ENGINEERING AND REGULATORY ISSUES FOR COAL COMBUSTION BY-PRODUCT CHARACTERIZATION AND UTILIZATION

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Introduction

The term coal combustion by-products (CCBs) generally refers to the typical high-volume residues that inevitably result from coal use in energy production. These high-volume residues are fly ash, bottom, ash, boiler slag, and FGD (flue gas desulfurization) byproducts. Many of these CCBs have properties advantageous for engineering, construction, and manufacturing applications (Baker, 1984; Helmuth, 1987; University of North Dakota Mining and Mineral Resources Research Institute [UNDMMRRI], 1988). The first university research study on coal fly ash was reported in the Proceedings of the American Concrete Institute (ACI) in 1937, where the term "fly ash" first appeared in the literature. In 1946, the Chicago Fly Ash Company was formed to market coal fly ash as a construction material for manufacturing concrete pipe (Faber and Babcock, 1987). The first large-scale use of coal fly ash was by the U.S. Bureau of Reclamation in the construction of the Hungry Horse Dam in Montana in 1949 (Faber and Babcock, 1987). Six other dams were constructed during the 1950s using coal fly ash concrete. Initial markets opened up by the Chicago Fly Ash Company were as a cement replacement and as an enhancer of the qualities of concrete to meet the new postwar demands. The technology used to establish these markets came from the U.S. Bureau of Reclamation and Army Corps of Engineers experience using natural pozzolans in concrete for dam construction. Pozzolanic technology dates back to Roman times, some 2000 years ago, in the building of the aqueducts and the coliseums.

Currently, CCBs are an underutilized industrial by-product in the United States. Approximately 20% of all U.S. by-products produced in 1991, including FGD material, were utilized (American Coal Ash Association [ACAA], 1991). Large potential markets for these byproducts have not yet been exploited. Many of the applications referred to above are in the initial stages of commercial development. Although extensive research, development, and promotional effort have been expended, much more work is needed to achieve full commercial potential. Research, development, and demonstration are continuing under the auspices of numerous institutions across the United States. The ACAA, Edison Electric Institute and the Utility Solid Waste Activities Group, the Electric Power Research Institute (EPRI), and many individual utilities and marketing organizations are devoting their best efforts to promote CCB use, especially in engineering and construction applications.

Engineering Applications for CCBs

Historically, the principal use of coal by-products has been in concrete, and this still holds true today. However, many other utilization applications are discussed in the literature, including controlled low-strength materials, highway road base and subgrade, soil amendments for agricultural uses, waste stabilization, extenders in plastics and paints, and the manufacture of products such as cement, insulating materials, lightweight building block, brick, and other construction materials.

The use of CCBs in concrete and concrete products is primarily in the incorporation of fly ash as a partial replacement for portland cement in concrete. This use generally has the following beneficial effects:

- Reduced water requirements
- Increased ultimate strength
- Improved workability
- Extended setting time
- Reduced heat release
- Lower permeability
- Improved durability
- Increased resistance to chemical degradation

Mechanisms proposed to explain the improved microstructure and density obtained by using fly ash are 1) the packing of finer fly ash particles into interstices, 2) an increased binder-water ratio resulting from this packing, and 3) the pozzolanic reaction of calcium hydroxide and fly ash occurring over a period of weeks or months. Analytical characterization of fly ash cement during curing shows that a variety of calcium-silicon- hydrate gels are responsible for the gain in both strength and density notably occurring from about 28 days (Pietersen and others, 1991). These reactions are restricted by low alkalinity, low temperatures, or high water-solid ratios in pozzolanic systems. Reaction mechanisms overall are similar for either pozzolanic or cementitious fly ash, except that cementitious fly ash provides both cementitious calcium and silicon reactants, whereas pozzolanic fly ash supplies primarily silicon, which reacts more slowly with the calcium hydroxide released from the portland cement.

Fly ash used in this application generally must meet one of the commonly applied standard specifications developed by ASTM (American Society for Testing and Materials) or AASHTO (American Association of State Highway and Transportation Officials). These specifications contain both chemical and physical requirements for fly ash to be used as a mineral admixture in concrete. Cementitious fly ash generally falls into the ASTM and AASHTO specification for Class C, and pozzolanic fly ash generally falls into the ASTM and AASHTO specification for Class F. These are material specifications and not performance-based standards, so they do not always accurately predict performance.

