BARRIERS TO THE INCREASED UTILIZATION OF COAL COMBUSTION/DESULFURIZATION BY-PRODUCTS BY GOVERNMENT AND COMMERCIAL SECTORS – UPDATE 1998

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Submitted by:

Debra F. Pflughoeft-Hassett
Everett A. Sondreal
Edward N. Steadman
Kurt E. Eylands
Bruce A. Dockter

Energy & Environmental Research Center
PO Box 9018
Grand Forks, ND 58202-9018

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	autoclaved aerated concrete
AASHTO	American Association of State Highway and Transportation Officials
ACAA	American Coal Ash Association
ACI	American Concrete Institute
AFBC	atmospheric fluidized-bed combustor
Al_2O_3	aluminum oxide
ASTM	American Society for Testing and Materials
BFBC	bubbling fluidized-bed combustion
BGL	British Gas–Lurgi
BOR	Bureau of Reclamation
CAAA	Clean Air Act Amendments
CaO	calcium oxide
$CaSO_4$	calcium sulfate
CCB	coal combustion by-product
CCP	coal combustion product
CCT	clean coal technology
CDF	controlled density fill
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFBC	circulating fluidized-bed combustor
CIBO	Council of Industrial Boiler Owners
CLSM	controlled low-strength materials
CO_2	carbon dioxide
DOE	U.S. Department of Energy
DOT	Department of Transportation
EEI	Edison Electric Institute
EERC	Energy & Environmental Research Center
EIA	Energy Information Administration
EP	extraction procedure
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EQB	Environmental Quality Board
ESP	electrostatic precipitator
FBC	fluidized-bed combustion
Fe_2O_3	ferric oxide
FETC	Federal Energy Technology Center
FFC	fossil fuel combustion
FGD	flue gas desulfurization
FHWA	Federal Highway Administration
FWDC	Foster Wheeler Development Corporation
GNE	Global New Energy, Inc.
HAP	hazardous air pollutant
HDPE	high-density polyethylene
HVFA	high-volume fly ash
IGCC	integrated gasification combined cycle

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

IGT	Institute of Gas Technology
K_2O	potassium oxide
KRW	Kellogg Rust Westinghouse
LASH	limestone ash
LIMB	limestone injection modified burner
LNB	low-NO_x burners
LOI	loss on ignition
MRT	Mineral Resource Technologies
NAFTA	North American Free Trade Agreement
Na_2O	sodium oxide
NH_3	ammonia
NORM	naturally occurring radioactive material
NO_x	nitrogen oxides
NSPS	New Source Performance Standards
OFA	overfire air
ORNL	Oak Ridge National Laboratory
pc	pulverized coal
PCB	polychlorinated biphenyl
PCFB	pressurized circulating fluidized-bed combustor
PFBC	pressurized fluidized-bed combustor
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RD&D	research, development, and demonstration
RTC	Report to Congress
SBIR	Small Business Innovation Research
SCR	selective catalytic reduction
SiO_2	silicon dioxide
SNCR	selective noncatalytic reduction
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_x	sulfur oxides
SPLP	synthetic precipitation leaching procedure
SWDAA	Solid Waste Disposal Act Amendment
TAC	Texas Administrative Code
TCAUG	Texas Coal Ash Utilization Group
TCLP	toxicity characteristic leaching procedure
TRI	toxic release inventory
TVA	Tennessee Valley Authority
USDA	United States Department of Agriculture
USGS	U.S. Geological Survey
USWAG	Utility Solid Waste Activities Group
UTRC	United Technologies Research Center
w/c	water-to-cementitious (ratio)
WRAG	Western Region Ash Group

TERMINOLOGY AND DEFINITIONS

TERMS RELATING TO THE MATERIALS COMMONLY GENERATED DURING COAL COMBUSTION

Boiler slag is the molten inorganic material from the coal that drains to the bottom of cyclone-type or other wet-bottom furnaces and discharges into a water-filled pit where it is cooled and removed as glassy particles resembling sand.

Bottom ash is the ash that falls to the bottom of the furnace and is removed as nonmolten particles or clinkers.

FBC materials consist of unburned coal, ash, and spent bed material used for sulfur control. The spent bed material (removed as bottom ash) contains reaction products from the absorption of gaseous sulfur oxides (SO_2 and SO_3).

FGD materials are derived from a variety of processes used to control sulfur emissions from boiler stacks. These systems include wet scrubbers, spray-dry scrubbers, sorbent injectors, and a combined sulfur oxide (SO_x) and nitrogen oxide (NO_x) process.

Fly ash is the fine ash that is carried out of the boiler with the flue gases. Almost all of these are particles, except for the smallest size fraction, and are usually collected by either an electrostatic precipitator (ESP) or a fabric filter (baghouse).

TERMS RELATING TO COAL

Bituminous coal is soft coal that may vary from low to high volatile content, with calorific values ranging from 10,500 to 14,000 Btu/lb on a moist, mineral-matter-free basis. Bituminous coal is prevalent in the eastern United States.

Coal rank indicates the degree of coalification that has occurred for a particular coal. Coal is formed by the decomposition of plant matter without free access to air and under the influence of moisture, pressure, and temperature. Over the course of the geologic process that forms coal—coalification—the chemical composition of the coal gradually changes to compounds of lower hydrogen content and higher carbon content in aromatic ring structures. As the degree of coalification increases, the percentage of volatile matter decreases and the calorific value increases. The common ranks of coal are anthracite, bituminous, subbituminous, and brown coal/lignite.

Excluded minerals are minerals (inorganic compounds) that may be mined with the coal but are not an intrinsic part of the coal.

Included minerals are minerals (inorganic compounds) that are part of the coal particle and matrix.

Lignite, or brown coal, is the lowest-rank solid coal. Lignite typically has a high moisture content and calorific values of less than 8300 Btu/lb on a moist, mineral-matter-free basis. U.S. lignites are found in North Dakota, Montana, Texas, and other Gulf Coast states.

Subbituminous coal is a black coal with calorific values ranging from 8300 to 10,500 Btu/lb on a moist, mineral-matter-free basis. Subbituminous coals are found in the western United States, primarily in Montana, Wyoming, and Alaska, with significant additional deposits in New Mexico and Colorado.

TERMS RELATING TO POWER PRODUCTION

Alkali gettering involves using a mineral to capture alkalies such as sodium and potassium from a combustion process. Commonly used alkali getters include kaolin clay, bauxite, and other alumina silicate-based materials.

Baghouse collection of coal combustion fly ash refers to mechanical collection by means of a fabric filter that must be cleaned periodically.

Barrier filters remove ash from the flue gas of combustion systems by forcing the gas to pass through a filter medium. Baghouses are the most common barrier filters.

Cyclone is the cone-shaped air-cleaning apparatus operated by centrifugal separation that is used in particle collecting and fine-grinding operations.

Cyclone firing refers to slagging combustion of coarsely pulverized coal in a cylindrical (cyclone) burner. Some wet-bottom boilers are not cyclone-fired. The primary by-product is a glassy slag referred to as boiler slag.

Electrostatic precipitator (ESP) collection of coal combustion fly ash requires the application of an electrostatic charge to the fly ash, which then is collected on grouped plates in a series of hoppers. Fly ash collected in different hoppers may have differing particle size and chemical composition, depending on the distance of the hopper from the combustor. The ESP ash may also be collected as a composite.

Fluidized-bed combustion (FBC) accomplishes coal combustion by mixing the coal with a sorbent such as limestone or other bed material. The fuel and bed material mixture is fluidized during the combustion process to allow complete combustion and removal of sulfur gases. Atmospheric FBC (AFBC) systems may be bubbling (BFBC) or circulating (CFBC). Pressurized FBC (PFBC) is an emerging coal combustion technology.

TERMINOLOGY AND DEFINITIONS (continued)

Flue gas desulfurization (FGD) is removal of the sulfur gases from the flue gases, typically using a high-calcium sorbent such as lime or limestone. The three primary types of FGD processes commonly used by utilities are wet scrubbers, dry scrubbers, and sorbent injection.

Gasification is the conversion of coal to a combustible gas, volatiles, char, and ash/slag. By-products from gasification systems vary widely.

Getter is a special metal alloy that is placed in a vacuum tube during manufacture and vaporized after the tube has been evacuated; when the vaporized metal condenses, it absorbs residual gases.

Impactor is an instrument that samples ash in combustion flue gas streams by impaction to allow separation of the ash into different size fractions.

pc (pulverized coal) combustion refers to any combustion process that uses very finely ground (pulverized) coal in the process.

Slag is the nonmetallic product resulting from the interaction of flux and impurities in the smelting and refining of metals.

Slag cyclone is the primary combustion chamber for a cyclone-fired boiler. Ash from the coal melts in the cyclone and is removed as a slag.

Stoker firing refers to the combustion of coal on a grate, which may be stationary or moving.

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

Coal is a vital part of energy production in the United States, and both conventional and advanced coal conversion technologies result in the generation of solid by-products. The nearly 90 million tons of coal combustion/desulfurization by-products (CCBs) produced annually in the United States is a valuable national resource that is vastly underutilized. Current use of about 30% of the coal ash and only 2% of the flue gas desulfurization products represents a failed opportunity when compared to the nearly complete utilization already achieved in some western European countries. Future opportunities can be seized by concerted action to offer substantial benefits to the nation's electric generation, construction, and manufacturing industries; to agriculture; and to the environment, whereas failure to act will create, literally, mountains of solid waste, an unnecessary legacy of future energy production.

The value of CCBs is well established by research and commercial practice both in the United States and abroad. As engineering construction materials, these products can add value and enhance strength and durability while reducing cost. In agricultural applications, gypsum-rich products can provide plant nutrients and improve the tilth of depleted soils over large areas of the country. In waste stabilization, the cementitious and pozzolanic properties of these products can immobilize hazardous nuclear, organic, and toxic metal wastes for safe and effective environmental disposal. Public benefits of CCB utilization are substantial, including conservation of land, energy, and natural resources; reduction in CO_2 emissions generated in the production of competing materials; improvements in the balance of trade (e.g., fewer cement imports); and prevention of solid waste pollution. Increasing cost and heightened regulation are making the disposal of CCBs an undesirable option.

The U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC) has in recent years taken the lead role in research and development on management of CCBs. DOE has determined that the management of these by-products needs to be addressed more effectively from both technical and economic standpoints. In the Energy Policy Act of 1992, the United States Congress charged the Secretary of Energy to "conduct a detailed and comprehensive survey on the institutional, legal, and regulatory barriers to increased utilization of coal combustion by-products by potential governmental and commercial users." Section 1334 of the Energy Policy Act of 1992 designated that:

> At a minimum, such report shall identify actions that would increase the utilization of coal combustion by-products in A) bridge and highway construction; B) stabilizing wastes; C) procurement by departments and agencies of the Federal Government and State and local governments; and D) federally funded or federally subsidized procurements by the private sector.

This need was addressed primarily through the DOE 1994 Report to Congress (RTC), *Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors*, based on 1993 Energy & Environmental Research Center (EERC) report of the same title. The review for the update presented here was funded by DOE.

2.0 CCB PRODUCTION AND MANAGEMENT

U.S. coal production totaled a record high of 1088.6 million short tons in 1997 according to preliminary data from the Energy Information Administration. Utilities and independent power producers continue to be the dominant coal consumers and used a record 922 million short tons in 1997 as a result of a substantial decline in nuclear-powered generation and moderate growth in electricity demand. It is forecast that the United States will continue to rely heavily on coal for energy production at least through 2020. It is further forecast that future coal consumption will be primarily in existing power generation facilities or in facilities that use clean coal technologies (CCTs) such as fluidized-bed combustion (FBC) and gasification. The CCT processes have been designed to meet ever-tightening emission control standards set by the U.S. Environmental Protection Agency (EPA) and state agencies, but it is important to note that any use of coal in future energy production will continue to result in the generation of solid materials. These solids, CCBs, vary with the type of coal used, the conversion system, the emission controls applied to the system, the solid collection system, and specific operating conditions.

Annual summaries of CCB production and consumption have been prepared by the American Coal Ash Association (ACAA) since 1966. These surveys generally cover the highest-volume CCBs: fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material. A summary of CCB production and use for 1966 through 1993 indicates that CCB production increased from 1966 to about 1980 (ACAA, 1996). Since 1980, CCB production has remained relatively constant, with the exception of FGD materials. FGD material production began in 1987 and has remained relatively constant through 1996.

2.1 By-Product Characteristics

The characteristics of the solid residues produced in FBCs depend on the bed material, fuel and ash compositions, unburnt carbon, desulfurization products, and unreacted sorbents. The residues can be collected from several locations in the system, including the bed offtake, primary cyclone, and final particulate control device. In most cases in the United States, the residues are combined. In other countries, the residues are separated for utilization; i.e., the Netherlands separates the spent bed material from the fly ash. The quantity of the residues depends on the coal characteristics. High-sulfur coals require more sorbent to collect SO_2. Certain high-sodium western coals require high bed turnover rates to minimize bed agglomerations.

The chemical, mineralogical, and physical characteristics of gasifier ash residues have been found to vary significantly as a function of process configuration, operation, coal feed composition, and coal handling. The elemental compositions of the slags produced in gasification systems are similar to the bottom ash from conventional coal combustion systems. The bulk compositions of cyclone dust samples were found to be similar to those for conventional coal combustion fly ash. The mineralogical examination of slags indicated that many of the same high-temperature silicate minerals are present in the slag samples along with reduced iron-bearing compounds. A key difference in coal gasification ash and slag compared to combustion ash is the lower level of sulfur. In the absence of limestone injection for in-bed sulfur capture, sulfur is present in small quantities in the ash, usually in the form of a sulfide. In addition, the other ash species in the system may also be in reduced form.

In gasification systems, postgasifier sulfur recovery units are used to remove sulfur to convert it to sulfuric acid or elemental sulfur. Alternatively, or as a complement to a sulfur recovery system, reduced forms of sulfur can be oxidized and removed with a calcium-based sorbent in the form of calcium sulfate. Fluidized-bed gasifiers that incorporate in situ sulfur capture produce calcium sulfide that must be oxidized to sulfate before it is suitable for either use or disposal.

Integrated gasification combined cycle (IGCC) is being demonstrated on the commercial scale in three major joint projects between DOE and industry. The by-products formed in IGCC processes can be better understood in the context of process and operating variables. It is important to note that the by-product streams are not the same for each process. Also important to note, the by-products have generally been designed to be utilized rather than disposed of as part of the overall project plan.

A pressurized slagging combustor coupled with hot-gas cleaning is a potentially simple system for producing hot gas for a gas turbine combined cycle. The major problems encountered in using coal directly as a gas turbine fuel are due to the inorganic components in the fuel. Direct-fired slagging combustors offer potential capital cost savings for coal-fired combined cycle systems, but only if the hot gases generated can either be used directly or economically cleaned to remove particulates, sulfur, and alkalies. The ash by-products produced from the systems tested to date are a vitreous slag and the particulate collected in collection devices. Slagging combustors retrofit to a package boiler were able to produce a vitreous slag with relatively high ash retention. The fly ash produced was chemically and physically similar to typical pulverized coal fly ash. The reported high levels (up to 90%) of nonequilibrium sulfur captured on limestone in the reducing section of a slag combustor have, in fact, provided no more than about 50% sulfur control overall, even with rapid slag removal, owing to reemission of sulfur at high temperature under more fuel-lean conditions. Sulfides that may occur in reduced slag would pose problems in either use or disposal, possibly requiring subsequent oxidative treatment. Calcium sulfide produces poisonous and odoriferous hydrogen sulfide on contact with water.

Externally fired combined cycle systems based on currently available gas turbine technology supporting a turbine inlet temperature of 2500°C when using air as the working fluid offer potential efficiencies of 47% to 50%, fired either on coal alone or on a combination of coal and natural gas. Accordingly, DOE is vigorously pursuing a system development program, Combustion 2000, based on high-temperature coal-fired air heaters using advanced materials such as oxide dispersion-strengthened alloys. The generic United Technologies Research Center (UTRC) system configuration includes a high-temperature advanced furnace consisting of the combustor, slag screen, radiant and convective air heaters, and a heat recovery steam generator, together with the gas turbine/steam turbine combined cycle power system and conventional sulfur oxide (SO_x) and particulate control modules. The Foster Wheeler Development Corporation (FWDC) system uses a series of three air heaters fired on coal char, pyrolysis gas, and natural gas. Low nitrogen oxide (NO_x) emissions in these various systems would be achieved by combustion controls, using staging (rich–lean) or aerodynamically controlled mixing. Combustion 2000 aims at commercial demonstration by 2005 of an ultraclean system for achieving a minimum efficiency of 47% operating on a wide range of coals. The characteristics of the ash and slag from these systems will likely be similar to those found in conventional combustion systems.

2.2 CCB Management

CCBs as produced in the United States currently are primarily a result of emission control technologies installed to meet emission regulations. Emission regulations first mandated reduction of particulate matter released to the atmosphere by utilities, which required utilities to install collection devices for fly ash generated. Later emission regulations with significance to CCB production mandated limits on SO_x emissions. As a result, utilities using high-sulfur coal could change coal sources, resulting in a different by-product character, or scrub the flue gas using sorbents to remove the SO_x gases. The result of FGD is high volumes of spent FGD sorbent material. There are a wide range of FGD technologies, so FGD materials have broadly varied characteristics, but most contain high concentrations of calcium and sulfur.

Currently utilities are responding to regulation placing limits on NO_x emissions, which also impact the character of ash by-products. Issues related to air toxic emissions, including mercury, and CO_2 emissions are currently under technical and regulatory scrutiny. Regulations that limit utility emissions, further are expected to have additional impacts on by-product quantity, quality, and characteristics. Changes in CCB characteristics require an associated evaluation of technical issues related to CCB performance in conventional utilization applications and perhaps development of new markets.

Some useful generalizations can be drawn from the characterization data that have been presented in several reports. Eastern CCBs, generally produced from bituminous coal, are chemically composed mainly of oxides of silicon, aluminum, and iron, and the fly ash is usually pozzolanic and particularly well-suited for use as a concrete admixture and for high-volume applications such as structural and flowable fills. Western coal ashes from subbituminous coals, categorized as Class C ash by the American Society for Testing and Materials (ASTM), additionally contain cementitious calcium compounds that render these materials suitable for cement replacement; however, certain of these ashes may also contain high concentrations of sodium, which can contribute to alkali–aggregate reactions that cause swelling and cracking in concrete. Fly ash from lignitic coal (found primarily in North Dakota and Texas) may be pozzolanic, or it may be both pozzolanic and cementitious. It also has the potential to contain relatively high concentrations of sodium. Glassy slags and, to a lesser degree, bottom ash tend to be vitrified inert materials suitable for use as fine aggregate in a range of products from road base to cast concrete products.

FGD by-products from emission control processes using lime or limestone for sulfur capture typically contain a hydrated mixture of unreacted calcium carbonate, lime, calcium sulfite, and calcium sulfate, along with either small amounts of ash, as in most wet scrubber installations where the ash is collected separately, or larger amounts of ash, as in a lime slurry spray-dryer system attached to a baghouse that collects both the ash and the spent lime adsorbent together. Low-ash FGD by-products, depending on their oxidation state, can be used either directly or with additional processing in the production of gypsum wallboard. High-ash FGD by-products can be used along with other materials in formulated products such as low-temperature bonded aggregate and lightweight concrete block.

Effective management of CCBs will be a significant factor in determining the environmental acceptability and economics of future coal-fired electrical generation and coal conversion technologies. High disposal costs will impact utility economics in an increasingly competitive utility industry. CCB management options may range from complete utilization to complete and final disposal. The more desirable option is to take advantage of the inherent value of the material to generate income and avoid disposal cost. Many utilities will need to build new disposal facilities, which will be costly and difficult to permit under new to state regulatory requirements. More and more frequently, utilization will be selected as the preferred CCB management option for both economic and environmental reasons.

The management of high-volume combustion products needs to be considered in process economics for the life of the facility. All of the options in CCB management require thorough material and environmental characterization as a basis for understanding and, ultimately, predicting behavior in the final environment over a long period of time.

The factors impacting utility CCB management decisions reflect the barriers discussed in the 1993 EERC report to DOE. These factors can be summarized as follows:

- Economics of management options
- Environmental, regulatory, and legal factors
- Operational factors

Although the quality characteristics of the CCBs currently being produced vary widely, all CCBs have the potential to be used rather than discarded as a solid waste. The challenge of full economic utilization can be met only by appropriately matching by-products with utilization specifications, taking into account the physical and chemical properties of the by-products and the performance specifications applying to their use.

3.0 LANDMARKS

3.1 Preliminary Work

Institutional constraints to coal fly ash use in construction were evaluated based on survey data in a 1992 study report prepared by GAI Consultants, Inc. for EPRI. The findings and conclusions of this EPRI study were generally valid for CCBs with respect to institutional barriers, although the constraints posed by technical and economic issues were not addressed.

The Barriers Workshop was held at the DOE Morgantown Energy Technology Center (now FETC) in Morgantown, West Virginia, on September 27–28, 1993. A leading recommendation growing out of the workshop called for taking action to remove barriers in a proposed 1994 National CCBs Utilization Act, which would provide leadership at the highest levels of government and give the most comprehensive relief possible, consistent with environmental protection, in the areas of legal and regulatory reform. The key provisions of this proposed act, as contained in the first two of the ten recommendations which follow, were 1) to establish National Goal status for CCB utilization and 2) to provide for a due process addressing environmental safety through regulatory classifications that would progressively define preapproved uses entirely removed from the controls imposed on solid wastes by the Resource Conservation and Recovery Act (RCRA), whether administered by federal or state agencies. Coal by-product materials that meet established environmental criteria would effectively be deregulated and become products in interstate commerce.

3.2 EERC 1993 Report to DOE

To meet the directive by Congress to identify barriers and recommend ways to increase CCB usage, DOE FETC contracted with the Energy & Environmental Research Center (EERC) to assess barriers to the utilization of CCBs. The EERC study completed in October 1993 was based on data obtained from a large number of organizations, both public and private, involved with CCB utilization and disposal. The study concluded that the real barriers to increased by-product utilization are complex and interrelated, including economic, environmental, attitudinal, and other factors that ultimately manifest themselves in institutional, legal, and regulatory impediments to increased utilization. The Executive Summary of the EERC report to DOE titled *Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors* is included as Appendix B to this report.

3.3 DOE 1994 Report to Congress

The information gained from the EERC study was used in DOE's preparation of the July 1994 Report to Congress, also titled *Barriers to the Increased Utilization of Coal Combustion/ Desulfurization By-Products by Government and Commercial Sectors*. The Executive Summary of the DOE RTC is included as Appendix A to this report.

The DOE RTC made a number of recommendations for action by the federal government. DOE FETC has implemented the recommendations by supporting research, development, and demonstration (RD&D) of CCB utilization technologies; by developing and providing information for federal, state, and local government agencies; and by working with industry to make CCBs from emerging conversion technologies more useful or readily disposable.

Industry has also responded to the recommendations in DOE's RTC through a variety of activities, including RD&D and commercialization efforts, standards and specification development, development and submission of CCB utilization information to government agencies and the public, and review of legal and regulatory issues.

3.3.1 Barriers Identified in DOE's RTC

The DOE RTC indicated that institutional, regulatory, and legal barriers are very much interrelated, but the report discussed these barriers separately. Institutional barriers are those that constrain or restrict the use of CCBs through requirements, standards, specifications, policies, procedures, and attitudes of various organizations and agencies that are involved in CCB use or disposal. Regulatory barriers are those caused by federal and state legislation affecting the beneficial use of CCBs. Legal barriers include these regulatory barriers together with contract, patent, and liability issues.

Eleven **institutional barriers** were identified as follows:

- Lack of familiarity with potential ash uses.
- Lack of data on environmental and health effects.
- Restrictive or prohibitive specifications.
- Belief that fly ash quality and quantity are not consistent.
- Lack of fly ash specifications for noncementitious applications, resulting in substitution in these applications of the more restrictive specifications for use of fly ash in cement and concrete.
- Belief that raw materials are more readily available and more cost-effective.
- Viewpoint of states that EPA procurement guidelines for fly ash in concrete are a rigid ceiling rather than general guidelines for use.
- Actions by environmental agencies that normally support beneficial ash uses in principle, but that frustrate the actual implementation by restrictive regulations.
- Restrictive regulation of fly ash as a solid waste in most states.
- Lack of state guidelines on beneficial ash use.

- Lack of clear federal direction on regulation of beneficial ash use.

Regulatory barriers result from the EPA RCRA designation of CCBs as solid wastes even when they are utilized rather than disposed of. In the absence of special state exemptions from solid waste regulations for beneficial use, the "waste" designation can trigger case-by-case approval and permitting procedures that discourage the use of CCBs because of cost and the time required to complete adjudicatory processes. The ineffectiveness of federal agencies to promulgate regulations and guidelines to overcome this barrier continues to hinder use of by-products.

