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The Ohio State University

INTRODUCTION
Coal preparation and mining practices in the United States, in the years prior to the enactment of stringent environmental protection and reclamation laws in 1972, frequently resulted in dumping coal cleaning refuse into large piles. Other surface mine sites were simply abandoned without adequate reclamation of iron sulfide-containing materials, the source of much acid mine drainage. In Ohio, more than 35,000 acres of degraded lands associated with coal mining remain to be reclaimed. However, the problems associated with reclamation of abandoned and active coal-mined lands are not only found in the United States. It is a worldwide environmental concern as mining impacts surface water quality, groundwater quality, revegetation and aesthetics.

The properties of disturbed, mined soils make them a poor medium for plant growth, and natural recolonization by plants on these soils is slow. When compared to native soils, new mine soils often have large quantities of coarse fragments, lower cation exchange capacity, decreased organic matter, lowered nutrient status, poor water-holding capacity, low pH, and increased iron (Fe) oxides. Some refuse on abandoned mine sites can produce copious amounts of acid that eventually drains into lakes, streams and rivers. Soils are also affected by the acid drainage and become unsuitable for production of crops, or use as pasture lands or woodlands.

Use of topsoil and limestone to restore coal-mined land is a well-established technology with many sites in the U.S. remaining in sound ecological condition many years after treatment. Current reclamation laws require spreading stockpiled topsoil on mine spoil (the rock and debris that remain) to facilitate revegetation. However, topsoil was generally not conserved when the older sites were surface mined for coal prior to the reclamation laws. Thus, soil must be borrowed from adjacent land thereby creating another disturbed area. The cost of reclamation becomes prohibitive if sufficient borrowed soil is not available adjacent to the mine site.

The Clean Air Act, as amended in 1992, confirmed the need to develop and implement processes for sulfur dioxide (SO$_2$) removal from flue gases when S-containing coal is burned. Some flue gas desulfurization (FGD) processes generate by-product materials consisting of various amounts of excess sorbent, reaction products containing SO$_4^{2-}$/SO$_3^{2-}$ and fly ash. These scrubbing processes create a product that, because of the unspent sorbent component, are highly alkaline and have significant neutralization potential. Many studies have shown that this property enables FGD by-products to be successfully used as alkaline amendments for agricultural and mine land soils.

An example of a field-scale research project in which we were involved, and where a highly degraded and acid-forming, abandoned surface coal-mined land was reclaimed using a dry flue gas desulfurization product, is described below. We provide information on the properties of the dry FGD material used, the results obtained and some conclusions made as a result of this project.

STUDY DETAILS
Reclamation Site
The study site, the Fleming abandoned mined land (AML) site (Figure 1), is located in Franklin Township, Tuscarawas County, OH (40° 33’ 19” north latitude and 81° 31’ 13” west longitude). Prior to reclamation, the Fleming AML site consisted of approximately 25 acres of exposed, highly erodible underclay (the layer below the coal seam) bordered on two sides by 45 acres of spoil and 5 acres of coal refuse. Acid mine drainage was a significant problem with surface water pH ranging from 2.9 to 3.9 and iron and aluminum concentrations in surface runoff as high as 120 mg/L and 336 mg/L, respectively. Oxidation of pyrite (FeS$_2$) associated with the Middle and Upper Kittanning coal beds was a major cause of the acidity. The spoil was derived from Pennsylvanian age rocks of the Allegheny Formation, which consists of sandstones and shales interbedded with coal, clay,
and limestone. The spoil and underclay at the site were extremely acidic (Table 1) and the ability of these materials to support plant growth was severely limited.