There are varying reports of the effects of the use of fly ash in concrete relative to its performance in several situations. Freeze-thaw durability of fly ash concrete can be ensured by the use of practices that ensure good freeze-thaw performance for other concretes (Tyson, 1991; Dunstan, 1991). Freeze-thaw performance is reported to improve with the addition of Class C fly ash up to a 50% replacement level (von Fay and others, 1993). Overall, the resistance of fly ash concrete to salt scaling due to deicing in cold climates appears to be similar to that of conventional concrete, and improved resistance correlates with strength and reduced permeability (Soroushian and Hsu, 1991). Unwanted alkali-silica reactions are the cause of detrimental expansion in concrete both during and after curing. This problem occurs in various forms when free alkalies (usually reported in terms of Na_2O and K_2O) are introduced with any of the raw materials and is common when portland cement is used with high-silica aggregate. As commonly used, the term alkali-silica reaction appears to represent a class of related problems. These problems are variously reported to be remedied or aggravated by the addition of specification-grade fly ashes, suggesting that mineralogical properties not currently considered may be important, In general, the addition of fly ash, and particularly Class F ash, is considered to be beneficial because of the ability of finely divided silicious particles to tie up alkalies and free lime by pozzolanic reactions (Butler and Ellis. 199 1; Smith, R. L., 1993). The concrete expansion encountered during curing when using certain Class C fly ashes has been reported to depend on the amount of free lime introduced with the ash, which has been correlated with reduced furnace temperatures and a less vitrified (fused) ash (Kruger and Kruger, 1993). High concentrations of sodium in certain western coals, occurring in an organically associated form. are an identifiable cause of alkali-silica reaction.

Manufacture of artificial aggregates from fly ash or other CCBs can be accomplished by either sintering processes (Puccio and Nuzzo, 1993) or hydrothermal and cold-bonding processes. Sintering processes are well-established technology and have operated successfully for decades, but lower-temperature processes under development have attracted more recent attention because of their lower energy requirement and greater cost-effectiveness. Commercial production of lightweight aggregate for building block based on low-temperature processing has commenced recently in Florida using the Aardelite process (Smith, C.L., 1993; Hay and Dunstan, 1991) and in Virginia using the Agglite process (Courts, 199 1).

Synthetic aggregate was experimentally produced from lime-based spray dryer FGD byproducts in the early 1980s by pelletizing at pressures of 5 to 20 tons per square inch followed by extended l0- to 60-day curing under controlled moisture conditions (Donnelly and others, 1986). Strength properties were adequate for confined applications such as road base. Pellets produced from Coolside, LIMB (limestone injection modified burner), and fluidized-bed combustion (FBC) by-products in the Ohio Coal Development Office demonstration project have passed the ASTM abrasion test for use as road base aggregate (Hopkins and others, 1993). Commercial production of lightweight aggregate suitable for use in lightweight building block commenced in Florida in 1992 using bituminous coal fly ash and FGD scrubber sludge as raw materials in the low-temperature Poz-0-Lite process (Smith, C.L., 1993).

A novel method for producing lightweight aggregate by agglomerating fly ash or sand in foamed cement has been developed in Germany (Gorsline, 1986). The properties of the aggregate can be controlled to meet a range of specifications on size, strength, density, and porosity. The cellular structure imparts high strength in relation to weight and reduces the amount of cement required.

Autoclaved cellular concrete used in building blocks, roof slabs, and other cast products represents an important market for fly ash in Europe. In this process (Pytlik and Saxena, 199 1; Payne and Car-roll, 1991), fly ash is combined with cement, lime, sand, and aluminum powder and mixed with hot water. The reaction of aluminum and lime generates hydrogen gas which forms an aerated cellular structure. Curing in high-pressure steam autoclaves produces a physic chemically stable product.

The use of fly ash alone or together with lime or cement in self-hardening road base is an evolving technology which is receiving increased attention. New information in this area includes the results of laboratory testing and extended field monitoring, use of reclaimed pond ash, incorporation of FGD by-products, and use of the ash-based aggregates discussed previously.