Inconsistency in regulations for use of by-products among federal and state agencies results in a confusing patchwork of incentives and disincentives. This apparent uncertainty fosters overly conservative regulatory practices, often involving case-by-case review and approval. There is a need for widely accepted environmental criteria and tests that deal more realistically with environmental compliance for fairly broad classes of CCB applications.

Legal barriers are closely tied to regulatory barriers. Environmental liability becomes a strong deterrent to use of any by-product that is designated and regulated as a solid waste. CCB producers are concerned that they may be exposed to an overwhelming legal and financial liability for cleanup if the by-products are used and later found to cause environmental contamination. Other legal barriers identified include uncertainties in applying commercial and contract law to the sale of CCBs and confusion concerning how patent law applies to CCB applications.

Additional marketing and environmental compliance barriers were summarized in the RTC. Marketing barriers included the relatively low cost of disposal in the past, compositional variability, diverse markets, varying local demand, the high costs of storage and transportation, preferences for other materials, lack of information on CCBs on the part of potential users, and the designation of CCBs as wastes. Additional environmental barriers include ignorance on the part of regulators and the public with regard to acceptable environmental risk and a lack of appropriate environmental test protocols.

3.3.2 Summary of Recommendations Made in the RTC

DOE's recommendations focused primarily on actions for federal agencies. These included 1) development of affirmative procurement guidelines for CCBs; 2) development of information on advanced coal use process by-products that can be used by EPA in continuing RCRA determinations; 3) working with state and local agencies on RD&D and information transfer; 4) review, revision, or development of specifications and regulations on CCB utilization; 5) demonstration of high-volume CCB utilization applications; and 6) working to make new by-products more useful.

In developing the recommendations for action in this report, several criteria were used. These were as follows:

- Actions recommended should fall within budgetary and personnel resource constraints imposed by today's federal budget and manpower reduction initiatives.

- Recommended actions should attempt to maximize use of existing federal resources and cooperation among federal agencies.

- Any successful effort to promote the increased use of CCBs will require a cooperative effort of federal and state government agencies and the private sector, including industry, environmental interest groups, and private citizenry.

- Recommended actions should promote an environmentally protective and beneficial increase in CCB utilization.

State governments were encouraged to 1) follow the federal lead in specifications and standards in procuring products and services, 2) revise their regulatory standards based on EPA determinations for environmentally safe preapproved uses for CCBs, and 3) sponsor development of improved CCB utilization technology.

Private industries were encouraged to 1) respond to increased demand for CCBs with adequate by-product quality assurance programs, 2) become more involved in activities of standard-setting organizations, 3) provide quality information on by-product utilization to federal and state government organizations involved in developing new standards and specifications for by-product use, 4) use environmentally sound utilization technology, and 5) continue to support RD&D work on utilization of CCBs.

3.4 The EERC 1998 Report to DOE

While the DOE RTC called attention to the technical, economic, and environmental advantages of CCB utilization and the barriers to increasing CCB utilization, it is evident by the statistics and anecdotal information that the barriers still existed in 1998 despite the concerted efforts of DOE, the CCB industry, and other interested parties. It is for this reason DOE decided to review the barriers and recommendations of the RTC and to update the information on institutional, legal, and regulatory barriers. This review serves to document the progress made since 1993, reassess the status of barriers identified, identify any new barriers, and reevaluate priorities for reducing or removing barriers to the increased utilization of CCBs.

This report is designed to provide a tool for both government and industry to assess technical, economic, institutional, legal, and regulatory issues related to CCB utilization as the preferred CCB management option. It summarizes and updates information previously collected by DOE for the July 1994 RTC. DOE, other government agencies, industry, and research groups provided information critical to the preparation of this report. This update represents a scope and level of effort quite restricted compared to the original "Barriers" report prepared for DOE by the EERC, which has nevertheless made an effort to solicit input from a wide cross section of the CCB industry, government agencies, and related industries.

4.0 CHANGES SINCE 1993

The current status of barriers to the increased utilization of CCBs was reevaluated in less detail in 1998 than in the 1993 EERC study supporting DOE's RTC. Barriers identified in the 1993 RTC were reassessed relative to the actions taken by industry, DOE, and other government agencies. New data and statistics were reviewed in an effort to identify any new barriers. It is evident that industry and DOE have been active in addressing the barriers identified in 1993 and in responding to the recommendations in the RTC. Some other federal agencies have also responded to the recommendations. More states have addressed CCB utilization through laws, regulations, policies, and/or guidance.

Although informal input offered by industry and anecdotal information indicates that the efforts expended have resulted in reduction of some barriers, the reduction is difficult to quantify. Changes have occurred in 1) the wide variety of CCBs available, 2) use of CCBs and competing materials at different locations, 3) marketing by utilities and vendors, 4) technology options for utilization, and 5) regulations.

Government agencies and industry have taken significant action as a result of the DOE RTC, DOE-sponsored activities that facilitated the identification of barriers, and the development of recommendations made by DOE. DOE has responded through RD&D efforts in partnership with industry and has participated with other federal agencies, state agencies, and industry in exchange efforts to address key questions. DOE will continue to address CCB utilization through a consortium of government and industry partners to identify and perform high-priority CCB research with primary emphasis on emission control applications for CCBs.

Other federal agencies have also acted to reduce barriers to CCB utilization:

- EPA has continued to collect and evaluate information in preparation for a RCRA determination on the nonhazardous classification of additional CCBs beyond conventional coal fly ash, bottom ash, boiler slag, and FGD material.

- The U.S. Department of Agriculture has continued to develop and demonstrate agricultural uses for CCBs.

- The Federal Highway Administration continued to support research related to the utilization of recycled materials in road building.

- The U.S. Geological Survey prepared and distributed information on the production and characteristics of CCBs.

Industry has been active in RD&D efforts in cooperation with government agencies, in educational activities, in development of standards and specifications, and in working with federal, state, and local government agencies to remove barriers to CCB utilization. Key industry organizations involved in these efforts are the Utility Solid Waste Activities Group (USWAG), the ACAA, EPRI, Texas Coal Ash Utilization Group (TCAUG), and the Western Region Ash

Group (WRAG). In addition to the industry groups mentioned, numerous individual companies, including utilities, marketers, and CCB users, have been similarly active. University research groups have also contributed to both industry and government efforts. International exchanges of information and technology on CCB utilization continue through various avenues, with ACAA taking a lead role in developing relationships in Canada, Europe, and Japan.

While numerous efforts by government and industry can be cited that have addressed the barriers to CCB utilization identified by DOE, it is important to note that the impact of these efforts may be assessed differently by different groups. It is also important to note that some promotional efforts in the CCB industry have resulted in unsuccessful demonstrations, poorly planned commercial projects, poorly designed experiments, and inappropriately interpreted or presented information, which has damaged the industry and set back the concerted industry effort to promote the technically sound, environmentally safe, and economically viable utilization of CCBs.

4.1 Barriers Perceived as Unchanged

Some barriers that were identified previously appear not to have changed despite directed efforts. These are described below.

4.1.1 Legal Barriers

- CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) – The status of CCBs under CERCLA remains unchanged despite industry efforts. CCBs have not been excluded from CERCLA, and liability for environmental damage assessed at a site where CCBs are present still includes the generator of the CCB. Environmental liability is not fault-based, so the extensive data indicating that CCBs are not hazardous do not provide protection against CERCLA liability.

4.1.2 Institutional Barriers

- Education – As a result of continued technical changes in the CCB industry, the need to educate a wide variety of groups and individuals continues. These groups continue to include regulators, engineers, scientists and other professionals, and the public. The diversity of the industry, the CCBs and utilization applications, and the audience makes this a particularly challenging barrier to address. Another challenge to addressing this barrier is that there are continued reports (substantiated and not substantiated) of technical and environmental problems with the utilization of CCBs. These reports require regular efforts to provide factual and scientifically defensible information in order to defend against poor scientific/engineering information or the results of inappropriately applied CCBs.

- Changes in CCBs due to CAAA (Clean Air Act Amendments) – The most frequently cited change to the character of CCBs noted in the EERC study was the impact of NO_x control technologies on fly ash. The industry is now having to address that concern through implementation of fly ash beneficiation processes or disposal of some fly ash from sources that previously marketed the fly ash. The CCB industry is also currently seeing an increased amount of high-calcium by-products from advanced coal use technologies such as fluid-bed combustion, which is a response to the need for more energy production coupled with the CAAA. These are high-volume by-products requiring new technical information to facilitate responsible utilization. At the time of the DOE RTC, the CCB industry had not yet anticipated the potential impact on CCBs from regulations that might require control technologies for air toxics such as mercury. Technologies under development for mercury control will likely use a sorbent, which may impact CCB character. Considering this, it might be said that only the initial impact of the CAAA on CCBs has been felt, and it may actually become more severe as regulations tighten.

4.2 Summary of Reduction of Barriers

Interpretation of the information presented in this report leads to the conclusion that some previously identified barriers have been reduced, although perception as to the level of reduction likely varies widely within the CCB industry.

4.2.1 Regulatory Barriers

- Federal and state regulation – The EPA *Final Regulatory Determination of Four Large-Volume Wastes from the Combustion of Coal by Electric Utility Power Plants* (*Federal Register; Code of Federal Regulations*, Part 261, Title 40) stating that fly ash, bottom ash, boiler slag, and FGD emission control waste are nonhazardous industrial wastes and should therefore be regulated under Subtitle D of RCRA was a positive step toward reducing the regulatory barriers and reducing the concerns of users and the public that these materials must be hazardous. The RCRA determination encouraged the use of CCBs and supported the issuance of several EPA procurement guidelines indicating preference for products containing CCBs. It is important to note that industry worked hard to provide information for both of these EPA actions and that industry is continuing to work to take advantage of the procurement guidelines. It was stated in the 1993 EERC report that industry perceived a lack of federal guidance on the use of CCBs because of the interim status of CCBs under RCRA Subtitle D prior to the final determination. The final determination provided the federal guidance needed to allow states to reassess CCB regulation. Industry also played a role by working with individual state regulatory agencies.

4.2.2 Institutional Barriers

- Environmental and public perception – The need to reduce CO_2 emissions because of potential global warming has provided an opportunity for the CCB industry to promote the use of fly ash in concrete as an environmental benefit. Utilities have taken credit for their sales of fly ash to the concrete market as part of their contribution to a voluntary program to reduce greenhouse gases. When fly ash is used as part of a concrete mix, the cement content can be reduced. Since cement kilns emit CO_2, it can be shown that reducing the demand for cement by using fly ash reduces overall CO_2 emissions. Since about 90 million tons of CCBs and about 80 million tons of portland cement are produced annually, it may be possible for the use of fly ash in concrete to substantially reduce CO_2 emissions from cement kilns. In order for this to occur, the cement and CCB industries, which historically have seen each other as competitors, are going to need to work together. As a result of changes in both industries, there has been some movement toward cooperative efforts, but this area will need to continue to evolve.

- Economic – The perception that cost avoidance is the only economic advantage to CCB utilization probably remains intact at some utilities. However, the move toward utility deregulation has resulted in a more detailed review of the economics of CCB marketing on the part of some utilities. The results seem to indicate that utilities, at least those active in trade associations, perceive an economic advantage in selecting CCB utilization as a preferred management option. Certainly, the permitting difficulties and cost of new disposal sites have not diminished since the 1994 RTC, and these issues are economic drivers for utilities to increase CCB sales.

- Economic – While not a result of any efforts related to the RTC, cement shortages in various parts of the United States have had a significant impact on the demand for fly ash. These shortages and other factors may increase the future price of admixture-grade fly ash. Other factors include 1) several buyouts and mergers that have formed a smaller number of CCB marketing companies, some of which are also cement manufacturers, and 2) the potential for a reduction in the availability of admixture-grade fly ash due to implementation of NO_x control technology. These factors have not yet been reflected in an increase in the price of fly ash. However, if the price for fly ash does increase, it can only have a positive effect on the economics of CCB utilization. It has been suggested that a higher price would help to alleviate the common misperception that fly ash is used in concrete simply to lower the cost.

- Technical – Industry has worked diligently to develop new standards for key CCB utilization applications and to update current standards. Although the standard development process is a slow one by design, several standards have been completed and more are in process. These standards will be used by end users and specifiers to provide assurance that materials and procedures will result in a successful project. The CCB industry needs standards to be able to guarantee suitable materials and predict performance. Working toward the development of performance standards for CCBs in new utilization applications remains a high priority for the industry.

4.3 New Barriers

4.3.1 Institutional and Technical Barriers

- Climate change – The issue of global climate change and the need to reduce greenhouse gas emissions has the potential to impact coal-fired utilities. It is anticipated that coal-fired power plants may be required to substantially reduce CO_2 emissions. One approach is to incorporate biomass as a portion of the fuel. The ashes produced by cofiring biomass will need to be characterized and their performance in utilization applications evaluated. This is an unmet need at this time and can likely be best addressed through cooperation between industry and DOE.

- Opportunity fund – As utilities move toward a more competitive industry, adjustments have been made in fuel selection. Utilities are less likely to enter into long-term coal contracts and are more likely to purchase coal on the spot market and to incorporate alternate fuels such as petroleum coke, biomass, tires, and other wastes. These decisions can have an impact on the CCBs produced and on their performance in utilization applications. This issue requires the industry and DOE to cooperate in evaluating the impact of the inclusion of alternate fuels on CCB quality and in the development of performance-based standards in place of specifications based on fuel source.

4.3.2 Regulatory Barriers

- NORM (naturally occurring radioactive materials) – The issue of NORM in CCBs has recently become high priority and is both a new regulatory and new institutional barrier. It is a regulatory barrier because EPA includes CCBs in a list of eight industrial materials that contain NORM and require some assessment. To date, EPA's assessment of NORM in CCBs has incorporated faulty assumptions in calculating risks related to NORM exposure. Currently, EPA is reviewing comments to a draft report it released for comment. The final report will provide an indication of the potential risk for humans exposed to the NORM in CCBs, which will likely impact state regulation of CCB management. This issue is also an institutional barrier because of the potential negative impact to the perception of CCBs by users and the public. The level of response that may be needed to address this barrier remains an unknown, but it can best be addressed jointly by industry and government.

- Toxic release inventory (TRI) – TRI reporting was changed to include utilities in 1998. There are two primary issues: 1) utilized CCBs are excluded from TRI reporting because they are not considered a "release," and 2) utility TRI reports will be included with other industry TRI reports on a publicly accessible Internet site, which has been speculated to cause a level of concern on the part of groups or individuals who have limited technical background. The impact on CCB utilization is unknown, but needs to be followed.

4.4 Next Steps

Industry and government have worked constructively together, but it is apparent that in the short time since the RTC, the progress toward reduction/removal of barriers to the increased utilization of CCBs has been limited. It is important that the cooperation between industry and DOE continue, and DOE has initiated an effort to accomplish that. The DOE Emission Control By-Products Consortium will provide a framework for industry, DOE, and other government agencies to improve cooperation and communication. Using the infrastructure of the consortium, identified barriers, recommendations, and actions can be prioritized, and RD&D efforts can be directed to meet identified priorities. The consortium is expected to address primarily technical issues, which are the basis for many of the barriers identified. With input and cooperation from industry, the consortium has the potential to speed the process of barrier reduction.

Industry should continue to take advantage of regulatory policies and guidelines that encourage CCB utilization, including federal procurement guidelines. Industry must continue its efforts to obtain fair legislation and regulation that defines the status of CCBs within sound technical and environmental guidelines to reduce uncertainty and further encourage utilization.

5.0 CONCLUSIONS

The following conclusions are drawn from the information presented in this report:

- Joint efforts by industry and government focused on meeting RTC recommendations for reduction/removal of barriers have met with some success. The most notable of these are the changes in regulations related to CCB utilization by individual states. Regionally or nationally consistent state regulation of CCB utilization would further reduce regulatory barriers.

- Technology changes will continue to be driven by the CAAA, and emission control technologies are expected to continue to impact the type and properties of CCBs generated. As a result, continued RD&D will be needed to learn how to use new and changing CCBs in environmentally safe, technically sound, and economically advantageous ways. Clean coal technology CCBs offer a new challenge because of the high volumes expected to be generated and the different characteristics of these CCBs as compared to conventional CCBs.

- Industry and government have developed the RD&D infrastructure to address the technical aspects of developing and testing new CCB utilization applications, but this work, as well as constant quality control/quality assurance testing, needs to be continued to address both industry-wide issues and issues related to specific materials, regions, or users.

- Concerns raised by environmental groups and the public will continue to provide environmental and technical challenges to the CCB industry. It is anticipated that the use of CCBs in mining applications, agriculture, structural fills, and other land applications will continue to be controversial and will require case-by-case technical and environmental information to be developed. The best use of this information will be in the development of generic regulations specifically addressing the use of CCBs in these different types of CCB applications.

- The development of federal procurement guidelines under Executive Order 12873 titled “Federal Acquisition, Recycling and Waste Prevention,” in October 1993 was a positive step toward getting CCBs accepted in the marketplace. Industry needs to continue to work with EPA to develop additional procurement guidelines for products containing CCBs and to take advantage of existing guidelines to encourage the use of CCBs in high-profile projects.

- Accelerated progress toward increased utilization of CCBs can be made only if there is an increased financial commitment and technical effort by industry and government. The framework for this has been set by the successful cooperation of industry and government under DOE leadership. Cooperation should continue, with DOE fulfilling its lead role established in the RTC. It is clear that the RTC recommendations continue to have validity with respect to increasing CCB utilization, and they continue to provide guidance to industry and government agencies.

BARRIERS TO THE INCREASED UTILIZATION OF COAL COMBUSTION/DESULFURIZATION BY-PRODUCTS BY GOVERNMENT AND COMMERCIAL SECTORS – UPDATE 1998

1.0 INTRODUCTION

Coal plays a vital part in energy production in the United States, and both conventional and advanced coal conversion technologies result in the generation of solid by-products. The U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC) has in recent years taken the lead role in research and development on management of coal combustion/desulfurization by-products (CCBs). DOE has determined that the management of these by-products needs to be addressed more effectively from both technical and economic standpoints. This report is designed to provide a tool for both government and industry to assess technical, economic, institutional, legal, and regulatory issues related to CCB utilization as the preferred CCB management option. It summarizes and updates information previously collected by DOE for a July 1994 Report to Congress (RTC) titled *Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors*. The Executive Summary of the DOE RTC is included in Appendix A.

The July 1994 DOE RTC was submitted in response to direction in the Energy Policy Act of 1992, where the United States Congress charged the Secretary of Energy to "conduct a detailed and comprehensive survey on the institutional, legal, and regulatory barriers to increased utilization of CCBs by potential governmental and commercial users." Section 1334 of the Energy Policy Act of 1992 designated that:

> At a minimum, such report shall identify actions that would increase the utilization of coal combustion by-products in A) bridge and highway construction; B) stabilizing wastes; C) procurement by departments and agencies of the Federal Government and State and local governments; and D) federally funded or federally subsidized procurements by the private sector.

The language used in the Energy Policy Act underlined Congressional awareness of under-utilization of CCBs in the United States. Then, as now, utilization of these materials was well below their potential. The concern Congress indicated by including this issue in the Energy Policy Act of 1992 conveyed a directive to government and industry to take steps to proceed with the beneficial use of these materials in the interest of the U.S. economy and environment.

To meet the directive by Congress of identifying barriers and recommendations for increased usage of CCBs, DOE FETC contracted with the Energy & Environmental Research Center (EERC) to conduct a study to assess barriers to the utilization of CCBs. The EERC study completed in October 1993 was based on data obtained from a large number of organizations, both public and private, that were involved with CCB utilization and disposal. The study concluded that the real barriers to increased by-product utilization are complex and interrelated, including economic, environmental, attitudinal, and other factors that ultimately manifest themselves in institutional, legal, and regulatory impediments to increased utilization. The information gained from the EERC study was used in DOE's preparation of the RTC on barriers; however, the full EERC report was not made publicly available at that time. The Executive Summary of the EERC report to DOE titled *Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors* is included in Appendix B of this report to provide a benchmark for the barriers identified during that effort in 1993.

The DOE RTC made seven recommendations for actions by the federal government as summarized in the Executive Summary in Appendix A. Five of these recommendations called for specific actions by DOE, and three requested that DOE work with other federal, state, and/or local government agencies to implement the recommendations. DOE FETC has done this by supporting research, development, and demonstration (RD&D) of CCB utilization technologies; by developing and providing information for federal, state and local government agencies; and by working with industry to make CCBs from emerging conversion technologies more useful or readily disposable.

Industry has also responded to the recommendations in DOE's RTC through a variety of activities, including 1) RD&D and commercialization efforts, 2) standards and specification development, 3) development and submission of CCB utilization information to government agencies and the public, and 4) review of legal and regulatory issues.

This report provides an update on the success of government and industry activities directed toward removal of the barriers to CCB utilization. DOE provided support for the review, and DOE, other government agencies, industry, and research groups have provided information critical to its preparation. The scope and level of effort of this update are quite restricted compared to the original "Barriers" report prepared for DOE by the EERC. However, within this constraint, the EERC has made an effort to solicit input from a wide cross section of the CCB industry, government agencies, and related industries.

1.1 DOE's 1994 Report to Congress – Background

The nearly 90 million tons of CCBs produced annually in the United States is a valuable national resource that is vastly underutilized. Current use of about 30% of the coal ash and only 7%–9% of the flue gas desulfurization products represents a failed opportunity compared to the nearly complete utilization already achieved in some western European countries. Future opportunities can be seized by concerted action to offer substantial benefits to the nation's electric generation, construction, and manufacturing industries; to agriculture; and to the environment, whereas failure to act will create, literally, mountains of solid waste, an unnecessary legacy of future energy production.

The value of CCBs is well established by research and commercial practice both in the United States and abroad. As engineering construction materials, these products can add value and enhance strength and durability while reducing cost. In agricultural applications, gypsum-rich products can provide plant nutrients and improve the tilth of depleted soils over large areas of the country. In waste stabilization, the cementitious and pozzolanic properties of these products can immobilize hazardous nuclear, organic, and toxic metal wastes for safe and effective environmental disposal. Public benefits of CCB utilization are substantial, including conservation of land, energy, and natural resources; reduction in CO_2 emissions generated in the production of competing materials; improvements in the balance of trade (e.g., fewer cement imports); and prevention of solid waste pollution. Increasing cost and heightened regulation are making the disposal of CCBs an undesirable option.

1.2 Barriers Identified in the DOE RTC

The DOE RTC indicated that institutional, regulatory, and legal barriers are very much interrelated, but the report discussed these barriers separately. Institutional barriers are those that constrain or restrict the use of CCBs through requirements, standards, specifications, policies, procedures, and attitudes of various organizations and agencies that are involved in CCB use or disposal. Regulatory barriers are those caused by federal and state legislation affecting the beneficial use of CCBs. Legal barriers include these regulatory barriers together with contract, patent, and liability issues.

Eleven institutional barriers were identified as follows:

- Lack of familiarity with potential ash uses.
- Lack of data on environmental and health effects.
- Restrictive or prohibitive specifications.
- Belief that fly ash quality and quantity are not consistent.
- Lack of fly ash specifications for noncementitious applications, which results in application of the more restrictive specifications for use of fly ash in cement and concrete.
- Belief that raw materials are more readily available and more cost-effective.
- Viewpoint of states that U.S. Environmental Protection Agency (EPA) procurement guidelines for fly ash in concrete are a rigid ceiling rather than general guidelines for use.
- Actions by environmental agencies that normally support beneficial ash uses in principle, but that frustrate the actual implementation by restrictive regulations.
- Restrictive regulation of fly ash as a solid waste in most states.
- Lack of state guidelines on beneficial ash use.
- Lack of clear federal direction on regulation of beneficial ash use.

Regulatory barriers result from the EPA Resource Conservation and Recovery Act (RCRA) designation of CCBs as solid wastes even when they are utilized rather than disposed of. In the absence of special state exemptions from solid waste regulations for beneficial use, the "waste" designation can trigger case-by-case approval and permitting procedures that discourage the use of CCBs because of cost and the time required to complete adjudicatory processes. The ineffectiveness of federal agencies to promulgate regulations and guidelines to overcome this barrier continues to hinder use of by-products.

Inconsistency in regulations for use of by-products among federal and state agencies results in a confusing patchwork of incentives and disincentives. The implication of uncertainty fosters overly conservative regulatory practices, often involving case-by-case review and approval. There is a need for widely accepted environmental criteria and tests that deal more realistically with environmental compliance for fairly broad classes of CCB applications.

