In 1998, 1.1 billion tons of coal were mined in the U.S. Eighty-four percent of this was used to produce electricity, and 108 million tons of coal combustion by-products (CCB), which are: fly ash, bottom ash, boiler slag and flue gas desulfurization materials, were also produced. A conventional pulverized coal boiler produces 158 pounds of CCB per ton of coal burned. Fly ash, the material collected in electrostatic precipitators or bag houses, constitutes 60 percent of CCB. Approximately 30 percent of the fly ash produced annually is utilized in cement and concrete, structural fills, waste stabilization and mine reclamation. But in 1998, over 40 million tons of fly ash were placed in landfills and ponds. Since ponds are being phased out and landfills are becoming more expensive to permit and operate, there is economic and environmental impetus to increase the utilization of CCB.

CCB are primarily the inorganic residue from coal; they are approximately 50 percent silica with variable amounts of aluminum, iron and calcium. CCB also contain any carbon that was not consumed during combustion and small amounts of other elements (antimony, arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, nickel, lead, selenium and zinc). These are often referred to as heavy metals or trace elements, but there is no standard definition of these terms, and they can be considered as either essential nutrients, toxic elements, or priority pollutants. Although the allowable concentration in water depends on which standards are applied, most of these elements are believed to have some environmental or public health consequences. The potential release of trace elements from CCB by natural liquids is a factor in estimating the environmental risk of beneficial uses such as bulk fill and mine remediation.

Under the Bevill Amendment to the Resource Conservation and Recovery Act (RCRA), the Environmental Protection Agency (EPA) is required to assess high volume low toxicity wastes. In 1993, EPA concluded that regulation of wastes from the combustion of coal by electric utility power plants under Subtitle C (Hazardous Wastes) of RCRA was not warranted. In 1999, EPA expressed concern with respect to the use of CCB in agricultural applications and in mine backfills. In its comments, the U.S. Department of Energy (DOE) summarized field and laboratory data that supported these beneficial uses. In May, 2000, EPA issued a regulatory determination that continued the Subtitle C exclusion, but indicated that national Subtitle D (Non-hazardous) regulations would be developed for CCB placed in landfills and impoundments and used in mine backfill.

The DOE study used a column leaching system to simultaneously leach 4 CCB samples with 7 leaching solutions: deionized water is the control, acetic acid simulates landfill fluids, sodium carbonate is a caustic leaching solution, synthetic groundwater is used to determine the effect of other naturally occurring cations, (continued, page 2)
synthetic precipitation mimics acid rain and ferric chloride and sulfuric acid are acid mine drainage surrogates. The 2 liter columns are made of 1 meter sections of 5 cm id acrylic pipe, closed with PVC caps (Fig. 1). Each column holds approximately 1 kg of fly ash or other CCB. The nominal flow rate for each leaching solution is 230 mL/d, and each test lasts between 30 and 180 days or until the natural alkalinity of the CCB is consumed. The leachate is sampled at 2 to 3 day intervals and analyzed for pH, acidity and/or alkalinity, ferrous iron, total iron, aluminum, manganese, magnesium, calcium, sodium, potassium, sulfate and the trace elements: arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, nickel, lead, antimony and zinc. To date, 48 fly ash samples from commercial power plants around the US have been studied.

The results of this leaching study indicated that the release of the trace elements from fly ash is a function of the element, the leaching solution, and the sample. Direct correlation between the concentration of an element in the sample and the amount released is not strong. Solubility was related to the leaching solution, but was not a simple function of pH. Barium is the most soluble element, and it is most soluble in ferric chloride, acetic acid, water and synthetic precipitation. It is slightly soluble in the basic solution, and least soluble in synthetic groundwater. Arsenic is ten times more soluble in a basic (Na₂CO₃) solution than in water or sulfuric acid (Fig. 2). The average amount of beryllium, cadmium, antimony and selenium released is less than 2 mg/kg in all leaching solutions. Chromium, copper and lead are more soluble in the ferric chloride solution, an oxidant, than in the other acid solutions. Zinc is soluble in acetic and sulfuric acids, as well as the ferric chloride solution.