Monitoring of a 1500-ft test section using cement-fly ash base for a Michigan 4-lane highway has indicated quite satisfactory performance since its construction in 1987 (Gray and others, 1991). Some heaving and cracking occurred in winter months due to frost effects. Laboratory leachate concentrations for heavy metals using ASTM and RCRA (Resource Conservation and Recovery Act) (U.S. Environmental Protection Agency [EPA]) procedures approached drinking water standards. Replacement of lime with Class C fly ash in the subbase for a Kansas racetrack reduced the cost by one-half; swelling potential was reduced compared to lime stabilization, but strength was reduced at soil temperatures below 40°F (Ferguson and Zey, 1991). Laboratory evaluation of fly ash stabilization of caliche, a red-brown calcareous material used for roadways in South Texas, indicated that both Class C and Class F ashes were more effective than lime for reducing plasticity and that Class C fly ash also significantly increased strength (Keshawarz and others, 1991). Laboratory and field tests on the use of artificial aggregate produced from fly ash in asphalt paving, both as road base and in the asphalt mix, indicated that bitumen is absorbed in the pores of the aggregate, producing good bonding but a relatively dry and stiff mix; replacement of commonly used gravel with fly ash aggregate did not result in higher leaching of any of the heavy elements analyzed (Mulder and Houtepen, 1991).

Reclaimed pond ash containing fly ash and bottom ash from Canadian lignite has been used to stabilize road base for asphalt paving (Culley and Smail, 1986). The wet pond ash, when compacted in I-in. layers using standard equipment and handling procedures, had good structural bearing, but the unconfined surface suffered rapid surface abrasion when dry. Adequate bonding between the ash subbase and asphalt paving was achieved by blade-mixing the first layer of asphalt into the underlying ash. Road surface condition was adequate over time where appropriate construction techniques were used. Recent laboratory testing on strength development for a reclaimed high-calcium fly ash used along with kiln dust to stabilize road base materials indicated strengths in the range of 200 to 1000 psi (Bergeson and Overmohle, 199 1).

Fly ash has been successfully used in combination with lime sludge to stabilize unstable sand in Florida road base projects (Jones, 1986). A base prepared by mixing lime and fly ash with in situ sand hardened sufficiently after several weeks to allow heavy truck traffic. By-products from coolside, LIMB, and FBC sulfur control technologies are currently being evaluated for use in road base. Laboratory tests on the compaction, swelling, shear strength, permeability, and leaching properties of the coolside FGD by-product indicate a good potential for use in road base applications, but final assessment awaits the performance of field trials and engineering analysis (Hopkins and others, 1993).

Controlled low-strength material (CLSM) is a fill formulated from a pozzolanic material such as fly ash along with small amounts of cement, a natural filler such as sand, and water. CLSM is also commonly called flowable fill, flowable mortar, or controlled- density fill (CDF). CLSMs have been investigated for numerous applications, including subbase for paving and foundations; backfills for trenches, culverts, and bridge abutments; and fillings for abandoned tanks, sewers, and mine shafts. Starting in the late 1960s, the Detroit Edison Company working with the Kuhlman Corporation pioneered the development of flowable fill formulations using fly ash, which they call K-Krete. Advantages of CLSM over compacted soil include delivery in ready-mix trucks, placement without tamping or compacting, strength development supporting equipment within 24 hours, and the opportunity to formulate mixes having an ultimate strength well in excess of that of compacted fill. Significant savings in time and related cost can be achieved in designing rapid turnaround projects for high-traffic road applications. For example, bridge replacement in the Mississippi Basin in the aftermath of the 1993 flood could be accomplished more quickly and economically by substituting large culverts imbedded in fly ash fill for damaged abutment-type bridges, where applicable. This type of bridge replacement has been reported to save as much as 75% o the cost of conventional construction (Buss, 1990).

The properties of CLSM vary widely depending on the class of fly ash used and the mixing proportions. Nonspecification fly ashes, relative to requirements established for fly ash as a mineral admixture in concrete, can be quite satisfactory for flowable mortar. Compressive strengths within a nominal range of 50 to 1500 psi can be tailored to fit the requirements of the application, including the possible requirement for reexcavating. In flowable tills, Class F fly ash serves primarily as aggregate, and large amounts can be used. Recent research on the mechanical properties of formulations using Class F fly ash (Maher and Balaguru, 1991) indicates that satisfactory 28-day strengths in the range of 198 to 1726 psi were obtained for mixes containing u to about 40% fly ash along with sand and 3% to 7% portland cement; strength development continued up to and possibly beyond 180 days, at which time a 7 % cement mixture testing at 172 psi at 28 days had reached a strength of 3000 psi. Class C fly ash is itself a cementing agent, and 1500-psi 28-day strength is achieved using only about 3% portland cement and 5% high-calcium ash (Naik and others, 1991). The amount of Class C fly ash that can be used in CLSM is limited by the desired strength, where higher proportions of fly ash alone, without cement, will produce compressive strengths exceeding low-strength concrete.