Legal barriers are closely tied to regulatory barriers. Environmental liability becomes a strong deterrent for use of any by-product that is designated and regulated as a solid waste. CCB producers are concerned that they may be exposed to a large legal and financial liability for cleanup if the by-products are used and later found to cause environmental contamination. Other legal barriers identified include uncertainties in applying commercial and contract law to the sale of CCBs and confusion concerning how patent law applies to CCB applications.

Additional barriers in marketing and environmental compliance were summarized in the RTC. Marketing barriers include the relatively low cost of disposal in the past, compositional variability, diverse markets, varying local demand, the high costs of storage and transportation, preferences for materials, lack of information on CCBs on the part of potential users, and the designation of CCBs as wastes. Environmental barriers include the application of disposal regulations to the utilization of CCBs, lack of knowledge and acceptance by regulators and the public on acceptable environmental risk, and a lack of appropriate environmental test protocols.

1.3 Summary of Recommendations Made in the RTC

DOE's recommendations focused primarily on actions for federal agencies (see Appendix A). The seven recommendations for federal agencies included 1) development of affirmative procurement guidelines for CCBs; 2) development of information on advanced coal use process by-products that can be used by EPA in continuing RCRA determinations; 3) work with state and local agencies on RD&D; 4) work with state and local agencies on information transfer; 5) review, revision, or development of specifications and regulations on CCB utilization; 6) demonstration of high-volume CCB utilization applications; and 7) work to make new by-products more useful.

State governments were encouraged to 1) follow the federal lead in specifications and standards in procuring products and services, 2) revise their regulatory standards based on EPA determinations for environmentally safe preapproved uses for CCBs, and 3) sponsor development of improved CCB utilization technology.

Private industries were encouraged to 1) respond to increased demand for CCBs with adequate by-product quality assurance programs, 2) become more involved in activities of standard-setting organizations, 3) provide quality information on by-product utilization to federal and state government organizations involved in developing new standards and specifications for by-product use, 4) practice environmentally sound utilization technology, and 5) continue to support research and development work on utilization of CCBs.

1.4 Summary of Government and Industry Responses to the 1994 RTC

Government agencies and industry have taken significant action as a result of the DOE RTC, DOE-sponsored activities that facilitated the identification of barriers, and the development of recommendations made by DOE. DOE has responded through RD&D efforts, both in-house and in partnerships with industry, and has participated with other federal agencies, state agencies, and industry in exchange efforts directed toward key questions. The details of DOE's efforts are described in following sections of this report. In addition, DOE will continue to address CCB utilization through a consortium of government and industry partners to identify and perform high-priority CCB research with primary emphasis on emission control applications for CCB by-products (Aljoe and Black, 1998).

Other federal agencies have also performed activities that have served to reduce barriers to CCB utilization:

- EPA continued to collect and evaluate information in preparation for a RCRA determination on the nonhazardous classification of additional CCBs beyond conventional coal fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material.

- The U.S. Department of Agriculture (USDA) continued to develop and demonstrate agricultural uses for CCBs.

- The Federal Highway Administration (FHWA) continued to support research related to the utilization of recycled materials in road building.

- The U.S. Geological Survey (USGS) prepared and distributed information on production and characteristics of CCBs.

Industry has been active in RD&D efforts in cooperation with government agencies, in educational activities, in development of standards and specifications, and in working with federal, state, and local government agencies to remove barriers to CCB utilization. Key industry organizations involved in these efforts are the Utility Solid Waste Activities Group (USWAG), the American Coal Ash Association (ACAA), EPRI, Texas Coal Ash Utilization Group (TCAUG), and the Western Region Ash Group (WRAG). The activities of these organizations detailed in following sections of the report focused on technical, regulatory, and legal issues. In addition to the industry groups mentioned, numerous individual companies, including utilities, marketers, and CCB users, have been active in similar activities. Many university research groups have also contributed to both industry and government efforts.

International exchanges of information and technology on CCB utilization also continue through various avenues, with ACAA taking a lead role in developing international relationships in Canada, Europe, and Japan.

While numerous efforts by government and industry can be cited that have addressed the barriers to CCB utilization identified by DOE, it is important to note that the impact of these efforts may be assessed differently by different groups. It is also important to note that some promotional efforts in the CCB industry have resulted in historically unsuccessful demonstrations, poorly planned commercial projects, poorly designed experiments, and inappropriately interpreted or presented information that have damaged the industry and set back the concerted industry effort to promote the technically sound, environmentally safe, and economically feasible utilization of CCBs.

2.0 BACKGROUND

2.1 U.S. Energy Production from Coal

U.S. coal production totaled a record high of 1088.6 million short tons in 1997 according to preliminary data from the Energy Information Administration (EIA) (Figure 1). Utilities and

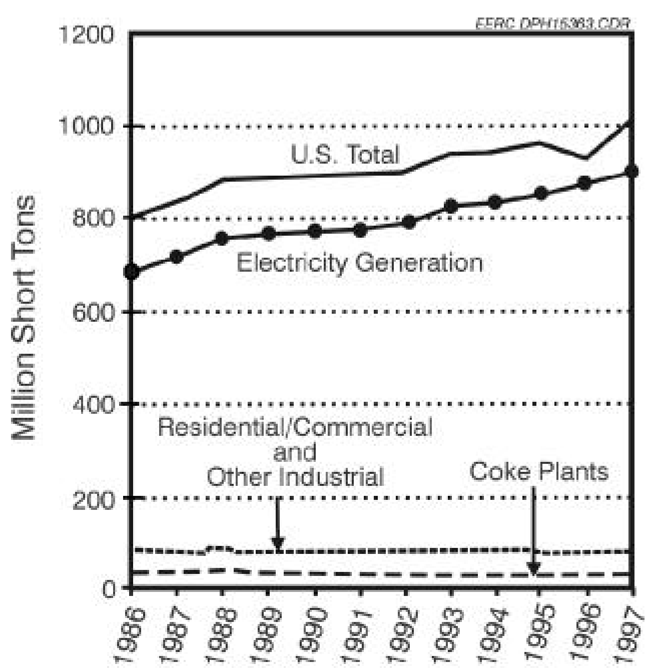

Figure 1. U.S. coal production (Hong, 1998).

industry (independent power producers) continue to be the dominant coal consumers and used a record 922.0 million short tons in 1997 as a result of a substantial decline in nuclear-powered generation and moderate growth in electricity demand. Coal consumption in the nonelectricity sectors (residential/commercial and industrial users) fell by 2.6 % to 105.8 million short tons in 1997.

Western coal output continued its growth in 1997, but coal production in Appalachia also rose significantly, at the same rate of 2.8 % as for western coal. Coal output in the interior region was virtually unchanged. The rising demand for western low-sulfur coal for electricity generation, driven by its low cost and the sulfur emissions reduction requirements of the 1990 Clean Air Act Amendments (CAAA), continued to boost coal production in the western region.

U.S. coal consumption by all users in 1997 showed a 2.2% increase over 1996 (Figure 2). Growth came entirely from the electric power industry, as coal consumption in the nonelectricity sectors decreased. Coal continued to be the principal energy source for electric power generation in the United States, accounting for 52% of total generation in 1996 (Hong, 1998). Coal consumption in the nonelectricity sectors (coke plants, other industrial plants, and residential/commercial users) totaled 105.8 million short tons in 1997, down by 2.6 % from the 1996 level of 108.7 million short tons.

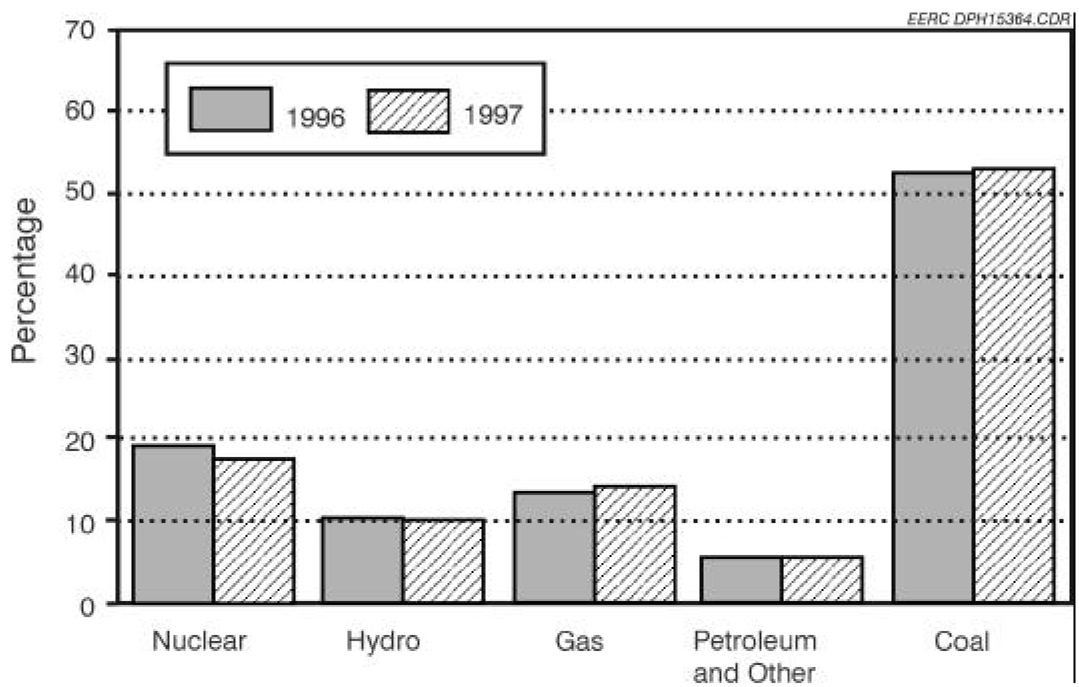

Figure 2. U.S. coal consumption 1996 and 1997 (Hong, 1998).

As indicated by the figures in Table 1, it is forecast that the United States will continue to rely heavily on coal for energy production at least through 2020. It is further forecast that future coal consumption will be primarily in existing power generation facilities or in facilities that

TABLE 1

Forecast of Energy Production and Consumption for Year 2020

Sensitivity Factors	1995	1996	Low Economic Growth	High Economic Growth	Low World Oil Price	High World Oil Price
Primary Production (quadrillion Btu)						
Petroleum	16.26	16.17	13.13	14.28	11.47	16.03
Natural Gas	19.12	19.55	25.65	30.12	27.28	28.62
Coal	21.98	22.64	26.10	31.28	28.68	28.64
Nuclear Power	7.19	7.20	4.09	4.09	4.09	4.09
Renewable Energy	6.40	6.91	7.28	8.45	7.68	7.74
Other	1.36	1.33	0.46	0.51	0.46	0.48
Total Primary Production	72.31	73.80	76.71	88.73	79.66	85.60
Consumption (quadrillion Btu)						
Petroleum Products	37.74	36.01	42.65	52.31	50.02	46.12
Natural Gas	22.18	22.60	30.19	35.43	32.00	33.69
Coal	19.96	20.90	23.08	28.34	25.71	25.67
Nuclear Power	7.19	7.20	4.09	4.09	4.09	4.09
Renewable Energy	6.40	6.91	7.31	8.48	7.72	7.77
Other	0.39	0.39	0.42	0.45	0.44	0.42
Total Consumption	90.86	94.01	107.74	129.10	119.98	117.75

utilize clean coal technologies (CCTs) such as fluidized-bed combustion (FBC) and gasification. The CCT processes have been designed to meet ever-tightening emission control standards set by EPA and state agencies, but it is important to note that any use of coal in future energy production will continue to result in the generation of solid materials. These solids, referred to as wastes or by-products, vary with the type of coal used, the conversion system, the emission controls applied to the system, the solid collection system, and specific operating conditions.

The type of coal or **coal rank** indicates the degree of coalification that has occurred for a particular coal. Coal is formed by the decomposition of plant matter without free access to air and under the influence of moisture, pressure, and temperature. Over the course of the geologic process that forms coal, coalification, the chemical composition of the coal gradually changes to compounds of lower hydrogen content and higher carbon content in aromatic ring structures. With an increase in degree of coalification, the percentage of volatile matter decreases and the calorific value increases. The common ranks of coal in the United States are anthracite, bituminous, subbituminous, and brown coal/lignite. Anthracite is the highest-ranked coal in the series, exhibiting the lowest volatile matter and higher calorific value, while lignite is the lowest-ranked coal in the series, with significantly greater volatile matter and lower calorific value. Table 2 indicates the coal ranks (classes) as the American Society for Testing and Materials (ASTM) lists them in D 388. Figure 3 shows the geographic location of U.S. coal fields and the associated coal rank. Table 3 summarizes typical proximate and ultimate analysis results. It is also generally true that the higher-ranked coals have a lower-percentage ash content and the lower-ranked coals have increasing percentages of ash, with the notable exception in certain Powder River Basin (Montana and Wyoming) subbituminous coals, which yield a very low ash percentage.

All coal contains minerals. These minerals are composed of inorganic constituents and can be present as included minerals, which are inherent in the coal particles, or as excluded minerals, which are separate from the coal substance. Excluded minerals may be dispersed in the coal or may be present simply because of the inadvertent mining of adjacent mineral strata by procedures used to extract the coal. Figure 4 gives a graphical representation of included and excluded minerals. This inorganic material becomes the ash or CCB following combustion or conversion.

Combustion and conversion systems can generally be categorized into the following two groups: 1) current commercial technologies and 2) emerging technologies. The CCBs being produced and utilized primarily result from current commercial technologies, and of these the most common are pc (pulverized coal) combustion, cyclone firing, and stoker firing. FBC is also a current commercial technology. The emerging technologies are discussed later in this document.

Emission control systems currently widely used to control sulfur dioxide emissions are referred to as FGD controls. These systems usually remove the SO_2 gases through use of a sorbent (frequently lime or limestone) and generally are one of three basic types: 1) wet scrubber, 2) dry scrubber, or 3) sorbent injection. The by-products of these FGD systems are usually a calcium sulfite or sulfate. Fly ash may be used as part of the scrubbing medium, and in these cases, fly ash is a component of the FGD by-product.

TABLE 2

ASTM D 388-84 Classification of Coals by Rank[a]

Class	Group	Fixed Carbon Limits, % (dry, mineral matter-free basis): Equal to or Greater Than	Fixed Carbon Limits, % (dry, mineral matter-free basis): Less Than	Volatile Matter Limits, % (dry, mineral matter-free basis): Greater Than	Volatile Matter Limits, % (dry, mineral matter-free basis): Equal to or Less Than	Calorific Value Limits, Btu per pound (moist,[b] mineral matter-free basis): Equal to or Greater Than	Calorific Value Limits, Btu per pound (moist,[b] mineral matter-free basis): Less Than	Agglomerating Character
I. Anthracitic	1. Meta-anthracite	98	–	–	2	[d]	–	Nonagglomerating
	2. Anthracite	92	98	2	8	[d]	–	Nonagglomerating
	3. Semianthracite[c]	86	92	8	14	[d]	–	Nonagglomerating
II. Bituminous	1. Low-volatile bituminous coal	78	86	14	22	[d]	–	Commonly agglomerating[e]
	2. Medium-volatile bituminous coal	69	78	22	31	[d]	–	Commonly agglomerating
	3. High-volatile A bituminous coal	–	69	31	–	14,000[d]	–	Commonly agglomerating
	4. High-volatile B bituminous coal	–	–	–	–	13,000[d]	14,000	Commonly agglomerating
		–	–	–	–	11,500	13,000	Commonly agglomerating
	5. High-volatile C bituminous coal	–	–	–	–	11,500	13,000	Agglomerating
III. Subbituminous	1. Subbituminous A coal	–	–	–	–	10,500	11,500	Nonagglomerating
	2. Subbituminous B coal	–	–	–	–	9500	10,500	Nonagglomerating
	3. Subbituminous C coal	–	–	–	–	8300	9500	Nonagglomerating
IV. Lignitic	1. Lignite A	–	–	–	–	6300	8300	Nonagglomerating
	2. Lignite B	–	–	–	–	–	6300	Nonagglomerating

[a] This classification is applicable to coals that are composed mainly of vitrite. Certain coals, principally nonbanded varieties, rich in inertinite or exinite do not fit into the classification.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class and that there are notable exceptions in high-volatile C bituminous group.

1 Btu/lb = 2326 J/kg

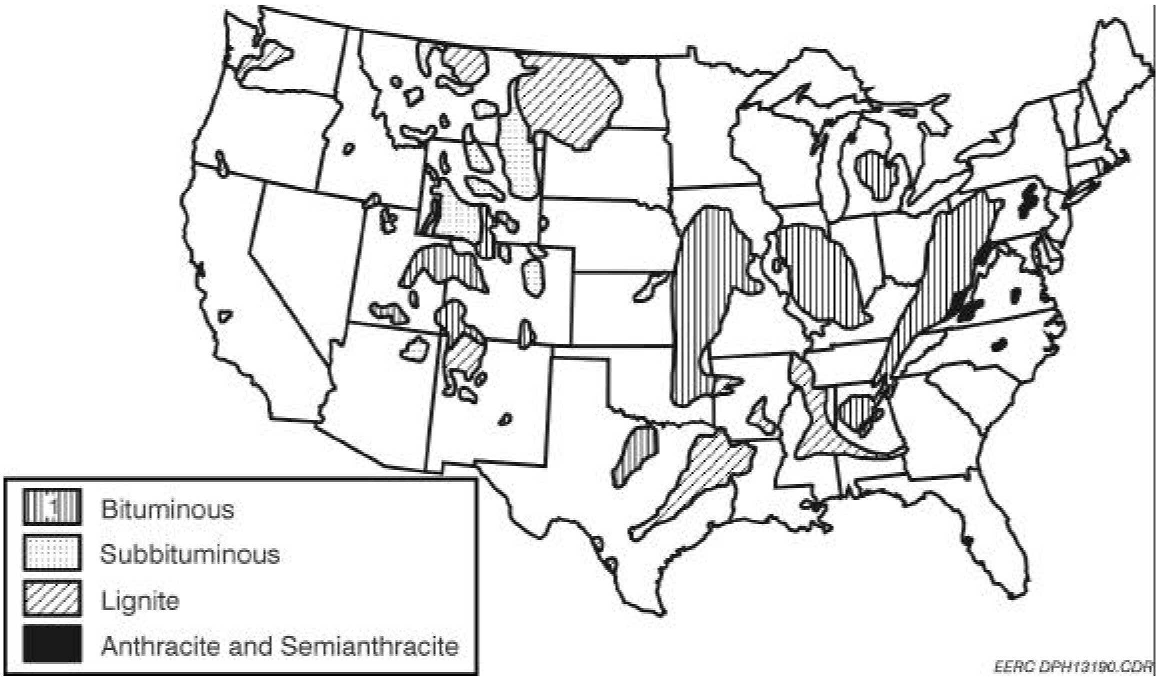

Figure 3. Map of U.S. coal fields.

TABLE 3

Results of Proximate and Ultimate Analyses
for Some Specific Examples of Differently Ranked Coals

Coal Rank:	North Dakota Lignite	Montana Subbituminous	Utah Bituminous[a]
Proximate (as received), wt%			
Moisture	26.8–34.4	20.00	2.5–2.7
Ash	7.37–14.6	7.56	9.2–9.5
Volatiles	29.6–32.4	35.10	44.1–45.5
Fixed Carbon	25.9–32.5	37.34	42.6–44.2
Heating Value, Btu/lb	6907–7810	9414	Unavailable
Ultimate (as received), wt%			
Hydrogen	2.7–3.1	4.31	5.5–5.6
Carbon	39.7–45.8	54.29	69.8–71.5
Nitrogen	0.56–0.70	0.89	1.4–1.5
Sulfur	0.69–1.53	0.57	0.4–0.7
Oxygen (calculated)	10.8–14.7	12.38	11.2–13.2
Ash	7.3–14.6	7.56	9.2–9.5

[a] From Helmuth, 1987.

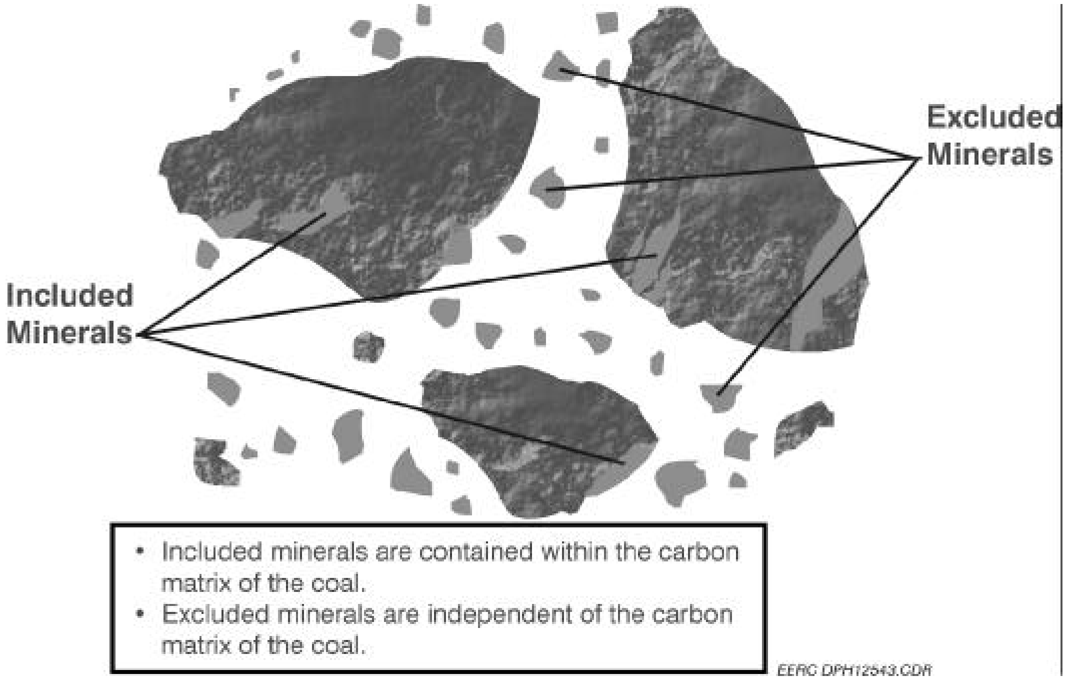

Figure 4. Included and excluded minerals in coal.

Additional controls are either already in use or planned for NO_x emissions, typically using one of two methods, both of which have an impact on the by-product produced. These are low-NO_x burners (LNB) and ammonia injection for selective catalytic reduction (SCR). LNB provide a more reducing combustion atmosphere and typically allow a higher percentage of carbon carryover to the fly ash. Some of the ammonia injected as an emission control remains in the fly ash until the fly ash is subjected to moisture at an alkaline pH (as would be the situation when the fly ash is used as a cement admixture). Ammonia gas is then released, making the fly ash from this process a less desirable product.

Solid or **by-product collection** and handling can impact the CCB produced from several standpoints, including whether the material is collected wet or dry or whether by-product streams are mixed in the handling system, thus potentially limiting by-product usefulness. There are two primary types of collection systems generally used to collect fly ash. These are fabric filters, also commonly referred to as baghouses, and electrostatic precipitators (ESPs). Both of these systems have high collection efficiencies. A baghouse collects the total range of particle sizes, while an ESP collects the fly ash in a series of hoppers, which can result in differing particle-size and chemical composition, depending on the distance of the hopper from the combustor. The ESP ash may also be collected as a composite.

Operating conditions for any single unit can vary over the course of a day and over longer periods based on many variables. Some of these variables include the boiler load (reflecting the percentage of rated capacity at which the unit is operating), coal quality variations, and firing conditions. Firing conditions, such as the amount of excess oxygen, the burner settings, flue gas recirculation, and sootblowing schedule can also be varied, resulting in changes to the ash formation process. Equipment wear and malfunction may also affect the ash produced. One significant example of equipment malfunction occurs when the coal mills used to pulverize the coal in a pc-fired unit are not performing to specification, resulting in coarser feed coal, reduced combustion efficiency, and greater amounts of unburned carbon in the ash.

2.2 U.S. Utility Industry – Coal Use Technologies

Table 1 is consistent with the illustration of the evolution of the coal-fired power systems published by Douglas (1990) (Figure 5). A time line for advanced coal use technologies is shown in Table 4. Relative efficiencies of conventional and advanced technologies are shown in Figure 6.

