" in 2015; and one of the recipients of the American Coal Ash Association "Champion Award" for extraordinary contributions to beneficial use of coal combustion products (CCP) in 2015.

Dr. Watts is a faculty affiliate with Auburn University's Department of Crop, Soil and Environmental Sciences and Alabama A&M University's Department of Biological and Environmental Sciences, where he collaborates with research faculty and helps mentor graduate student projects. Dr. Watts' research recognition has also allowed him the opportunity to work with international scientists visiting from Turkey and China.

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IN & AROUND ACAA



PHOENIX, AZ

Thomas Adams, American Coal Ash Association Executive Director (right), meets an attendee at the Geotechnical & Structural Congress of the American Society of Civil Engineers on February 15, 2016.

Approximately 1800 engineers were in attendance.



WASHINGTON, DC

A well-attended news conference at the National Press Club on December 15, 2015, was the setting for release of American Coal Ash Association's annual Coal Ash Production and Use Survey results. Thomas Adams, ACAA Director, presented the data to national and trade publication reporters.



WASHINGTON, DC

Citizens for Recycling First conducted a coal ash beneficial use briefing for U.S. Congress staff members December 15, 2016. Represented at the briefing were (from left) Kirk Benson, Headwaters; Danny Gray, Charah; Sharon Madden, Headwaters; Terry Peterson, Boral; Thomas Adams, ACAA; and John Scoggan, Boral.



TAMPA, FL

ACAA's Winter Meeting (February 2-3, 2016) attracted a record 260 attendees to hear speakers such as Dr. Grace Bochenek, Director of the U.S. Department of Energy's National Energy Technology Lab. Dr. Bochenek described NETL's work, including research into recovery of rare earth metals from coal combustion products.



TAMPA, FL

The American Coal Ash Association Women's Leadership Forum met during ACAA's Winter Meeting. The Forum is an informal group of ACAA women members whose broad goals are to develop interest and qualifications of women members for ACAA committee leadership and officer positions; to acquaint members with the wide range of energy and building materials careers, and professional organizations and meetings with the goal of opening paths for further career development; and to promote professional interactions and camaraderie among members and women in related fields, including government, energy, building materials, and consulting.



ASH ALLIES: GYPSUM ASSOCIATION

For Many Gypsum Association Member Companies, Flue-Gas Desulfurization Gypsum (FGD) Offers Alternative

By Steve Meima, Gypsum Association Executive Director

Born in the depths of the Great Depression, the Gypsum Association (GA) has operated for 86 years. Today, the GA is one of the premier building materials organizations in North America. The Association's mission is to promote the use of gypsum while advancing the development, growth, and general welfare of the gypsum industry in the United States and Canada on behalf of its member companies. Members include all the active gypsum panel product manufacturers in the United States and Canada. To be eligible for membership in the Association, a firm or corporation must calcine gypsum and manufacture gypsum board (also known as drywall or wallboard) under the provisions of the ASTM C1396 standard.

Gypsum board is ubiquitous as a building material for wall, ceiling, and partition systems in residential, institutional, and commercial structures. More than 97% of homes constructed in the United States, along with countless hospitals, schools, office complexes, and other buildings, require gypsum board in construction. When joints and fastener heads are covered with a joint treatment system, a monolithic surface results. Walls composed of gypsum panel products are an economical means of providing a smooth, readily decorated surface that is also easily repaired.

Even more importantly, gypsum board is an excellent fire-resistive material and is the most commonly used interior finish where fire resistance classifications are required. Its noncombustible core contains chemically combined water which, under high heat, is slowly released as steam, effectively retarding heat transfer. Even after complete calcination, when all water has been released, it continues to act as a heat-insulating barrier. In addition, tests conducted in accordance with ASTM E84 show that gypsum board has a low flame-spread index and smoke density index. When installed in combination with other materials, it serves to effectively protect building elements from fire for prescribed time periods.

A/E/C professionals have long embraced standard drywall, including those panels developed for extra fire resistance, for interiors. However, more recently, thanks to innovations and efforts by the gypsum industry, newer categories of specialty boards have emerged and are gaining traction. Indeed, gypsum panel products are the natural choice for interior and exterior surface applications thanks to their versatility, ease of installation, fire resistance, and sustainability.

Specialized performance boards share the enduring properties of gypsum board while offering additional attributes aimed at specific applications. Newer performance board categories offer mold and moisture resistance; abuse and impact resistance; and include exterior gypsum sheathing, interior glass mat, and shaft liner panels. At the same time, they retain the fire resistance inherent to gypsum.

While gypsum is a plentiful mineral that is mined in 17 states, for more than three decades, flue gas desulfurization (FGD) gypsum has been used by most GA member companies, either alone or in combination with natural gypsum. FGD gypsum is manufactured by capturing the sulfur dioxide that would otherwise be released into the air, feeding it through a mixture of limestone and water, and combining it with calcium carbonate. This process produces calcium sulfate dehydrate, commonly known as gypsum.

Electric utilities use a multi-step manufacturing process to meet precise gypsum industry product specifications for FGD gypsum. Not all gypsum produced through flue gas desulfurization can be beneficially used. The grade of FGD gypsum used by wallboard manufacturers is commonly called "washed FGD gypsum."

Today, roughly half of all gypsum used in the United States is FGD gypsum. FGD gypsum production and sales encourages power producers to capture "waste" for use. Use of this coal combustion product (CCP) benefits the environment in several ways. Landfilling is avoided, and natural resources are preserved for future generations. Moreover, new wallboard plants frequently are sited in close proximity to major population centers, saving energy and limiting air pollution from transport. Decreased distance between manufacture of building products and installation sites is one of several factors that can contribute to Leadership in Energy and Environmental Design (LEED) certification.

The environmental value of FGD gypsum was underscored by the EPA's February 2014 final report *Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard*. The report corroborates the safety of FGD gypsum and encourages its continued use, concluding "EPA supports the beneficial use of...FGD gypsum in wallboard. The Agency believes these beneficial uses provide significant opportunities to advance Sustainable Materials Management (SMM)."



Steve Meima, MBA, APR, LEED Green Assoc., is the Executive Director of the Gypsum Association. In addition to serving as the GA's Director of Promotion from 1996 to 1999, he returned as Chief Operating Officer in 2013. During the interim, he served within a GA member company for over a decade, taking on various marketing and communications leadership roles.



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ASH CLASSICS

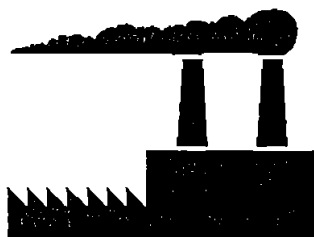
Gypsum Utilization Contributes to a Growing ACAA

"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.

This issue of ASH at Work from 1992 features an ACAA member announcement regarding flue gas desulfurization (FGD) gypsum marketing, as well as some other topics that may seem familiar nearly a quarter-century later.



June 1992



ASH AT WORK is the voice of
American Coal Ash Association

Erast Borissoff, Executive Director

ACAA/USWAG COORDINATION ON TRACK

On May 28, Tim Nechvatal of Wisconsin Electric Power represented ACAA at a regularly-scheduled meeting of the Utility Solid Waste Activities Group (USWAG) in Dallas, TX.

Tim reports that USWAG is not optimistic about RCRA being reauthorized this year (see **RCRA WATCH**, p. 2), with or without ACAA/USWAG language exempting utilized coal ash from regulation as a solid waste. There was also concern the Bush administration may sign the Basel Convention limiting international movement of "wastes," i.e., materials subjected to characteristic tests. This would not only run counter to USWAG's long-standing position that such tests do not apply to coal ash as a Bevill Amendment by-product, but would also hinder U.S. exports of coal combustion by-products to Canada and the Caribbean. Tim notes that a recent USEPA report on NORM recommended a nation-wide risk assessment, but did not include power plant coal ash disposal sites in its scope.

CHINESE MUM ON VISIT TO ACAA

The Shanghai Building Sciences Research Institute has passed the ball back to China's Department of Energy Conservation in the Ministry of Energy in planning a tour of U.S. coal-fired power plants and ash-handling facilities later this year. The Chinese had requested ACAA help, but a preliminary survey of ACAA utility members reveals limited interest in hosting the delegation. Call Helen Tesfaye for details.

USEPA: POLLUTION PREVENTION = WASTE REDUCTION

Bad News for Utilization?

Inside EPA reports that a May 28 EPA memo states that **only waste reduction prior to recycling treatment or disposal should be considered pollution prevention.**

EPA does concede that "recycling that is conducted in an environmentally sound manner shares many of the advantages of prevention -- it can reduce the need for treatment or disposal, and conserve energy and resources." But EPA sources stress that they intend **this definition of pollution prevention to "force people up the hierarchy"** of reduction first, recycling second, treatment third, and disposal last, **redirecting budgets toward reduction and away from recycling.** Look for similar state actions to follow.

RCRA WATCH: PROGRESS SHAKY



Moderate Senate Republicans joined conservatives from both parties in threatening to stop the S. 976 RCRA bill passed on May 20 by a Senate committee if it gets to the floor, reports Inside EPA. Sen. Steve Symms (R-ID) calls it "anti-competitive, anti-capitalist, anti-growth...destined for the dustbin." Such talk may keep Senate Majority Leader Mitchell (D-ME) from even bringing it to the floor.

Industry opposes S. 976 recycling provisions, saying they'll hurt packaged goods manufacturers without reducing waste destined for landfills. Environmentalists say those provisions "do nothing to increase recycling," while its toxics provisions "ignore 99% of the waste stream." But S. 976 sponsor Max Baucus (D-MT) "probably won't let it die without a fight," possibly lacking it on to, or proposing it as a substitute for, a bill by Dan Coats (R-IN) to allow states to block municipal trash imports.

Sources say S. 976 could still move if House Committee Chairman Al Swift's (D-WA) streamlined "RCRA-lite" bill (H.R. 3865), dealing only with solid waste, moves quickly through markup in mid-June.

Meanwhile, seven House Republicans--Bliley (VA), Lent (NY), McMillan (NC), Dannemayer (CA), Holloway (LA), Barton (TX) and Oxley (OH)--sent a letter to Energy & Commerce Committee Chairman Dingell (D-MI) on May 27, concerned that among other things, **H.R. 3865 would create a new federal solid waste management program, shifting authority away from states and localities and prohibiting cost considerations in setting regulations.**

Most Inside EPA sources believe that RCRA may be "dead" for 1992. For the moment, S. 976 is silent on coal ash, and the only ash covered by H.R. 3865 is from waste incinerators, not from coal.

COAL ASH SUCCESS IN IOWA:

Member Utility Moves FGD Material

ACAA member Muscatine Power & Water announced an agreement to sell synthetic gypsum from its scrubber to U.S. Gypsum for \$1/ton, delivered by truck to a Sperry, Iowa, wallboard factory 35 miles from the power plant. Output will range from 8,000 to 140,000 tons annually, with a 1992 target of 80,000 tons. MP&W expects to save \$112,000 in avoided disposal costs in 1992.

"Economic savings are not the only benefit derived from the utilization of this by-product. Environmental benefits will also be achieved," said MP&W General Manager Larry Koshire. "We have basically...refined the process to where the synthetic product has become an environmentally responsible and cost-effective alternative to a natural resource. This achievement portrays how ingenuity in recycling not only improves the environment but also demonstrates our commitment to control costs, remain sensitive to the environment, and responsive to the consumer's needs," he added. For details call MP&W's Gary Wieskamp 319-262-3350.



TECH WORLD

FEDS TO STUDY ASH VITRIFICATION

Energy Secretary Jim Watkins announced on May 27 that his Department will negotiate a grant to the Vortec Corporation of Collegeville, PA, to conduct "feasibility testing of a coal-fired wastewater sludge ash vitrification system."

Selecting Vortec as one of 202 applications from small, high-tech firms in 26 states under DOE's Small Business Innovation Research program, Admiral Watkins said, "These grants are an excellent way to involve small companies in meeting the changing research needs of the Nation while at the same time stimulating technological innovation and commercialization."

NEW USEPA RULE ON NO_x CONTROL

Next Hurdle for Ash?

On May 21, USEPA issued the so-called "WEPCo rule," which environmentalists contend would allow utilities to upgrade power plants through modifications that may result in emission increases, yet not trigger [Clean Air] "new source review."

Inside EPA reported on May 29 that EPA tried to placate environmentalists by dropping a proposal in the rule to define low-NO_x burners as the "best available control system" (BACT) for nitrogen dioxide, which environmentalists contended was not the "best," given existing, more stringent controls.

Industry sources clearly believe low-NO_x burners to be BACT. Regardless of the technology, many ACAA member utilities are suggesting ACAA should devote more effort to study the effect of NO_x-controls on the quality of coal ash.

AMONG CONCRETE GROUPS, ONLY ACAA PROSPERS

On May 27-28, ACAA Executive Director Erast Borissoff represented ACAA at American Concrete Institute's 13th Annual Summit Meeting of Concrete-Related Associations in Detroit, MI. While ACAA's funding and membership continue to grow, most execs spoke of shrinking budgets and membership losses through attrition or mergers.