The use of CLSM to correct acid mine drainage and subsidence in old underground coal mines is a well-demonstrated technology that could be more widely applied (Ryan, 1979). The bonding material in the grouting used is typically fly ash and cement in a 1O:l ratio, although ash alone can be used in less critical applications. Subsidence can be prevented either by backfilling the entire mine void with a low-strength grout or by establishing stronger grout/gravel columns at appropriate intervals to support the mine roof. Acid mine drainage and underground burning in spoil piles can be remediated by similar grouting methods engineered to isolate. fill. and/or extinguish affected areas in a mine. Advantages of using flowable mortars are minimum disturbance (no excavation), engineering flexibility, and low cost. Fly ash is returned to the in from whence it came, while at the same time remedying in related environmental problems,

Manufacturing Applications for CCBs

A large number of potential uses for CCBs in industrial applications have been investigated. Commercial practice is limited in the United States, but is more common in some other countries. These applications include the following:

- Gypsum
- Brick
- Fillers in paint, plastics, and metal
- Mineral wool
- Ceramics

Land Applications for CCBs

It is important to point out land application of CCBs as a special case of CCB utilization. Land application includes use as soil amendments and in mining applications. Soluble forms of calcium, magnesium, sulfur, and certain necessary trace metals such as boron, molybdenum, zinc, selenium, and copper that are present in CCBs can be used to provide needed plant nutrients. No significant amounts of the primary nutrient elements-nitrogen, phosphorus, and potassium-are found in CCBs, but wood ash is rich in potassium and phosphorus. By-product gypsum ($CaSO_4 \cdot 2H_20$) can be used to improve the tilth of clayey soils and mitigate the toxicity of exchangeable aluminum in acid soils. Calcium contributes to soil aggregation by displacing sodium on clay minerals and providing microscopic cementation. Concerns relating to the agricultural use of CCBs involve the presence of soluble salts and trace concentrations of toxic metals which may be present in CCBs.

Soil Amendment Auulications

A review of past work on the effect of CCBs on plant growth (Clark and others, 1993) indicates that little agricultural utilization is occurring and that information is limited. Scrubber sludge impoundments have been successfully vegetated using wheat grass, tall fescue, sweet clover, millet, cottonwoods, and red cedars. Scrubber sludges have been successfully used as a source of boron and selenium trace nutrients. FBC bed residues are variously reported to increase maize and soybean yields and to provide a necessary source of calcium for apples. Research has been conducted by the Tennessee Valley Authority (TVA) on the inclusion of lime/limestone scrubbing waste into fertilizer formulations (Santhanam and others, 1981). Research is being conducted on the agricultural use of wood-fueled power plant ash from generating units in California (Wheelabrator Shasta Energy Company, 1991; Meyer and others, 1992).

In controlled greenhouse tests on several different CCBs (Clark and others, 1993) the addition of FBC residues to an acid soil of known severe aluminum toxicity served to double the yield of maize at an optimum add rate of 2% to 3% in the soil mix, but yields decreased at higher use rates. The effect of fly ash addition varied with coal type, with a bituminous Class F fly ash showing its highest growth enhancement at 3% addition. whereas lignitic Class C fly ash continued to increase yields at rates up to 25% of the soil mix. FGD by-products generally provided less growth enhancement, and optimum results were obtained at very low rates of 1% or less of the soil mix, possibly owing to detrimental effects of sulfite contained in these by-products. The use of an FGD sludge that had been processed to convert sulfate to gypsum enhanced growth rates at add rates up to 75% of the soil mix, consistent with the known beneficial effect of gypsum application to acid soil.