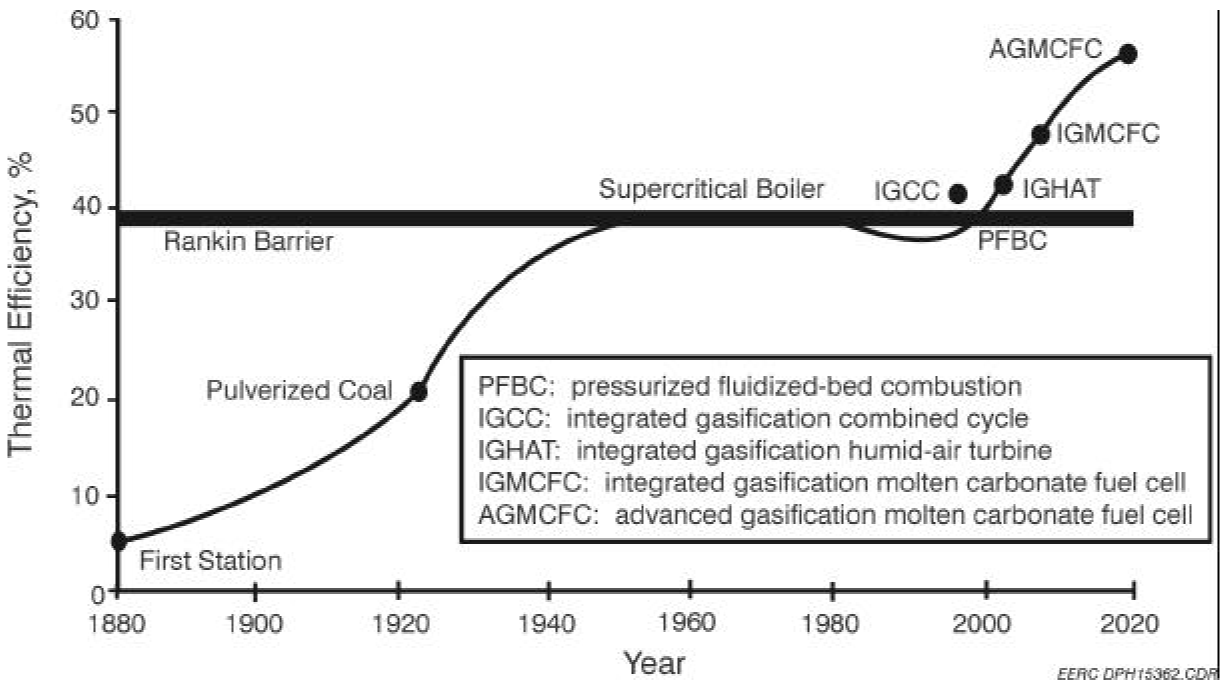

Figure 5. Evolution of the coal-fired power plant (Douglas, 1990).

2.2.1 Conventional Combustion Systems

The most common utility combustion systems in place in the United States today are pc combustion, cyclone firing, and stoker firing, with pc-fired units outnumbering the cyclone and stoker units.

TABLE 4

Time Line for Advanced Technology Demonstrations (EIA, 1998)

Year:	2000	2005	2010	2015
Technology	PFBC IGCC	Advanced IGCC	Fuel cells	Advanced fuel cells
Efficiency	42%	47%	55%	60%
Emissions	1/3 NSPS[a]	1/4 NSPS	1/10 NSPS	1/10 NSPS
CO_2 Reductions	24%	32%	42%	47%
Cost of Energy	10%–22% lower			

[a] New Source Performance Standards.

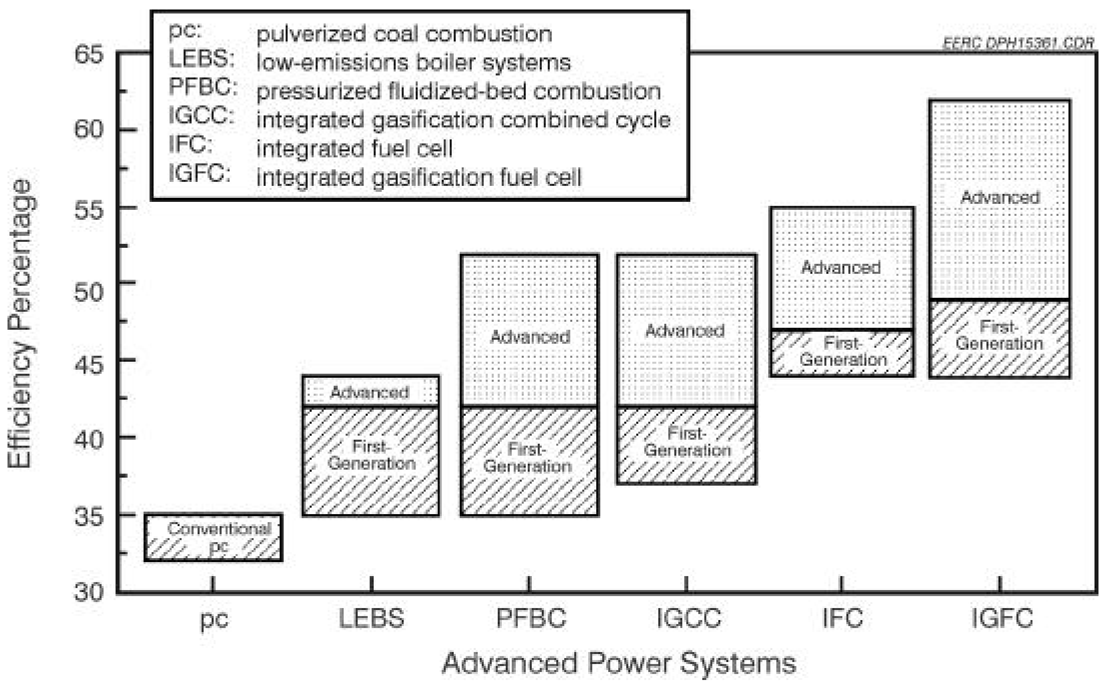

Figure 6. Comparison of efficiencies of conventional and advanced coal use technologies.

Figure 7 shows a simple schematic diagram for a typical pc combustion system. In this type of combustion system, the coal is prepared by grinding to a very fine consistency for combustion. Typically, 70% of the coal is ground to pass through a 200-mesh per unit screen. There are several configurations for commonly used pc furnaces, which can impact ash formation, but the primary advantage of pc combustion is the very fine nature of the fly ash

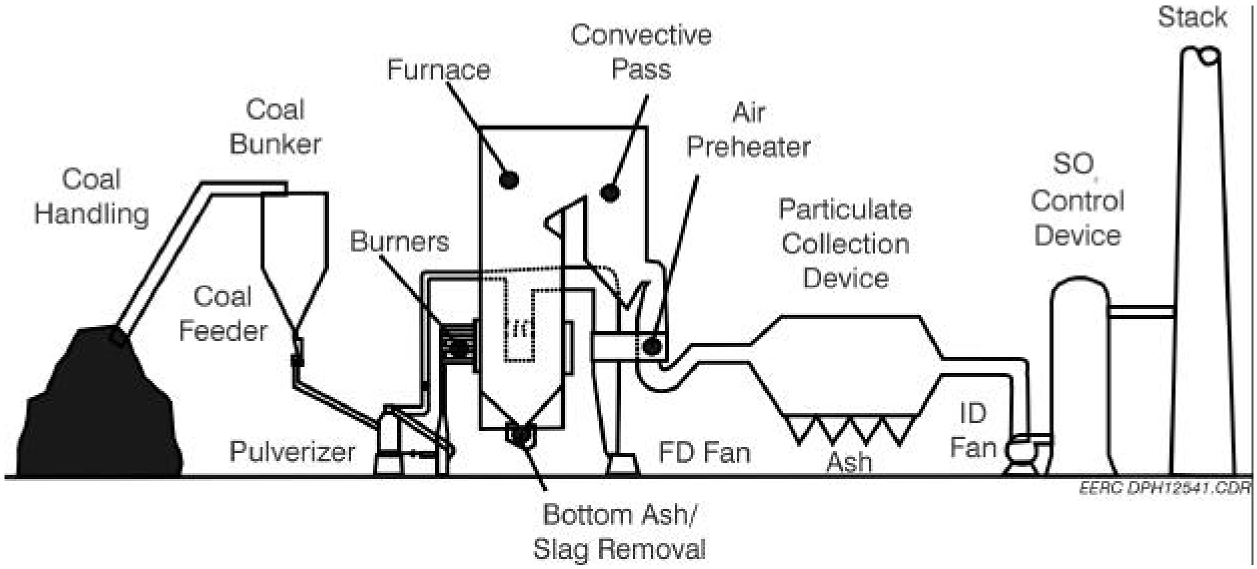

Figure 7. Typical pulverized coal combustion system.

produced. In general, pc combustion results in approximately 65%–85% fly ash, and the remainder in coarser bottom ash (dry-bottom boiler) or boiler slag (wet-bottom boiler). Cyclone combustion uses coarsely pulverized coal (95% −¼ in.) and produces much higher percentages of bottom ash (up to 75%–90%, depending on coal type) and smaller amounts of fly ash. Stoker-fired units do not require the same level of coal grinding (e.g., −¾ in.) because the coal generally stays in the hot zone for an extended period of time, allowing complete combustion of larger coal particles.

Utilities use a variety of techniques for air pollution or emission control. Currently, emission control technologies are fairly broadly applied for control of particulates, SO_2, and NO_x. ESPs have been commonly installed on U.S. coal-fired steam–electric power plants to reduce particulate emissions. In recent years, baghouses have been specified for some new units as well as retrofits of existing units. At present, every operating U.S. utility-owned coal-fired unit is believed to have particulate control equipment in place.

U.S. utilities generally employ one of two strategies to control SO_2 in the flue gas stream: 1) use of compliance fuel or 2) use of FGD units. Many western coals and some eastern coals are naturally of low sulfur content, and these can be used to meet SO_2 compliance requirements. Utilities may also physically clean or wash all or part of the fuel prior to combustion. Physical coal cleaning at the mine, transhipment point, or power plant is quite widespread in the United States not only because it results in reduced emissions, but also because some increase in steam generator efficiency is often possible if the fuel feedstock can be made more homogeneous. Utilities may also blend coals of different sulfur contents in order to obtain a mix allowing compliance with applicable regulations. A schematic of one type of FGD system, a calcium spray dryer, is shown in Figure 8.

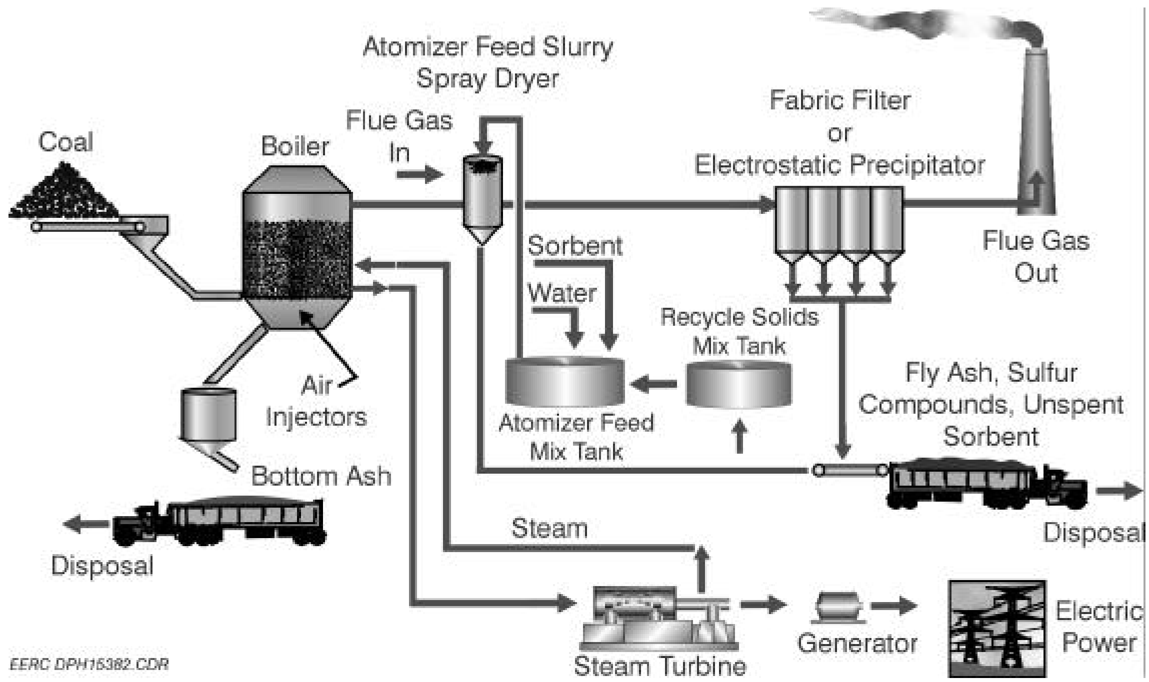

Figure 8. Calcium spray-dryer diagram.

Control of NO_x emissions, which is relatively new for the utility industry, is complicated, since these emissions are related both to the nitrogen content of the fuel and to the formation of various NO_x species during the combustion process. NO_x controls include combustion modifications such as use of overfire air or low-NO_x burners. Selective noncatalytic reductions (SNCR) and SCR are just beginning to be used as postcombustion NO_x control. Commercial installations have been made, but research and evaluation continue in the area of NO_x control.

Each of the emission control technologies that an individual coal-fired unit needs to use has the potential to impact the quantity and the character of the by-products generated. A discussion of these impacts is included later in the report. Current research on air toxic emissions (Benson and others, 1995; Miller and others, 1996; Pavlish and others, 1995) is evaluating the potential need for further emission controls for trace elements such as mercury and other hazardous air pollutants (HAPs). Technologies that may be required to control these emissions will also impact CCBs.

2.2.2 Fluidized-Bed Combustion

The FBC process consists of two subprocesses: 1) the fluidization of solids, by which solid particles/granules are suspended in an upward-flowing stream of gas and 2) the combustion process, in which fuel particles are burned to sustain temperature. The solids in FBCs are typically fuel ash, bed material, sorbent used to control pollutants, and reaction products formed by sulfur capture and other sorbent–coal interactions. FBC systems operated at atmospheric pressure are classified as atmospheric fluidized-bed combustors (AFBCs), which usually also denotes low fluidization velocities resulting in a bubbling bed. Circulating fluidized-bed combustors (CFBCs) operate at fluidization velocities approximately 2 to 3 times higher. At these velocities, the rising gas entrains the bed materials; the resulting bed consists of a turbulent cloud of solids that fills the combustion chamber. A portion of the bed material is continuously carried out with the offgas and recirculated to the combustion chamber. Pressurized fluidized-bed combustor (PFBC) systems are similar to AFBCs but operate under pressure. The compressed air used contains more oxygen per unit volume and, therefore, sustains a higher intensity of combustion, allowing for the design of smaller combustors. The other principal advantage of the PFBC is the increased conversion efficiency (coal-to-electricity) that can be achieved by passing the hot, pressurized combustion gases through both a gas turbine and a waste heat boiler serving a steam turbine to extract more useable energy in a combined cycle system.

The characteristics of the solid residues produced in FBCs depend on the bed material, fuel and ash compositions, unburnt carbon, desulfurization products, and unreacted sorbents. The residues can be collected from several locations in the system, including the bed offtake, primary cyclone, and final particulate control device. In most cases in the United States, the residues are combined. In other countries, the residues are separated for utilization; e.g., the Netherlands separates the spent bed material from the fly ash (Smith, I.E., 1990). The quantity of the residues depends on the coal characteristics. High-sulfur coals require more sorbent to collect SO_2. Certain high-sodium western coals require high bed turnover rates to minimize bed agglomerations (Mann and others, 1992).

Fluidized-bed combustion systems operate at low temperatures, typically less than 900°C, which prevents significant fusion and melting of the ash particles. The FBC fly ash particles are, therefore, angular and very different from the spherical fused ash particles produced in pc firing (Mann and others, 1985; Smith, I.E., 1990). Entrained bed material also influences the physical and chemical properties of the fly ash collected in the particulate control devices. The characteristics of the spent bed material depend on the properties of the coal ash, the bed material, and the sorbent and degree of sulfation due to sulfur capture. The solids recirculations of a CFBC and the higher pressure of a PFBC cause these systems to achieve higher sorbent utilization, resulting in a higher sulfation level in their residues. High-calcium materials used for sulfur capture (i.e., limestone or dolomite) produce residues containing high levels of calcium sulfate, free lime, and coal ash, which reflects the chemical characteristics of the sorbent and coal used. Selection of coal and sorbent combinations may provide an opportunity to adjust residue compositions to meet a particular utilization specification. The particle size of the fines collected from an FBC baghouse is similar to that of pulverized coal fly ash (mass mean diameter of 10 to 15 µm). The respective particle sizes of the bed offtake, cyclone, and baghouse residues were similar for eight test coals burned under similar conditions (Dearborn Environmental Consulting Services, 1988). Comparison of the AFBC and CFBC residues indicates finer particle-size distributions for the CFBC because of the high degree of solid recycle (Dearborn Environmental Consulting Services, 1986). Problems can arise in the disposal of FBC residues as a result of the high levels of CaO and $CaSO_4$, the alkalinity of leachate, and dust associated with residues that contain high levels of CaO. Rapid exothermic reactions and solidification occurring with the addition of water require that care be used in handling, utilizing, and disposing of the FBC residuals (Smith, I.E., 1990).

PFBC technology has been investigated under the DOE CCT program, including demonstration of commercial-scale systems. The current terminology applied to PFBC technologies is “first-generation PFBC” and “second-generation PFBC.” The first-generation PFBC technology was demonstrated at the Tidd Pressurized Fluidized-Bed Coal Technologies Project. A schematic of a PFBC is shown in Figure 9.

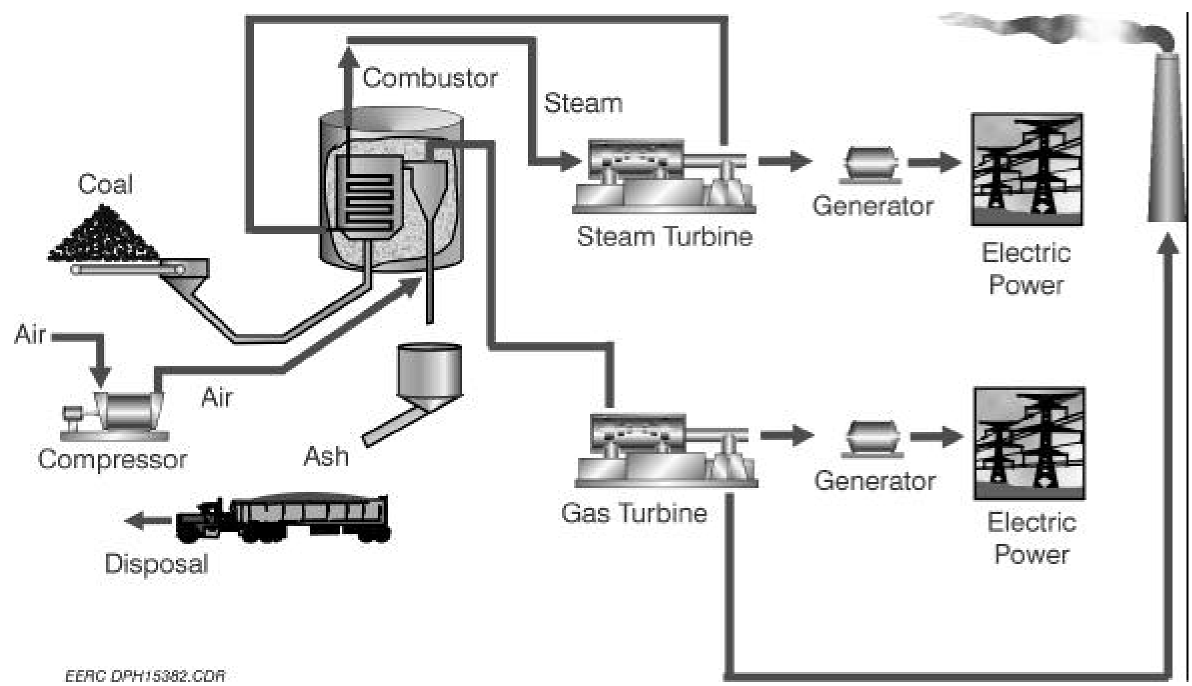

Figure 9. Pressurized fluidized-bed combustion diagram.

Successful demonstration of the PFBC technology at that site was encouraging, and two additional DOE PFBC demonstration projects were planned. These were proposed for sites in Iowa and Kentucky, but because of uncertainties regarding regional power requirements, these two projects were combined into a demonstration of second-generation PFBC technology, basically combining the high-tech pressurized circulating fluidized-bed (PCFB) combustor, which captures sulfur and other pollutants from the coal fuel, and the production of high-pressure coal gases that can power a combined cycle gas and steam turbine similar to that used by integrated gasification combined cycle (IGCC). If the PCFB technology is successful alone on the basis of tests scheduled to begin in 2000, it is proposed to add another advanced technology to the system. This will be a carbonizer added to the coal-burning process to produce fuel gas and char from coal. The char will be fed with fresh coal to the PCFB combustor, and the gas will be cleaned and fed to a topping combustor to drive the gas turbine. This addition is expected to increase the efficiency of the system up to approximately 46% and add another 12 megawatts of power output.

2.2.3 Coal Gasification

In coal gasification systems, the coal is converted to a combustible gas, volatiles, char, and ash/slag. Coal gasification has been technically and economically feasible for many years. Commercial gasifiers differ widely in the way in which they produce ash, and either a dry ash, an agglomerated ash, or slag may result. The Lurgi and other fixed-bed gasifiers operate by passing air or oxygen and steam under pressure up through a bed of coal, which is fed to the top of the bed through a lock hopper. Coal and char move to the bottom as they are gasified, and the dry ash is removed through a bottom grate. Alternatively, a fixed-bed gasifier can be designed to operate at high temperatures, producing a bottom slag that is tapped through a hearth, i.e., the British Gas–Lurgi (BGL) process. Fluidized-bed gasifiers, including the U.S. Kellogg Rust Westinghouse (KRW) and Institute of Gas Technology (IGT) processes and the German Winkler process, operate in a gasification mode using steam and air or oxygen in a fashion resembling PFBC. Either dry ash or a fused agglomerated ash may be produced depending on the design, operating temperatures, and the fusion temperature of the ash. Gasificaton in the M.W. Kellogg transport reactor operating as a fast fluid bed with solids recycle will produce a dry ash. Entrained-flow gasifiers, including Dow, Texaco, and Shell designs, all operate at very high temperatures and produce a vitreous slag. IGCC systems directly link these various types of gasifiers with a gas turbine/steam turbine cycle to achieve high conversion efficiency.

2.2.3.1 Characteristics of Gasifier Ash and Slag

The chemical, mineralogical, and physical characteristics of gasifier ash residues have been investigated (Eklund, 1986; McCarthy and others, 1985; Stevenson and Larson, 1985; Hassett and others, 1985), and the characteristics of ash produced from the Shell pilot-scale testing (Mahagaokar and others, 1990) and Texaco testing (EPRI, 1990) have been reported. Slag/ash samples have been characterized from eight gasifiers (Eklund, 1986). Materials examined included coarse ash or slag and cyclone dust. The materials were found to be nonhazardous, but the physical characteristics and chemical compositions varied significantly as a function of process configuration, operation, coal feed composition, and coal handling. The elemental compositions of the slags produced in gasification systems were similar to those of the bottom ash from conventional coal combustion systems (Turner and Lowry, 1983). The bulk compositions of cyclone dust samples were found to be similar to those for conventional coal combustion fly ash (Wetzel and others, 1982). The mineralogical examination of slags (McCarthy and others, 1985) indicated that many of the same high-temperature silicate minerals are present in the slag samples along with reduced iron-bearing compounds. A key difference in coal gasification ash and slag compared to combustion ash is the lower level of sulfur. In the absence of limestone injection for in-bed sulfur capture, sulfur is present in small quantities in the ash, usually in the form of a sulfide. The other ash species in the system may also be in reduced form. The entrained-flow slagging gasifiers recycle all fly ash to the vitreous slag. Slag samples produced in the Shell process (Mahagaokar and others, 1990) were shown to be depleted in several trace elements. The fine fly slag contained carbon and a higher level of trace metals.

In gasification systems, postgasifier sulfur recovery units are used to remove sulfur to convert it to sulfuric acid or elemental sulfur. Alternatively, or as a complement to a sulfur recovery system, reduced forms of sulfur can be oxidized and removed with a calcium-based sorbent in the form of calcium sulfate. Fluidized-bed gasifiers that incorporate in situ sulfur capture produce calcium sulfide that must be oxidized to sulfate before it is suitable for either use or disposal.

2.2.3.2 Integrated Gasification Combined Cycle

Coal gasification has been technically feasible for many years. Coal gasification can be compared to fuel-rich coal combustion. Essentially the same physical and chemical processes occur during gasification and direct combustion. The similarities between gasification and direct combustion include fuel preparation and grinding, which is important to note relative to waste management. The interactions of the processes common to gasification and direct combustion are different, and the results are different as well. Table 5 gives a comparison of the processes for gasification and direct combustion.