**Reclamation Practice**  
In the autumn of 1994, six one-acre plots were constructed by regrading underclay and mine spoil at the Fleming AML site. The three treatments applied to the six plots (Figure 1) were 1) FGD product at a rate of 125 tons/acre incorporated into graded spoil to a depth of 8 inches; 2) FGD+compost (FGD/C) at a rate of 125 tons/acre of FGD product and 50 tons/acre of yard-waste compost incorporated into graded spoil to 8 inches depth; and 3) soil+lime (SOIL) where agricultural limestone was applied at a rate of 50 tons/acre and incorporated into graded spoil and then covered with 8 inches of borrow soil (transferred material used for refill) treated with additional 20 tons/acre agricultural limestone. The dry FGD product came from an atmospheric fluidized bed combustion (AFBC) burner located at a General Motors plant Pontiac, MI, which burned eastern Ohio coal and used dolomitic limestone (from Findlay, Ohio) for desulfurization. Selected properties of the various amendment materials are shown in Table 1.

The application rates for the Fleming AML site were selected based on the lime test index of the spoil. The lime test index, as determined by The Ohio State University, was 44 for the Fleming AML site spoil. In order to adjust the final soil cover pH to pH 7, the Ohio Agronomy Guide recommends adding 50 tons/acre of limestone with 100% calcium carbonate equivalent. Since the FGD by-products had a calcium carbonate equivalency of approximately 40%, FGD application rates had to be adjusted accordingly to provide neutralization potential equivalent to that of pure limestone. The application rates for compost were based on preliminary experiments conducted at The Ohio State University prior to conducting the field study. The amount of soil cover used was recommended by the Ohio Department of Natural Resources.

The plots were seeded in November, 1994 after applications of treatments using a seed mixture consisting of orchard grass, timothy, annual ryegrass, ladino clover, birdsfoot trefoil and winter wheat. Biomass measurements were made in 1995 and 2008; plant tissue and subsurface (i.e. at four feet deep) drainage water samples were collected in 1995 and 2008; and soil samples in 1995 and 2009. Analyses of samples was conducted at The Ohio State University.

**RESULTS**

**Plant Biomass Production and Element Concentrations**

Vegetative cover is absolutely necessary to attenuate erosion of surface mined lands. In 2008, visual observation indicated that grasses and legumes grew very well in all treatment plots, but no plants grew in an adjacent untreated area (Figure 2). Plant biomass production was significantly higher for the SOIL treatment than for the FGD and FGD/C treatments in 1995, but 14 years later there were no treatment differences (Figure 3). In general, The FGD and FGD/C treatments in 2008 showed more abundance of the legumes, ladino clover and birdsfoot trefoil, than did the SOIL treatment. We surmise that the initial lush growth of grass in the SOIL-treated plots choked out the legumes. Legumes take nitrogen out of the air and fix it in plant biomass where it eventually enters the soil and is recycled for use by subsequent plants. The 2008 observation of excellent plant biomass production for the FGD- and FGD/C-treated plots suggests that the nitrogen introduced into these plots by the greater number of legumes can lead to sustained long-term vegetative growth. This demonstrates the potential of FGD, with and without addition of an organic amendment, to provide long-term sustainability of vegetative cover.

Calcium, magnesium and sulfur are essential plant macronutrients, and iron and boron are essential plant micronutrients. Concentrations of calcium, the major element in the FGD, in the plant tissue were not significantly different for FGD or FGD/C treatment as compared to SOIL treatment in both 1995 and 2008 (Table 2). Concentrations of magnesium, sulfur, aluminum, iron, and boron were significantly greater when mine spoil was reclaimed with FGD and FGD/C compared to SOIL in 1995. However, only the concentration of boron in plant tissue was increased by FGD and FGD/C treatments in 2008.