A major study on land application of FGD and pressurized fluidized-bed combustion (PFBC) by-products (Beeghly and others, 1993) is in progress in Ohio, sponsored by the Ohio Coal Development Office, the U.S. Department of Energy (DOE), EPRI, Ohio Edison. American Electric Power, Dravo Lime Company, and Ohio State University. By-products from fifteen sources are being investigated, representing four major clean coal technologies, including furnace injection FGD (LIMB), duct injection FGD. spray dryer FGD. and fluidized-bed combustion (atmospheric FBC and PFBC). These by-products are characterized by high alkalinity expressed as calcium carbonate equivalents of 25%-70%; sulfur contents of 2.4%-10.3%; fly ash contents of l0%-32%; and, with the exception of FBC bed material, a high surface area and fineness. Selected by-products, alone or in combination with sewage sludge, were mixed with acid soils and mine spoils and tested in greenhouse growth studies. Interactions of different materials gave somewhat different results. For example, growth of tall fescue was enhanced in overburden spoil, but was suppressed in acid underclay. Sulfite-bearing material did not harm seed germination. LIMB by-product was successfully composted with sewage sludge. The conclusion reached from the greenhouse tests was that the by-products tested, when used appropriately, are suitable substitutes for traditional soil-liming materials for acid soils. Field tests are under way to demonstrate the practicality of this use.

The commercial N-Viro Soil Process (Burnham, 1993) combines agricultural use with waste stabilization by composting CCBs, or cement/lime kiln dust as originally used, with municipal wastewater treatment sludge. The soil conditioner produced has a low nutrient value (I % N, P, K); a high lime equivalency of 25%-60%; good storage, handling, and spreading properties; and acceptable odor. The product is being produced from sludges produced in several municipalities and is used in agriculture and in cover for landfill. The key to the success of this process is that pathogenic microorganisms are destroyed by the alkalinity and heat associated with the addition of CCBs and possibly quicklime (CaO), followed by temperature-controlled composting and air drying. Leachability tests at various pH levels have indicated that the heavy metals are below EPA toxicity limits.

The efficacy of using CCBs in agricultural applications cannot be generalized since it is evident in comparing case studies that success is varied and depends on the suitability of the amendment to the soil and use conditions. For example, composting coal fly ash with field-collected waste vegetation was found to have no detrimental effect on bean germination in clayey and sandy soil, but reduced germination in a high-humus soil (Varallo, 1993). Alkaline treatment is appropriate for eastern acidic soil, but not for many midwestem soils that are already alkaline in nature. Novel applications in specialized areas may provide some of the more immediate commercial opportunities. FBC bed residues have been used at high rates of over 100 tons per acre as a mulching agent applied directly to cap the soil surface in orchards and raised-bed tomato rows (Korcak, 1993). Coal bottom ash has been demonstrated as an acceptable root medium for growing flowers in a hydroponic nutriculture system (Bearce and others, 1993). Widespread acceptance of CCBs in agriculture still has performance and economic barriers to overcome, but opportunities exist today where the properties of a utility's by-products meet the needs of a local market,

Some concerns still exist about the environmental safety of using CCBs in agriculture, despite findings that leachable concentrations of toxic metals are very low (Beeghly and others, 1993; Burnham, 1993: Bennett and others, 1981). While results vary somewhat for different by-products and soil types, the general finding reported is that leachates are nontoxic relative to the eight RCRA toxic metals (arsenic, barium. cadmium, chromium, lead, mercury, selenium, and silver) and often approach the more stringent primary standard for drinking water. The mobility of metals depends on the mineral matrix and on pH. and solubility is generally reduced at the high pH levels associated with alkaline CCBs. Certain beneficial trace plant nutrients present in coal fly ash, such as boron, selenium, and molybdenum. are assimilated in animal tissues (Lisk, 198l), and selenium deficiency in farm animals has been shown to be correctable by feeding the animals fly ash-grown crops. In coordinated tests on farm crops and animals (Bennett and others, 198l), there has been little evidence of detrimental effects on the food chain. One reason for caution is that standard tests for determining the leachability of trace metals, primarily the EPA toxicity characteristic leaching procedure (TCLP) tests for acid solubility, do not accurately represent all utilization environments, and they may either evidence problems that do not exist or miss vvorst-case problems that would occur in practice. At the current stage of understanding, states will tend to regulate ash reuse on farmland as solid waste management, requiring case-by-case permitting (e.g., California [Marshack. 19921).