TABLE 5

Comparison of Gasification and Direct Combustion[a]

	Direct Coal Combustion	Coal Gasification
Operating Temperature	Lower	Higher
Operating Pressure	Usually atmospheric	Often high-pressure
Ash Condition	Often dry	Often slagging
Feed Gases	Air	Steam, oxygen
Product Gases	CO_2, H_2O	CO, H_2, CH_4, CO_2, H_2O
Gas Cleanup	Postscrubbing	Intermediate scrubbing
Pollutants	SO_2, NO_x	H_2S, HCN, NH_3
Char Reaction Rate	Fast (with O_2)	Slow (with CO_2, H_2O)
Oxidizer	In excess	Deficient
Tar Production	None	Sometimes
Purpose	High-temperature	Fuel-rich gas

[a] After Smoot and Smith, 1985.

IGCC is being demonstrated on the commercial scale in three major joint projects between DOE and industry. These commercial IGCC demonstrations represent two different entrained-flow gasifiers (Texaco and Destec, two sites) and a fluidized-bed gasifier (KRW, one site). A diagrammatic representation of an entrained-flow gasifier is shown in Figure 10 and a similar representation for a fluidized-bed gasifier in Figure 11. A schematic of IGCC is shown in Figure 12, which includes lists of the potential by-product streams.

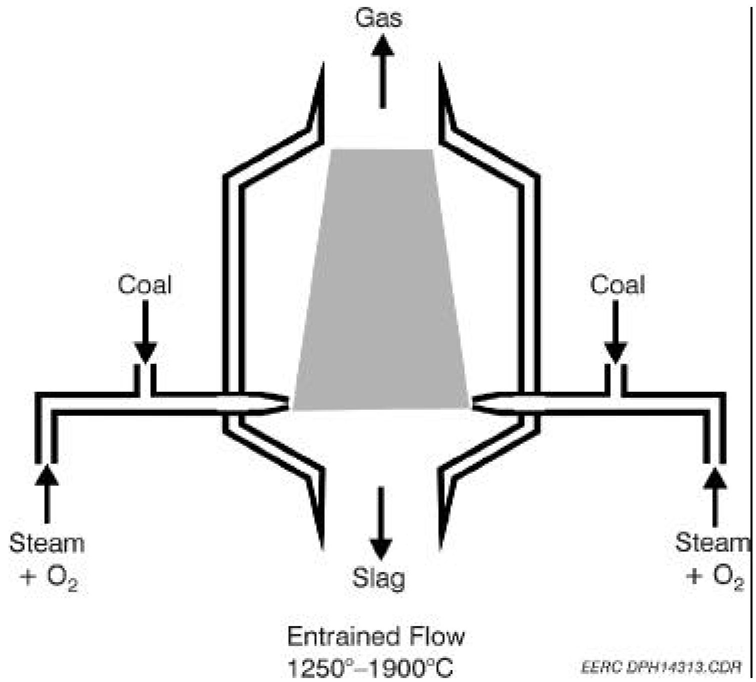

Figure 10. Entrained-flow gasifier (up-flow).

The by-products formed in these IGCC processes can be better understood in the context of process and operating variables. Table 6 provides key information relative to the specific process for each of the three commercial-scale IGCC demonstration sites in the United States. It is important to note that the by-product streams are not the same for each process. The by-products generated by each process are listed separately on the table. Also important to note, the by-products have generally been designed to be utilized rather than disposed of as part of the overall project plan.

2.2.4 Slagging Combustors and Direct-Fired Gas Turbines

A pressurized slagging combustor coupled with hot-gas cleaning is a potentially simple system for producing hot gas for a gas turbine combined cycle. The major problems encountered in using coal directly as a gas turbine fuel are due to the inorganic components in the fuel. Direct-fired slagging combustors offer potential capital cost savings for coal-fired combined cycle systems, but only if the hot gases generated can either be used directly or economically cleaned to remove particulates, sulfur, and alkalies. A slagging combustor direct-fired gas turbine system

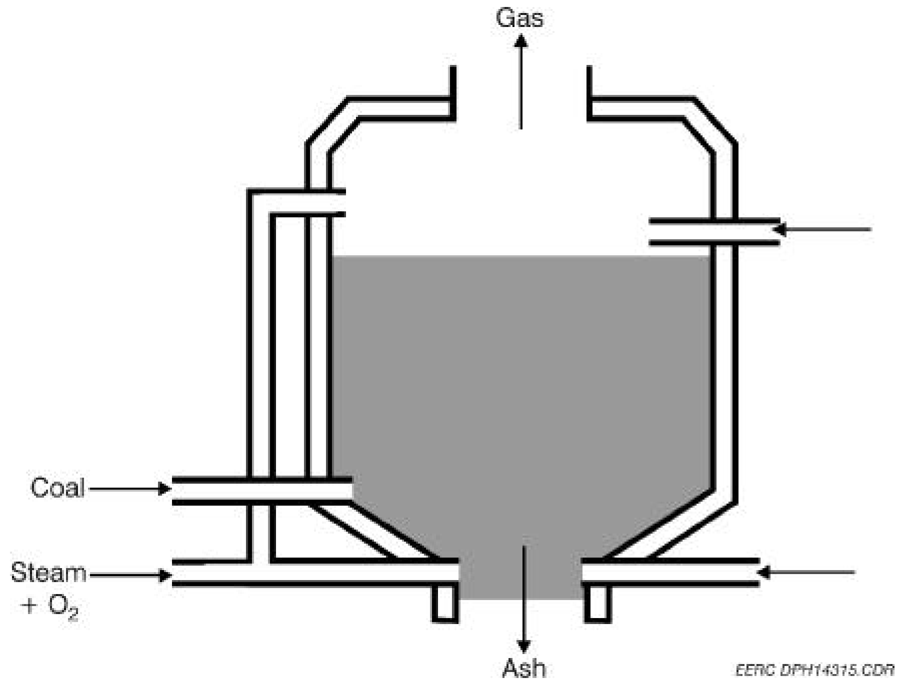

Figure 11. Fluidized-bed gasifier.

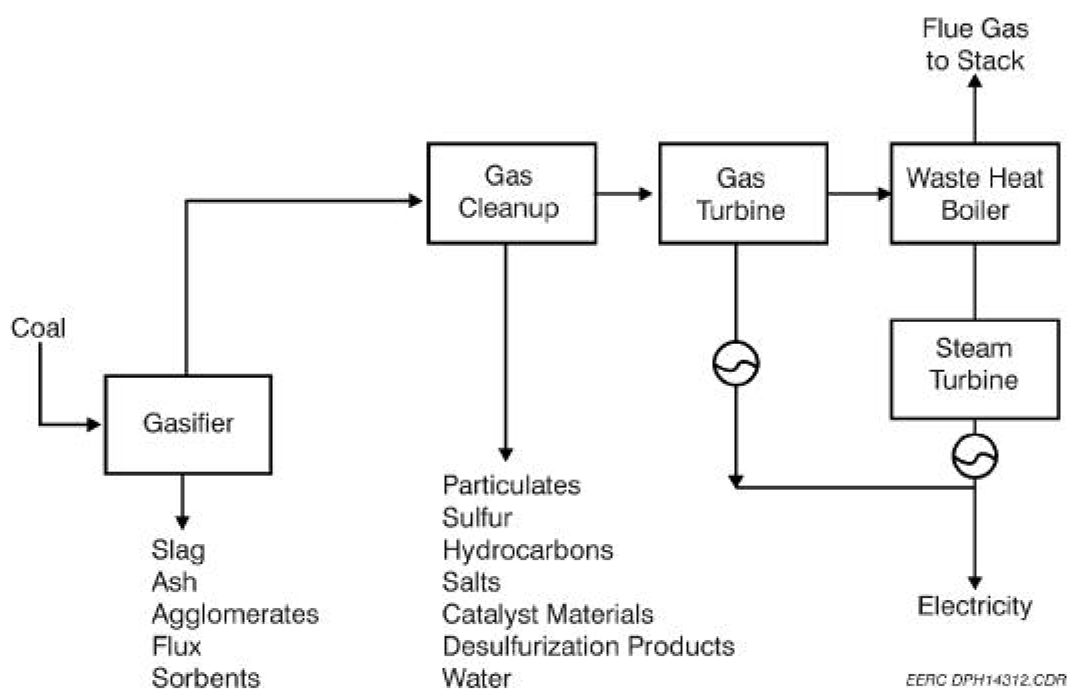

Figure 12. Schematic of the IGCC process.

TABLE 6

Summary of DOE IGCC Demonstration Projects

Project Name	Industrial Partners	Location of Project	Generation Capacity (MWe)	Key Process Descriptors	Fuel and Other Process Feeds	Reaction Temperature, °F/°C	Initiation Date of Operation	By-Products Generated
Coal Gasification Wabash River Repowering Project	1. Wabash River Coal Repowering Project Joint Venture 2. PSI Energy, Inc. 3. Destec Energy, Inc.	Wabash River Generating Station, West Terre Haute, Indiana	162	Destec process – Entrained-flow – Oxygen-blown – Two stages – Gas conditioning – Gas cleanup – Combined cycle	High-sulfur bituminous coal Flux	2500/1260	Aug. 1995	Slag Particulates from gas cleaning Sulfur
Tampa Electric Integrated Gasification Combined-Cycle Project	1. Tampa Electric Company 2. Texaco Development Corporation 3. General Electric Corporation 4. Air Products and Chemical, Inc. 5. Bechtel Corporation	Polk County Plant, Mulberry, Florida	250	Texaco process – Entrained-flow – Oxygen-blown – Single-stage – Downward firing – Hot-gas cleanup – Combined cycle	Eastern U.S. bituminous coal Oxygen Slurry water Nitrogen	2500–2700/ 1260–1450	Oct. 1996	Ammonium chloride Sulfuric acid Solidified slag
Piñon Pine Power Project	1. Sierra Pacific Power Company 2. Foster Wheeler Development Corporation 3. M.W. Kellogg Company	Tracy Power Plant, Stoney County, near Reno, Nevada	100	KRW process – Pressurized fluidized-bed – Air-blown – Hot-gas cleanup – Combined cycle	Low-sulfur bituminous coal Limestone Steam Air	1800/982	Nov. 1997	LASH,[a] a combination of excess limestone, lime, ash, and $CaSO_4$

[a] Limestone ash.

has been tested (Lecren and others, 1992) and so has a three-stage slagging combustor (Lecren and others, 1992). The ash by-products produced from these systems are a vitreous slag and the particulate collected in collection devices. Slagging combustors retrofit to a package boiler (Zauderer and Fleming, 1991) were able to produce a vitreous slag with relatively high ash retention. The fly ash produced was chemically and physically similar to typical pc fly ash. The fine particulates generated from volatilized inorganic components or organically associated inorganics in low-rank coals would be expected to reduce the percentage of total ash that could be removed in the slag cyclone or impactor alone, thereby adding to the need for a barrier filter. High-alkali coals would likely require alkali gettering. In reference to controlling sulfur along with slag, the reported high levels (up to 90%) of nonequilibrium sulfur captured on limestone in the reducing section of a slag combustor have, in fact, provided no more than about 50% sulfur control overall, even with rapid slag removal, owing to re-emission of sulfur at high temperature under more fuel-lean conditions (Diehl and others, 1992). Sulfides that may occur in reduced slag would pose problems in either use or disposal, possibly requiring subsequent oxidative treatment. Calcium sulfide produces poisonous and odoriferous hydrogen sulfide on contact with water.

2.2.5 Externally Fired Combined Cycle Systems

Externally fired combined cycle systems based on currently available gas turbine technology supporting a turbine inlet temperature of 2500°C when using air as the working fluid offer potential efficiencies of 47% to 50% fired either on coal alone or on a combination of coal and natural gas. Accordingly, DOE is vigorously pursuing a system development program, Combustion 2000, based on high-temperature coal-fired air heaters using advanced materials such as oxide dispersion-strengthened alloys. Lead contractors for Combustion 2000 are United Technologies Research Center (UTRC) (Seery, 1993) and Foster Wheeler Development Corporation (FWDC) (Shenker and McKinsey, 1992). The generic UTRC system configuration includes a high-temperature advanced furnace consisting of the combustor, slag screen, radiant and convective air heaters, and a heat recovery steam generator, together with the gas turbine/steam turbine combined cycle power system and conventional SO_x and particulate control modules. The FWDC system uses a series of three air heaters fired on coal char, pyrolysis gas, and natural gas. Low NO_x emissions in these various systems would be achieved by combustion controls using staging (rich–lean) or aerodynamically controlled mixing. Combustion 2000 aims at commercial demonstration by 2005 of an ultraclean system for achieving a minimum efficiency of 47% operating on a wide range of coals. The characteristics of the ash and slag from these systems will likely be similar to those found in conventional combustion systems.

3.0 CCB PRODUCTION AND MANAGEMENT

CCBs as produced in the United States currently are primarily a result of emission control technologies installed to meet emission regulations. Emission regulations first mandated reduction of particulate matter released to the atmosphere by utilities, which required utilities to install collection devices for fly ash generated. Later emission regulations significant to CCB production mandated limits on SO_x emissions. As a result, utilities using high-sulfur coal could change coal sources, which resulted in a different by-product character, or scrub the flue gas using sorbents to remove the SO_x gases. The result of flue gas desulfurization was high volumes of spent FGD sorbent material. There is a wide range of FGD technologies, so FGD materials have broadly varied characteristics, but most contain high concentrations of calcium and sulfur. Currently utilities are responding to regulation placing limits on NO_x emissions, which also impacts the character of ash by-products. Issues related to air toxic emissions, including mercury and CO_2 emissions, are currently under technical and regulatory scrutiny. Regulations that limit utility emissions further are expected to have additional impacts on by-product quantity, quality, and characteristics. Changes in CCB characteristics require an associated evaluation of technical issues related to CCB performance in conventional utilization applications and perhaps development of new markets.

3.1 CCB Production

3.1.1 Current Production of Conventional CCBs

The quality characteristics of the CCBs currently being produced vary widely, but all CCBs have the potential to be used rather than discarded as a solid waste. The challenge of full economic utilization can be met only by appropriately matching by-products with utilization specifications, taking into account the physical and chemical properties of the by-products. Characterization data have been presented in several reports (Pflughoeft-Hassett and others, 1993; ICF Northwest, 1987). Some useful generalizations can be drawn from the information presented throughout these reports. Eastern CCBs generally produced from bituminous coal are chemically composed mainly of oxides of silicon, aluminum, and iron, and the fly ash is usually pozzolanic and particularly well suited for use as a concrete admixture and for high-volume applications such as structural and flowable fills. Western coal ashes from subbituminous coals, categorized as Class C ash by ASTM, additionally contain cementitious calcium compounds that render these materials suitable for cement replacement; however, certain of these ashes may also contain high concentrations of sodium, which can contribute to alkali–aggregate reactions that cause swelling and cracking in concrete. Fly ash from lignitic coal (found primarily in North Dakota and Texas) may be pozzolanic, or it may be both pozzolanic and cementitious. It also has the potential to contain relatively high concentrations of sodium. Glassy slags and, to a lesser degree, bottom ash tend to be vitrified inert materials suitable for use as fine aggregate in a range of products from road base to cast concrete products. FGD by-products from emission control processes using lime or limestone for sulfur capture typically contain a hydrated mixture of unreacted calcium carbonate, lime, calcium sulfite, and calcium sulfate, along with either small amounts of ash, as in most wet-scrubber installations where the ash is collected separately, or larger amounts of ash, as in a lime slurry spray-dryer system attached to a baghouse that collects both the ash and the spent lime sorbent together. Low-ash FGD by-products, depending on their oxidation state, can be used either directly or with additional processing in the production of gypsum wallboard. High-ash FGD by-products can be used along with other materials in formulated products such as low-temperature bonded aggregate and lightweight concrete block.

Annual summaries of CCB production and consumption have been prepared by the ACAA since 1966. These surveys generally cover the highest-volume CCBs: fly ash, bottom ash, boiler slag, and FGD material. Production data from 1966, 1976, 1986, 1993, and 1996 (the most recent summary available from the ACAA) are presented in Table 7. A summary of CCB production and use for 1966 through 1993 that was published by ACAA (1996) indicates that CCB production increased from 1966 to about 1980. Since 1980, CCB production has remained relatively constant, with the exception of FGD materials. FGD material production began in 1987 and has remained relatively constant through 1996.

The quantity of CCBs produced is directly proportional to the amount of coal burned, the ash content of the coal, and the use of FGD. The average ash content of coal used by U.S. electric power utilities is approximately 10%, and as indicated by Table 8, ash content has decreased significantly since 1975 (ICF Resources Inc., 1993). This reduction has resulted from a nominal increase in coal cleaning and a large increase in the use of low-sulfur, low-ash western coals to meet the sulfur dioxide emission requirements of the Clean Air Act (CAA). U.S. coal consumption for electric power generation has doubled since 1975 and is projected to increase an additional 25% by 2010 (EIA, 1993a). Approximately 22% of U.S. coal-fired generating capacity is currently equipped with FGD controls, and additional retrofit installations are projected to increase FGD coverage to about one-third of generating capacity by the year 2000, when the sulfur control provisions of the 1990 CAAA are fully implemented (EIA, 1993a, b).

TABLE 7

Summary of CCB Production
(ACAA, 1996, 1997)

	By-Product Production[a]				
	1966	1976	1986	1993	1996
Fly Ash	17.1	42.8	49.26	47.76	59.36
Bottom Ash	8.1	14.3	13.41	14.21	16.06
Boiler Slag	NA[b]	4.8	4.13	6.23	2.57
Combined Ash and Slag	25.2	61.9	66.80	68.20	77.98
FGD Material	NA	NA	NA	20.34	23.85

[a] All values shown in million short tons.
[b] No data available.

3.1.2 Future Production of Conventional CCBs

Trends in the production of CCBs can be estimated from future changes in electric power generation projected by DOE (EIA, 1993a). Between 1990 and 2010, demand for electricity is expected to grow at an annual rate of between 1.3% and 1.9%, which is well below historic electricity growth rates of 4.2% in the 1970s and 2.8% in the 1980s, but still well above the expected future growth in total U.S. energy consumption, estimated in the range of 0.9% to 1.4%.

A high percentage of the generating capacity added between 1990 and 2000 is expected to be from natural gas-fired units serving intermediate and peak-load needs, but coal may regain the predominant role after 2000 as base load requirements increase and gas prices outpace coal prices. U.S. coal consumption for electricity generation is projected to grow from 774 million tons in 1990 to 1006 million tons in 2010, with 81% of the increased coal production expected to come from producers west of the Mississippi.

TABLE 8

Ash Content of Coal Used by Electric Utilities – Selected Years (ICF Resources Inc., 1993)

Year	Coal Delivered to Electric Utilities, thousand short tons	Average Ash Content, wt%	Total Ash, thousand short tons
1975	429,215	13.50	57,944
1980	593,995	11.10	65,933
1985	666,743	10.05	67,008
1990	785,222	9.81	77,030

Source: DOE EIA *Cost and Quality of Fuels*, 1975, 1980, 1985, 1990.

Provisions in Title IV of the 1990 CAAA addressing emission reduction targets for SO_2 and NO_x, along with new technology developed under the DOE CCT Demonstration Program, will have major effects on the quantity and quality of CCBs produced in the future. Phase I of the CAAA targets for SO_2 set for 1995 will be largely met by fuel switching, which will reduce upward trends in the production of both coal ash and FGD materials as natural gas and low-sulfur, low-ash western coal replace midwestern and eastern coal. Phase II targets for SO_2 set for the year 2000 will result in only a modest increase in FGD retrofit capacity, estimated by DOE at approximately 10% of total U.S. generating capacity through 2000 and 14% through 2010 (EIA, 1993a); additional fuel switching and clean coal retrofit and repowering projects will satisfy the remaining Phase II requirements. Important considerations beyond the year 2000 are the permanent cap on SO_2 emissions and the trading of emission allowances, both of which will encourage the commercialization of ultraclean and efficient advanced power systems. Most of the coal-fired generating capacity added after 2005 is likely to be in advanced clean coal plants. Currently, many utilities are responding to the CAAA requirements for NO_x emissions. The typical responses involve combustion modifications of overfire air (OFA) and/or low-NO_x burners, which have a significant potential for adversely affecting ash quality by increasing the amount of unburned carbon (EIA, 1993c). DOE has sponsored annual conferences on the topic of unburned carbon on utility fly ash since 1995, primarily addressing the effects of requirements for combustion modifications for NO_x content. Further NO_x reduction will likely not be achieved through the use of LNB, even combined with OFA (DOE, 1997), so other measures are likely to be required. SCR and SNCR are postcombustion technologies that utilities are applying to meet more stringent NO_x reduction requirements. These technologies also have the potential to affect coal fly ash quality because of the requested addition of ammonia (NH_3). The NH_3 slip is lower with SCR technology. A recent paper (Comparato, 1998) indicates that SCR may be most effective for NO_x reduction when used jointly with SNCR.

Certain trends in CCB production can be discerned based on the changes in coal use patterns discussed above. The production of CCBs can be expected to increase by about 20% to 25% between 1990 and 2010, reflecting an annual growth rate of about 0.8% early in the period and 1.5% after 2005. These annual rates are somewhat below the 1% to 2% annual increase in coal use for power generation projected by DOE between 1990 and 2010, owing to the increased use of low-ash western coal. The use of western compliance coal will also increase the amount of cementitious Class C ash available in eastern markets previously accustomed to Class F bituminous coal ash. The amount of FGD by-product produced through the year 2010 will increase roughly in proportion to added scrubber capacity, which increases by 14% of the total generating capacity for retrofit installations (EIA, 1993a), plus an unknown but perhaps similar contribution for new plants equipped with scrubbers. The effect of more stringent NO_x standards will depend on the emission level selected. Utilities will continue to address NO_x requirements and the resulting impacts on by-products. The future adoption of advanced coal-fired power generation technologies expected after 2005 will begin to change CCBs in revolutionary ways, resulting over time in the substitution of FBC-type material and gasifier slag for fly ash and bottom ash as predominant by-products. These new by-products will be produced over a much wider range of conditions than the boiler ashes produced today, and the range and distribution of their properties will only be known as future plant designers choose among the emerging mix-and-match technologies for pressurized combustion, gasification, gas-cleaning, turbine–combined cycle, and fuel cell systems.

3.1.3 Advanced Coal Use Technologies – By-Product Production and Characteristics

As previously noted, the quantity and composition of CCBs produced in the United States are changing because of the 1990 CAAA. Since the new coal use technologies summarized in this report are anticipated to be key to future U.S. power generation, the future use and disposal of residues from these technologies should be given a high priority in actions taken to remove barriers to by-product utilization.

The characteristics and subsequent utilization potential of residues from new coal use technologies will be determined by the uniquely different thermal transformations of the coal ash, new process provisions for sulfur and NO_x control, and new particulate collection methods (hot-gas cleaning). In many new technologies, the sulfur is captured along with the ash residues, producing large volumes of high-calcium and high-sulfur residues. These residues do not exhibit properties at all similar to those for conventional CCBs such as fly ash, bottom ash, or boiler slag, and they are not generally suitable for use in the same applications. However, high-calcium and high-sulfur materials can provide a source of calcium and sulfate for cementitious reactions in numerous applications where controlled cementation is required. The properties and chemistry exhibited by these residues give them a high utilization potential in many of the new application technologies, including specialty cements, aggregates, lightweight block, brick, waste stabilization, mine reclamation, agriculture, and soil stabilization. Many of these applications take advantage of the unique chemistry and cementitious properties of these residues. Research to date has not adequately addressed the utilization potential of these materials, but they have been shown to be environmentally acceptable for many use applications and disposal by conventional methods (Sutton and Stehouwer, 1992; Weber and others, 1993; Beeghly and others, 1993). More work is needed to achieve high levels of utilization and to reduce the landfilling that would otherwise be required.