The Portland Cement Association did report that while well below the levels of two and three years ago, March cement shipments were up 10.8% over 1991, and 1992's first quarter was 9.8% higher than 1991. Some of the increase was due to mild weather for the first three months of 1992, but construction activity is also generally reviving. Every U.S. census district except the West South Central reported gains in March; the first quarter gain was evenly spread except for the Pacific district, where rain dampened construction.

ACAA TELLS COAL MINERS:

Help Utility Customers with Ash!

On May 5, ACAA Executive Director Erast Borissoff spoke about the "Coal Industry's Stake in Coal Ash" on an environmental issues panel at the American Mining Congress Coal Convention in Cincinnati, OH. Erast told more than 90 assembled industry execs:

- o Coal companies can strengthen America's commitment to coal-fired power generation by citing current and future opportunities offered by coal ash utilization.
- o Coal companies can further improve their service to their electric utility customers by helping them to avoid the disposal of coal ash by using coal ash in surface and underground mine reclamation.
- o Coal companies can dramatically strengthen America's commitment to coal by urging federal and state governments to merge that commitment with a new, environmentally responsible commitment to the use of coal ash as an engineering material in federal and state infrastructure reconstruction.

EEI EXEC MOVES UP

John Shlaes, EEI's Director of Government Relations for 13 years and advisor to US delegations to two UN conferences, recently took over as Executive Director of the Global Climate Coalition in DC.



"THE DEFENDANT IS ACCUSED OF EMBEZZLEMENT, GRAND THEFT AUTO, AND NON POINT SOURCE POLLUTION."

Harley Schwadron. Reprinted with permission.

ASH CRISIS IN IOWA: Utility Disposal Challenged

USA Today reported on April 27 that a group called the Fly Ash Action Team is opposing Iowa Electric Light & Power plans to site a state-of-the-art landfill on land it owns near Coon Creek to dispose of 70,000 tons of coal ash a year. The group called the site a "dirty old dump," and stated it would ruin property values.

MANAGEMENT

Ten Tips for Crisis Communication

Everyone has heard about some catastrophic event that kills a business: labor disputes, accidents, legal actions, safety violations, layoffs, product liabilities, food poisonings, rumors of financial improprieties or the slings and arrows of disgruntled workers.

Yet few small and medium sized businesses or public agencies can point to a written crisis communication plan capable of helping a company get the facts to the media accurately and ensure that the company's side of the story is told.

Timing is very important during any crisis. Failure to show a quick response will generate ill-will long after a crisis is handled. A business perceived as unresponsive in a crisis will face the chimera of ill will again and again, as it defends itself in courts of law—and courts of public opinion.

The following 10 tips will help your firm manage communications in a business crisis.

1. Prepare a written crisis communications plan in advance. It should offer a method determining what information to release, when, where and by whom.

2. Before a crisis occurs, senior management should seek media training from professionals.

3. In advance, establish a crisis management team. It should include key executives and the senior public relations representative on staff (if you have one). It may include a legal advisor, but keep in mind that a lawyer's job is to keep the company out of court, not to keep the company from going bankrupt because of negative publicity.

4. Appoint a single spokesperson. To ensure accurate and consistent messages, the organization must speak with one voice.



5. Make employees aware of the contents of the crisis communications plan. During a crisis, employees should know what has happened, and what's being done about it. Employees should know to refer media calls to the company spokesperson.

6. Try to make an initial statement to the media no more than two hours after the event has occurred. Always try to provide as timely and accurate information to the media as is humanly possible.

7. Show proper concern about resolving the problem. Though their concern is genuine, many companies fail to show it effectively.

8. Do not be emotional, exaggerate, mislead, speculate, cover up or lie to the media. Display compassion, not defensiveness. Displaying compassion will not imply liability.

9. Do not say "no comment." It implies guilt. If you must refrain from talking about a particular subject, tell the media why you cannot talk about it.

10. Do not discuss anything "off the record." Assume anything you say will be quoted. If you don't know answers to questions, say so.

By Thomas E. Eppes, president
Price/McNabb Public Relations

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.

Warren A. Dick, Professor of Soil and Environmental Chemistry in the School of Environment and Natural Resources at The Ohio State University (OSU), is widely regarded as an expert in the use of flue gas desulfurization gypsum use in agriculture and a pioneer in that field. He has been on the faculty at OSU since 1980 after receiving his PhD in soil science from Iowa State University. *Ash at Work* asked Dr. Dick to evaluate the birth and growth of this important beneficial use.



Ash at Work (AW): What is the history of using gypsum in agriculture?

Warren Dick (WD): Gypsum has a long history of use as a soil amendment and this has been documented by Dr. William Crocker. Dr. Crocker was associated with the University of Chicago and then appointed Director of the Thompson Institute for Plant Research in Yonkers, NY. He originally wrote his history of gypsum use in North America in 1918. Gypsum use as a soil amendment was already an established agricultural practice by then, and its use went back to the colonial period of the United States. Dr. Crocker's history was originally circulated in mimeographed form, but the demand for it was so great it was eventually published in 1922 in print form by the Gypsum Industries Association, Chicago, IL.

AW: When did you first begin to do research on the use of flue gas desulfurization (FGD) gypsum in agriculture and why?

WD: My experience working with gypsum goes back to the late 1980s. We were working with some of the new materials being created when sulfur dioxide scrubbers were first coming online at coal-fired power plants due to the clean air act. There were different scrubbing technologies being tested with by-products that had different types of properties. We found that gypsum-based materials were excellent in helping remediate abandoned and highly degraded surface coal mine soils. We have published extensively on our results from this work. As this work was winding down, it seemed natural to begin to extend the use of gypsum to agriculture because of its long history as a soil amendment. This work really took off about 25 years ago with the support of many and included our establishment of a natural network of sites across the United States to investigate the use of FGD gypsum as a soil amendment.

AW: What are some of most important benefits from the use of FGD gypsum in agriculture?

WD: There are numerous agricultural and environmental benefits associated with use of FGD gypsum as a soil amendment. They include gypsum 1) serving as a calcium and sulfur source for plant nutrition; 2) as a material that is moderately soluble and that improves plant rooting in acid subsoils; 3) improving soil structure in soils with high concentrations of sodium and magnesium, which leads to greatly increasing water infiltration into soil and percolation through soil; 4) increasing carbon sequestration in soil and thus helping to prevent carbon dioxide buildup in the atmosphere; 5) being applied with manure and nitrogen fertilizers to enhance crop uptake of nitrogen and nitrogen fertilizer use efficiency; and 6) reducing soluble phosphorus runoff from farm fields, thus improving water quality in receiving lakes and rivers.

AW: Is the growth in the use of FGD gypsum occurring at rates you expected? Is FGD use in agriculture significant globally?

WD: Since 2002, when the use of FGD gypsum in agriculture was first reported by the American Coal Ash Association, there has been an increase from 78 thousand tons to 1.3 million tons in 2014 (www.acaa-usa.org/Publications/Production-Use-Reports). The biggest jump was between 2013 and 2014, when use more than doubled from 0.58 to 1.3 million tons. This indicates to me that more and more farmers are becoming aware of gypsum's benefits as a soil amendment. Of course, the increased research on gypsum use and the agricultural economy have also played important roles that affect overall farm use. Probably one the biggest reasons for expanded gypsum use on farms, however, is that with sulfur scrubbers being installed at utilities, the amount of sulfur being deposited onto farmlands has greatly decreased. It is common now for universities and crop consultants to see sulfur deficiencies in crops, which thus leads to recommendations for application of sulfur fertilizers to maximize crop yields. Of course, gypsum is an excellent sulfur fertilizer because it is in a sulfate form that is immediately and readily available for crop uptake. FGD gypsum is also produced in other countries. I was recently involved in a project with scientists in Shanghai, China, where gypsum was used to remediate sodic/saline soils reclaimed from the sea.

AW: Are there significant developments on the immediate horizon that would expand the use of FGD as a soil amendment and what does the future of FGD gypsum use look like?

WD: The most significant recent development in the use of gypsum as a soil amendment is related to its ability to decrease the movement of soluble phosphorus off of fields into our lakes and streams. There is increasing awareness and concern across our country about the role of phosphorus in degrading water quality and creating algal blooms. Our research to date clearly shows a benefit in significantly reducing such phosphorus movement. In



fact, some of our studies have shown we can achieve the target of a 40% reduction in soluble phosphorus concentrations in tile water that drains from farmer fields. Because farmers are already applying gypsum to their fields, due to other benefits that are brought about by gypsum, the improved water quality is an added bonus.

AW: You have worked closely with the USDA Research Service, industry, and other academics on agricultural uses of FGD gypsum. In your opinion, is there more work that should be done?

WD: There are still many questions that need to be answered that will lead to FGD gypsum use that is economically and environmentally sustainable. We have conducted extensive environmental tests and have shown that FGD gypsum is a safe and excellent material for agriculture. Questions that remain often relate to what is the best rate to use for various end purposes, how often should gypsum be reapplied to soil, what crops benefit the most from gypsum use, how does gypsum effect and improve fertilizer use efficiency and by how much, and what are the benefits of using gypsum as a soil amendment in aggregate across a watershed? Also, there are still questions related to economic returns when using gypsum as a soil amendment and an Ohio State University study has specifically addressed this issue.

AW: Thank you, Professor Dick.

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Educational Foundation Scholarship Winners Selected

The American Coal Ash Association Educational Foundation awarded \$8500 in scholarships to three university students with interests in advancing the sustainable and environmentally responsible use of coal combustion products (CCPs).

Trevor Williamson of the University of Texas at Austin was selected to receive the \$5000 David C. Goss Scholarship. A graduate student in civil engineering, Williamson is researching fly-ash-based inorganic polymer concrete—a new class of materials that replaces 100% of portland cement with chemically activated fly ash.

Ryan Holmes of the University of Missouri – Kansas City was selected to receive the \$2500 John Faber Scholarship. Also a graduate student in civil engineering, Holmes is researching the use of permeable reactive concrete containing fly ash as a method of remediating heavy metals from ground and surface waters.

Rich Pepper, a University of North Carolina at Chapel Hill law student, was selected to receive a \$1000 scholarship. Pepper's winning essay examined the recent U.S. Environmental Protection Agency's coal ash disposal regulation's applicability to municipal solid waste landfills.

Three other applicants received honorable mentions:

- Jenberu Feyyisa, PhD student in civil and environmental engineering at the University of North Carolina at Charlotte;
- Xiangyu Liu, PhD student in petroleum engineering at the University of Texas at Austin; and
- Mina Mohebbi, PhD student in civil and environmental engineering at Pennsylvania State University.

Williamson and Holmes presented summaries of their research ACAA Winter Meeting in Tampa, Florida, in February 2016. The complete scholarship application essays by all three scholarship winners are published in this edition of *ASH at Work* magazine on pages 52-57.

Scholarship applications were judged by 18 ACAA member volunteers. At the Winter Meeting, Scholarship Committee Chair Dawn Santoianni of Duke Energy turned over the committee's leadership to Dawn DeJardin of Wisconsin Public Service.

The ACAA Educational Foundation Scholarship Program's 2016-2017 program will accept applications from September 1, 2016, through October 16, 2016. Awards will be based on essays, coursework, academic credentials, recommendations, and a demonstrated interest in the use of coal combustion products. This year, a third scholarship may be awarded at the Foundation's discretion with a preference toward undergraduate students in an effort to increase awareness, experience, and understanding of CCP management and use opportunities.

The ACAA Educational Foundation is a financially self-sustaining, not-for-profit organization that promotes understanding of CCP management and use through communications and outreach initiatives that are aimed at government and industry



Scholarship winners Trevor Williamson (left) and Ryan Holmes (right) presented their research at the ACAA Winter Meeting in Tampa, FL, in February 2016.



Rich Pepper, a University of North Carolina at Chapel Hill law student, also received a scholarship from the Educational Foundation.

decision-makers and the public. Foundation initiatives consist of awarding university-level scholarships, development and distribution of educational materials, financial support for research, and sponsorship of CCP forums. For more information, visit www.acaa-usa.org/About-ACAA/Educational-Foundation.

ACAA Officers and Directors Elected

During the American Coal Ash Association's Winter 2016 meeting, ACAA members elected six new officers and directors.

Officers elected to serve 2-year terms include Chairman Charles Price of Charah, Inc.; Vice Chairman Kenneth Tapp of LG&E and KU Services Company; and Secretary/Treasurer Lisa J.N. Bradley, PhD, of Haley & Aldrich.

The leadership transition took place at ACAA's Spring Meeting in Indianapolis, IN. At that time, ACAA Chairman Hollis Walker of Southern Companies transitioned to an ex-officio role of Past Chairman.

Elected to 3-year terms on the ACAA Board of Directors were Laurie Cook of DTE Energy, Steve Benza of Headwaters Resources, and Gwen Eklund of Weston Solutions. Cook will represent the utilities membership category, Benza will represent ash marketers, and Eklund will represent affiliate members of the Association.

Promotional Efforts Focus on Ash Supply Issues

American Coal Ash Association staff and volunteers have devoted substantial time and effort over the past year addressing the impact of changing electric utility resource patterns on fly ash supply.



New ACAA officers include (left to right): Charles Price, Chairman; Lisa J.N. Bradley, PhD, Secretary/Treasurer; and Kenneth Tapp, Vice Chairman.