Based on the percentage of element released, the majority of the trace elements are most soluble in sulfuric acid and the ferric chloride solution (Fig. 3). The exceptions are arsenic and selenium, which are more soluble in the caustic solution. For most elements, less than 5 pct of the amount in the sample is released in water, sodium carbonate, synthetic groundwater and synthetic precipitation. Between 5 and 15 pct of beryllium, cadmium, cobalt, chromium, copper, nickel, selenium and zinc in the sample is released in acid leaching solutions. At these levels, concentrations in water would generally meet water quality criteria.

Attempting to evaluate the release of trace elements from CCB based on average rates of release is problematic. For about 20 % of the samples, the concentration of an element in the leachate was below detection limits throughout the test. Also, the presence of one excessively high value raises the mean value. For example, the maximum amount of arsenic released in sulfuric acid is 25 mg/kg. The average amount released is 3 mg/kg, and the amount released by 75 pct of the samples is equal to or less than the mean.

The amount of an element in the CCB and the nature of the leaching solution affect the amount released, but are not the only controlling factors. The release of trace elements from CCB can’t be described by simple solubility relationships; it appears to be controlled by a unique set of chemical, thermodynamic and kinetic factors. It is also apparent that these trace element factors are not the same in all fly ash samples. Factors that may contribute to the solubility of a particular element are the pH, the ionic activity of the solution, and the mineralogy of various compounds in the fly ash.
The leaching system described here has generated a large data set. The challenge is to relate chemical or physical characteristics of the individual CCB samples to the release of trace elements and to use these relationships to predict release in a natural environment. The data from this study indicate some general trends. The solubility of most elements in synthetic groundwater and synthetic precipitation is less than 2 mg/kg of solid or 0.01 mg/L of leaching solution. Arsenic and selenium are soluble in basic solutions (pH>9). The release of other elements from CCB appear to be related to oxidative and/or acidic mechanisms. Determination of the predominant mineral species in the samples, with the data from the leaching tests, may provide a rationale for estimating the potential for the release of trace elements from CCB materials. The tests completed to date indicate that leaching solutions simulating natural liquids such as groundwater, acid rain or AMD, do not release trace elements in concentrations that would constitute an environmental problem from more than 75 pct CCB studied.

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Wetland Remediation (cont.)

In 1993, there were eight direct discharges of mine drainage into Fourmile Run. Natural wetlands had developed around these discharges; however, they had limited effects on water quality due to preferential flow paths and channeling. A comprehensive monitoring program was initiated to determine the chemistry of the discharges and the biology of the streams. All of the discharges have pH values between 5.9 and 6.4, total iron concentrations between 50 and 90 mg/L and high alkalinity values. Maximum flow rates for the discharges varied from 20 gpm to 1200 gpm. Several of the discharges had no flow during dry summer months. The receiving streams have been negatively impacted by the AMD discharges. In Fourmile Run, the iron concentration greatly increased after the AMD discharges. Iron concentrations in Fourmile Run varied from 10 mg/L to 50 mg/L. Even Loyalhanna Creek, which has a much larger total flow, was impacted by AMD. Above the confluence with Monastery Run, the concentration of iron in the Loyalhanna is below our method detection limit, but below the confluence, the concentration fluctuates between 2 and 8 mg/L. The iron concentration in the Loyalhanna is high enough to stain the water and the streambed orange.

Since 1993 the Loyalhanna Creek Mine Drainage Coalition has coordinated the efforts to remediate the Monastery Run watershed. Based on the data from the discharges, the steering committee developed a remediation plan. It was determined that constructing a series of three aerobic, cattail wetlands (Fig.1) would treat most of the discharges. Previous work (RS Hedin 1993, 1994) indicated that alkaline discharges such as these are best treated by aerobic wetlands. The necessary size of each wetland was determined from the total loading from the discharges to be treated.