Mining Applications

There are several scenarios in which CCBs may be utilized in a mined setting:

- The use of CCBs for abatement of acid mine drainage or for treatment of acid mine spoils (Schueck and others, 1993; Ackman and others, 1993; Stehouwer and others, 1993).
- The use of CCBs in reclamation activities or highwall mining (Bergeson and Lapke, 1993; Paul and others, 1993; Rob1 and Sartaine. 1993).

The placement of ash, as a low-strength structural material, in an underground mine for reclamation and prevention of subsidence (Chugh, 1993, Butler and others, 1995).

These three options represent most, but not all, scenarios under which CCBs would be returned to the environment in a mined setting. Mine applications have previously been considered disposal but, because of the relatively benign nature of CCBs, should more appropriately be considered reuse for reclamation of mined land because of the benefits derived in these applications.

Solid residues from the combustion of low-rank coals, which generates leachate at extremely high pH, tend to form the mineral ettringite. The alkaline nature of some CCBs (including duct injection residues/FBC residues and low-rank coal fly ash) can be capitalized on for abatement of acid mine drainage and spoils (Schueck and others, 1993; Ackman and others, 1993; Stehouwer and others, 1993). Ettringite has the capacity to chemically fix elements such as arsenic, boron, chromium, molybdenum, selenium, and vanadium that exist as oxyanions in aqueous solution. Thus ash that generally leaches low concentrations of most potentially problematic trace elements tends to form stable minerals of some of the most highly problematic of the trace elements known to concentrate in ash from coal combustion (Hassett and others, 1991). Although CCBs are generally benign with respect to leaching significant concentrations of potentially problematic elements, proper and environmentally sound testing should be conducted (Hassett, 1991; Hassett, 1994). This testing should be done using long-term as well as short-term leaching to determine the total mass of trace elements that may potentially be mobilized and the trends of analyte chemistry evolution (Hassett, 1987; Hassett and Pflughoeft-Hassett, 1993). Although leachate chemistry of most trace elements is accumulation of analyte to an equilibrium concentration that increases to a plateau, some of the oxyanionic trace elements can actually increase to a plateau quickly and then exhibit a trend of decreasing solution concentration. This is important to understand, since it is the long term that is usually important in assessment of potential for environmental impact.

A field demonstration at Center, North Dakota, where scrubber sludge was placed into a mined area was performed by the Energy & Environmental Research Center (EERC). The only observed impact was caused by the disturbande of the environment at the time of mining. An increase in total dissolved solids, mostly from sodium sulfate, was seen, but this rapidly returned to background levels (Beaver and others, 1987).

The primary conclusion that can be drawn is that return of ash to the mined settings is a sound high-volume use of this versatile engineering material. Not only can land be reclaimed, but in the case of underground mines, the setting can be stabilized to prevent future subsidence. Treatment of acid mine drainage and spoils has high potential, especially for high-volume alkaline residues from advanced coal processes. Impacts from trace elements, the primary concern, have been minimal or unmeasurable in almost all instances where monitoring has been carried out. There have been examples where groundwater quality has been shown to actually improve from the placement of CCBs in the environment (Ackman and others, 1993; Paul and others, 1993).

Coal Combustion By-Product Classification

Alternative classification standards are needed for a growing list of CCBs to address engineering and environmental performance in a manner that will provide public assurance of safety and effectiveness. while not impeding utilization. It is widely believed, as evidenced by this and other studies, that the present ASTM and EPA test protocols and specifications and related state standards do not adequately predict performance under actual use conditions. Important advances are being made in applicable analytical methods, but their application is hindered by misplaced reliance on existing empirical standards. For example, specifications developed for the use of fly ash in concrete are sometimes used by default in applications involving flowable fill or road base. New, automated analytical methods for statistically characterizing individual particles contained in bulk by-product samples by size, surface composition, and mineral type give a true indication of the chemical and mineralogical diversity in CCBs (Folkedahl and others, 1993). Leaching tests for determining the mobility of RCRA elements under conditions simulating actual field conditions are being compared with the EPA TCLP acid-leaching procedures (Hassett and Pflughoeft-Hassett, 1993). These and other advanced characterization methods provide powerful tools for understanding the behavior of various by-products in diverse applications. Advanced analytical characterization can be systematically correlated with practical performance experience to provide an entirely new basis for classifying CCBs for optimum beneficial use. A scientifically based classification offering broad coverage of different by-product types and applications would assist greatly over time in providing the added assurance of safety and effectiveness needed to break down overly conservative practices currently prevailing under federal and state regulations.