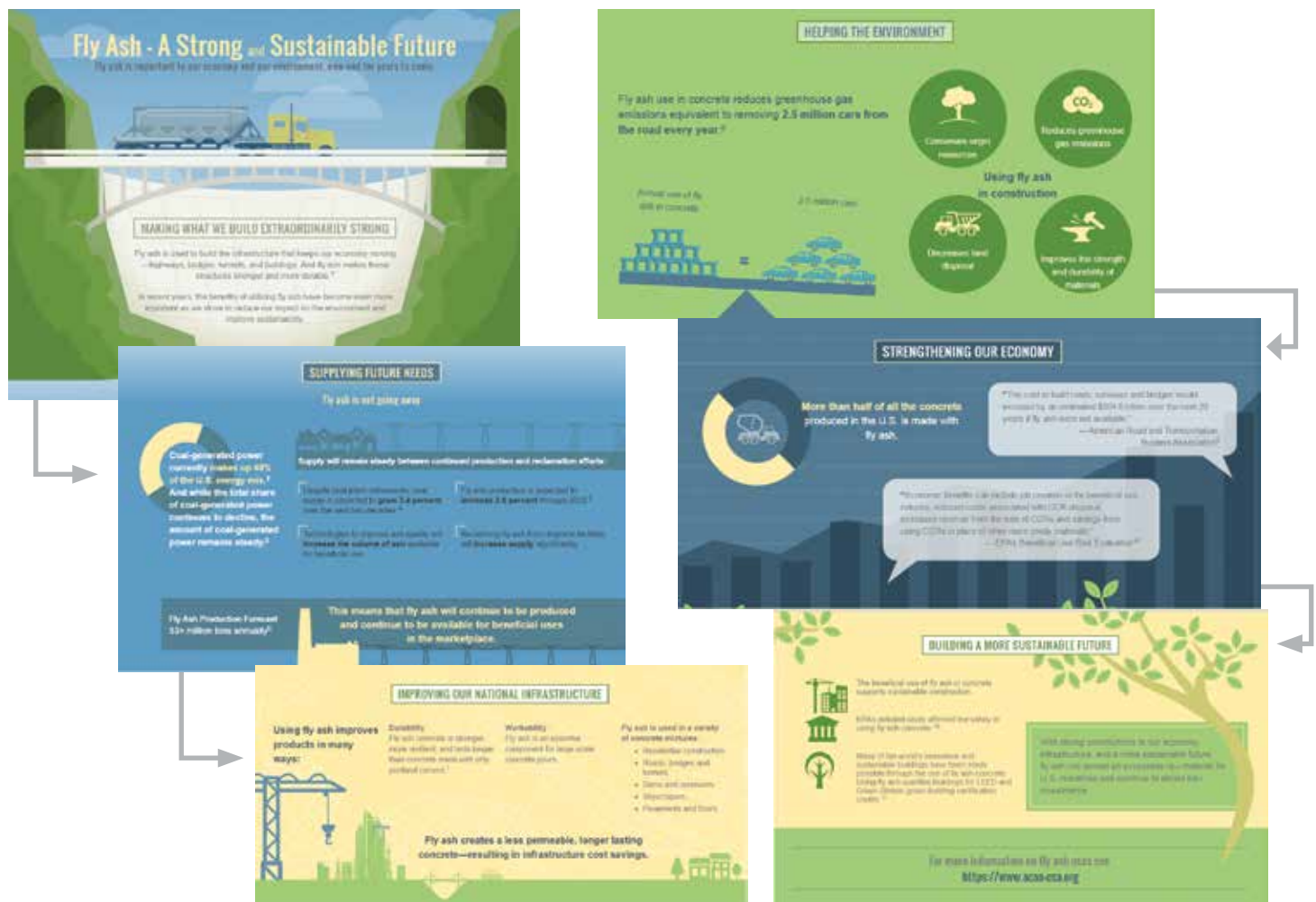
New ACAA directors include (left to right): Laurie Cook representing utilities, Steve Benza representing ash marketers, and Gwen Eklund representing associate members.

Competition from natural gas and increasing environmental regulations have caused a decrease in coal use for generating electricity. However, forecasts continue to show ample coal consumption over the next several decades that will continue to generate more fly ash than the United States has historically used beneficially.

An American Coal Ash Association commissioned study by the American Road and Transportation Builders Association in 2015 concluded: "Forecast models project that sufficient quantities of CCPs will be available for beneficial use over the next two decades. Given regulatory certainty, CCP markets will continue

to grow this recycling success story." (See "Key Findings Report," *ASH at Work* 2015, Issue 2.)

This edition of *ASH at Work* contains two additional resources that have been proven helpful in explaining ash supply dynamics. The "American Recycling Success Story" brochure is an annual ACAA publication that summarizes beneficial uses of coal combustion products and presents the most recent data from ACAA's annual production and use survey. (That document can be found on pages 70-75 of this magazine.) Additionally, ACAA launched a new infographic on the Association's website, which is reproduced below.



INCREASING FLY ASH UTILIZATION USING INORGANIC POLYMER CONCRETE

By Trevor Williamson

ABSTRACT

The disposal of coal combustion products (CCPs) is costly for electric utilities, particularly in the face of new EPA regulations (40 CFR 257 and 40 CFR 261). Additionally, CCP landfilling is detrimental to the environment because it requires land use for disposal sites, and risks soil and groundwater contamination by leachate. Investment in the right technologies, however, can turn these materials from a nuisance into a valued resource. The concrete industry currently accounts for the majority of CCP reuse, where fly ash is used as a partial replacement of portland cement. While typical replacement levels in ordinary concrete are about 25%, inorganic polymer concrete (IPC) provides an exciting possibility for substantially increasing CCP reuse by replacing 100% of cement with fly ash while achieving superior engineering properties in comparison to ordinary concrete. This research seeks to transform our ability to use IPC by forwarding our understanding of the basic chemistry that controls its property development.

ESSAY

Coal is an abundant fuel source that can be efficiently converted into usable energy, and will thus likely remain a major source of energy in the US for the foreseeable future. It is the largest domestically produced energy source in the United States, fueling approximately 39% of the country's electricity in 2014 [1]. One consequence of burning coal is the vast amount of residual solid waste that requires special landfilling, thus creating brownfields and risking soil and groundwater contamination. Fortunately, the unique chemical and physical properties of fly ash, which comprises about half of all coal combustion products, provide several opportunities for beneficial reuse. In 2013, coal-burning power plants produced roughly 53 million tons of fly ash, of which about 23 million was diverted from landfills [2]. Finding beneficial reuses for the remaining fly ash has numerous environmental and economical benefits such as conserving greenfield space, minimizing virgin material consumption, and reducing greenhouse gas emissions.

Roughly half of the 23 million tons of fly ash reused beneficially in 2013 was used in concrete products [2], where it primarily serves as a partial replacement for portland cement (PC). Typical replacement levels in PC concrete are about 25% and

are limited by the delayed setting times and low early-strength associated with higher dosages [4]. PC production releases about 0.9 tons of CO₂ per ton of cement [3], so displacing PC with fly ash has the added environmental benefit of reduced CO₂ emissions. Since more concrete is produced than any other manmade material in the world, there is a tremendous opportunity to divert enormous quantities of fly ash from landfills by increasing fly ash replacement levels.

Fly ash-based inorganic polymer concrete (IPC), is a new class of materials that replaces 100% of PC with fly ash. These binders are synthesized by activating fly ash with a highly alkaline aqueous solution, such as sodium hydroxide [5]. Previous research has demonstrated comparable mechanical properties (compressive strength, stiffness) [6–8] as well as superior dimensional stability [9] and durability (resistance to corrosion, alkali-silica reaction, acid attack) [10–12] of IPC compared to PC concrete. Much of the previous work on these materials, however, has taken a trial-and-error approach to dealing with the significant variation in composition and morphology between fly ash sources; widespread use of fly ash-based IPBs requires a better understanding of the basic chemistry that governs their product formation, microstructure development and ultimately, engineering properties.

My research examines the precursor-to-product relationships of IPC development, specifically aiming to quantify the effects of solution composition and speciation as well as equilibration temperature on the composition, structure, and solubility of sodium aluminosilicate hydrate (N-A-S-H), the primary binding phase in low-calcium IPBs. N-A-S-H gels are synthesized by mixing dilute solutions of sodium aluminate and sodium silicate across a range of compositions and allowing the gels to equilibrate at temperatures ranging from 4–70°C. By working with dilute systems, the complicating effects of kinetics (i.e., simultaneous dissolution of precursors and formation of products) are essentially eliminated. This approach allows complete stoichiometric control of the solution to directly evaluate the effect of a given solution composition on the development of N-A-S-H properties.

Composition of the N-A-S-H gels is measured by hydrofluoric acid digestion followed by solution analysis using inductively

coupled plasma optical emission spectrometry (ICP-OES). The structure of N-A-S-H is investigated using solid-state nuclear magnetic resonance and x-ray diffraction. Temperature dependent solubility products (K_{sp}) of the N-A-S-H gel are determined by monitoring the pH and ionic concentration of the solution (ICP-OES) over time until equilibrium is approached. The results are key to the development of thermodynamic modeling for IPC that can predict the solid phase assemblages and pore solution compositions of these materials as a function of the bulk composition and fly ash morphology. Such predictions will ultimately transform our ability to use IPCs by facilitating the design of mixtures with optimum engineering properties from a wider range of fly ashes despite the challenges associated with variation between fly ash sources.

There are many opportunities for diverting more CCPs from landfills, all of which benefit the environment, the economy, and ultimately, society as a whole. I believe that it is possible to approach 100% reuse of CCPs, but doing so requires investments in a range of existing and novel technologies to increase demand and decrease costs for reuse, making reuse economically viable for a larger portion of CCPs. IPC presents a unique opportunity for dramatically increasing CCP reuse because it relies on fly ash for 100% of the solid precursors and because of the sheer scale of the concrete industry. In addition to the benefits of diverting fly ash from landfills, substituting IPC for PC concrete dramatically reduces the CO₂ emissions associated with cement production while producing a more durable infrastructure to support today's growing society. Continued research in this and other technologies that reuse CCPs will transform these materials from a burdensome waste product into a valuable resource. ♦

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RESEARCH AS PART OF A LARGER SEPARATELY FUNDED PROJECT

This work is part of a larger separately funded project called Inorganic Polymers: Novel OPC-Free Binders For Transportation Infrastructure. The project is collaboration between The University of Texas at Austin, The University of California, Los Angeles, and The University of California, Santa Barbara.

Scope:

The overall scope of the project is broken down into three themes that aim to develop a molecular design strategy to engineer inorganic polymer concrete for the construction of transportation infrastructure. In the first theme, synthetic inorganic polymers are made using reagent grade materials to study the effect of solution composition on the composition, structure, and solubility of sodium aluminosilicate hydrate gel. This first theme is the portion of the work that I am conducting at UT Austin and is described in the essay. In the second theme, numerous analytical techniques are used to study the kinetics of the reactions and microstructural development in detail. This theme will provide a fundamental description of the dissolution-gelation-polymerization reaction pathways and link reaction evolution to microstructure. Finally, in the third theme, the findings of the first two themes will serve as inputs in a thermokinetic model that will simulate product development in inorganic polymers and predict the behavior of inorganic polymers produced from a range of fly ashes and synthesis conditions.

Funding source:

Federal Highway Administration (FHWA)

Funding amount:

\$900,000

Major milestones and schedule:

Theme # 1: Compositional Banding and Stoichiometric Control as Approaches to IP synthesis

- 1) Optimization of inorganic polymer composition – February 2014
- 2) Selection of precursors and activators – January 2015
- 3) Determination of physical, dry chemical, and wet chemical properties – February 2016
- 4) Characterization of engineering properties – March 2016

Theme # 2: Correlating the Progress of Reactions to Microstructure Evolution

- 1) Quantification and manipulation of aluminosilicate dissolution rates – November 2015
- 2) Solid and solution-state nuclear magnetic resonance: chemical studies – March 2016
- 3) Correlation of reaction evolution to the state of the microstructure – March 2016

Theme # 3: Development of a Thermokinetic Platform for Simulating IPB Systems

- 1) Development of thermokinetic engine – October 2015
- 2) Benchmarking and verification of the simulation platform and onsite training – May 2016

REMEDIATING HEAVY METALS USING PERMEABLE REACTIVE CONCRETE

By Ryan Holmes

ABSTRACT

Permeable reactive concrete (PRC) is a promising method of remediating heavy metals from ground and surface waters that has been developed at the University of Missouri-Kansas City. This research investigates the use and effectiveness of heavy metal removal using fly ash with high carbon or high sulfur contents. The use of these ashes not only improves the removal of heavy metals due to chemical compatibility but also eliminates the need for landfilling the unacceptable fly ash, as is the current situation. PRC has significant implications towards the improvement water quality across the United States as well as cost effective prevention of future environmental hazards.