Broad changes in by-product residues from coal-fired plants are also anticipated to occur as a result of technological changes in response to future EPA standards for Phase II NO_x reduction in 2000 and further NO_x reductions in ozone nonattainment regions in 1998 and 2003. New technologies designed to reduce NO_x emissions will be included in both advanced power systems and conventional combustion systems, adding yet another variable to the by-product production process. Recent reports from utilities indicate that they expect low-NO_x and low-SO_2 strategies, including retrofit LNB, OFA, and changes to low-sulfur coal, to impact CCB quality (Nikitenko and Barham, 1992; Makanski, 1993; Laursen and Duong, 1992; Kleisley and others, 1992). The by-product characteristic expected to change most significantly (the amount of carbon carryover in coal combustion fly ash, evidenced by an increase in loss on ignition [LOI]) has already been observed in some pilot-scale systems (Nikitenko and Barham, 1992; Makanski, 1993; Laursen and Duong, 1992; Kleisley and others, 1992). Combustion control technologies designed to achieve NO_x reduction commonly result in reduced combustion temperatures, causing significant changes in the chemical phases produced and in the relative amounts of crystalline versus amorphous or glassy material formed. These changes may not be immediately evident from standard testing of coal fly ash, but may impact the behavior of the materials in many different use applications. Other low-NO_x strategies may include the addition of NH_3 or urea to the flue gas, resulting in an unacceptable release of NH_3 from concrete that contains fly ash from these processes. Coal switching to low-sulfur coal may require the addition of sulfur trioxide (SO_3) to the flue gas to facilitate efficient particulate collection in ESP systems. The addition of SO_3 may impact the quality and properties of the coal fly ash, making it less suitable for use in cement replacement.

As already noted, the wide range of thermal and gas conditions experienced in advanced combustors and gasifiers will produce a far more diverse range of solid by-products than seen to date. Some of the general characteristics of residues from various technologies were discussed above. The classification of these typically high-calcium and high-sulfur residues by use application is necessarily speculative at this time, but some general observations can be made. Fly ash from pressurized combustors that do not introduce calcium for sulfur capture should be similar to conventional pc-fired fly ash and would have applications in the same types of cement replacement uses. High-strength vitreous slags from entrained-flow gasifiers would be suitable for most applications where fine aggregate (e.g., sand) is customarily used, which can include concrete products, asphalt filler, controlled low-strength material (CLSM), roofing granules, and brick or other ceramic products. Agglomerated ash, such as that obtained from high-temperature fluidized-bed gasifiers, is similar to bottom ash from conventional boilers and would be used in similar applications in road base and aggregate. Dry ash from fixed-bed gasifiers will be intermediate between fly ash and bottom ash and incorporate some reduced chemical phases; the most likely uses are in high-volume fill and specialty manufactured products. As previously noted, calcium sulfide produced by in situ sulfur capture in some gasifiers must be oxidized to sulfate prior to use or disposal. Additional research is needed to characterize many of these materials for regulatory classification and optimum beneficial use.

3.1.4 CCB Beneficiation

Several types of processes have been studied to improve the quality of the fly ash primarily for use in concrete. Air classification and grinding can be used to obtain a finer size fraction with enhanced pozzolanic activity (Frigione and others, 1993). Agglomeration of high-calcium fly ash with minimum water on a rotary pan has been used to produce microgranules that can be safely stored for later use (Kilgour, 1991). Controlled electrostatic separators can be designed to remove oversized, low-density, and nonspherical particles, including most of the unburned carbon (Yasuda and others, 1991). Combining fine fly ash and silica fume reduces the cost of high-strength concrete (Clarke, 1992). Unburned carbon (LOI) can be reduced by flotation, electrostatic separation, or reburning, and part of the iron can be magnetically separated (Michalikova, 1993; Whitlock, 1993; Cochran and Boyd, 1993). FBC by-products can be processed in steam at 200°C to make sulfitic expanding cement (Jiang and Roy, 1993).

Since the introduction of LNBs, interest in fly ash beneficiation has heightened considerably on the part of both utilities and ash marketers. Increased carbon content, indicated by increased LOI, has become an important technical and marketing issue. Numerous reports on the characteristics of LNB fly ash and on processes to separate or reduce the carbon in the ash have been presented and published (Baer and Luftglass, 1997; Groppo and others, 1997; Levy, 1997; Stencel and others, 1997; Cochran and Boyd, 1993; Whitlock, 1993), and DOE has sponsored an annual conference devoted to the topic of unburned carbon in utility fly ash. Commercial installations of systems for carbon separation (Gasiorowski and others, 1998) and carbon burnout (Frady and Hay, 1998) were reported at the 1998 DOE conference.

The extent of the need for beneficiation of high-carbon fly ash remains an unknown. There are conflicting technical and marketing issues relative to the utilization of high-carbon fly ash in concrete, which is both the single largest market and one of the higher-value markets for fly ash. Most other utilization applications are relatively unaffected by increased carbon content. Carbon in fly ash does change the air entrainment in concrete; however, the European concrete market uses very little air-entrained concrete, and it has been stated that air-entrained concrete is specified frequently in the United States more out of habit than need (discussion, ACAA– ECOBA joint meeting, 1998). Chemical admixtures are used to achieve air entrainment in concrete, so it has also been suggested that changes in the amounts or types of air-entraining agents might be effective in minimizing or eliminating the effect of the carbon in the fly ash up to a much higher content than has been typically accepted in fly ash used in concrete. If these technical issues can be successfully addressed, the difficulties in marketing a darker-colored, higher-carbon fly ash might be alleviated. Currently, consumer expectations require that fly ashes being marketed as mineral admixtures maintain LOI levels similar to historical levels. This issue may also serve to increase the price of mineral admixture-quality fly ash, especially if sources for that quality of fly ash become increasingly limited.

3.2 CCB Management

Effective management of CCBs will be a significant factor in determining the environmental acceptability and economics of future coal-fired electrical generation and coal conversion technologies. High disposal costs will impact utility economics in an increasingly competitive utility industry. CCB management options may range from complete utilization to complete and final disposal. The more desirable option is to take advantage of the inherent value of the material to generate income and avoid disposal cost. Many utilities will need to build new disposal facilities, which will be costly and difficult to permit under new state regulatory requirements. More and more frequently, utilization will be selected as the preferred CCB management option for both economic and environmental reasons. The management of high-volume combustion products needs to be considered in process economics for the life of the facility. All of the options in CCB management require thorough material and environmental characterization as a basis for understanding and, ultimately, predicting behavior in the final environment over a long period of time.

3.2.1 Factors Impacting CCB Management Decisions

The factors impacting utility CCB management decisions reflect the barriers discussed in the 1993 EERC report to DOE. These factors can be summarized as follows:

- Economics of management options
- Environmental, regulatory, and legal factors
- Operational factors

3.2.1.1 Economic Factors

Economic factors will be the overriding issue in utility management decisions, especially as the utility industry moves toward deregulation and free market competition. Keeping in mind that the primary job of any electric generating utility is to produce electricity, many of the operational changes that would enhance by-product utilization potential could also have positive effects on overall plant efficiency. For example, a high level of unburned carbon in fly ash by-products can both reduce or eliminate their potential for sale and use and lower electrical generating efficiency, since the unburned carbon represents lost thermal input to the boiler. The production of a usable by-product of consistent quality could be the natural outcome if power plants implemented a comprehensive management plan that included by-product management along with overall operational efficiency. However, for coal-fired electric utilities, the amount of revenues produced by the sale of by-products is often insignificant in relation to the revenue stream provided by the sale of electricity. The prices received for by-products are simply too low to justify a large financial commitment to by-product marketing. Therefore, there is little economic incentive for utilities to allocate personnel and equipment costs to improve on their by-product management strategy. By-product sales tend to take place only if they can be achieved with little effort and capital outlay, and by-product utilization is not is not a high priority for operations personnel who are focused on the production of electricity.

In many utilities, the sale of by-products is viewed as a means to reduce operational costs by avoiding disposal cost; this economic view of by-product utilization is referred to as cost avoidance. When by-product management is considered cost avoidance rather than revenue, the incentive for increased by-product utilization is limited. Also, as a regulated industry, utilities account for operational costs by applying them to the rate base, while revenue streams would be applied to the companies' profits.

Even if viewed merely as cost avoidance, by-product utilization becomes more of a priority where disposal costs are very high. Although there is general agreement that solid waste disposal costs are increasing, along with increasing environmental restrictions and the reduced availability of suitable disposal sites, the cost of by-product disposal given by respondents was very low in most cases. The only respondents who seemed especially concerned with increasing disposal costs were utilities that were nearing the end of the life of the landfill that they presently use and were currently involved with repermitting. In most cases, utilities are using landfills under long-term contract or ones that they own. Often, in the case of landfills owned by the company, the capital costs have already been depreciated and the only disposal costs considered are those associated with materials transport and landfill operations. Materials handling, transport, and landfill operational costs are low for established landfills.

Thus the strategy of disposing of by-products in landfills for the lifetime of a power plant was often established before solid waste disposal issues became costly and difficult. This has resulted in artificially low disposal costs and has reduced incentives for by-product utilization up to this time. Because of increased capital costs and site-permitting difficulties, it is likely that many of today’s power plants will be operated beyond the planned plant lifetime. As many of these power plants are repowered rather than replaced, their current disposal strategies will become obsolete, necessitating large capital outlays for new landfills and significantly increased disposal costs. Investments in utilization strategies now could extend the life of present utility landfills and reduce the economic burdens associated with building new disposal facilities for power plant life extension.

Recent presentations indicating profitable CCB marketing by utilities have indicated a greater utilitywide understanding of the potential for CCB utilization (Callaway, 1997; Nerison, 1996; Bennett 1997).

3.2.1.2 Environmental, Regulatory, and Legal Factors

Environmental, regulatory, and legal factors are closely related. Although the vast majority of technical evidence indicates that CCBs are environmentally safe, state regulations have only recently begun to include policy or regulation specifically for CCB utilization (Jagiella, 1993, ACAA, 1996, 1998). Regulation, and therefore legal liability, continues to be better defined for CCB disposal.

Because CCBs continue to be poorly understood and perceived to be a waste material, there is a concern that if detrimental environmental effects take place in use applications, the CCBs will be blamed. This is seen as a particular threat to utilities since they are perceived to have “deep pockets” and litigants tend to target the richest or largest company involved for damages. The idea is that large companies can afford to pay large sums of money and are therefore more likely to settle lawsuits and pay out damages regardless of their blame in the particular case. While some utilities were not affected by the fear of future lawsuits, other companies see the potential for damages as a definite deterrent in developing a more aggressive by-product utilization program.

3.2.1.3 Operational factors

Operational factors include a variety of issues that relate to the physical plant and operation. These factors include fuel selection and preparation, combustion or conversion systems, emission control technology, and CCB handling. Particularly in older coal-fired power plants, CCB management frequently considers only the most economical method of handling for disposal, frequently commingling both CCBs and low-volume wastes (EPRI, 1997) and in many instances using wet handling systems that are not conducive to the beneficial reuse of CCBs. Newer systems and updates to coal-fired plants have taken into account the potential for CCB utilization, and in the DOE CCT program, many systems have included CCB utilization as part of the design process (Pflughoeft-Hassett, 1997).

As utilities respond to CAAA and to restructuring to be more competitive, and as the economics of utility CCB marketing become more profitable, utilities will include potential CCB profits in their evaluations to select cost-effective plant design and operating practices.

3.2.2 Disposal of CCBs

CCBs are frequently, and often generically, referred to as wastes, although this classification is most logically dependent on the fate of the residues. If the end is disposal, then the material is, by definition, a waste. Regulatory agencies, the coal-mining industry, the utility industry, and the CCB industry all agree that the environmental goals of maintaining clean air and clean water are of the highest priority in considering utilization or disposal of coal conversion solid residues and other by-products. It is also agreed within the CCB industry that disposal regulations should not be generically applied to materials in use applications.

Disposal of CCBs continues to be the predominant CCB management option, with 70% to 80% of CCBs generated being disposed annually in the United States since 1987 (ACAA, 1996, 1997). Wet sluicing was the preferred handling method for fly ash and bottom ash in the 1950s and 1960s, but dry handling has become the preferred handling option where there is an interest in marketing and using CCBs and where dry, high-calcium by-products are being handled. Wet sluicing coupled with pond disposal is still a common scenario in the United States (EEI, 1993; EPRI, 1997; Clarke, 1994), and the CCBs may be either disposed of separately or combined in a single pond or lagoon. Ponds may be depression impoundments or dyked impoundments. Ponds generally require more space than dry disposal (landfills) because of the added volume requirements for sluice water. As a result of more stringent federal and state regulations, new utility disposal ponds are not being planned in the United States (Collins, 1992).

Dry CCB disposal is generally referred to as landfilling. CCB landfills maybe on-site or off-site and may be constructed one section or cell at a time. After the dry CCBs are transported to the site by truck or rail and placed, heavy equipment is used to compact the CCBs to reduce volume, decrease permeability, and increase stability.

CCB disposal facilities on-site at a utility generally incorporate low-volume utility by-products along with CCBs. An extensive report on comanagement of utility by-products was recently published by EPRI (1997). It is less common for CCBs to be transported off-site for disposal. If the disposal site is off the utility property, it is generally nearby to reduce the high cost of transporting high-volume materials. An exception may occur where the disposal of CCBs is in coal mines, as when utilities incorporate haulback clauses into coal contracts, which require the coal supplier to take the ash generated back to their mine site. While this is considered a disposal option, the case can be made that the return of CCBs to a mine site is a beneficial use in the mine reclamation process (Bergeson and Lapke, 1993; Ackman and Kim, 1993; Kim and Ackman, 1995). Mine haulback has recently become a controversial subject in some states, with restrictive regulatory requirements established in Indiana and Kentucky. It is important to note that the regulation of mine disposal may fall under the jurisdiction of an agency other than the state health or environmental departments, which would normally regulate CCB disposal.

It is also important to note that in some states, materials are classified as solid wastes if they are recycled or applied to or placed on the land in a manner that constitutes disposal. This definition places some utilization applications (structural fill, some road-building applications, and any use where the CCB might be covered with soil) into the disposal category.

EPA has completed a study of CCBs for the U.S. Congress and has issued a formal regulatory determination (EPA, 1993) that placed large-volume CCBs (fly ash, bottom ash, boiler slag, and FGD materials) under RCRA Subtitle D for solid wastes. This determination gives states the authority to regulate disposal of CCBs as they see fit. The EPA determination did not provide guidelines on the regulation of CCB utilization. Many states still address only disposal of CCBs in their regulations. State CCB disposal regulations are designed with protection of surface and groundwater as the highest priority. Leaching tests are frequently required, and there are usually very definitive requirements for the construction of disposal sites. In recent years, disposal site requirements have included multiple liners and leachate collection and monitoring. These requirements add to the cost of new disposal sites. The recovery or reclamation of CCBs from disposal sites is also being investigated (Bergeson and Wright, 1997; Culley and Smail, 1988) because it has high potential to help utilities to extend the life of currently permitted sites.

3.2.3 Utilization of CCBs

3.2.3.1 Brief History of CCB Use in the United States

Utilization of CCBs began with the utilization of fly ash. 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 (BOR) 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 for fly ash as a cement replacement and as an enhancer of the qualities of concrete to meet the new postwar requirements. The technology used to establish these markets came from BOR 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.

Historically, the principal use of CCBs has been in concrete, and this still holds true today. The use of CCBs in concrete and many other utilization applications, including CLSMs, 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, are discussed in Section 3.2.3.3. Because of the high volumes of CCBs generated, the focus has primarily been on high-volume utilization applications, generally in the engineering and construction areas.

The ACAA has surveyed the CCB industry to determine utilization statistics since 1966. Table 9 gives a summary of utilization data for 1966, 1976, 1986, 1993, and 1996.

3.2.3.2 Current Status of CCB Utilization

As indicated by the data presented in Table 9, the utilization figures did increase from 1966 to 1996, although the percent usage of total CCBs has remained relatively constant since 1976. A notable change is indicated between 1993 and 1996 (the most recently published statistics). These data do require interpretation, which must include the following considerations :

- Increased coal use and a resulting increase in CCB generation
- Introduction of FGD systems in 1987, which resulted in an additional 13–20 million tons of CCBs being generated annually
- Introduction of nonutility CCBs that are not represented in the ACAA survey results
- Reduced fly ash marketability at specific coal-fired units due to introduction of NO_x reduction systems

TABLE 9

Summary of CCB Utilization
(ACAA, 1996, 1997)

	By-Product Utilization[a]				
	1966	1976	1986	1993	1996
Fly Ash	1.4 (8.2)[b]	5.7 (13.3)	8.78 (17.8)	10.51 (22.0)	16.23 (27.4)
Bottom Ash	1.7 (21.0)	4.5 (25.0)	3.58 (26.7)	4.23 (29.8)	4.87 (30.3)
Boiler Slag	NA[c]	2.2 (45.8)	2.14 (51.8)	3.43 (55.0)	2.4 (93.3)
Combined Ash and Slag	3.1 (12.4)	12.4 (20.0)	15.5 (23.2)	18.17 (26.6)	23.5 (30.1)
FGD Material	NA	NA	NA	1.16 (5.7)	1.65 (6.9)
Total CCBs	3.1(12.4)	12.4 (20.0)	15.5 (23.2)	19.33 (21.8)	25.15 (24.7)

[a] All values shown in million short tons.
[b] Values in parentheses are % of production for the year indicated. Production figures are noted in Table 7.
[c] No data available.

- Limited resources to facilitate reduction or removal of the wide range of numerous barriers to utilization identified in the DOE RTC

Considering these points, the CCB industry has been successful in accomplishing a steady increase in CCB utilization in the United States. However, the 20%–30% utilization figures that have been achieved in recent years fail to take full advantage of CCBs as a national resource, which leads to the conclusion that continued work is still needed to increase their utilization. International statistics (Manz, 1997) and individual plant statistics (Spear, 1997) indicate that a much higher utilization rate should be possible, perhaps even approaching 100%.

In its final regulatory determination on fly ash, bottom ash, boiler slag, and FGD materials, EPA indicated that the agency “encourages the utilization of CCBs and supports state efforts to promote utilization in an environmentally beneficial manner” (*Federal Register*, 1992). In the DOE RTC, utilization of CCBs is also encouraged, and DOE has indicated that it will work with federal agencies and state and local governments to increase CCB utilization. However, there is currently no regulatory program at the federal level that provides guidance for the utilization of CCBs. Additionally, many states do not have specific regulations addressing the use of CCBs, and applications for permission to use CCBs are frequently handled on a case-by-case basis or under generic state recycling regulations. A few states have adopted laws, regulations, policies and/or guidance governing CCB use, but requirements vary widely between states. Information on regulation of CCBs is presented in more detail in Section 4.0.

3.2.3.3 CCB Utilization Applications – Technical Summaries

In addition to the tonnage utilization statistics noted in Table 9, ACAA also collects statistics on the applications in which CCBs are utilized and on the amounts of different CCBs used in the most commonly reported utilization applications. The 1996 ACAA report detailing this information is included as Appendix C. A graphical representation of the leading applications for fly ash, bottom ash, boiler slag, and FGD material as reported in 1996 (ACAA, 1997) are shown in Figures 13 through 16 respectively.

Extensive published and unpublished information on CCB utilization for numerous applications can be obtained from patents, laboratory- and commercial-scale product development reports, demonstration projects, and tests evaluating fundamental properties of CCBs and competing materials in various applications. The following summaries of technical information are included as background information for the discussion of barriers to CCB utilization. These summaries are not fully comprehensive, but they do provide up-to-date information on the way in which CCBs can be effectively utilized—and the limitations on use of CCBs in various applications. They also identify technical information gaps that are barriers to CCB utilization.

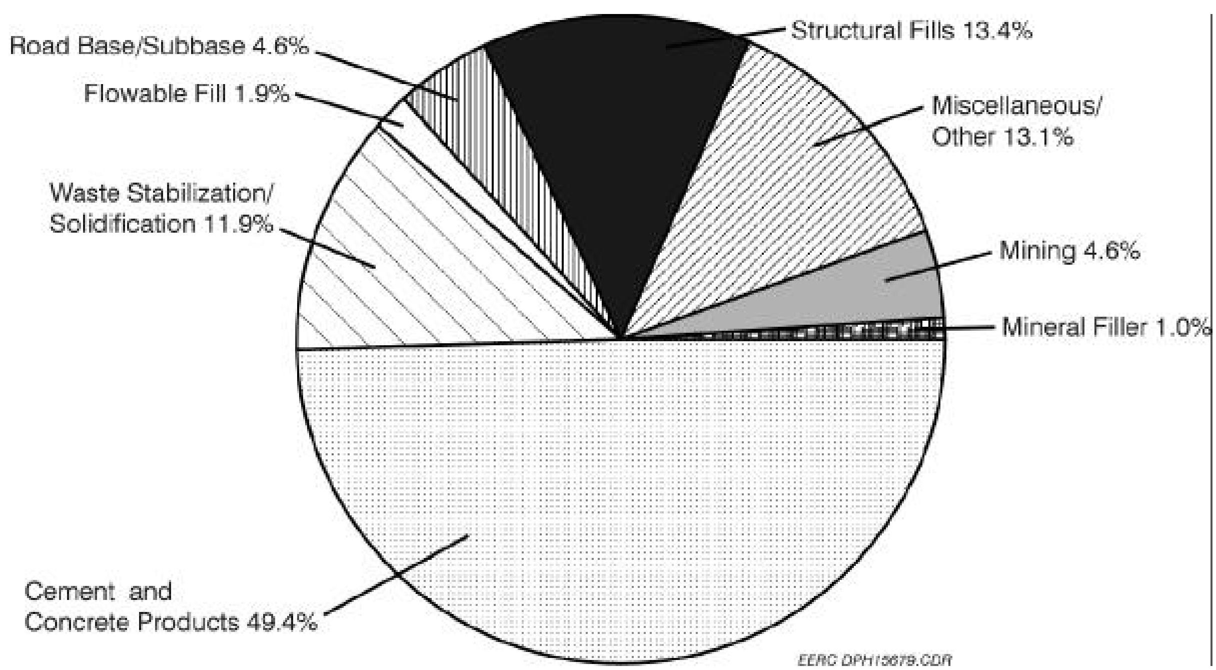

Figure 13. Leading fly ash applications – 1996.

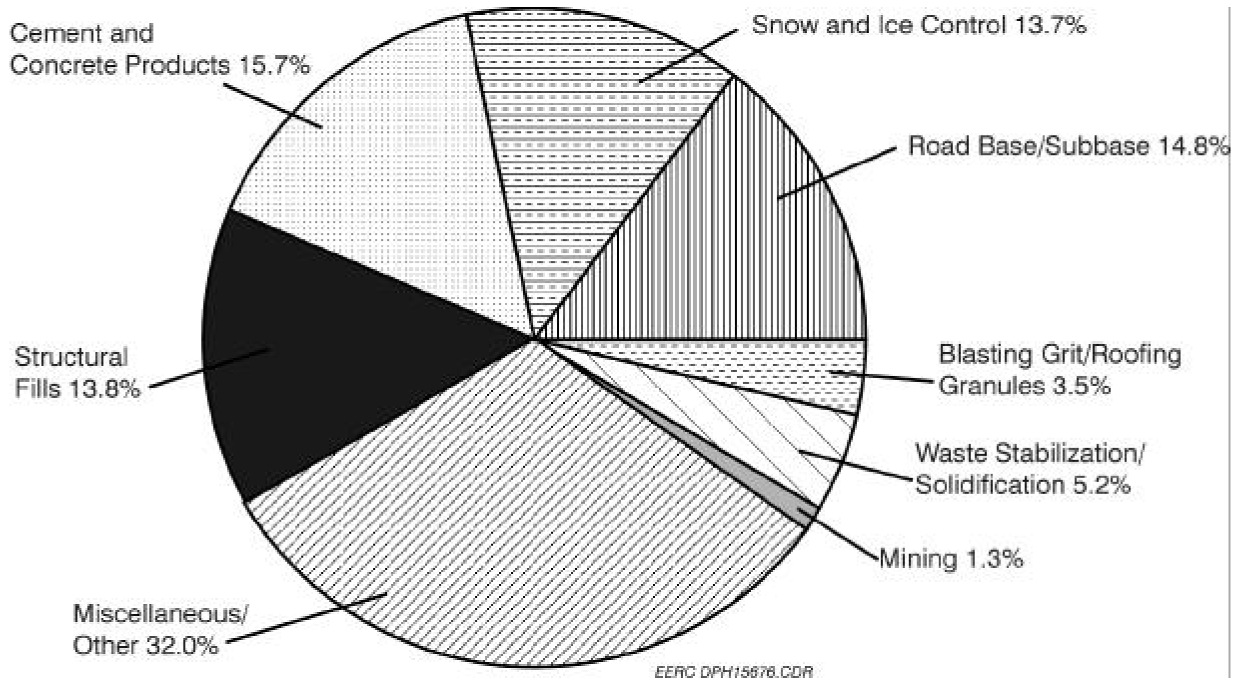

Figure 14. Leading bottom ash applications – 1996.