Federal Regulations Applying to Coal Combustion By-Products

The Resource Conservation and Recovery Act of 1976 and the 1980 Solid Waste Disposal Act Amendments provide for comprehensive cradle-to-grave regulation of solid waste generation, collection, transportation, separation, recovery, and disposal (Jagiella, 1993; Findley and Farber, 1992; Butler and Binion, 1993). Subtitle C of RCRA and its implementing regulations impose specific federal requirements on materials deemed to be "hazardous," either because of being listed by EPA as hazardous or by reason of having hazardous or toxic characteristics. Subtitle D of RCRA delegates regulation of nonhazardous solid wastes to the individual states. In its original form, RCRA did not specify whether CCBs fell under Subtitle C or D. The 1980 amendments temporarily excluded CCBs from Subtitle C regulation pending an EPA study report addressing appropriate classification. In the interim, CCBs were subject to regulation under state laws pertaining to solid wastes.

On August 2, 1993, EPA presented its final regulatory decision on fly ash, bottom ash, boiler slag, and flue gas emission control waste (40 CFR Part 261), stating that, effective September 2, 1993, these materials are not regulated as hazardous wastes under Subtitle C and officially placing them under Subtitle D as solid wastes under the jurisdiction of individual states. Further evaluation will be made by EPA of hazardous or toxic properties of industrial solid wastes, but at this time, CCBs are expected to remain under state regulation where little positive change is expected regarding beneficial use.

An important barrier issue originating in RCRA legislation is the indiscriminate designation of CCBs as solid wastes, whether they are recovered for use or disposed of in a landfill. In the absence of special state exemptions from solid waste regulations for beneficial use, which exist in only a few states, the "waste" designation can trigger case-by-case approval and permitting procedures that discourage CCB use because of unreasonable cost and delay. The remedies for this barrier problem include both the elimination of the "waste" designation and the creation of appropriate exemptions from regulation based on environmentally sound regulatory classifications for various classes of by-product use.

While RCRA is the principal federal law affecting the regulation of CCBs, a larger statutory framework of federal laws that are more or less integrated with state and local statutes may ultimately have to be considered. It is not within the scope of this study to unravel this potential regulatory maze. However, other federal statutes that potentially apply to CCB use or disposal in particular circumstances, as well as to virgin raw materials and derived products, include the Clean Water Act of 1972, the Safe Drinking Water Act of 1974. the Toxic Substances Control Act of 1976, and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, the Superfund Act). All of these statutes deal with the control of toxic substances and ultimately rely on environmental testing and risk assessment to establish regulatory criteria. The final answer to regulatory questions constituting barriers to beneficial use, therefore, lies in obtaining adequate environmental data to demonstrate environmental safety, a process which is well advanced for CCBs but requires systematic compilation and refinement to provide the basis for regulatory classification.

State Regulation of Coal Combustion By-Products

Limited information has been gathered and reported that defines and discusses state regulations pertaining to CCB utilization and barriers to utilization. State regulations have been summarized in a survey of use and disposal provisions (Jagiella, 1993). Hudson and others (1982) discussed barriers to CCB utilization in Maryland, Alabama, Illinois, New York, Pennsylvania, Ohio, Texas, Virginia, and West Virginia. Changes in regulations and practices relating to CCB utilization in these states have been noted in more recent works. The Texas Coal Ash Utilization Group (TCAUG) (1992) addressed regulatory issues in Texas in a recent report. The *Pennsylvania Bulletin (1992)* discussed current regulatory issues in Pennsylvania. These summaries point out that most state regulation of CCBs is designed to regulate disposal. Very few states have regulations regarding utilization of CCBs, either allowing or disallowing use. Common uses include concrete paving by state highway departments. A summary of state department o f transportation CCB utilization specifications was prepared by the EERC (Dockter, 1994) for the Coal Ash Resources Research Consortium. This report also summarizes the percentages of fly ash typically allowed as a mineral admixture and other utilization applications accepted by the state departments of transportation where specified, although these are not common.