**Soil Chemical Response**

All treatments were effective in raising the pH of the reclaimed surface (0-8

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**Table 1. Selected chemical characteristics of Fleming AML spoil and amendments.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spoil</th>
<th>FGD product</th>
<th>Compost</th>
<th>Borrow soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (1:1 water)</td>
<td>3.1</td>
<td>12.4</td>
<td>7.4</td>
<td>4.3</td>
</tr>
<tr>
<td>Al (g/kg)</td>
<td>115</td>
<td>25.0</td>
<td>ND†</td>
<td>86.0</td>
</tr>
<tr>
<td>Fe (g/kg)</td>
<td>55.7</td>
<td>59.0</td>
<td>17.7</td>
<td>39.6</td>
</tr>
<tr>
<td>S (g/kg)</td>
<td>10.2</td>
<td>123</td>
<td>ND</td>
<td>0.6</td>
</tr>
<tr>
<td>Ca (g/kg)</td>
<td>0.40</td>
<td>261</td>
<td>16.9</td>
<td>0.70</td>
</tr>
<tr>
<td>Mg (g/kg)</td>
<td>5.0</td>
<td>36.5</td>
<td>3.5</td>
<td>5.3</td>
</tr>
<tr>
<td>B (mg/kg)</td>
<td>ND</td>
<td>418</td>
<td>39.1</td>
<td>ND</td>
</tr>
</tbody>
</table>

†Not determined.

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**Figure 2. Comparison of vegetation on reclaimed coal-mined area and an untreated area at the Fleming site.**

**Figure 3. Vegetative biomass production in 1995 and 2008 on Fleming mine spoil reclaimed with SOIL (left bar), FGD (middle bar) and FGD/C (right bar). Different letters over each bar represent a statistical difference at P ≤ 0.05. NS = no statistical difference among treatments.**
Reclamation of Abandoned Surface Coal Mined Lands (cont.)

Table 2. Tissue concentration of selected parameters in vegetation grown on mine spoil reclaimed with SOIL, FGD, and FGD/C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Calcium (mg/kg)</th>
<th>Magnesium (mg/kg)</th>
<th>Sulfur (mg/kg)</th>
<th>Aluminum (mg/kg)</th>
<th>Iron (mg/kg)</th>
<th>Boron (mg/kg)</th>
</tr>
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<tbody>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>2050</td>
<td>866 b</td>
<td>987 b</td>
<td>57 b</td>
<td>64.8 b</td>
<td>5.6 b</td>
</tr>
<tr>
<td>FGD</td>
<td>2370</td>
<td>1860 a</td>
<td>1560 a</td>
<td>145 ab</td>
<td>170 a</td>
<td>45.3 a</td>
</tr>
<tr>
<td>FGD/C</td>
<td>1940</td>
<td>2080 a</td>
<td>1670 a</td>
<td>204 a</td>
<td>168 a</td>
<td>39.8 a</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>4730</td>
<td>2400</td>
<td>2690</td>
<td>88.2</td>
<td>173</td>
<td>4.5 b</td>
</tr>
<tr>
<td>FGD</td>
<td>5870</td>
<td>1920</td>
<td>2400</td>
<td>133</td>
<td>289</td>
<td>7.7 a</td>
</tr>
<tr>
<td>FGD/C</td>
<td>5570</td>
<td>1620</td>
<td>2450</td>
<td>179</td>
<td>340</td>
<td>7.2 a</td>
</tr>
</tbody>
</table>

†Treatments with different letters for each year are statistically different at the P ≤ 0.05 level.

Table 3. Soil pH, electrical conductivity and concentrations of selected parameters in Mehlich-III extracts from mine spoil reclaimed with SOIL, FGD, and FGD/C in 1995 and 2009.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC† (dS/m)</th>
<th>Calcium (mg/kg)</th>
<th>Magnesium (mg/kg)</th>
<th>Sulfur (mg/kg)</th>
<th>Aluminum (mg/kg)</th>
<th>Iron (mg/kg)</th>
<th>Boron (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>6.1 a‡</td>
<td>0.71 b</td>
<td>2460 b</td>
<td>304</td>
<td>263</td>
<td>783</td>
<td>274 b</td>
<td>2.23 b</td>
</tr>
<tr>
<td>FGD</td>
<td>6.9 b</td>
<td>2.92 a</td>
<td>15600 a</td>
<td>2750 a</td>
<td>5260 a</td>
<td>999</td>
<td>341 b</td>
<td>21.5 a</td>
</tr>
<tr>
<td>FGD/C</td>
<td>5.5 b</td>
<td>3.12 a</td>
<td>10200 a</td>
<td>1350 b</td>
<td>5700 a</td>
<td>986</td>
<td>520 a</td>
<td>8.8 b</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>6.7 b</td>
<td>0.54 b</td>
<td>2920 c</td>
<td>759 b</td>
<td>365 b</td>
<td>577 b</td>
<td>125</td>
<td>0.95 b</td>
</tr>
<tr>
<td>FGD</td>
<td>6.6 a</td>
<td>2.09 a</td>
<td>12600 a</td>
<td>1450 a</td>
<td>3970 a</td>
<td>1060 a</td>
<td>153</td>
<td>3.85 a</td>
</tr>
<tr>
<td>FGD/C</td>
<td>6.0 a</td>
<td>1.97 a</td>
<td>8470 b</td>
<td>801 b</td>
<td>3410 a</td>
<td>968 a</td>
<td>175</td>
<td>2.76 ab</td>
</tr>
</tbody>
</table>