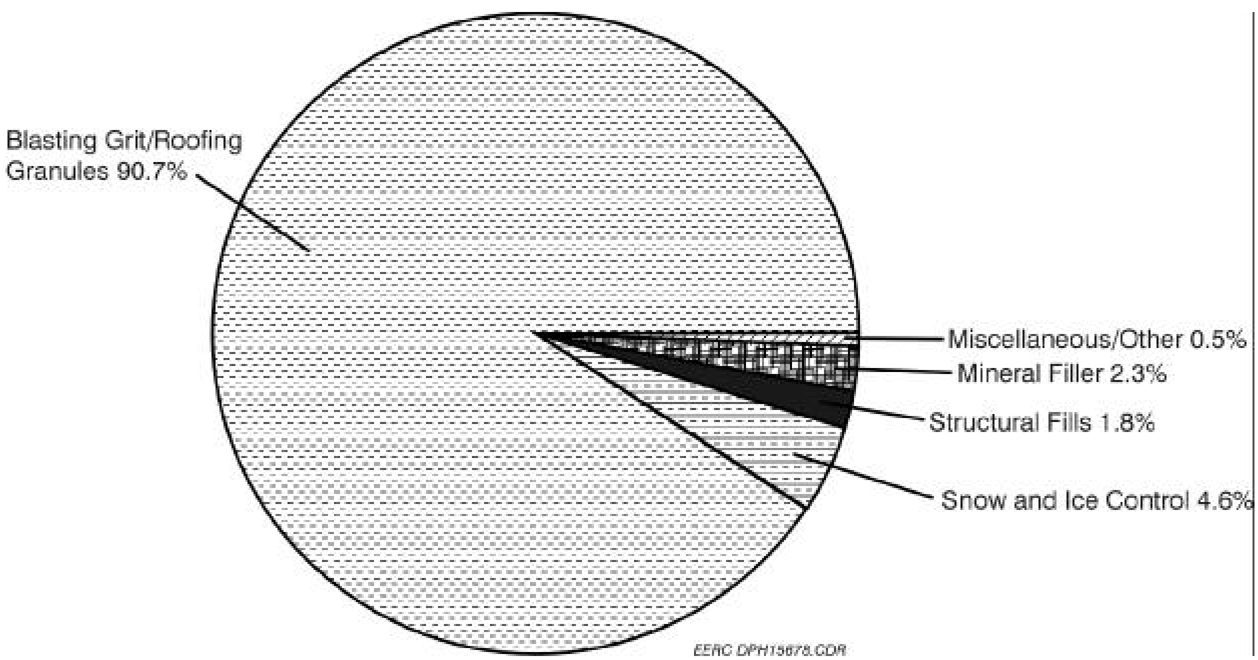

Figure 15. Leading boiler slag applications – 1996.

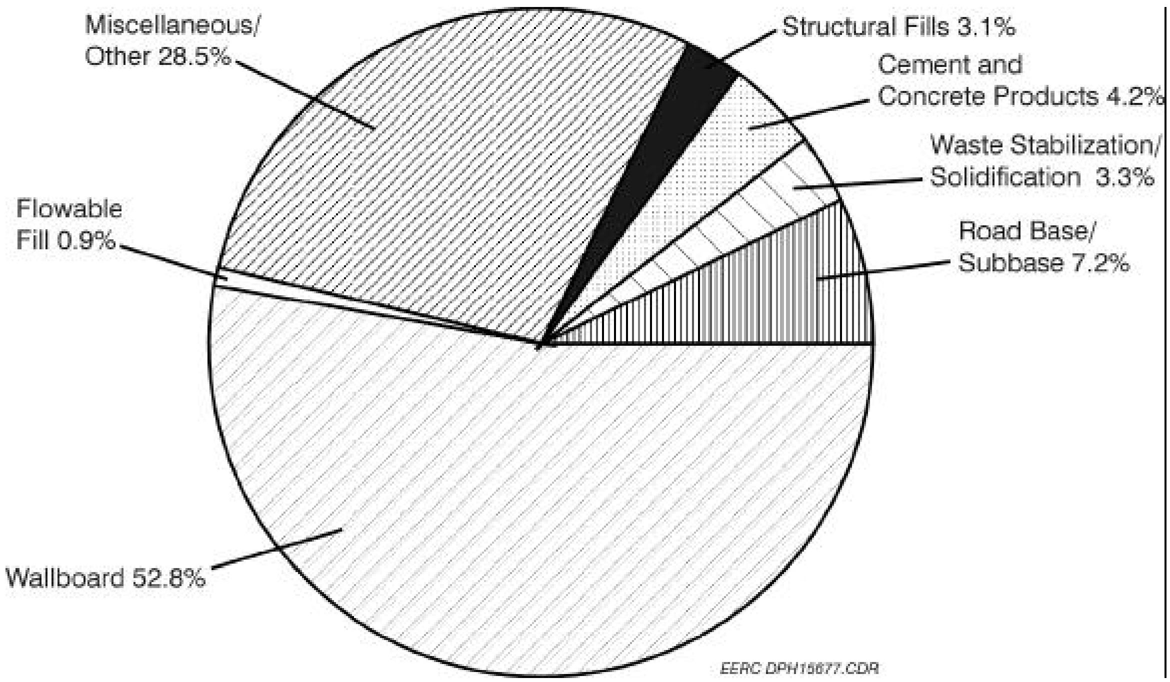

Figure 16. Leading FGD material applications – 1996.

3.2.3.3.1 Cement Manufacture

The fly ash can be incorporated into cement manufacturing either by substituting fly ash for the slag or rock normally used in the cement kiln to produce cement clinker or by blending fly ash directly with portland cement to produce blended cements. Fly ash for use in cement kilns is a potentially large market in areas where suitable fly ash is produced in the immediate vicinity of the cement plant and where transportation costs are favorable. Fly ash for general purpose blended cement is a more limited market in the United States because of its competition with direct replacement of cement at the ready-mix plant. However, intergrinding the ash with the clinker or blending it with ground cement and adding anhydrous $CaSO_4$ (anhydrite) produces a blended cement with characteristics that closely approximate those of portland cement.

In many European countries, the production of ordinary portland cement is being gradually replaced by production of portland–fly ash blended cement (Clarke, 1993). A European blended cement that combines cement kiln technology with direct blending could offer large-tonnage use of U.S. fly ash (Manz and Mitchell, 1985). The Belgian LTM process involves first sintering 40% fly ash with 60% limestone and fine-grinding the fused material and then blending this product with additional fly ash in a 40:60 ratio.

An EPRI (1998a) study of the raw materials used in U.S. cement plants found that a minimum of 40 plants could advantageously use fly ash as a raw material. They could each consume on average about 75,000 tons of high-carbon ash annually. If only 50% of this capacity is used, 1,500,000 tons of high-carbon ash could find beneficial reuse. This application could make a significant contribution to replacing outlets in ready-mix concrete, particularly if used in concert with other methods for separating ash into high- and low-carbon fractions. Several processing, operational, and product benefits can be expected from the use of fly ash in raw kiln feed. They are 1) reduced material-processing cost; 2) reduced dusting due to reduced comminution of raw materials; 3) improved burnability, resulting in lower burning; 4) lower temperatures and a consequent savings in fuel; 5) increased clinker production; 6) reduced SO_2 , hydrocarbon, and NO_x emissions (in the wet process); and 7) reduced generation of cement kiln dust.

Specialty blended cements variously used in mortars, plasters, and expanding grouts represent a smaller but viable market for fly ash. In these specialty applications, fly ash is mixed with other materials such as portland cement, lime, gypsum, slag, and alkaline activators. The cementing action and expansion properties of these CCBs are influenced by reactions of soluble calcium, aluminum, and sulfate to form ettringite, which has been studied extensively (Hassett and others, 1990, 1991; McCarthy and others, 1992). Spray-dryer and wet-limestone FGD by-products and Class C fly ash may be suitable sources of lime and gypsum in these applications.

Approximately 5% gypsum is typically interground with cement clinker in the production of portland cement. Portland cement is manufactured at numerous locations nationally, and U.S. cement production uses approximately 4 million tons of gypsum annually. The primary issues in gypsum use are cost, purity, and moisture content. While figures for the use of by-product gypsum or FGD gypsum in cement production were not available, it was indicated by one national manufacturer that by-product gypsum, and especially FGD gypsum, was used regularly and successfully at several locations nationally. Another smaller manufacturer indicated hesitancy to consider FGD gypsum because it was concerned about trace element content. Portland cement itself has been shown to contain high concentrations of certain potentially hazardous trace elements, such as chromium, and the industry and/or specific manufacturers are sensitive to environmental issues for regulatory and public relations purposes.

Recently, two U.S. patents have been obtained by Mineral Resource Technologies (MRT) for the manufacture of a series of cement products that utilize up to 90% fly ash and meet the ASTM standard specification for blended hydraulic cement. Commercial demonstration of this product is scheduled for fall 1998. Another recently reported cement-manufacturing process (GNE, 1998) purports to produce cement clinker directly in pulverized coal-fired furnaces by introducing proprietary chemical additives that combine with the coal ash. GNE also reports reduced CO_2, NO_x, and SO_x emissions when this technology is used. Processes such as these that rely on coal ash as their main feedback will likely be applicable in only a limited range of ash analysis.

3.2.3.3.2 Concrete Applications

As noted previously, the first high-volume use of fly ash was in concrete for construction of dams under the direction of the U.S. Army Corps of Engineers and BOR. The utilization of fly ash in concrete remains the highest-volume application for fly ash, representing nearly 50% of the fly ash and over 30% of the total CCBs used in 1996 (ACAA, 1997). Bottom ash is also used in concrete, but at a much lower rate and primarily as an aggregate. A discussion of the use of

CCBs in aggregates is included later in this section. The following list indicates the concrete applications where fly ash has been demonstrated or commercially used:

- Mass concrete
- Structural concrete
- Pavement
- Low-strength concrete
- Concrete products – block, pipe, prestressed panels and building components, parking stops
- Autoclaved aerated concrete (AAC) and foamed concrete
- High-performance concrete – high-strength, sulfate-resistant, salt-resistant, chemical-resistant, freeze–thaw durable, low-permeability
- Roller-compacted concrete
- Asphaltic concrete
- Sulfurcrete

Mineral mixture. The incorporation of fly ash into portland cement concrete generally requires the fly ash to meet one of two common standard specifications, ASTM C 618 and American Association of State Highway and Transportation Officials (AASHTO) M295. These specifications, noted in Tables 10 and 11, are very similar and specify limits for both chemical and physical characteristics of fly ash and natural pozzolans. Both standards designate specifications for Class F and Class C fly ash. Class F fly ash generally contains more silicon, aluminum, and iron (expressed as oxides) than Class C fly ash, which generally has a higher calcium content. As noted earlier, Class F fly ash is generally produced from bituminous coal or Gulf Coast lignite and Class C fly ash is produced from western U.S. subbituminous or lignite coal. The ASTM and AASHTO standards address the use of fly ash in concrete as a mineral admixture; however, in high-volume fly ash concrete, the fly ash is actually used as a partial replacement for portland cement. The technically sound use of fly ash in concrete generally results in the following beneficial effects:

- Reduced water requirements
- Increased ultimate strength
- Improved workability
- Extended setting time
- Reduced heat release

TABLE 10

ASTM C 618-98 Chemical and Physical Specifications (ASTM, 1998)

	Mineral Admixture Class		
	N	F	C
Chemical Requirements			
Silicon Dioxide, Aluminum Oxide, Iron Oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$), min. %	70.0	70.0	50.0
Sulfur Trioxide (SO_3), max. %	4.0	5.0	5.0
Moisture Content, max. %	3.0	3.0	3.0
Loss on Ignition, max. %	10.0	6.0[a]	6.0
Available Alkalies, as Na_2O, max. %[b]	1.5	1.5	1.5
Physical Requirements			
Fineness			
Amount retained on 325-mesh sieve, max. %[c]	34	34	34
Strength Activity Index[d]			
With Portland Cement at 7 days, min. % of	75[e]	75[e]	75[e]
control 28 days, min. % of control	75[e]	75[e]	75[e]
Water Requirement, max. % of control	115	105	105
Soundness[f]			
Autoclave Expansion or Contraction, max. %	0.8	0.8	0.8
Uniformity Requirements			
The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:			
Density, max. variation from average, %	5	5	5
Percent retained on 45-µm (No. 325), max. variation, percentage points from average	5	5	5

[a] The use of Class F pozzolan containing up to 12% LOI may be approved by the user if either acceptable performance records or laboratory test results are made available.

[b] Applicable only when specifically required by the purchaser for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation on alkali content.

[c] Care should be taken to avoid the retaining of agglomerations of extremely fine material.

[d] The strength activity index with portland cement is not to be considered a measure of the compressive strength of concrete containing the mineral admixture. The mass of mineral admixture specified for the test to determine the strength activity index is not considered to be the proportion recommended for the concrete to be used in the work. The optimum amount of mineral admixture for any specific project is determined by the required properties of the concrete and other constituents of the concrete and is to be established by testing. Strength activity index with portland cement is a measure of reactivity with a given cement and may vary as to the source of both the mineral admixture and the cement.

[e] Meeting the 7- or 28-day strength activity index will indicate specification compliance.

[f] If the mineral admixture will constitute more than 20% by weight of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated percentage. Excessive autoclave expansion is highly significant in cases where water-to-mineral admixture and -cement ratios are low, for example, in block or shotcrete mixes.

- 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 on (Pietersen and others, 1991). These reactions are inhibited by low alkalinity, low temperatures, or high water:solid ratios in pozzolanic systems. Reaction mechanisms overall are similar for either

TABLE 11

AASHTO M295-90 Chemical and Physical Specifications

	Mineral Admixture Class		
	N	F	C
Chemical Requirements			
Silicon Dioxide, Aluminum Oxide, Iron Oxide, ($SiO_2 + Al_2O_3 + Fe_2O_3$), min. %	70	70	50
Sulfur Trioxide (SO_3), max. %	4.0	5.0	5.0
Moisture Content, max. %	3.0	3.0	3.0
Loss on Ignition, max. %	10.0	6.0[a]	6.0
Calcium Oxide (CaO), max. %	30.0	30.0	30.0
Magnesium Oxide (MgO), max. %[a]	5.0	5.0	5.0
Available Alkalies, as Na_2O, max. %[a]	1.5	1.5	1.5
Physical Requirements			
Fineness, amount retained on 325-mesh sieve, max. %	34	34	34
Strength Activity Index with Portland Cement at 7 days, min. % of control	60	60	60
Water Requirement, max. % of control	100	100	100
Autoclave Expansion, soundness, max. %	0.8	0.8	0.8

[a] Optional requirement, applies only when specifically requested.

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.

The well-established empirical specifications for using Class C and Class F fly ashes in cement replacement do not always reliably predict performance. Additionally, it is important to note that use of the different classes of fly ash and different fly ashes of the same class can result in very different product performance. There are varying reports of the effects of the use of fly ash in concrete relative to its performance in express situations. Freeze–thaw durability of fly ash concrete can be ensured by 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). A June 1998 EPRI report (EPRI, 1998b) indicates that the resistance to scaling decreases with increasing amounts of fly ash and increasing water-to-cementitious materials (w/c) ratio. For concrete containing up to 35% Class F ash and up to 25% Class C ashes, a w/c ratio of below 0.4 exhibited satisfactory resistance. For the ashes used in concrete mixed above a w/c ratio of 0.4, the salt scaling was unsatisfactory. The curing conditions of the concrete were found to be a significant factor in the scaling resistance. The longer the duration of the drying period before testing, the greater the salt scaling. The microstructure of the curing cement paste at the onset of the freezing and thawing cycle appears to affect the deicing salt scaling of the concrete. Study results showed that the use of curing compounds to control the drying of the concrete during curing greatly improved the scaling resistance of all the concretes tested, but was even more beneficial to the fly ash concretes.

The resistance of fly ash concrete to salt scaling due to deicing in cold climates appears overall 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 siliceous particles to tie up alkalies and free lime by pozzolanic reactions (Butler and Ellis, 1991; Smith, R.L., 1993). The concrete expansion encountered during curing when certain Class C fly ashes are used 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 (Krüger and Kruger, 1993). High concentrations of sodium in certain western coal ashes, occurring in an organically associated form in the coal, are an identifiable cause of alkali–silica reaction.

Some of the fly ash concrete uses are described here in more detail because of the special role of the fly ash, special performance or environmental criteria, or impact to the CCB industry.

High-volume fly ash (HVFA) concrete. Investigations on HVFA concrete using up to 80% ash in the total cementitious material have shown that excellent mechanical properties can be achieved by using high dosages of superplasticizers (Berry and others, 1992; Naik and others, 1992a). National Minerals Corporation developed an HVFA called Pozzo-Crete that uses Class C fly ash from lignite for 70% of the cementitious material in the concrete mix. Pozzo-Crete was demonstrated extensively on the commercial scale in North Dakota through cooperation with local ready-mix concrete suppliers. Similar 70% fly ash concrete was placed at Cooperative Power's Coal Creek Station (EPRI, 1996a), and long-term performance evaluations were reported. HVFA (40%–70% fly ash) continues to be a viable commercial product in North Dakota (Dockter, 1994). The initial rate of strength development in HVFA is slowed by the addition of fly ash, especially Class F fly ash. At later stages of curing, increased strength relative to no-fly-ash concrete is attributed to pozzolanic reactions, which are highly dependent on the mineralogical properties of the fly ash. The use of higher levels of fly ash reduces early-time heat generation, volume change, thermal stress, and thermally induced cracking in massive concrete structures, thus permitting larger lift sizes (Hirata and Hammons, 1991). Extensive research on HVFA is being performed worldwide to develop optimum proportioning methods for a wide range of fly ash analyses in order to achieve predictable properties of water requirement, workability, setting time, bleeding, modulus, shrinkage, creep, permeability, freeze–thaw durability, abrasion resistance, compressive and flexural tensile strength, and fatigue strength (Thomas and others, 1993; Malhotra and others, 1993). The new mix technology expands the potential for large-volume fly ash use in applications such as massive foundations, dams, and piers. HVFA concrete is very adaptable to rolled concrete applications to provide the additional paste content needed for full consolidation (Saucier, 1982; Thomas and others, 1993). Data on long-term strength and durability of HVFA concrete are still not adequate to provide the confidence levels required for general acceptance of HVFA concrete for large construction projects, and further demonstration is needed.

Concrete products. Utilization of fly ash in high-strength prestressed concrete has been limited because of concerns that fly ash would retard early strength development and disrupt production cycles. Delayed strength development must be evaluated on the basis of the ash used and the replacement levels, and is not problematic with all fly ashes. Experimental production of both centrifugally and static-cast utility poles using up to 35% Class C fly ash from subbituminous low-sulfur western coal as a replacement for portland cement has been demonstrated to improve strength, workability, and finish by reducing the water requirement (Prusinski and others, 1993). Producers of precast and prestressed concrete products can realize substantial cost savings through development of mixes using locally available fly ash types.

The technology for using fly ash as part of the cementing agent in concrete building block parallels that for concrete in general. A recent study (Wei and others, 1993) indicated among its key findings that the substitution of 40% Class C fly ash for cement produced blocks with a slightly higher compressive strength than no-fly-ash reference block. In a separate study, Stephens and Nallick (1995) reported that concrete masonry blocks made with Class C fly ash did not begin to decrease in strength until more than 50% of the cement was replaced with fly ash. Fly ash blocks, because of the slower setting characteristics of fly ash concrete, were more sensitive to curing temperature and benefitted from accelerated steam curing. Fly ash blocks evidenced water absorption slightly higher than the reference block, but still within the requirement of the ASTM C 90 standard. The use of bottom ash as a replacement for natural aggregate beneficially reduced the weight of the block, but also reduced strength and increased water absorption.

Autoclaved aerated concrete and foamed concrete. Autoclaved aerated concrete (AAC) used in building blocks, roof slabs, and other cast products represents an important market for fly ash in Europe, but attempts to introduce fly ash in this technology in the United States have not succeeded commercially (Clarke, 1992; Sauber, 1991). In this process (Pytlik and Saxena, 1991; Payne and Carroll, 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 physically and chemically stable product. Two British firms (Kingsway Technology and Thermalite) have been using fly ash to produce AAC for more than 30 years. AAC blocks can contain up to 80% fly ash by weight, so the levels of ash use are much greater than in conventional concrete. Commercial production of AAC is currently under way in the United States. An AAC plant in Chattanooga is using fly ash from a Tennessee Valley Authority (TVA) plant.

Fly ash is used in foamed concrete in several European countries (Clarke, 1992), but it is not known to be in general use for this purpose in the United States. Foamed concrete is cast in place to construct floors, roofs, and walls because of its insulating properties; partial replacement of cement with up to about 30% fly ash has no significant effect on the properties of the foamed concrete product. Recent reports of the use of foamed concrete in the United States do not indicate that fly ash is being used commercially in this application.

Concrete in marine applications. Fly ash concrete, blocks, and precast products have been experimentally used in fresh and saltwater applications for breakwaters, reefs, substrate for marine aquaculture, and waterfront bulkheads replacing rotting timber. Concerns in using fly ash concrete in a marine environment are the slower rate of strength gain after pouring, the possible penetration of salt water, abrasion resistance and freeze–thaw tolerance in the splash zone, aerobic degradation, and possible leaching of heavy metals. These expressed concerns have not been noted as serious problems in documented demonstration projects, and marine applications appear to be a large potential market for CCBs along coastlines, inland lakes, and waterways. All of the available study reports indicated no significant heavy metal leaching or adverse effects on marine organisms (Kuo and others, 1991).

Sulfurcrete. Sulfurcrete is a manufactured structural product produced by blending aggregate material with molten sulfur and tamping the mixture into a mold. The material has high compressive strength and has been used in Canada, where it was developed, for making precast products such as parking curbs and support beams. Studies performed on the use of gasifier bottom ash from the Great Plains (now Dakota) Gasification Plant demonstrated that a very successful product could be prepared by combining ash with 25% sulfur (Manz and Mitchell, 1985).

Asphaltic concrete. The use of CCBs as filler in conventional asphaltic concrete pavement has been demonstrated. Currently, the ACAA and the National Center for Asphalt Technology are working closely in evaluating the potential for fly ash to be a preferred mineral filler in two new asphalt technologies, Stone Matrix Asphalt and Superpave. These asphalt technologies require specific characteristics for mineral filler, and preliminary work indicates that fly ash may be a good technical match.

3.2.3.3.3 Road-Building Applications

Road-building applications use high volumes of CCBs annually. Figure 17 provides an indication of the wide variety of applications where CCBs have been and continue to be used in road building. These applications have been researched, developed, and demonstrated effectively through numerous research projects funded by EPRI (EPRI, 1989a–d, 1996a). Because of the high-volume usage of CCBs in these applications, RD& D continue with the goal of developing fully commercially acceptable technologies. The use of CCBs in various surface applications includes concrete and asphaltic concrete pavement as well as surface for unpaved roads. Road building also involves a variety of fill applications, embankments, and base applications for which CCBs have valuable engineering properties. These applications represent some of the best opportunities for getting new CCB materials incorporated into specifications used by highway engineers, which accounts for the numerous demonstration projects performed nationwide.

Road base and subbase. Road base and subbase are among the leading applications noted in the ACAA utilization statistics, which have been widely demonstrated and have gained

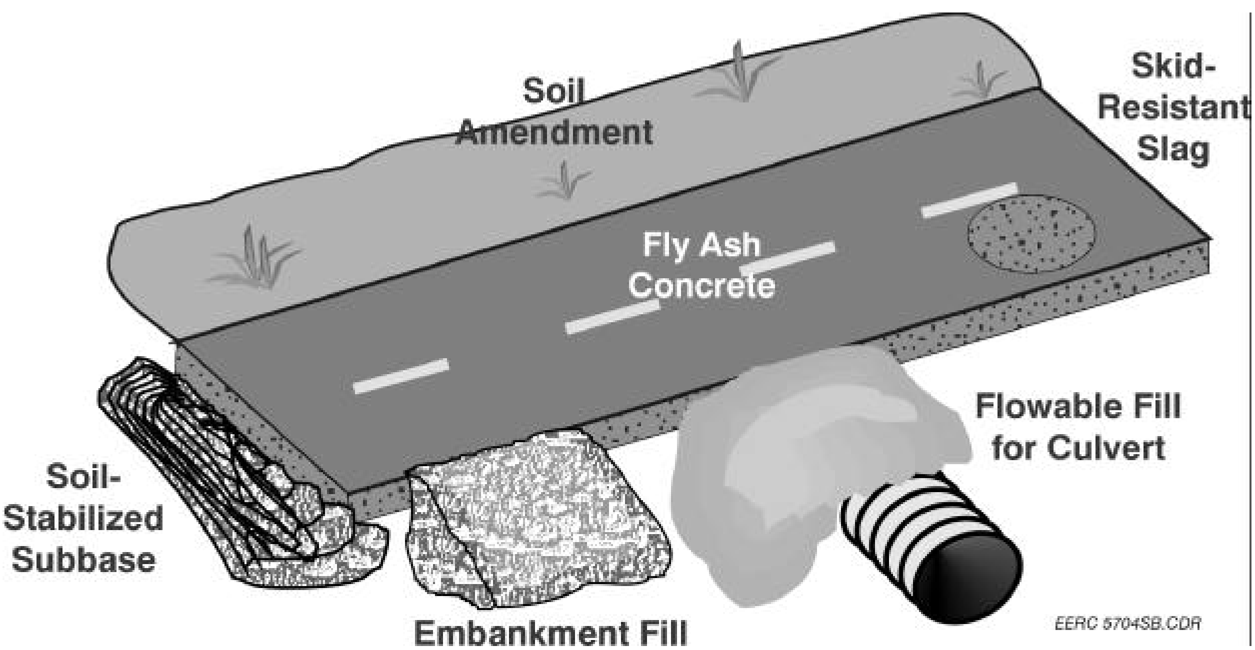

Figure 17. Use of CCBs in road building.

commercial acceptance in some states. The use of fly ash alone or together with lime or cement in self-hardening road base is an evolving technology. New information in this area includes 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 four-lane highway has indicated quite satisfactory performance since its construction in 1987 (Gray and others, 1991a). Some heaving and cracking occurred in winter months as a result of frost effects. Laboratory leachate concentrations tested for heavy metals using ASTM and RCRA (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, 1988). The wet pond ash, when compacted in 4-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, 1991).