ACAA ESSAY

Recent regulation changes to improve air quality emissions from coal-fired power plants have had negative effects on the production of its most sought after byproduct, fly ash. Use of activated carbon to reduce mercury emissions has increased the overall loss on ignition of fly ashes which use this method. High sulfur bearing coal is used in some regions and produces a fly ash that has a high percent of sulfur by mass. These two types of fly ash are of particular interest both from a financial and environmental view point especially considering they are currently being land-filled since they do not meet specifications for normal concrete use. A significant portion of Superfund sites are contaminated with heavy metals from mining and other industrial processes. Using current technology, these sites require significant expenditures and maintenance to mitigate these contaminants, which left untreated could have even greater costs. In recent news, approximately 3 million gallons of mining waste was released into the Animas River in Colorado and effected thousands of people including the local Native American tribes, such as the Southern Ute and Navajo tribes, who rely heavily on the river. (1-2)

Permeable reactive barriers (PRBs) are one method of removing heavy metals in groundwater, but are costly due to the expense of the materials used for sorption or fixation such as activated carbon or other inorganic compounds (i.e. activated persulfate) (3). Annually PRB installations for only Department of Energy remediation sites exceeds 1 billion dollars (3). Heavy metal solubility is especially dependent on pH and will decrease as pH increases (4). Portland cement concrete has a pH around 12.0 S/U, and is a compatible system using fly ash as a supplementary cementitious material. By combining all of these elements, PRC has a high likelihood of removing heavy metals. Preliminary results show PRCs containing fly ash, especially out of spec ashes, exhibit high removal efficiencies of lead, cadmium, and zinc. PRC does not have the same strength requirements for shrinkage or workability that typically preclude the use of high carbon/sulfur fly ash in ordinary concrete applications.

By removing heavy metals from the contaminated sites using a waste product that would normally be landfilled, this research is endeavoring to valorize the fly ash while improving the environment. PRC as a product could become the most cost effective and resilient remediation technique for heavy metals and several other contaminants, and could prevent catastrophes similar to the Colorado mine spill. ♦

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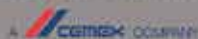
DESCRIPTION OF SEPARATELY FUNDED PROJECT

This study is part of a much larger ongoing research portfolio which is investigating several uses of these waste fly ashes, including soil, surface water, and groundwater remediation. Current research is being funded by UM System Intellectual Property FastTrack Research Initiative and NSF Grant number CBET-1439378. The provisional patent application number is 61/995,737. Total funding was approximately \$150,000 and is coming to a close. Due to the high efficiency and wide application of PRC, approximately 70% of the

preliminary research required for proving the technology has been completed. Future milestones include the completion of jar testing for all mix designs and breakthrough curve testing (approximately 3-6 months). The time table for current testing has significantly exceeded initial estimations due to the success of the material. At least 6 final reports and peer-reviewed publications are expected within the next 6 months. Several conference presentations have already occurred with at least 4 more in the next 9 months.



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- The background of the slide is a photograph of an industrial facility. A large, white, cylindrical silo with multiple horizontal bands and a complex network of pipes and ladders is the central focus. In the foreground, a white cement truck is parked, and another smaller truck is visible in the background. The sky is blue with some clouds.
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 - Ash Handling and Loading
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CCR RULE'S APPLICABILITY TO NEW AND EXISTING MUNICIPAL SOLID WASTE LANDFILLS

By Rich Pepper

ABSTRACT

The Coal Combustion Residuals Rule ("CCR rule") applies to new and existing CCR landfills¹ and CCR surface impoundments²—and any applicable lateral expansions—receiving CCR after the effective date of the rule (October 19, 2015).³ Municipal Solid Waste Landfills Facilities ("MSWLFs") do not fall under the purview of the regulations.⁴ This memo concludes that the rule will not apply to CCR monofill operations at existing MSWLFs and most likely not apply to co-disposal operations at existing MSWLF. Also, MSWLFs could probably be forced to follow additional regulations regarding fugitive dust criteria, groundwater monitoring, and CCR acceptance plans.

THE MSWLF EXCEPTION

Municipal Solid Waste Landfill Facilities ("MSWLFs") do not fall under the purview of the new regulations.⁵ The agency recognizes that some MSWLFs accept CCR for disposal, use it as daily cover, or both.⁶ EPA defines MSWLF units as a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined in this section. A MSWLF unit also may receive other types of RCRA Subtitle D wastes, such as commercial solid waste, nonhazardous sludge,

and industrial solid waste. Such a landfill may be publicly or privately owned. A MSWLF unit may be a new MSWLF unit, an existing MSWLF unit or a lateral expansion.⁷

In guidance, EPA states a MSWLF must be permitted by a state with a municipal solid waste program approved by EPA under 40 CFR § 258.⁸ Because EPA modeled the new CCR standards after the rules applying to MSWLFs in 40 CFR § 258, the agency has concluded that applying the CCR Rule to such facilities would be duplicative.⁹ Because EPA modeled the CCR rule after the MSWLF rule, it appears that the agency wants to ensure that any containment area receiving CCR falls under either set of regulatory requirements.

Off-site landfills are subject to the CCR rule unless they qualify as a MSWLF.¹⁰ As mentioned above, to qualify as a MSWLF, a facility must be permitted by an applicable state program under 40 CFR § 258.¹¹ The EPA received many comments during rulemaking regarding the co-disposal of CCR with other non-MSW.¹² In response, the agency noted that "rather than exclude MSW landfills that receive CCR for disposal or daily cover from the definition of CCR landfill, the Agency is excluding MSW landfills from the requirements of the final rule by including them in a listing of excluded facilities or activities."¹³ The agency is very vague as to the meaning of the exclusion's placement. However, this placement could be to exclude MSWLFs that are not considered landfills, such as impoundments. Some comments to the rule also centered on the definition of CCR landfills including "sites that are excavated so that more coal ash can be used as fill."¹⁴ Some parties were concerned that this

1 CCR landfills are areas of land or excavations that receive CCR, with some exceptions. 40 CFR § 257.2; 80 Fed. Reg. 21302, 21468. The term also includes sand and gravel pits and quarries that receive CCR, CCR piles, and any practice that does not meet the definition of a beneficial use of CCR. 80 Fed. Reg. 21302, 21355. EPA also excluded treatment facilities, surface impoundments, underground injection wells, salt dome and bed formations, underground mines, caves, and corrective action management units. 40 CFR § 257.2; 80 Fed. Reg. 21302, 21355.

2 CCR surface impoundments are natural topographic depressions, man-made excavation, or diked areas, which are designed to hold an accumulation of CCR and liquids. 40 CFR § 257.2; 80 Fed. Reg. 21302, 21468. Existing CCR landfills and impoundments either receive CCR both before and after October 14, 2015 or are constructed prior to October 14, 2015 and receive CCR on or after that date. 40 CFR § 257.53. New CCR landfills and impoundments receive CCR or are constructed after October 14, 2015. 40 CFR § 257.53. The agency considers construction to have begun when the owner or operator of a facility has obtained the federal, state, and local permits necessary to being physical construction and continuous on-site, physical construction has begun. 40 CFR § 257.53.

3 Criteria for Classification of Solid Waste Facilities and Practices, 40 CFR § 257.50(b) (2015); Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities, 80 Fed. Reg. 21302, 21302–21304 (Apr. 17, 2015).

4 40 CFR § 257.50(i).

5 *Id.*

6 Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities, 80 Fed. Reg. at 21341.

7 40 CFR § 257.2.

8 Comment Summary and Response Document ("Comment Summary") Vol. 3, 35 (on file with author). The document is a collection of the comments and agency answers associated with the promulgation of the CCR rule.

9 *Id.* at 53 ("Therefore, the Agency sees no need to impose duplicative requirements for MSW landfills that receive CCRs."). Both regulatory regimes require new units to have composite liners or their equivalent, and all units are subject to location restrictions, run-on and run-off controls, fugitive dust controls, ground water monitoring and corrective action, and closure and post-closure care requirements. 80 Fed. Reg. 21302, 21341.

10 Comment Summary Vol. 3, 35; See 40 CFR § 257.50(b).

11 *Id.*

12 *Id.* at 53.

13 *Id.*; See 40 CFR § 257.50.

14 *Id.* at 51.

ambiguous language did not make clear whether this “excludes co-disposal with MSW or other non-MSW, which leaves open the potential that [MSWLFs] would also be [considered] CCR landfills subject to the rule.”¹⁵ EPA ambiguously responded by saying CCR disposed in a non-MSW facility would be subject to the new rule.¹⁶

When asked about monofill operations, the agency responded that an exclusion of a CCR monofill from the rule is acceptable as long as the facility qualifies as a MSWLF.¹⁷ As long as the facility is not one of those explicitly rejected by the definition of MSWLF (i.e. land application unit, surface impoundment, injection well, or waste pile receiving household waste) and is properly permitted under the applicable state’s MSWLF program, then the facility will qualify for the classification.

ADDITIONAL REGULATORY REQUIREMENTS SUGGESTED BY THE EPA

Since the CCR rule was modeled after those applying to MSWLFs, the agency sought to avoid the duplicative application of similar requirements for MSWLFs receiving CCR. In spite of the agency’s exclusion of MSWLFs from the rule’s requirements, we have identified several recommendations made by the EPA for states to adopt in their MSWLF regulations. The following paragraph provides a brief summary of those recommendations.

- a. Fugitive Dust Criteria: While MSWLF fugitive dust criteria are not as specific compared to those in the CCR Rule, 40 CFR § 258.4 requires any owners or operators of a MSWLF to not violate any applicable requirements developed under a State Implementation Plan (“SIP”). The agency expects the states to promulgate and enforce additional requirements in their respective SIP to address fugitive dust.¹⁸ Illinois’ 415 ILCS 5/9(a) (2012) provides an example of an acceptable provision.¹⁹
- b. Ground Water Monitoring: Although EPA is not requiring MSWLFs housing CCR to modify their groundwater monitoring programs, the agency expects that state directors will “require MSWLFs to modify their MSWLF permits to address the addition of CCR to the unit as it relates to groundwater monitoring and corrective action.”²⁰ Current regulations allow approved states to promulgate an alternative list of inorganic indicator parameters for MSWLF units if the alternative parameters would provide a warning of inorganic releases from a CCR landfill.²¹ Specifically, EPA expects state directors

to change the detection monitoring constituents for MSWLF units to those contained in the CCR Rule.²² The constituents listed in the rule are: boron, calcium, chloride, fluoride, pH, sulfate, and total dissolved solids.²³ These contaminants are known to be the leading indicators of CCR groundwater contamination.²⁴ The agency strongly recommends the inclusion of these chemicals to be monitored in the groundwater when a MSWLF decides to accept CCR.²⁵

- c. CCR Acceptance Plans: The agency also recommends State Directors to encourage applicable MSWLF units to promulgate a “CCR acceptance plan” that is maintained in the facility operating record.²⁶ A plan will ensure a MSWLF understands the physical and chemical characteristics of the waste received and “handles it with the additional precautions necessary to avoid dust, maintain structural integrity, and avoid compromising the gas and leachate collection systems of the landfill so that human health and the environment are protected.”²⁷ ❖

²² *Id.*

²³ *Id.*

²⁴ *Id.*

²⁵ *Id.*

²⁶ *Id.*

²⁷ *Id.*

¹⁵ *Id.*

¹⁶ *Id.* at 53. (“[T]he Agency has no information that this is occurring, however, non MSW [sic] waste facilities with landfills or surface impoundments (e.g., industrial waste facilities) that receive CCR for disposal would be subject to today’s regulations.”).



¹⁷ *Id.* at 35.

¹⁸ Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities, 80 Fed. Reg. 21302, 21341 (Apr. 17, 2015).

¹⁹ *Id.*

²⁰ *Id.*

²¹ *Id.* at 21342 (citing 40 CFR § 258.54(a)(2)).