†EC, electrical conductivity.
‡Treatments with different letters for each year are statistically different at the P ≤ 0.05 level.

Inch depth) soil in 1995 (Table 3). Note that the pH of the original spoil was 3.1 (Table 1). After approximately 15 years of natural weathering and leaching, the surface pH in 2009 remained high enough for the growth of vegetation with a soil pH of 6.6 for the FGD treatment. In 1995 and 2009, mine soil electrical conductivity (a measure of salt concentration in soil) was statistically higher for the FGD and FGD/C treatments compared to the SOIL treatment (Table 3). In general, however, mine soil electrical conductivity for FGD treatment could be classified as non-saline (<4 dS/m) by agricultural standards. Concentrations at a 0-8 inch depth soil of calcium, magnesium, sulfur and boron extracted by a Mehlich III acid extractant were significantly higher for the FGD treatment than the SOIL treatment in 1995 and 2009 (Table 3). Extractable calcium and magnesium concentrations were lower for the FGD/C treatment than FGD treatment due to compost binding of the calcium and magnesium. In general, FGD product both effectively increased mine spoil pH and also provided essential plant nutrients such as calcium, magnesium, sulfur, and boron for plant growth. In addition, the excellent growth of legumes (ladino clover and birdsfoot trefoil), that were seeded and grew on the reclaimed mine spoil, also provided nitrogen.

**Water Quality Response**

In 1995, electrical conductivity and concentrations of magnesium, sulfur, and boron in drainage water were increased by FGD and FGD/C treatments compared with SOIL treatment (Table 4). The alkaline materials applied to the spoil during reclamation initially caused a rapid rise in pH to 7.8 that precipitated iron, aluminum and other metals. Thus the levels of these elements in drainage water in 1995 were very low. The pH of the water collected from the FGD/C treatment decreased electrical conductivity and concentrations of magnesium and boron compared to FGD treatment. The use of compost with FGD during reclamation thus seemed to provide an additional benefit over that of FGD alone.

In 2008, the boron levels in the FGD/C and FGD treatments had decreased and boron toxicity of plants was no longer a concern. During the 14 years post-reclamation, the pH also decreased to about 5.5 for all treatments and this pH, while lower than immediately after reclamation, was still high enough to produce good-quality drainage water. Meanwhile the aluminum and iron concentrations had increased in 2008 compared to 1995, but were still greatly below pre-reclamation levels that were 120 mg/L for aluminum and 336 mg/L for iron. The value of 191 mg/L of iron in the drainage water from the FGD treatment is probably due to lack of organic matter that can inhibit iron solubilization, as well as continued leaching of soluble iron that existed in the pre-mine spoil.

In general, the use of the FGD products not only successfully promoted good long-term vegetative growth, but also greatly improved overall water quality at the Fleming site.

**CONCLUSIONS**

Biomass production after 14 years in the FGD-treated plots was similar to that in the more conventionally reclaimed plots using re-soil material. Long-term monitoring of plants, soil, and drainage water also suggests a stable functioning ecosystem has developed in the plots treated with FGD product. If rates of FGD product containing neutralization potential are properly matched to a degraded mine site, long-term reclamation can be accomplished.