Legal Barriers

It is important to include a brief discussion of the key legal barrier to CCB utilization, which is the potential for environmental liability. Other issues involving commercial law and patents pose limited constraints of much less significance. The most serious environmental issue centers on the wide divergence in the legal and regulatory treatment of the beneficial use of CCBs under state laws. Whereas EPA confirmed in a ruling on August 2, 1993, that CCBs (fly ash, bottom ash, boiler slag, and FGD material) are not hazardous materials under RCRA Subtitle C; the delegation of regulatory authority under RCRA Subtitle D for solid waste allows various states to regulate the use and disposal of CCBs by very different standards (EPA, 1993). Some states restrictively control CCBs as a de facto hazardous material. while other states treat recycled ash as an unregulated construction material (Jagiella, 1993). Some states regulate CCBs on a case-by-case basis. In recent years, several states have adopted statutes prohibiting the importation of solid wastes. Although these statutes have been regularly overruled as restraint of trade, their temporary status has impeded ash sales in some instances.

The principal federal statute affecting the regulation of solid waste, and therefore related beneficial use, is RCRA. Other federal environmental statutes that may affect barriers to CCB utilization are the Clean Water Act and CERCLA. A 1988 summary of state statutes compiled by the Utility Solid Waste Activities Group (USWAG) identified 43 states that exempt CCBs from hazardous waste regulations; seven states-Kentucky, Tennessee, Oklahoma, Washington, New Jersey, Maine, and California-require testing to determine whether the ash would be regulated as a solid waste or a hazardous material and one state, Ohio, exempts CCBs from both solid and hazardous waste regulations (Wald and others. 1983).

Legal review is needed to clarify the grounds and remedies that apply to environmental liability. As a general consideration, statutory liability under environmental law is not based on fault and imposes strict responsibility without regard to negligence. Tort law, on the other hand, applies where a dangerous condition can be traced back to the point of manufacture of a product, which is not a condition that commonly applies to CCB utilization. The commonly held opinion, that semantic reclassification of CCBs as a product rather than a solid waste would by itself simplify regulatory liability, appears to have little legal validity since the intent of the statutes would not change and their wording could be readily adapted. Also. compliance with one statute would not remove jeopardy on others: therefore, compliance with state regulations under delegated RCRA authority does not prevent liability under the Clean Water Act or CERCLA. The CERCLA statute appears to be the broadest statute covering hazardous materials that present "substantial danger to public health or welfare or the environment," and it incorporates by reference any substance designated as hazardous or toxic in the Clean Water Act or RCRA (Findley and Farber, 1992). CERCLA places strict liability for remediation and restitution on the party responsible for the hazardous material without regard to negligence. However, it is very significant to note that petroleum and natural gas are specifically exempted from liability under CERCLA. This type of exemption from liability establishes a precedent that could appropriately be considered in legislation for CCBs, owing to its importance as the largest- volume recyclable material in the United States and the record of environmental testing that indicates CCBs are not hazardous substances, pollutants, or contaminants.

Other legally recognized remedies for environmental liability, apart from statutory exemption, involve demonstration of compliance with a regulatory authority based on recognized technical specifications and environmental criteria. Improved regulatory classification of CCBs for use in various classes of applications would help to reduce environmental liability by providing background and specificity for legally defending particular utilization practices. By controlling the end use of CCBs, utilities and marketers can limit their liability by providing material only for those uses that are demonstrated to be environmentally safe (Hudson and others, 1982). More effectively, exemption from regulatory control as solid wastes under RCRA could be provided for pre-approved classes of by-product use. Although such federal deregulation of pre-approved products may be politically difficult, it would permit approved CCBs to move into unrestricted interstate commerce. Federal regulatory clarification and improved specifications would, at a minimum, provide leadership and direction for state regulators.

Some difficulties may exist in applying commercial or contract law to the sale of CCBs because of the current lack of both technical specifications and environmental criteria applying to some uses. Suggestions have been advanced for developing a uniform commercial code for by-product transactions that would incorporate specifications to assist buyers and sellers in writing clear and enforceable contracts.. Legal research is needed to establish the usefulness of this approach. As better specifications are incorporated, quality control in the production of CCBs becomes a more significant factor in meeting legal responsibility (Hudson and others, 1982).

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