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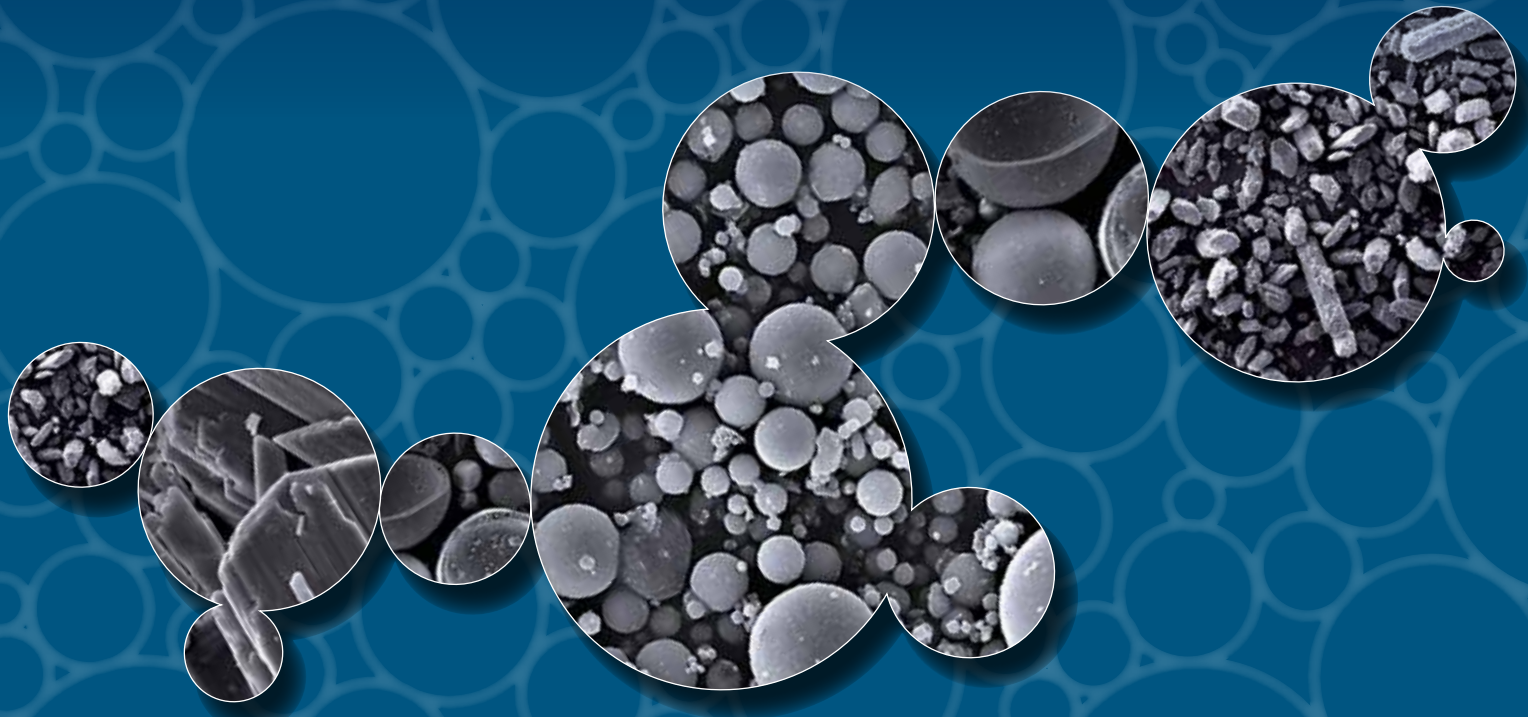
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Phone: 859-257-0305, Fax: 859-257-0220
www.coalcgp-journal.org/
ccgp-journal@uky.edu

Editor: Dr. James C. Hower
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Experimental and modelling evaluation of slagging behaviour of German lignite

Martin Kaiser¹, Alexander Ilyushechkin²

¹Department of Energy Process Engineering and Chemical Engineering, Technische Universität Bergakademie Freiberg - VIRTUHCN, Reiche Zeche, Fuchsmühlenweg 9, Haus 1, 09599 Freiberg Germany

²CSIRO Energy Technology, PO Box 883, Kenmore QLD 4069 Australia

The behaviour of mineral matter is important for the characterisation of coal for use in entrained flow gasification technologies. We investigated four behavioural characteristics – ash fusion temperatures (AFT), slag viscosity versus temperature profiles, temperatures of critical viscosity (T_{CV}) and slag phase compositions – of Rhenish lignite coal ash using laboratory and modelling tools.

Assessment of AFT models used coal ash composition shows a wide range of the calculated data, with only one (modified) model demonstrating agreement with experimental data.

Experimental slag viscosity data were obtained over a temperature range from 1200–1500 °C. Where relevant, T_{CV} was also measured. Comparison of the data to calculated viscosities, shown below, revealed significant variation due the different databases used in these models.

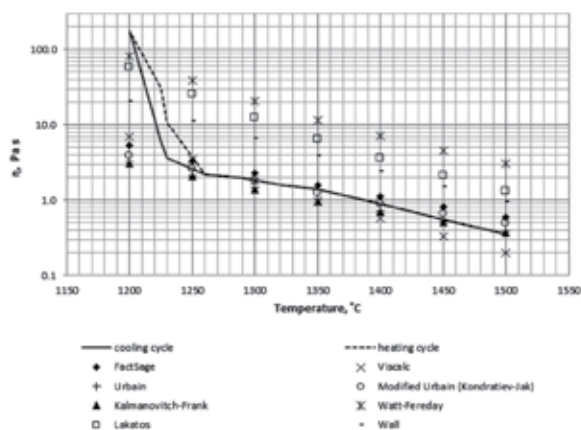


Figure. Measured and calculated (without solid phase input) viscosities of TUF101/104 slag

Models that calculate T_{CV} on the basis of ash composition fail to predict the data due to very high silica/alumina ratio. However, models based on AFT data match well with the experimental T_{CV} values.

The formation of solids in the slags in the temperature range below liquidus was calculated using thermodynamic modelling tools and compared with the microstructure of laboratory quenched samples. This revealed a strong relationship between solids formation and increasing viscosity. The composition of the predicted phases fits to the experimental investigation. However, the predicted amount of solids is higher than in the quenched samples, indicating an overestimation of solids by FactSage.

We also examined a modification of slagging behaviour by blending the Rhenish ash with ash of an Australian coal in

different ratios. We show that greater viscosity and a wider operational temperature can be achieved by using an appropriate blending ratio.

Full paper available at: www.coalcp-journal.org

Fly Ash as a Potential Scrubber of Acidic Wastes from the Phosphate Industries in Israel

Roy Nir Lieberman^{1,2}, Eli Lederman³, Ithamar Pelly³, Haim Cohen^{1,4*}

¹Department of Chemical Biology, University of Ariel, Ariel, 40700, Israel

²Department of Chemistry, Bar-Ilan University, Ramat-Gan, Israel

³Department of Geological and Environmental Sciences, Ben-Gurion University, Beer Sheva, Israel

⁴Department of Chemistry, Ben-Gurion University, Beer Sheva, Israel

Fly ash (FA) is produced in Israeli utilities via bituminous coal combustion. It is used as a cement additive or in concrete production, and its economic value is low. The FA produced in Israel is very basic (defined as class F) owing to ambient air quality standards that impose low sulfur content in the imported coals. Because the lime content is high (in the South African coal, 10 wt%), it is a good potential chemical scrubber to acidic wastes. The phosphate industry in Israel produces mainly phosphate fertilizers and water-treatment products as well as phosphoric acid. The production methods rely heavily on dissolution of phosphate rock in strong acids, either sulfuric acid (Rotem Amfert plant) or hydrochloric acid (Haifa Chemicals plant). Thus, large quantities of acidic wastes are produced. These wastes have to be treated and neutralized before final storage. The treatment is based upon the addition of lime or calcium carbonate to the liquid waste. We have checked the possibility of using FA to neutralize the acidity and fix the trace elements contained within the wastes. The results show that FA is an excellent scrubber and a very efficient absorber to the trace elements from the waste. The final product is an aggregate substitute, and because it passes the California Waste Extraction Test leach test, it can be used as a partial substitute for aggregates in the concrete industry. Initial calculations show that the actual economic value of the ash is in the range of 3-5 times better than its present value in utilizing it as a building material (cement additive or as aggregate in the construction industry). Thus, using two wastes (FA and the acidic waste) can result in a green nonpolluting product with an appreciable economic value.

Full paper available at: www.coalcp-journal.org

Geochemistry and Mineralogy of Coal-Fired Circulating Fluidized Bed Combustion Fly Ashes

Luis F.O. Silva^{1,2}, Marcos L.S. Oliveira³, Rubens M. Kautzmann¹, Claudete G. Ramos¹, Maria Izquierdo⁴, Shifeng Dai⁵, Jennifer Wilcox⁶, Jeremy Hoffman⁶, James C. Hower^{7*}

¹Laboratory of Environmental Researches and Nanotechnology Development, Centro Universitário La Salle, Mestrado em Avaliação de Impactos Ambientais em Mineracão, Victor Barreto, 2288 Centro, 92010-000 Canoas, RS, Brazil

²Environmental Science and Nanotechnology Department,

Catarinense Institute of Environmental Research and Human Development – IPADHC, Capivari de Baixo, Santa Catarina, Brazil

³ Development Department of Touristic Opportunities, Catarinense Institute of Environmental Research and Human Development – IPADHC, Capivari de Baixo, Santa Catarina, Brazil

⁴ School of Applied Sciences, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK

⁵ China University of Mining & Technology, Haidian, Beijing, China

⁶ Department of Energy Resources Engineering, Stanford University, Stanford, CA 94305-2220, USA

⁷ Center for Applied Energy Research, University of Kentucky, 2540 Research Park Drive, Lexington, KY 40511, USA

The fuel, bed ash, and fly ash were sampled from a circulating fluidized bed combustion (CFBC) unit at two times. The first sampling was a high-sulfur (S) coal-only run, and the second sampling coincided with an experimental burn of up to 10% switchgrass (*Panicum virgatum*) pressed pellets mixed with a high-S coal. The latter blend had a higher moisture content and a lower heating value than the coal-only fuel. Given the time between the samplings and the special needs for the experimental run, unavoidable changes in the coal and limestone complicate comparisons of the bed ash and fly ash chemistry between the sampling times. The bed ash is dominated by CaO and SO₃, and the fly ash has a higher CaO content than would be expected for a pulverized-coal burn of the same coal. The fly ash chemistry bears a superficial resemblance to class C fly ashes, but given the different combustion conditions and consequent differences in the ash mineralogy, the fly ash should not be considered to be a class C ash. The bed ash mineral assemblages consist of anhydrite, mullite, portlandite, and anorthite, while the fly ash has less portlandite and more anorthite than the bed ash.

Full paper available at: www.coalcbg-journal.org

Synthesis and Characterization of High-Iron Alite-Calcium Sulfoaluminate-Ferrite Cements produced from Industrial By-Products

Tristana Duvallet^{1,2}, Yongmin Zhou³, Thomas L. Robl¹, Rodney Andrews^{1,2}

¹ University of Kentucky, Center for Applied Energy Research (CAER), 2540 Research Park Drive, Lexington, KY, 40511

² University of Kentucky, College of Engineering, Chemical and Materials Engineering, 177 F. Paul Anderson Tower, Lexington, KY 40506-0046

³ College of Material Science and Engineering, Nanjing Tech University, No.5 Xinnofan Road, Nanjing, Jiangsu Province, 210009, China

*Corresponding author: 859-806-4916; tristana.duvallet@uky.edu

Ordinary Portland cement (OPC) and calcium sulfoaluminate cement (CSAC) are well-known and commonly used construction materials. The clinker phases mainly responsible for their strength development are C₃S (alite) in OPC, which hydrate to form a calcium silicate gel phase; and C₄A₃S (calcium sulfoaluminate) in CSAC, which hydrates to rapidly form ettringite.

The purpose of this work was to produce high-iron alite-calcium sulfoaluminate-ferrite cements, by combining C₄AF (ferrite), from 5% to 50% by weight, to the C₃S and C₄A₃S clinker phases. The

advantages of producing this alite-calcium sulfoaluminate-ferrite cement would decrease the requirement of bauxite in the raw materials, which would consequently reduce its cost. The use of industrial by-products would also reduce the CO₂-emissions and the firing temperature by 200-250°C compared to OPC. This paper presents the synthesis and characterization of five compositions produced from industrial by-products (hydrated lime related to carbide lime, fly ash, slag, and red mud) and bauxite, formulated as follows: C₃S from 20-50%, C₂S from 10 to 20%, C₄A₃S from 10 to 20%, C₄AF from 5 to 50% and C₂S from 4 to 6% by weight. The clinker with the lowest ferrite content required a higher firing temperature (1275°C) than the compositions with high ferrite contents (1250°C). The impurities, such as MgO and TiO₂ introduced by the industrial by-product, affected the mineralogical compositions and some adjustments of the raw mix were necessary to obtain the clinker compositions desired.

Conclusions: Iron-rich alite-calcium sulfoaluminate-ferrite cements, containing 5% to 50% by weight of ferrite, can be produced from industrial by-products by following specific modulus values, with the aid of mineralizers and fluxes, and by selecting the optimum firing regime for each composition. As demonstrated in this paper, the composition with low amount of ferrite (5% by weight) has to be fired at a higher firing temperature of 1275°C for 60 minutes, whereas all the others compositions, with a content of ferrite from 15% to 50% by weight, required a firing regime of 1250°C for 60 minutes. Moreover, Rietveld analyses indicated that impurities present in the raw materials can affect the clinker compositions and that small variations in the raw mix were necessary to obtain the desired mineralogical compositions. These iron-rich alite-calcium sulfoaluminate-ferrite cements are expected to present great mechanical properties due to the combination of the highly active clinker phases present, such as alite and calcium sulfoaluminate. Further experiments are in progress to demonstrate the chemical and physical properties of these cements.

Full paper available at: www.coalcbg-journal.org

Trends in coal utilization and coal-combustion product production in Kentucky: Results of the 2012 survey of power plants

James C. Hower, Gerald A. Thomas, Shelley G. Hopps

University of Kentucky, Center for Applied Energy Research, 2540 Research Park Drive, Lexington, KY 40511 USA, (1+859-257-0261; james.hower@uky.edu)

The University of Kentucky Center for Applied Energy Research has conducted a survey of Kentucky's utility coal-fired power plants every five years since 1992. The survey includes a collection of the feed coal and the coal-combustion products (CCP). The latest collection was in 2012, with the accompanying information survey covering trends in 2011. Overall coal-fired energy production decreased and the nature of the coal-combustion products changed for a number of reasons, including but not limited to, increased gas production in the Appalachians; a series of warm winters; energy conservation; depletion of Appalachian coal reserves; and utility responses to regulations. From 2011 to 2012, Kentucky's coal-fired generation decreased from 91.656 GWh to 82.762 GWh while gas-fired generation rose from 1.163 GWh to 2.401 GWh. About 10% of the CCP produced in 2011 were sold compared to 30% in 2006.