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As the state representative for the 99th legislative district, which covers Boyd, Elliott, Lawrence and Rowan Counties, I know first-hand the important role coal plays in Kentucky’s economy. I have spent several decades working in the coal industry and know the good jobs, great paychecks and excellent health care benefits coal provides thousands of families in Eastern and Western Kentucky. And because we have an abundance of coal, Kentuckians enjoy one of the cheapest electric rates in the country.

But things are changing in the coal-fields of Kentucky and it has to do with America’s growing dependence on foreign oil. As the price of gasoline at the pump increases and our relations with the dictatorships that controlled oil prices become fractured, I realize, like many Americans, that we have to find ways to break that dependence on foreign oil and become self-sufficient.

The House of Representatives began our push for energy independence in the 2006 session, with the passage of the Kentucky Energy Independence National Leadership Act (House Bill 299.) This legislation required the Kentucky Office of Energy Policy to develop and implement a strategy for production of transportation fuels and synthetic natural gas from fossil energy resources and biomass resources. House Bill 299 also encouraged energy efficiency measures in state construction projects.

In addition to House Bill 299 setting the stage, the legislature committed $3.5 million per year of the 2006-2007 biennial budget for the Office of Energy Policy to invest in alternative energy projects mainly in the research and development area.

A special legislative session in the summer of 2007 produced House Bill 1. Its main focus was to expand research and development in the energy field here in Kentucky.

Two million dollars were appropriated for the Center for Applied Energy Research at the University of Kentucky to continue efforts in cutting-edge research on gasification and renewable energy.
carbon capture technologies. These funds were also used for infrastructure upgrading.

This was important because few people understand the critical work CAER is doing right here in Kentucky, and that funding will help the Center garner the national and international recognition it deserves.

As chairman of the Southern Legislative Conference’s Energy Committee, I put together a program for this summer’s meeting that focused on coal and the research and development being done at CAER and in Kentucky. I invited CAER Director Rodney Andrews to share his expertise with southern legislators and he impressed everyone in the standing-room only ballroom with the scope of the work being done at the Center. Hearing about the work being done in South Africa, the Algae Symposium recently held in Western Kentucky, and the many projects under development at CAER was quite illuminating. Those legislators left that meeting with a whole new level of respect for Kentucky and what we are accomplishing in the energy arena.

House Bill 1 also appropriated 5 million to the Kentucky Geological Survey to begin pilot projects in eastern and western Kentucky on carbon sequestration and other applications for CO₂. I am proud that this was the largest earmark for this type of research of any state in America.

The bill improved tax credits for the production of biodiesel and ethanol and established the Center for Renewable Energy and Environmental Stewardship. Also included were economic development incentives to give Kentucky a tool to hopefully attract private investments in the new energy technologies of the future.

Thanks to House Bill 1, Kentucky has tentatively approved over $1 billion in tax incentives through its Incentives for Energy Independence Act program since last fall for six companies that want to build alternative energy projects in Kentucky.

At the time House Bill 1 was enacted, it was acknowledged by the Kentucky Legislature that we still needed to focus on the demand side of the energy equation by encouraging the use of renewable energy resources and energy conservation if Kentucky was to have a comprehensive and balanced energy policy.

On February 18, 2009, Governor Steve Beshear announced that his administration would establish new high-performance building standards that place Kentucky in the national vanguard of greening public facilities. Pursuant to House Bill 2, new regulations were issued that will make Kentucky’s public facilities among the greenest and most energy efficient in the country. The regulations were created by the High Performance Buildings Advisory Committee, made up of Kentucky environmentalists, architects, engineers and builders who worked for six months to create public building standards based upon the nationally-recognized rating system LEED (Leadership in Energy and Environmental Design). These standards place Kentucky in an elite group of 12 states with laws requiring that some or all design, construction and operation of state buildings earn LEED Silver or other comparable standard.