Wetland 1 is a 9.5-acre wetland constructed of four cells. (Fig. 2a) Construction was completed in 1998 and was designed to treat three large discharges. This wetland was difficult to design for two reasons. First, it had very high flows in the spring, but it was constructed on a portion of the flood plane for Fourmile Run, which has a history of flooding. Therefore, the permits required that the elevation of the dikes and berms in the wetland not exceed the elevation of the land before construction. In order to meet this demand and maintain high water retention times, a great deal of excavating occurred. During excavation, new discharges were discov—

\[
4 \text{FeS}_2 + 15 \text{O}_2 + 14 \text{H}_2\text{O} \rightarrow 4 \text{Fe(OH)}_3 + 8 \text{H}_2\text{SO}_4
\]

Pyrite + Oxygen + Water →

Ferric Hydroxide + Sulfuric Acid

In order to meet this demand and maintain high water retention times, a great deal of excavating occurred. During excavation, new discharges were discov—

(continued, page 4)
Wetland Remediation, (cont.)

The design of this wetland was modified to try to accommodate the potentially higher flows. The second difficulty in design was that the water was net acidic during the early spring. Therefore, limestone was used in the first cell to neutralize the acidity.

Wetland 2 is the largest of the three wetlands at 17.1 acres (Fig. 2b). It was constructed to have excess capacity so that water from other sites could be diverted into this wetland if necessary. This wetland was completed in 1998. It has a simple design of two cells separated by a single dike. There are outside dikes on only three sides, giving a more natural appearance to the wetland. The external dike is constructed with an inner core of bentonite clay to prevent flow-through of water into the stream. The flow control devices are pipes with baffle boards that can be raised and lowered. The flow pattern of the wetland is flexible. The output of cell 1 can be discharged into the stream or into cell 2. In a similar manner, cell 2 discharge usually flows into the stream but some of the flow can be diverted into Wetland 3 (Fig. 2c).

Early in the planning stages, one of our challenges was the Bubbler. In 1974, engineering borings adjacent to Fourmile Run intercepted mine water causing an artesian discharge (300-600 gal/min) that was known as the Bubbler. Because of inadequate space for wetland remediation adjacent to the discharge, water from the Bubbler had to be relocated for treatment. Investigation by the technical committee of the coalition determined that there was approximately 10 ft of hydraulic head above ground level. This was enough head to move the Bubbler upstream to Wetlands 2 and 3. Both of these wetlands had some excess capacity. During construction of wetland 3 the Bubbler was captured and piped into wetland 3. The piping was continued when wetland 2 was constructed. Approximately 70% of the flow from the Bubbler was diverted into cell 2 of wetland 2, and the remaining water was treated in wetland 3.

Wetland 3 is a 5.9-acre wetland with five cells (Fig.2c). It was completed in 1997. The wetland was initially designed to treat a small discharge that was piped into the existing wetland. However, water from the Bubbler is also being treated in this wetland. The first cell of the wetland is pond-like with a depth of about 3 feet. Cells 2-5 are shallower and are inhabited with cattails and other aquatic organisms. The discharge into the stream is from cell 5. Flow control devices are located between each cell and allow control of water depth and flow.

The most successful system is Wetland 3, which can treat up to 200 gal/min of mine drainage and reduce the iron concentration from about 80 mg/L to less than 1 mg/L. The other two systems are still under evaluation. During low flow conditions, the treatment is excellent with a significant reduction of iron in the streams. Unfortunately, wetland 1 has had flow rates above 2500 gal/min during the early spring, which is much higher than it was designed to treat. During the summer of 1999, a pipe was installed that connected Wetland 1 and 2. Therefore, the output of Wetland 1 now flows into Wetland 2 for further treatment. We saw a significant improvement in the treatment with the combined system during the high flows of spring 2000.

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When some engineering graduates were having processes for placing new engineering graduates, the College of Engineering team that focuses on our new engineers in some of the other disciplines were mining engineers were receiving job offers while recall a time, not that long ago, when all graduating mining industry has typically been cyclical, I can blame, but the current demand for people in the high tech sector has made it more difficult for the basic industries to compete for talented young professionals. Although employment of engineers in the mining industry has typically been cyclical, I can recall a time, not that long ago, when all graduating mining engineers were receiving job offers while new engineers in some of the other disciplines were having difficulties finding jobs. In fact, I serve on a College of Engineering team that focuses on our processes for placing new engineering graduates. This team was formed about five or six years ago when some engineering graduates were having trouble finding employment. The robust economy has made the work of this team easy. Our experience in the most recent years has shown that all engineering graduates (regardless of specialization) and all computer science graduates are in high demand.