Some of this can be attributed to an increase in the amount of CCPs in certain categories, primarily flue-gas desulfurization (FGD) gypsum. The latter increase was due to regulations requiring the installation of FGD while stagnation and decreases in sales were due to multiple factors, including the slowdown in housing construction and to the saturation of the Ohio River Valley market. Overall, comparing 2011 to 2006, all categories of CCPs experienced a decline in sales. The change from low-S to high-S coal with the installation of wet-FGD units has resulted in a shift from low- to high-Fe fly ashes.

Full paper available at: www.coalccp-journal.org

Recycling of lignite coal fly ash by its conversion into zeolites

Silviya Boycheva¹, Denitza Zgureva¹, Annie Shoumkova²

¹ Department of Thermal and Nuclear Power Engineering, Technical University of Sofia, 8 Kliment Ohridski blvd., 1700 Sofia, Bulgaria
e-mail: dzgureva@gmail.com

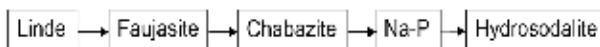
² Institute of Physical Chemistry, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl.11 1113 Sofia, Bulgaria

Fly ash (FA) is a mineral dust from the combustion of coals, which is carried by the flue gases out of the incineration chambers. This residue consists mainly of silica, alumina, glassy and crystalline aluminosilicates, and of a big variety of micro- and trace components. The disposal of FA is of serious ecological risk because of the infiltration of accumulating toxic elements into the soil, the low level of nutrients, and the undesirable pH value. The fact that enormous amounts of FA are generated worldwide determines the extraordinary importance of the development of reliable technological decisions and a strategy for the FA utilization. This approach is also referred to the natural materials economy and the environment protection for sustainable economic development. A promising approach for the utilization of FA is its conversion into low-cost synthetic zeolites with high adsorption and ion-exchange capacities.

This investigation is a part of a broad experimental program on the conversion of lignite fly ash into synthetic zeolites and their application in the flue gas cleaning systems. Our goal is the selective synthesis of Na-X zeolite, whose natural form is known as faujasite (FAU) and whose synthetic commercial analogous is called 13X.

The present study aimed the synthesis of faujasite from lignite FA containing SiO₂ and Al₂O₃ in a ratio of 2.25 without any additional silica through a double stage fusion-hydrothermal synthesis. The fusion is directed to obtain soluble sodium silicate and aluminate that are converted into gel after dissolution under continuous stirring, which is crystallized during the hydrothermal activation. The fusion stage was performed at three temperatures 550, 750, and 850 °C for 1 hour. The hydrothermal synthesis stage was performed at 90 °C with different durations of 2, 4, and 6 hours for the separate experiments. The nature and the composition of the synthesized materials were characterized by X-ray diffraction and scanning electron microscopy with energy dispersive X-ray spectroscopy. In our research, the thermodynamic consequence of the crystallization of zeolite phases is considered as a key parameter for the selective synthesis. It is assumed that Na-X zeolite appears as an intermediate phase in the studied reaction system determined by the process kinetics. The obtained results reveal the sequence in the

thermodynamic stability of the crystallized zeolitic forms from the investigated NaOH/FA mixtures at the settled synthesis conditions, which can be expressed as follows:



The investigated fly ash is considered to be an appropriate material for the preparation of synthetic Na-X zeolite, as a predominant Na-X phase was obtained at a NaOH/FA ratio of 2.0. The yield of zeolite X at this synthesis conditions is found to be 190 g/kg FA. BET surface area of the sample is measured of the order of 42.05 m²/g. At this composition of the reactant system, zeolite Na-X is crystallized as an intermediate thermodynamically unstable phase. The elevation of the NaOH/FA ratio from 1.6 to 2.0 enhances the degree of zeolitization and converts the zeolite from type A to type X. The conversion at a NaOH/FA ratio below 1.2 takes longer time and produces a mixture of zeolites. The obtained zeolitic material can be improved by increasing the sodium hydroxide concentration, as a deficit of sodium was incorporated into the resultant material in comparison with the pure faujasite. The fusion stage does not influence the zeolitization mechanism in the interval 550-850 °C but has an accelerating effect.

Full paper available at: www.coalccp-journal.org

Fabrication and Testing of Low-Energy CSAB Cements that Utilize Circulating Fluidized Bed Combustion Byproducts

Robert B. Jewell¹, Robert F. Rathbone², Tristana Y. Duvallet¹, Thomas L. Robl¹, Kamyar C. Mahboub³

¹ University of Kentucky, Center for Applied Energy Research, 2540 Research Park Drive, Lexington, KY 40511 (859-257-0216; 859-257-0302; bob.jewell@uky.edu)

² Boral IP Holdings LLC, 1150 Arion Parkway, San Antonio, TX 78216

³ University of Kentucky, Department of Civil Engineering, 369 RGAN Building, Lexington, KY 40506

The utilization of circulating fluidized bed combustion (CFBC) ash to make cement products that provide added value and offset CO₂ production is the objective of this research. CFBC burns coal in the presence of a bed of slaked limestone, which effectively absorbs sulfur dioxide (SO₂) to form anhydrite (CaSO₄). CFBC produces two kinds of spent bed materials, coarse bottom ash and a much finer fly ash. Both of these products are very high in calcium. When properly conditioned these materials are capable of acting as hydraulic cements, forming both calcium aluminosulfate minerals, most importantly ettringite, as well as calcium-alumina-silica gels, like that formed from portland cement.

The production of portland cement requires a large amounts of energy, mainly because of the high temperatures required to sinter the raw materials into clinker. Portland cement clinker, which is comprised mainly of calcium silicates, is also very hard and requires considerable energy to grind to the final product (Arjunan et al., 1999). Furthermore, limestone is a major raw material used to produce portland cement and releases large amounts of CO₂ during the thermal processing. In order to attain substantial reductions in energy consumption and CO₂ emissions, significantly lowering the clinkering temperature and the proportion of limestone in the feed is necessary (Gartner and Macphee, 2011). Energy-conserving or

“low-energy” cements can be produced at lower temperatures and using much less limestone than portland cement. An additional environmental benefit of low-energy cements, particularly calcium sulfoaluminate (CSA) cements, is that they can be prepared using substantial amounts of coal combustion wastes as the raw materials. CSA cements gain strength primarily from the formation of a calcium aluminum sulfate hydrate, referred to as ettringite (Arjunan et al., 1999; Beretka et al., 1993).

Calcium sulfoaluminate cements can potentially present considerable environmental advantages compared to portland cement because of the lower energy use, lower CO₂ emissions and use of coal combustion wastes as raw materials. In order to support widespread introduction of the cements in the marketplace there are several issues that must be addressed, namely, high cost, durability issues, and appropriate applications. As was discussed above, although only a limited amount of research has been conducted on the durability of CSA cements, there is sufficient information indicating that the cements can be quite durable in certain environments.

The research described herein has focused on the production of one class of FBC byproduct-based cement: CSAB cement produced by heating the FBC spent bed in the presence of limestone, bauxite, and PCC fly ash. The formulation, production and performance testing of this class of material are described.

Summary and Conclusions: Milling the laboratory CSAB clinker with Class F fly ash, in addition to FGD gypsum, appeared to improve the dimensional stability of CSAB mortar. In every cement that contained fly ash addition, destructive expansion did not occur and drying shrinkage improved. However, fly ash addition generally decreased the compressive strength, although the water reduction achieved with the fly ash, helped to offset this

A major issue regarding the production of CSAB cement is one of cost. Because CSAB clinker production requires substantial quantities of bauxite, the cost of these cements is high. In order to minimize or eliminate bauxite, alternatives to this raw material need to be pursued. The replacement of some bauxite with high-iron raw materials could have the net effect of replacing some of the aluminum with iron, which is considerably less expensive. Thus, future research should focus on the use of high-iron materials, such as certain Class F fly ashes and/or red mud, as partial replacements for bauxite.

Full paper available at: www.coalcgj-journal.org

Prediction of the unburned carbon content of fly ash in coal-fired power plants

Saeid Dindarloo¹ and James C. Hower²

¹ Department of Mining and Nuclear Engineering, Missouri University of Science and Technology, Rolla, Missouri 65409-0450 USA (Email: srd5zb@mst.edu; +1-573-201-0737)

² University of Kentucky, Center for Applied Energy Research, 2540 Research Park Drive, Lexington, Kentucky 40511 USA (james.hower@uky.edu; +1-859-257-0261)

Prediction of carbon content in fly ash is a valuable index in both designing and optimizing coal-fired boilers. In this study, methods of multiple regression, decision trees, and support vector machines

regression (SVR) were used for prediction of unburned carbon content of fly ash in a 300-MW power plant with a tangentially-fired furnace with a low-NO_x concentric firing system. Twenty-one boiler operational and coal petrological variables from 21 experiments in a previous benchmark study (Hao et al., 2004) were used. A variables correlation matrix was used for feature (independent variables) selection in order to reduce the dimensions (number) of input variables from 21 (e.g., O₂ vol., damper position, coal properties, burner tilt, etc.) to five (oxygen concentration in the flue gas, over-fire air, as-received volatile content, as-received ash content, and as-received net heat value), and three, (oxygen concentration in the flue gas, as-received volatile content, and as-received net heat value) for multiple regression (MR) and decision trees (DT), respectively. Both the MR and DT models were able to predict the carbon content with a reasonable accuracy. Furthermore, a support vector regression model was built considering all 21 input variables, which resulted in almost exact predictions of the unburned carbon content of fly ash. The advantage of multiple regression and decision trees, in this study, was using fewer input variables (oxygen concentration in the flue gas, over-fire air, as-received volatile content, as-received ash content, and as-received net heat value). A lesser number of explanatory variables resulted in more computational-time-efficient models. The advantage of the SVR was its very high accuracy in the predictions of the unburned carbon content of fly ash.

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Strengthening Black Cotton Soil with Fly Ash and Moorum : An Investigation of Role of Sub-grade and Sub-base Layer

Gourav Saxena¹ and Nikhlesh Chaurasia²

¹ ITM University Raipur, New Raipur, Chhattisgarh, India
gourav.egd@gmail.com

² VNIT Nagpur, Nagpur, Maharashtra, India

One of the most effective and economical method to strengthen clayey soils is addition of stabilizing agents such as fly ash to soil. In this study, highly plastic clay was stabilized using fly ash. The geo-technical properties such as Alterberg limits, UCS, and CBR value of virgin BC soil and soil treated with fly ash were evaluated. Soil was stabilized with various proportions of fly ash i.e. at 0%, 10%, 15%, 20%, and 30%. UCS of black cotton soil-fly ash mixes is found to be maximum at 20% fly ash content and thereafter the same reduces with further increase in fly ash content. However, in case of fly ash mixed with soil, the CBR value obtained was less as compared to virgin soil. Furthermore, CBR was performed with 2/3 part of fly ash soil mix with 1/3 part of moorum with better results. Maximum CBR value was found to be 5.03% at 20% fly ash content. These results are significant since it proves that we can use fly ash as sub-grade material since, in actual conditions, water does not easily enter in sub-grade layer since it is protected by a moorum (sub-base) course.

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Using Coal Fly Ash in Agriculture: Combination of Fly Ash and Poultry Litter as Soil Amendments for Bioenergy Feedstock Production

E. Kudjo Dzantor^{1,*}, Ekundayo Adeleke¹, Vanaja Kankarla¹, Oluwatosin Ogunmayowa¹, Dafeng Hui²

¹Department of Agricultural and Environmental Sciences, Tennessee State University, Nashville, TN 37209, USA;

²Department of Biological Sciences, Tennessee State University, 3500 John A. Merritt Boulevard, Nashville, TN 37209, USA.

Increasing fiscal, human and environmental costs of coal fly ash (FA) management and disposal are leading to advocacy for greater beneficial uses of the byproducts as soil amendments in agriculture. Greenhouse experiments were conducted in Armour silt loam soil (ASL) that was amended with 10FA (10% FA, w/w) with and without poultry litter (PL=75 mg N/kg) to determine biomass productivity by eastern gamagrass (GG), a warm season perennial grass (WSPG) that could serve as complementary biofuel feedstock to switchgrass (SG), a bioenergy model. FA was obtained from a site at the 2008 Ash Spill in Kingston, Tennessee. GG and SG were grown individually in 15cm W x 41cm H treepots, each containing 6kg soil (ods) and treated with the following combinations: 0FA/0PL, 10FA/0PL, 0FA/PL and 10FA/PL. Each treatment was replicated eight (8) times. The treepots were randomly arranged on greenhouse benches and watered as needed. Biomass production was assessed in soil adjusted to initial pH=4.5 or 6.5. After 12 weeks at initial pH =4.5, GG produced significantly higher biomass ($p<0.05$) in acidic ASL soil that was amended with a combination of 10FA/PL (21.8g/treepot) than in unamended ASL soil (13.3g/treepot. At initial pH=6.5, total biomass productivity of GG ranged from 13.2 to 15.7 g/treepot; the differences were not significant. Biomass productivity of SG trended similarly; the highest biomass productivity (18.2g/treepot) was observed in ASL soil amended with 10FA/PL combination, which was significantly higher than the control (14.3g/treepot). The treatment combinations did not have a significant effect on biomass productivity of SG at pH=6.5. X-ray imaging and analysis of selected washed roots grown at pH 4.5 confirmed significant enhancements of root system architecture (RSA) traits, namely root length, area and

numbers in the 10FA/PL treatments over all others. These results should have a considerable impact on goals for beneficial utilization of wastes (FA and PL) to produce biofuel feedstock in acid impacted soil while providing an understanding of plant root attributes that may be manipulated further to enhance waste utilization for biomass production under soil acidity, FA/PL amendment and, potentially, under other abiotic stressors.