Other fruits from House Bill 2 and our energy policy are being reaped around Kentucky. On January 26, 2009, the governor and University of Louisville President James Ramsey announced a memorandum of agreement to operate Kentucky’s Center for Renewable Energy Research and Environmental Stewardship at U of L’s J.B. Speed School of Engineering per House Bill 1. They also announced that U of L engineering and business alumnus Henry Conn and his wife Rebecca pledged more than $20 million to the university to support the work of the center. This is the largest individual donation to the University of Louisville - or any public Kentucky university - in our commonwealth’s history. The center - to be named the Conn Center for Renewable Energy Research and Environmental Stewardship - will provide leadership, research, support and policy development in wind, solar, geothermal and biomass resources as well as energy storage challenges.

House Bill 2 was recently recognized as a “Megatrend” national model by the Council of State Governments. CSG describes a megatrend as “a large, social, economic, political, environmental or technological change that is slow to form. Once in place, megatrends influence a wide range of activities, processes and perceptions, both in government and in society, possibly for decades. They are the underlying forces that drive trends.”

So, in this past 2008 session, we expanded our footprint in the area of renewable energy, energy efficiency and conservation with House Bill 2. This Bill, which passed unanimously out of both Houses, focuses primarily on providing incentives to encourage the development of renewable energy resources, the construction of energy efficient buildings, the purchase and installation of energy efficient insulation, doors, windows, heating and air conditioning units, and the use of solar, hydro and wind power.

Along with requiring new state building construction and renovations to meet certain energy efficiency standards, the legislation also established tax credits and provided funding sources to improve the energy efficiency of public and private buildings, as well as rebates for the building and selling of ENERGY STAR homes and manufactured housing.

Two bond pools were established in House Bill 2 - a $50 million grant pool for the renovation of public buildings including schools and universities to make them more energy efficient and a $30 million low interest loan pool for small business and industry to do the same. In addition, House Bill 2 established a program to help finance public and private sector green building initiatives to reduce energy consumption.

...I believe clean coal, liquefaction, biofuels, wind, solar and hydro power, and other renewable and alternative energy sources will create a national energy powerhouse...
Perhaps the most exciting aspect of House Bill 2 has been the $63 million Kentucky will receive for alternative energy projects under President Barack Obama’s economic stimulus plan.

Gov. Beshear, in his presentations to the president, highlighted what the Kentucky General Assembly has passed in the area of green building practices and opportunities to expand research and development at the Center for Applied Energy Research, U of L’s Speed School of Engineering and other Kentucky universities.

The $63 million stimulus funds that will be allocated in Kentucky will be used for energy efficiencies, low income weatherization programs, carbon capture and sequestration demonstration projects, and research and development for such renewable and alternative energy projects. There is also more than $6 billion in grants that states and local governments can apply for to expand and create energy-related projects such as solar cells and advanced batteries for automobiles. Because of the legislation the Kentucky General Assembly has passed, our commonwealth is well-positioned to tap into this pool of money.

A dual goal of the Obama Administration and Kentucky’s energy legislation is to create jobs that will help fuel our economy. Our nation needs scientists, hydrologists, surveyors, green construction workers, electricians, agricultural experts, builders, architects, and more to truly achieve a green economy. The green jobs of tomorrow demand a quality education today and with the president’s infusion of funding, Kentucky can better train the energy workforce we need.

I believe that the Kentucky General Assembly took a bold and decisive step in pursuing energy legislation, even when faced with sharp critics who sometimes questioned our ambitious goals. We did not allow those voices to detract us. Instead we charted the course for an aggressive and ambitious energy policy for Kentucky.

As primary sponsor of Kentucky’s energy legislation over the past three years, it is clear that I believe clean coal, liquefaction, biofuels, wind, solar and hydro power, and other renewable and alternative energy sources will create a national energy powerhouse that will put this country on a solid path to energy independence and security. And from that we will build a strong economy that produces the types of jobs our people need and deserve.

I believe that Kentucky will lead the way, thanks to innovative and landmark energy legislation passed by the Kentucky General Assembly and cutting edge technologies being discovered at the UK Center for Applied Energy Research.