Add to this competition some of the perception problems facing the mining industry and one can begin to understand the challenges we are facing. Probably the most damaging perception affecting career decisions of bright young people in this regard is the notion that the mining industry does not have a stable future. I believe this perception has its roots in two misunderstood facts. The first fact is that mechanization and, ultimately, automation have changed and will continue to change the face of the industry. Production is up while the size of the workforce is down. This phenomenon creates tremendous economic stresses in those regions that have traditionally depended upon mining to fuel the local economy. Not coincidentally, these are the same areas where, in the past, we have drawn most of our mining engineering undergraduate students. It is hard to sell mining engineering as a career in a traditional mining area with double-digit unemployment regardless of the number of tons produced or the number of engineers needed.

A second misunderstanding stems from the fact that we are always mining a depleting reserve. While the demand for minerals grows annually, and with it the need for technically-astute professionals, there have always been regional dislocations within the industry. At times, these dislocations are caused by factors other than depletion, such as economic factors caused by public policy decisions. The decline in Illinois Basin coal production as a result of more stringent air quality standards is a prime example. However, this did not result in a lower demand for coal on the national level but it did cause dislocation within the industry.

My experience has been that most high school students do not conduct a systematic investigation of career options. Rather, they rely heavily on input from their daily surroundings. If those surroundings present the mining industry negatively, it is difficult to recruit these students, especially when more attractive career options are abundant.

Given this rather bleak setting, what does the future hold for the mining engineering profession? My opinion is that the situation will worsen before it improves. Most mining companies have not yet fully recognized that a shortage of mining engineers exists. Many companies have just come through years of downsizing to enable them to survive in a highly-competitive market. There is no fat left in the management or engineering support areas. Some might argue that fat-trimming has cut into bone and muscle. Indeed, many mining engineers in both management and technical support positions are opting for early retirement due, in part, to fatigue.

From an academic perspective, we are attempting to utilize the resources at our disposal to address this pending shortage. First and foremost, we want to educate the public, in general, and prospective students, particularly, about the demand for minerals and the need for ever-smarter mining engineers. This is being done locally through visits and other personal contacts aimed at highly-qualified high school students. We are also incorporating the latest computer technology to spread our message over a multi-state region. Although scholarships may not have as much impact during good economic times as they do when times are bad, we continue to offer the best departmental scholarship program in the College of Engineering at UK. This scholarship program is made possible, in large part, by CAER whose leadership recognizes the critical need for mining engineers. Finally, we are striving to make the educational experience both challenging and rewarding. Like many other academic units, we have embarked upon a process of continuous improvement in our curriculum that is responsive to the needs of our constituents.

Will the current trend be reversed? I believe the answer to that question is “yes.” Why? and “Under what circumstances?” are more difficult questions to answer. It seems clear to me that industry participation is essential. In simplest terms, the mining industry must be an attractive place to work. If it hopes to entice bright young men and women into entering the profession, if industry and academia jointly commit to this objective, we can see a reversal of the current trend and a serious shortage may be averted.
UPCOMING MEETINGS

18th Annual International Pittsburgh Coal Conference
December 3 –7, 2001
New South Wales, Australia
Contact: (412) 624-7440, or BK Parekh (CAER) (859) 257-0239
Website: www.engng.pitt.edu/~pccwww/

US Department of Energy
2001 Conference on Unburned Carbon (UBC) on Utility Fly Ash
May 15-16, 2001
2001 Conference on Selective Catalytic Reduction and
Selective Non-Catalytic Reduction for NOx Control
Pittsburgh, PA
Contact: Karen (412) 386-4763 or John Stencil (CAER) (859) 257-0250

United Engineering Foundation
Solid –Liquid Separation Systems III
September 30 - October 5, 2001
Davos, Switzerland
Contact: +1-212-591-7836 or BK Parekh (CAER) (859) 257-0239

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