Full paper available at: www.coalcgp-journal.org

Multi-stage Concentration of Cenospheres in Fly ash using the Inverted Reflux Classifier

A. Kiani*, J. Zhou, K.P. Galvin

Centre for Advanced Particle Processing and Transport, Newcastle Institute for Energy and Resources, University of Newcastle, Callaghan, NSW 2308, Australia

*Corresponding Author. Tel: (+61) 2 40339251, Email: Ali.Kiani@uon.edu.au

Although some applications have been found for fly ash, almost 55% of the fly ash is still discarded to the lands surrounding the power stations (ACAA, 2014, Ash at Work, <http://www.aaa-usa.org/>, Issue 1, 2014). One of the most valuable components found in fly ash is cenospheres. Wet gravity separation can be effectively applied to the separation of cenospheres from fly ash given the significant difference between the densities of the particles and water. The combination of inclined settling and the bulk streaming effects was used in the Inverted Reflux Classifier (IRC), a system of parallel inclined channels located below a fluidized bed, to obtain an enhanced recovery of cenospheres from fly ash (Kiani, A., Zhou, J., Galvin, K.P., 2015. Enhanced Recovery and Concentration of Positively Buoyant Cenospheres from Negatively Buoyant Fly Ash Particles using the Inverted Reflux Classifier. Minerals Engineering, 79, 1-9), reporting an optimum feed solids concentration. In the present study, for the first time, a series of Inverted Reflux Classifiers was used to obtain the highest feasible upgrade of cenospheres from fly ash. Figure 1 shows a simple representation of the three-stage process. The compositions of

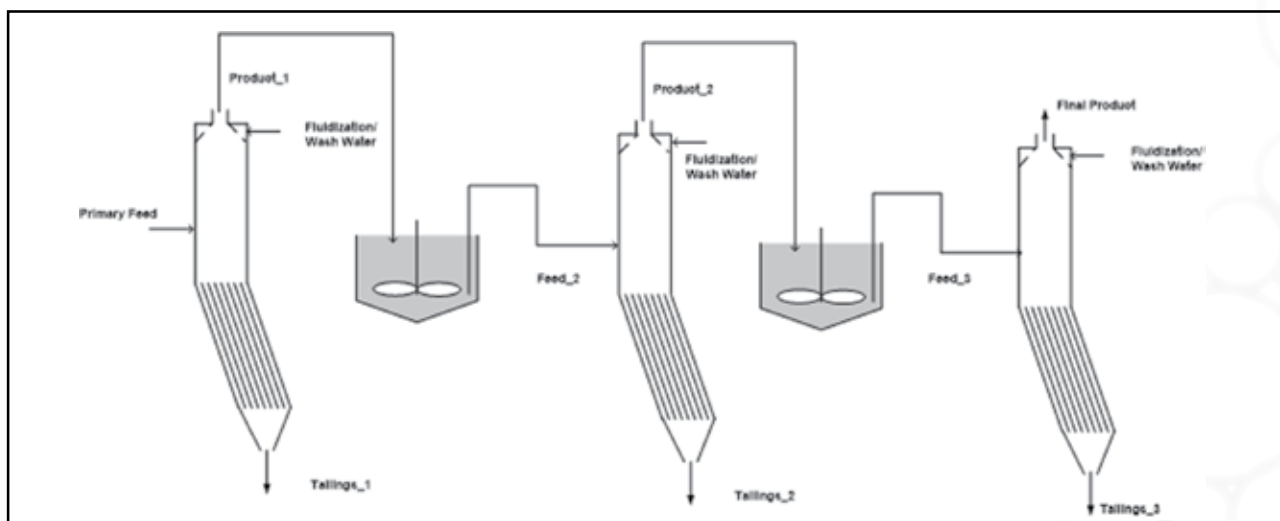


Figure 1. A schematic diagram of the three-stage IRC

all streams were measured using the sink-float method. The size distributions of the cenospheres and fly ash were determined by applying a laser scattering technique. A mass balance reconciliation method was used to minimize errors in all experimental data. The gas pycnometry method was used to measure the density of the cenospheres and fly ash. In the preliminary experiments, involving a fly ash feed with about 0.33 wt% cenosphere concentration, with volumetric split ratio of about 40%, and the feed and fluidization water volumetric fluxes of about 7.3 and 0.88 m³/(m² h), respectively, the cenospheres were upgraded from 0.33 wt% to 21.3 wt% at the end of the process. Here a total recovery of 65.4% was achieved. Therefore the multi-stage IRC process was concluded to be inefficient in separating cenospheres from the low grade fly ash feed. In the main part of the study, at the optimum feed solids concentration, three stages of IRC were applied to upgrade the cenospheres in a fly ash feed containing about 0.9 wt% cenospheres. The product grade and the cenospheres recovery obtained at different stages of the process are presented in Figure 2A. In the first stage, about 80% of the cenospheres was recovered while the product grade was relatively low at about 17%. In this stage of the process, the solids throughput was about 4.0 t/(m² h), when the feed solids concentration was an optimum at about 39%. In the second stage, the product grade increased to about 77% however the recovery was about 69%. In the third stage, the cenospheres grade of about 97%, and the cenospheres recovery of around 92% were achieved.

Figure 2B shows the cumulative upgrade and recovery during the multi-stage processing. The final upgrade and recovery of the cenospheres at the end of the multi-stage IRC were about 110

and 50%, respectively. The low solids concentration of the feed in the second stage of about 10.3 wt% could be the reason for the relatively low recovery of this stage and the whole process. In fact, the feed solids concentration in stage 2 was much lower than the required concentration to induce the streaming effect. The size and density separations occurring in each stage of the process were investigated in detail. Table 1 presents the Imperfection and d_{50} , indicating the efficiency of different stages of the process. It was found that the third stage of the process which involved a very dilute feed provided the lowest imperfection and hence sharpest separation. On the other hand, the separation efficiency was the

Table 1. $d_{50\%}$ and Imperfection showing the quality of separation in each stage

| Stage | $d_{50\%}$ | I (Imperfection) |
|-------|------------|------------------|
| 1 | 36 | 0.21 |
| 2 | 54 | 0.35 |
| 3 | 40 | 0.06 |

lowest in the second stage due to the lack of the bulk streaming phenomenon. The average density of the cenospheres in the product also slightly decreased from about 839 kg/m³ in the stage 1 to about 793 kg/m³ in the stage 2, reflecting the loss of high density cenospheres in the second stage. This paper suggests that the use of a one stage IRC process operating at a reduced feed rate may be beneficial over the multi-stage IRC process for achieving the target grade and recovery.

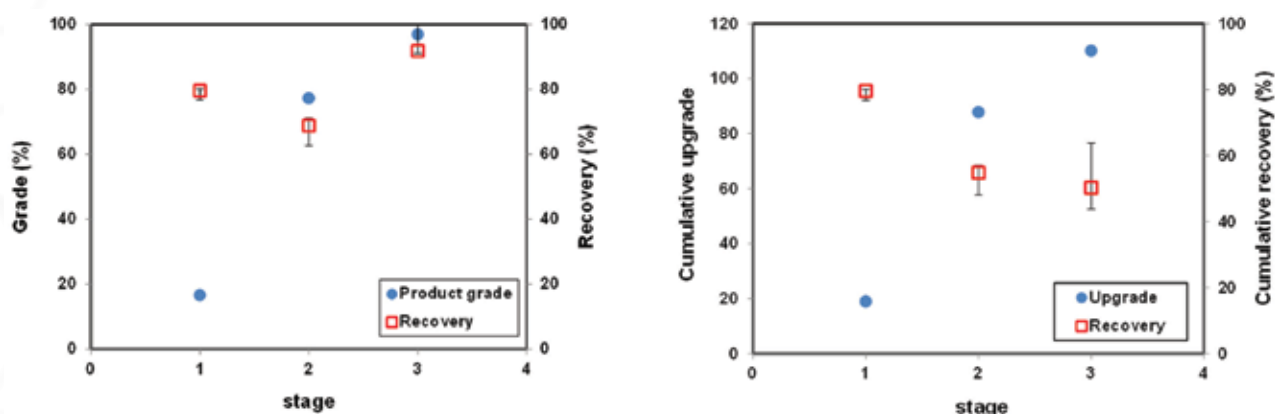


Figure 2. (A) Product grade and cenospheres recovery at different stages of the process, and (B) cumulative grade and recovery after each stage of the process.

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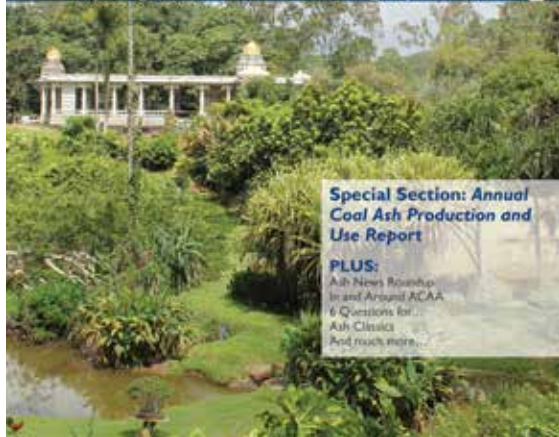
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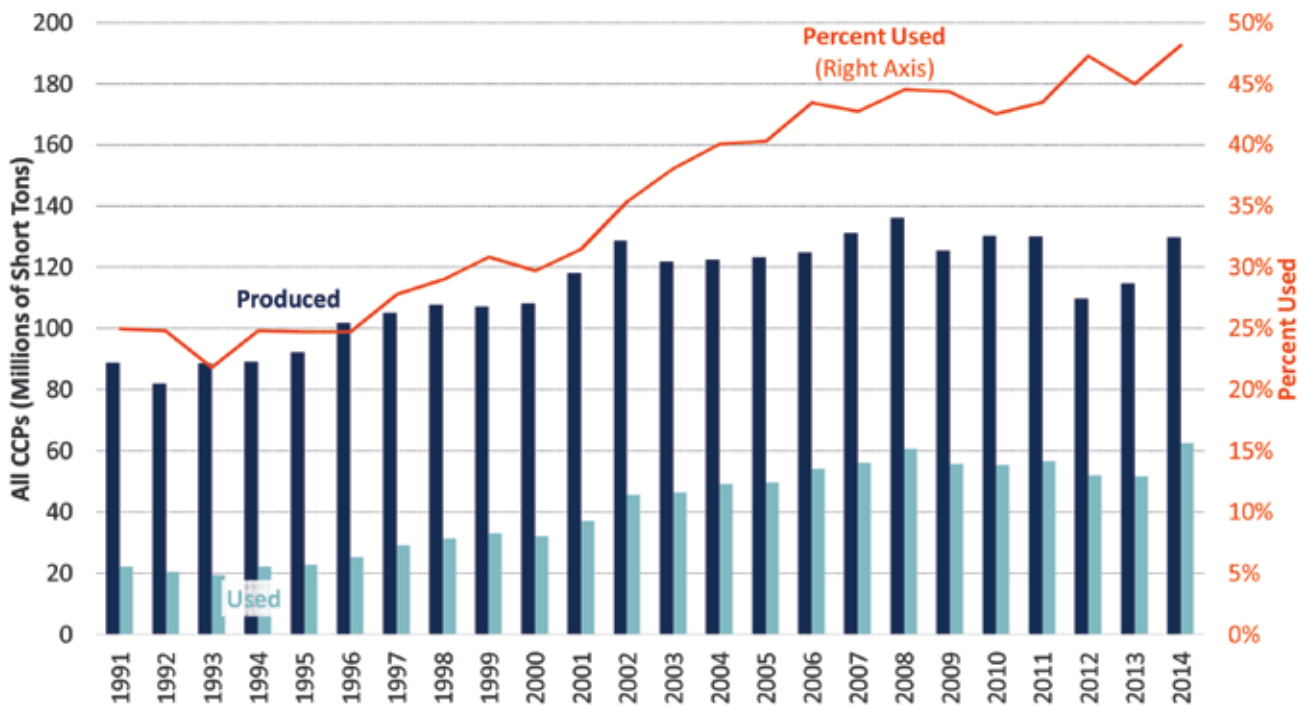
Coal Combustion Products – often referred to as “coal ash” – are solid materials produced when coal is burned to generate electricity. There are many good reasons to view coal ash as a resource, rather than a waste. Using it conserves natural resources and saves energy. In many cases, products made with coal ash perform better than products made without it.

As coal continues to be the largest energy source for electricity generation in the United States, significant volumes of coal ash are produced. Since 1968, the American Coal Ash Association has tracked the production and use of all types of coal ash. These surveys are intended to show broad

utilization patterns and ACAA’s data have been accepted by industry and numerous government agencies as the best available metrics of beneficial use practices.

In 2014, coal ash utilization rebounded after a half decade of stalled growth. The volume of coal fly ash used in concrete production increased to 13.1 million tons in 2014, for the first time exceeding the 12.6 million ton utilization mark set in 2008. Increases in the use of synthetic gypsum produced by power plant emissions control equipment also helped to push the recycling rate for all types of coal combustion products to a record 48 percent.

All CCPs Production and Use with Percent



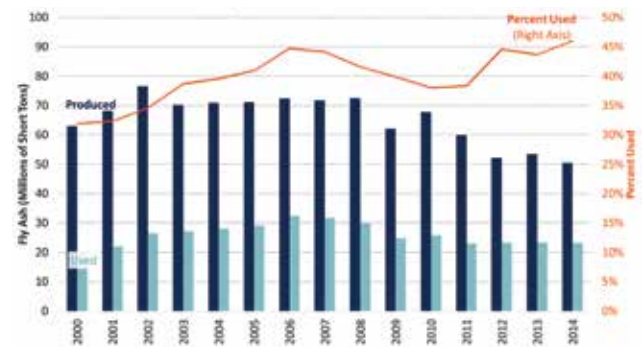
Fly Ash

Fly ash is a powdery material that is captured by emissions control equipment before it can “fly” up the stack. Mostly comprised of silicas, aluminas and calcium compounds, fly ash has mechanical and chemical properties that make it a valuable ingredient in a wide range of concrete products. Roads, bridges, buildings, concrete blocks and other concrete products commonly contain fly ash.

Concrete made with coal fly ash is stronger and more durable than concrete made with cement alone. By reducing the amount of manufactured cement needed to produce concrete, fly ash accounts for more than 11 million tons of greenhouse gas emissions reductions each year.

Other major uses for fly ash include constructing structural fills and embankments, waste stabilization and solidification, mine reclamation, and use as raw feed in cement manufacturing.

Fly Ash Production & Use 2000 – 2014



Fly ash ranges in color from gray to buff depending on the type of coal.



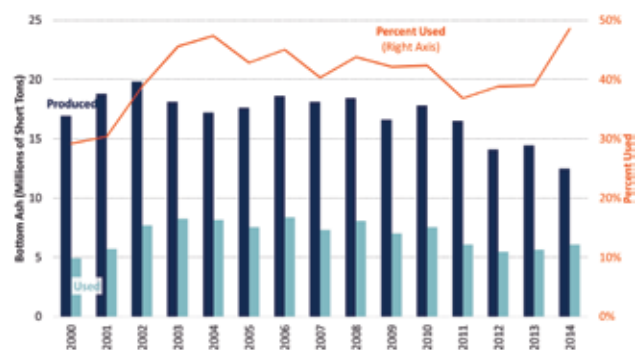
The American Road & Transportation Builders Association estimates coal fly ash use in roads and bridges saves \$5.2 billion per year in U.S. construction costs.

Bottom Ash

Bottom ash is a heavier, granular material that is collected from the “bottom” of coal-fueled boilers. Bottom ash is often used as an aggregate, replacing sand and gravel. Bottom ash is often used as an ingredient in manufacturing concrete blocks.

Other major uses for bottom ash include constructing structural fills and embankments, mine reclamation, and use as raw feed in cement manufacturing.

Bottom Ash Production & Use 2000 – 2014



Bottom ash can be used in asphalt paving.



Bottom ash is a granular material suitable for replacing gravel and sand.

Synthetic Gypsum

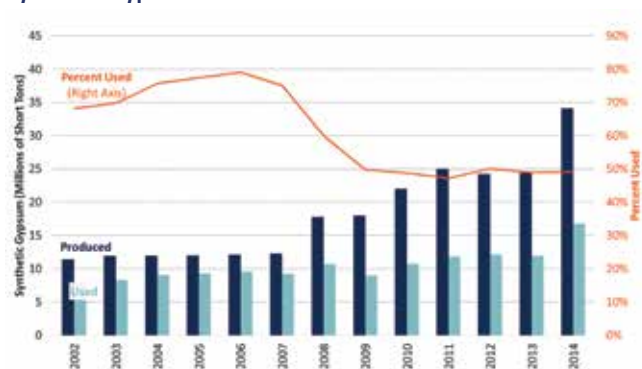
Power plants equipped with flue gas desulphurization (“FGD”) emissions controls, also known as “scrubbers,” create byproducts that include synthetic gypsum. Although this material is not technically “ash” because it is not present in the coal, it is managed and regulated as a coal combustion product.

Scrubbers utilize high-calcium sorbents, such as lime or limestone, to absorb sulfur and other elements from flue gases. Depending on the scrubber configuration, the byproducts vary in consistency from wet sludge to dry powdered material.

Synthetic gypsum is used extensively in the manufacturing of wallboard. A rapidly growing use of synthetic gypsum is in agriculture, where it is used to improve soil conditions and prevent runoff of fertilizers and pesticides.

Other major uses for synthetic gypsum include waste stabilization, mine reclamation, and cement manufacturing.

Synthetic Gypsum Production & Use 2002 – 2014



Synthetic gypsum is often more pure than naturally mined gypsum.



Up to half of the gypsum wallboard manufactured in the United States utilizes synthetic gypsum from coal-fueled power plants.



Synthetic gypsum applied to farm fields improves soil quality and performance.

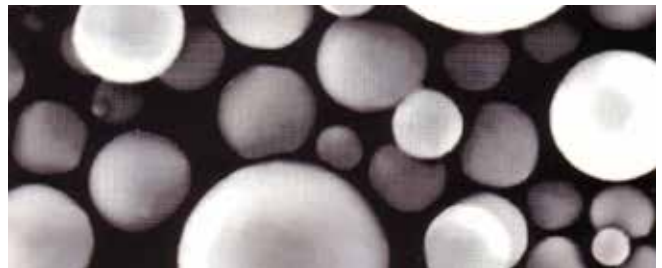
Other Products and Uses

Boiler Slag – is a molten ash collected at the base of older generation boilers that is quenched with water and shatters into black, angular particles having a smooth, glassy appearance. Boiler slag is in high demand for beneficial use as blasting grit and roofing granules, but supplies are decreasing because of the retirement from service of older power plants that produce boiler slag.



Nearly 90 percent of all boiler slag is beneficially used.

Cenospheres – are harvested from fly ash and are comprised of microscopic hollow spheres. Cenospheres are strong and lightweight, making them useful as fillers in a wide variety of materials including concrete, paint, plastics and metal composites.



Because of their high value, cenospheres – seen here in a microscopic view – are measured by the pound rather than by the ton.

FBC Ash – is a category of ash from Fluidized Bed Combustion power plants. These plants reclaim waste coal for fuel and create an ash by-product that is most commonly used to reclaim abandoned surface mines and abate acid mine drainage. Ash from FBC power plants can also be used for waste and soil stabilization.



This regional park was constructed with FBC ash on the site of a former waste coal pile.

New Uses on Horizon

New beneficial uses for coal ash are continually under development. Researchers and ash marketers are currently focusing heavily on the potential for reclaiming ash that has already been disposed for potential beneficial use. There is also renewed interest in the potential for extracting strategic rare earth minerals from ash for use in electronics manufacturing.



| 2014 Coal Combustion Product (CCP) Production & Use Survey Report | | | | | | | | | | |
|---|--|------------|------------|--|------------|----------------------------|----------------------------|-----------|------------|-------------------------------------|
| 2014 CCP Categories | | Fly Ash | Bottom Ash | Beneficial Utilization versus Production Totals (Short Tons) | | | | | | |
| | | | | Boiler Slag | FGD Gypsum | FGD Material Wet Scrubbers | FGD Material Dry Scrubbers | FGD Other | FBC Ash | CCP Production / Utilization Totals |
| Total CCPs Produced by Category | | 50,422,238 | 12,478,705 | 2,694,056 | 34,123,820 | 12,596,231 | 1,255,775 | 344,551 | 15,768,766 | 129,684,142 |
| Total CCPs Used by Category | | 23,181,723 | 6,063,028 | 1,706,621 | 16,750,990 | 1,163,434 | 275,999 | 0 | 13,285,766 | 62,427,561 |
| 1. Concrete/Concrete Products /Grout | | 13,126,930 | 609,558 | 0 | 423,613 | 0 | 0 | 0 | 0 | 14,160,100 |
| 2. Blended Cement/ Feed for Clinker | | 3,391,272 | 1,197,398 | 0 | 1,308,208 | 120,509 | 0 | 0 | 0 | 6,017,388 |
| 3. Flowable Fill | | 84,734 | 2,672 | 0 | 0 | 0 | 0 | 0 | 0 | 87,406 |
| 4. Structural Fills/Embankments | | 2,805,515 | 1,928,492 | 51,659 | 1,586,234 | 311,183 | 0 | 0 | 0 | 6,683,084 |
| 5. Road Base/Sub-base | | 365,868 | 306,936 | 12,992 | 0 | 0 | 0 | 0 | 0 | 685,796 |
| 6. Soil Modification/Stabilization | | 176,112 | 720,791 | 0 | 0 | 0 | 0 | 0 | 0 | 896,903 |
| 7. Mineral Filler in Asphalt | | 68,707 | 0 | 9,758 | 5,197 | 0 | 0 | 0 | 0 | 83,662 |
| 8. Snow and Ice Control | | 0 | 736,397 | 101,359 | 0 | 0 | 0 | 0 | 0 | 837,756 |
| 9. Blasting Grit/Roofing Granules | | 0 | 127,114 | 1,530,853 | 0 | 0 | 0 | 0 | 0 | 1,657,968 |
| 10. Mining Applications | | 1,392,935 | 41,330 | 0 | 813,419 | 578,244 | 229,766 | 0 | 13,151,161 | 16,206,855 |
| 11. Gypsum Panel Products | | 0 | 0 | 0 | 11,221,836 | 0 | 0 | 0 | 0 | 11,221,836 |
| 12. Waste Stabilization/Solidification | | 279,323 | 475 | 0 | 16,390 | 0 | 0 | 0 | 134,605 | 430,794 |
| 13. Agriculture | | 62 | 10 | 0 | 1,332,708 | 0 | 0 | 0 | 0 | 1,332,781 |
| 14. Aggregate | | 0 | 181,107 | 0 | 0 | 0 | 0 | 0 | 0 | 181,107 |
| 15. Oil/Gas Field Services | | 512,100 | 4,708 | 0 | 0 | 0 | 46,233 | 0 | 0 | 563,041 |
| 16. Miscellaneous/Other | | 978,165 | 206,039 | 0 | 43,384 | 153,498 | 0 | 0 | 0 | 1,381,086 |
| Summary Utilization to Production Rate | | | | | | | | | | |
| CCP Categories | | Fly Ash | Bottom Ash | Boiler Slag | FGD Gypsum | FGD Material Wet Scrubbers | FGD Material Dry Scrubbers | FGD Other | FBC Ash | CCP Utilization Total |
| Totals by CCP Type/Application | | 23,181,723 | 6,063,028 | 1,706,621 | 16,750,990 | 1,163,434 | 275,999 | 0 | 13,285,766 | 62,427,561 |
| Category Use to Production Rate (%) | | 46% | 49% | 63% | 49% | 9% | 22% | 0% | 84% | 48% |
| Data in this survey represents 189 GWs of Name Plate rating of the total industry wide approximate 302 GW capacity based on EIA's July 2015 Electric Power Monthly. | | | | | | | | | | |

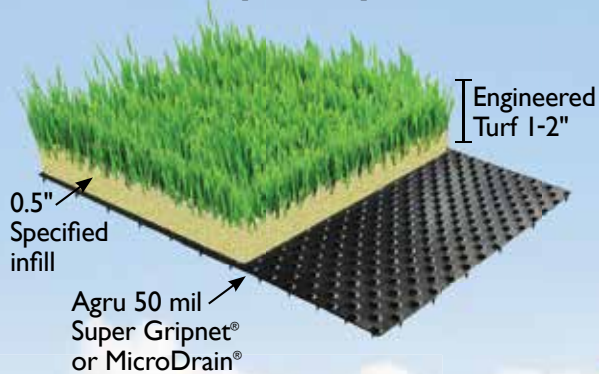
Notes:

These are estimates for entire U.S. utility and IPP sectors calculated by dividing the survey respondents data by the portion of the overall industries coal burn they represent, as reported in the July 2015 EIA Electric Power Monthly (58%).

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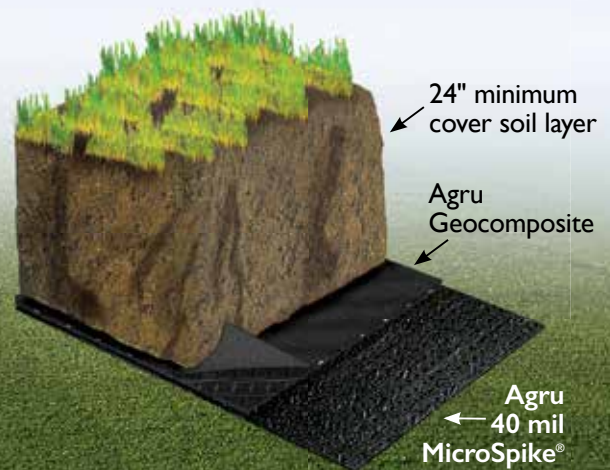
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