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, limestone injection modified burner (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).

The use of fly ash and bottom ash for the construction of permeable base course was demonstrated at laboratory scale at the EERC (Pflughoeft-Hassett and others, 1996) and is currently being demonstrated in a road project in North Dakota.

3.2.3.3.4 Engineered Fills

Structural fills and other high-volume fills. Structural fills and other high-volume fills are significant marketing opportunities to the industry from the perspective that they use large amounts of CCBs, generally with no other additives. In these applications, CCBs compete with borrow or soil fill. These applications fall into the area where regulation of CCB disposal versus utilization becomes an issue because large fill projects can appear to have similarities to disposal without the benefits of liners, leachate collection, and monitoring. The CCB industry has worked to develop ASTM standards that delineate the beneficial properties of CCBs in fill applications and detail appropriate test procedures to ensure technical and environmental performance when these projects are undertaken (ASTM, 1997).

Controlled low-strength materials. CLSMs are fills that are formulated from a pozzolanic material such as fly ash along with small amounts of cement, a natural filler such as sand, and water. ACI has developed a standard for CLSM. 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. A newly patented flowable fly ash fill developed by American Electric Power Company is made entirely from CCBs and water (Hennis and Frishette, 1993). 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 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 embedded 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% of 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 cement replacement 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 fills, 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 up 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 1726 psi at 28 days had reached a strength of 3000 psi. Class C fly ash is itself a cementing agent, and a 1500-psi 28-day strength is achieved using only about 3% portland cement and 5% high-calcium fly 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 that of 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 10:1 ratio, although fly 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 mine from whence it came, while at the same time remedying related environmental problems.

3.2.3.3.5 Mining Applications

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

- 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).

- Use of CCBs in reclamation activities or highwall mining (Paul and others, 1993; Robl and Sartaine, 1993).

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

These three options represent most, but not all, scenarios under which coal by-products 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 generate leachates at high pH, tend to form the mineral ettringite. The alkaline nature of some coal by-products (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; EPRI, 1996b). 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 would leach to release low concentrations of several problematic trace elements at lower pH tends to form stable minerals, incorporating some of the more problematic trace elements found in coal ash, at high pH. Although ash is generally benign with respect to leaching significant concentrations of potentially problematic elements, proper and environmentally sound testing should be conducted. This testing should be done using long-term as well as short-term leaching procedures to determine the total mass of trace elements that may potentially be mobilized and the trends of analyte chemistry evolution. Although the leachate chemistry of most trace elements is characterized by a slow increase in concentration toward an equilibrium 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 EERC. The only observed impact was caused by the disturbance of the environment at the time of mining. An increase in total dissolved solids, mostly from sodium sulfate, was observed, but this rapidly returned to background levels (Beaver and others, 1987). A similar mine fill study was done in a wet environment near Wilton, North Dakota (EPRI, 1996a), where the ash was placed below the water table. Again, there was an increase in dissolved solids that rapidly returned to background levels.

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 for land reclamation, and in the case of underground mines, for stabilization 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 coal by-products in the environment (Ackman and others, 1993; Paul and others, 1993).

3.2.3.3.6 Agriculture and Soil Amendments–Synthetic Soil–Compost

Coal use by-products are being evaluated as soil amendments. Soluble forms of calcium, magnesium, sulfur, and certain necessary trace metals such as boron, molybdenum, zinc, selenium, and copper that are present in coal ash and FGD by-products can be used to provide needed plant nutrients. No significant amounts of the primary nutrient elements—nitrogen, phosphorus, and potassium—are found in coal ash, but wood ash is rich in potassium and phosphorus. By-product gypsum ($CaSO_4 \cdot 2H_2O$) 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.

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 TVA on the inclusion of lime/limestone scrubbing waste into fertilizer formulations (Santhanam and others, 1981). Research has also been conducted on the agricultural use of wood-fueled power plant ash from generating units in California (Wheelabrator Shasta Energy Co., 1991; Meyer and others, 1992).

In controlled greenhouse tests on several different coal products (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 sulfite 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 PFBC by-products (Beeghly and others, 1993) was sponsored by the Ohio Coal Development Office, DOE, EPRI, Ohio Edison, American Electric Power, Dravo Lime Company, and Ohio State University. By-products from fifteen sources were investigated, representing four major clean coal technologies, including furnace injection FGD (LIMB), duct injection FGD, spray-dryer FGD, and FBC (AFBC 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 10%–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 were performed successfully (EPRI 1995a, b). The U.S. Department of Agriculture is currently working to develop guidelines for the use of these materials as an agricultural soil amendment (Ralph Clark, USDA, personal communication, Sept. 1998).

The commercial N-Viro soil process (Burnham, 1993) combines agricultural use with waste stabilization by composting coal ash by-products or cement/lime kiln dust as originally used with municipal wastewater treatment sludge. The soil conditioner produced has a low nutrient value (1% 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 coal ash by-products 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 coal ash residues 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 midwestern 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 coal ash by-products 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 coal ash by-products 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, 1981), 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, 1981), 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, including the EPA extraction procedure (EP) and 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 worst-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, 1992]). Well-coordinated research covering a carefully selected classification of by-product materials and utilization settings will be required to provide the confidence level required for large-scale, nonrestricted use of coal ash and FGD by-products in agriculture.

3.2.3.3.7 Ceramic and Brick Products

A number of studies have shown that fly ash can be used either as a replacement for clay in fired bricks or in combination with lime or cement in steam-cured bricks. Both types of fly ash brick offer advantages of lighter weight, better heat insulation, and less sound transmission compared to clay bricks. Economic analysis performed by the University of Wisconsin for EPRI indicates that the use of CCBs in brick manufacture is economically attractive (Naik and others, 1992b). Other coal ash-derived ceramic materials that have been investigated include glazed wall and floor tile and high-flexural-strength power poles and railroad ties (Manz and Mitchell, 1985; EPRI, 1979; Naik and others, 1992b; Dockter and others, 1997). Other studies have used beneficiated ash to produce mullite as a refractory material for ceramic-lined furnace walls (Huang and others, 1995).

Research on the manufacture of various types of brick from fly ash and bottom ash indicates that these products offer a good potential for achieving superior properties at reduced cost. The ash bricks are lighter in weight and provide better sound absorption and heat insulation compared to clay brick. Depending on the methods used in their production, they can offer lower shrinkage and higher resistance to freezing and thawing, but may also suffer from higher water absorption. Methods of manufacture involve either the replacement for clay in fired brick or the combination of fly ash with cement or lime binder in unfired but steam-cured bricks. Economic studies show that the use of coal ash in brick can provide substantial savings, both to the utility producing the ash and to the manufacturer of the brick (Naik and others, 1992b).

3.2.3.3.8 Aggregates

Methods for the manufacture of artificial aggregates from fly ash or other CCBs can be distinguished by the conditions employed for hardening the pellets. Sintering processes (Puccio and Nuzzo, 1993) rely on the residual carbon content of the fly ash, with addition of pulverized feed as required, to heat pellets to sintering temperatures above 900°C. Hydrothermal and cold-bonding processes applied to fly ash, portland cement, and lime use steam or extended curing time at temperatures ranging from ambient to about 250°C. Sintering processes are a 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, 1991).

Synthetic aggregate was experimentally produced from lime-based spray-dryer FGD by-products in the early 1960s by pelletizing at pressures of 5 to 20 tons per square inch followed by extended 10- to 60-day curing under controlled moisture conditions (Donnelly and others, 1986). Strength properties were adequate for confined applications such as road base. Production costs in 1982 were estimated to be $5.20/ton in a facility sized to process by-product from a 400-MW plant burning low-sulfur western coal. Pellets produced from coolside, LIMB, and 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). Similarly, recent work done at Iowa State University using Class C fly ash and AFBC by-product combinations in the manufacture of synthetic aggregates showed that satisfactory base and subbase aggregates can be produced (Bergeson and Waddington, 1995). In Montana, lightweight aggregate was produced using 90% Class C fly ash and 10% portland cement (Stephens and Nallick, 1995). The mixture is cast into thin sheets, steam-cured, and crushed in a standard hammer mill. 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-O-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. A similar cellular aggregate is produced in the United States by combining dewatered wastewater solids, fly ash, and bentonite. During treating, organic fractions are combusted, resulting in a hard, cellular lightweight aggregate (Nechvatal, 1995).

3.2.3.3.9 Industrial Uses

A large number of potential uses for CCBs in industrial applications have been investigated. Commercial practice is very limited in the United States, but is more common in other countries. For example, production of gypsum from FGD facilities is common practice in Europe, and substantial amounts of fly ash brick are produced in China.

Gypsum. The production of salable by-product gypsum from FGD is an economic opportunity that presents both technical and marketing challenges for utilities. The technical requirements for producing market-grade gypsum involve process adaptations to provide sufficient aeration and reaction time in the scrubber circuit to oxidize calcium sulfite sludge to a high-quality 92% to 95% gypsum product (Pauken and Wieskamp, 1993). Most existing lime/ limestone scrubbers operating in the United States are not designed to produce gypsum, as they generally are in Europe. However, a significant number of U.S. installations could be modified to produce gypsum by adding air bubbles (spargers) and reaction tanks to facilitate the required oxidation. Alternatively, oxidation can be accomplished by reprocessing the sulfite sludge in a separate facility. Markets for gypsum are found in masonry products and wallboard manufacture. Wallboard presents the largest and most promising market, using approximately 75% of the gypsum consumed in the United States (Luckevich and others, 1995), wherein FGD gypsum could be substituted for part of the 26 million tons of natural gypsum consumed annually. U.S. gypsum consumption is of the same order as the total U.S. sulfur control requirement after the CAAA are fully implemented in the year 2000, making this market a viable target for recycling. Successful marketing of FGD gypsum requires that utilities work collaboratively with wallboard manufacturers to ensure a dependable supply of specification-grade material meeting standards for purity and low levels of moisture and soluble salts.

Mineral wool. Mineral wool insulation has been experimentally produced from coal ash slags in tests performed by TVA, the University of North Dakota, and the University of West Virginia (Dockter and Manz, 1993; Manz, 1984). The process uses traditional methods for converting molten slag to fiber, either by centrifugally spinning the material off a rotating disk or by blowing with compressed air. Experiments indicate that slags produced in some cyclone-type utility boilers are within a range of chemical composition that would allow mineral wool to be produced directly from hot molten slag taken from the boiler. Engineering cost estimates show that this concept, which incorporates substantial energy savings by using hot slag directly from the boiler, could be highly competitive with traditional manufacturing processes that remelt steel mill slag or rock using coke for fuel.

Fillers for metals and plastics. Fly ash cenospheres can be uniformly distributed in cast aluminum alloy to reduce the weight and cost of aluminum castings (Rohatgi and others, 1993). Techniques have been developed for casting ash–alloy billets containing up to 20% by volume of fly ash cenospheres. Fluidity upon remelting is adequate to allow casting by standard foundry practices. The addition of fly ash decreases density and increases modulus (stiffness), hardness, and abrasion resistance. Tensile strength is decreased slightly, whereas compressive strength is increased. The ash–alloy has a higher strength-to-weight ratio than steel at a cost lower than aluminum. The greatest potential application of ash–alloys are in the automotive industry and for electromechanical machinery (Rohatgi and others, 1995).

Fly ash has been used experimentally as filler in both thermoplastic and thermosetting plastics, where its lightweight, high-temperature chemical inertness and electrical insulating properties make it a suitable substitute for glass microspheres or talc normally used in thermoelectric products (Quattroni and others, 1993). Studies have shown that fly ash can be used to replace commercial fillers in PVC, polypropylene, polyethylene, and nylon, with no loss of mechanical properties (Huang and others, 1995; Dockter and others, 1997).

Paint. Fly ash has been tested in a number of paint formulations including alkyd, epoxy and vinyl vehicles, and zero-solvent coatings (Growall, 1991). The spherical shape of fly ash particles and the beneficial chemical properties of certain ashes offer advantages when the ash is used as paint fillers or pigments. The minimum surface-to-volume ratio of spherical particles allows higher pigment concentrations and good flow and leveling properties with less vehicle or solvent. When compared with conventional formulations using pigments such as titanium dioxide, calcium carbonate, and iron oxide, primer paints made from selected fly ashes have been found to dry faster and set harder and, in certain cases, exhibit superior adhesion, rust inhibition, and durability.

Metals recovery from coal ash. Research has been performed on the recovery of alumina, magnetite (iron), and other valuable minerals and elements (e.g., zinc, titanium, molybdenum, nickel, gallium, germanium, selenium, and rare-earth elements) from coal ash by alkali/acid leaching and other physical and chemical separation methods (Hassett and Mitchell, 1985; Hassett, 1988; Gilliam and Canon, 1982). At present, these processes do not appear to be competitive with more established processes and sources of supply. However, over the long term, coal ash could potentially become an important source of minerals. For example, the aluminum content of fly ash produced in the United States is sufficient to completely offset bauxite imports (Santhanam and others, 1981). Zinc concentrations in some fly ashes are comparable to those in commercial ores. Commercialization of these applications will require either a technical breakthrough or a fundamental change in economics or availability of supply.

3.2.3.3.10 Waste Stabilization

The cementitious and pozzolanic properties of fly ash that make it useful in concrete also allow it to solidify and chemically immobilize soluble inorganic wastes and organic chemicals. Significant interest exists in using fly ash and CCT by-products for waste stabilization, and several commercial vendors have developed patented processes. Waste stabilization processes typically involve controlled mixing and curing using lime, fly ash, portland cement, and various additives. EPA is devoting substantial research efforts to developing better predictive capabilities for solidification, waste fixation, and long-term performance characteristics. Clean coal technology by-products, on the basis of their chemical composition, have an even better potential for hazardous waste stabilization than fly ash alone, and DOE and EPRI are jointly investigating these materials.

Review of waste stabilization applications. A 1991 survey of waste stabilization activities conducted by Radian Corporation for EPRI (EPRI, 1991a) identified 10 commercial applications and 19 research projects using fly ash for waste stabilization. The binders that were used included various Class C and Class F fly ashes combined with lime, cement, kiln dust, clay, recycled rubber, asphaltene, blast furnace slag, and calcium sulfite anhydrite. A large number of different organic and inorganic wastes were treated, including oily sludge, alcohols, benzene and other aromatic compounds, polychlorinated biphenyl (PCB)-contaminated soil, oil well drilling mud, radioactive wastes, metal (e.g., Mo and Zn) processing sludge, electroplating sludge, iron and steel wastes, sewage sludge, municipal incinerator ash, kiln waste, FBC bed ash, FGD scrubber sludge, acid-pickling liquor, and wastes containing cadmium, mercury, lead, and arsenic.

In order to understand the developmental status of waste stabilization using CCBs, it is helpful to consider the following selected case histories (Fazzini and others, 1991; Gilliam, 1991):

- The city of Wilmington, Delaware, has treated 150,000 tons of lagooned sewage sludge containing approximately 15% moisture by staged mixing with fly ash and lime kiln dust to produce a soil-like product that could be excavated for use as landfill cover.

- A Kentucky chemical plant treated 90,000 cubic yards of combined organic and inorganic sludge containing up to 35% moisture by blending with fly ash and a cementitious additive to produce a stable landfill.

- A Florida steel-manufacturing site remediated 62,000 cubic yards of PCB-contaminated soil under an EPA consent decree by transporting it to a central plant; mixing with fly ash, portland cement, and water; and returning the material to the excavation site for permanent placement.

- A Pennsylvania defense contractor treated 15,500 cubic yards of sludge and contaminated soil to meet stringent TCLP leaching requirements for cadmium, chromium, lead, nickel, and silver by first mixing the sludge with fly ash and lime to produce a manageable material for temporary stockpiling and subsequently blending this stabilized material with cement to achieve an unconfined compressive strength of 50 psi.

The final mixture was compacted in layers into a RCRA disposal cell, which was constructed using a 3-ft clay liner and a double high-density polyethylene (HDPE) liner system.

- Oak Ridge National Laboratory (ORNL) for many years disposed of low-level radioactive waste by mixing it with a blend of portland cement, Class F fly ash, and clay minerals and injecting the pumpable grout into an impermeable shale formation at a depth of 200 to 300 meters. ORNL and other DOE nuclear sites have used a variety of grouting processes to solidify large volumes of liquids, sludges, and fine solids containing heavy metals, organics, and radionuclides for disposal by deep injection, near-surface impoundments, and casting into durable monoliths.

Other recent studies of CCBs in waste stabilization have included work on the following topics: metal-bearing industrial wastes (Nonavinakere and Reed, 1993); lead-, zinc- and cadmium-contaminated soils (Baldwin, 1993; Oyler, 1993); electric arc furnace dust (Smith and Yu, 1991); incinerator ash (Vaquier and others, 1993); municipal waste sludge (Elini and Amodio, 1993; Oyler, 1993); cutoff walls to prevent lateral migration of landfill leachate (Gray and others, 1991b); low-permeability grout and liner for mineland reclamation (Bowders and Harshberger, 1991; Bergeson and Lapke, 1993); and use of treated municipal sludge for reclamation of mine spoils (Burnham, 1993)

4.0 1998 REVIEW OF BARRIERS TO CCB UTILIZATION

While the DOE RTC called attention to the technical, economic, and environmental advantages of CCB utilization and the barriers to increasing CCB utilization, it is evident by the statistics and anecdotal information that the barriers still exist in 1998 despite the concerted efforts of DOE, the CCB industry, and other interested parties. It is for this reason DOE decided to review the barriers and recommendations of the RTC and to update the information on institutional, legal, and regulatory barriers. This review serves to document the progress made since 1993, reassess the status of barriers identified, identify any new barriers, and reevaluate priorities for reducing or removing barriers to the increased utilization of CCBs.

4.1 Review of Barriers Reported in the Literature Prior to the 1994 RTC

Institutional constraints to coal fly ash use in construction were evaluated based on survey data in a 1992 study report prepared by GAI Consultants, Inc., for EPRI (1992). The findings and conclusions of this EPRI study are valid for CCBs generally concerning institutional barriers, although the constraints posed by technical and economic issues were not addressed. The principal findings in the report were as follows:

- No coherent policy exists among federal and state agencies covering the beneficial use of CCBs. The existing patchwork of incentives and disincentives creates confusion leading to inaction.

- Extremely wide variations exist among states in the uses allowed and the restrictions placed on use.

- A general lack of explicit guidelines has, by default, led to overly conservative regulatory practices, often involving case-by-case approval.

- Engineering specifications adopted by state and federal agencies for cement replacement, typically relating back to ASTM or AASHTO standards, have had a positive influence on ash use, but many states have adopted more restrictive specifications without evident justification. Efforts to achieve greater uniformity would be beneficial.

- Engineering specifications and environmental data are lacking for high-volume uses (other than cement replacement) such as CLSM, road base, and grouting. Development of guidelines within state and federal agencies is needed to expand ash use in these areas.

- Nine major institutional constraints were identified:
  - Lack of familiarity with potential ash uses
  - Lack of data on environmental and health effects
  - Lack of physical/engineering data
  - Restrictive or prohibitive specifications
  - Inconsistent fly ash quality and quantity
  - Fly ash regulated as a solid waste
  - Potential liability
  - Raw materials more readily available and more cost-effective
  - Unfavorable shipment taxes

- Federal agencies, the departments of transportation (DOTs), and environmental regulatory agencies in thirty-two of the major coal ash-producing states and the ash-marketing organizations and utilities and related organizations in ten countries were asked to comment on the above constraints:

  - Statewide DOTs identify 1) competing materials, 2) lack of uniformity in ash quality, 3) environmental liability, and 4) the related areas of regulatory classification and lack of environmental data as key issues.

  - State environmental agencies stress 1) regulation of solid waste and lack of environmental data, 2) lack of engineering data, and 3) variability in ash.

  - Federal agencies emphasize 1) engineering and environmental data and 2) competing materials.

  - Foreign agencies emphasize the regulation of solid waste as a key issue, indicating an emphasis on regulation rather than markets.

- – Ash marketers stress adverse perceptions as a major area of constraint more than substantive issues.

- The documentation of lessons learned in testing, demonstration, and extended use through the compilation and assessment of environmental and performance data was identified as an essential element relating to abatement of all other constraints.

- EPRI action recommendations for removing barriers were focused on five requirements:
  - Education
  - Demonstration
  - Collection of environmental data
  - Standardization of specifications
  - Development of state guidelines

In an earlier analysis of institutional barriers to the utilization of power plant ash in Maryland, ash storage and transportation were reported to be key constraints (Hudson and others, 1982). The necessity to control dust generation and surface runoff requires producers to store and transport ash materials in closed silos and sealed trucks or, alternatively, to wet down the by-products, making them of little use to marketers and end users. In these circumstances, cost, environmental protection, and quality control pose conflicting constraints. These findings and similar experiences in other states illustrate the close link between institutional, technical, and economic barriers.

4.2 Institutional Barriers

In the 1993 review performed by the EERC for DOE, similar barriers were identified after extensive interviews, open forums, and a workshop. The institutional barriers identified were as follows:

- Economic
- Marketing
- Environmental and public perception
- Technical
- Education and attitude

4.2.1 Economics

Economic barriers to increased CCB utilization can be considered key elements among all of the factors affecting by-product use. If the economic incentives are in place, often the necessary resources needed to overcome other barriers to increased CCB utilization will be available.

For coal-fired electric utilities, the amount of revenues produced by the sale of by-products is often insignificant in relation to the revenue stream provided by the sale of electricity. The prices received for by-products are simply too low to justify much of a commitment to by-product marketing. There is little economic incentive for utilities to allocate personnel and equipment costs to develop a by-product management strategy. In many cases, the sale of by-products will take place only if it can be achieved with little effort and capital outlay.

In many utilities, the sale of by-products is viewed as merely a means of reducing operational costs by avoiding disposal cost, referred to as “cost avoidance.” When ash management is considered an operational cost avoidance rather than a revenue stream, the incentives for increased by-product utilization are reduced. The way in which utilities account for costs is especially critical. As noted earlier, these issues are changing with the impending deregulation and the reports of significant profits from CCB sales realized by some utilities.

The market price of CCBs varied greatly, ranging from $4 to $25 per ton, depending on the material (bottom ash or fly ash) and the transportation costs. Most commonly, the price of fly ash was reported as $12 to $15 per ton of material. One of the reasons for this large variation in price is that some marketers purchase only ash from the power companies, while other marketers take all by-products as a service to the power companies, sell the marketable portion, and then dispose of the by-products that are not salable. Some power companies also sell their own ash, which also causes a variation in the price of these materials. The primary barriers for marketers is economics. There must be a profit available in marketing CCBs for a particular application. Some southeastern utilities are known to give away their FGD gypsum to the local farmers who will haul it away for agricultural applications. The opportunity for marketing these materials for agricultural uses is then eliminated. In some cases, transportation costs prohibit CCB use because of the distance from the source of the materials.

Traditionally, CCBs have been used to reduce the cost of a project or product. From the results of numerous research projects, demonstrations, and commercial and public projects, CCBs have also been shown to improve the quality of products. The best example is fly ash concrete, which typically has higher long-term strength, improved sulfate resistance, reduced permeability, and decreased alkali–silica reactions compared to portland cement concrete. Cost savings and end product quality were of key importance to most individuals interviewed, and anything that would improve or at least maintain product quality while maintaining or reducing the cost would be favorably considered. It was widely indicated that products containing CCBs are often viewed as low quality because of lack of familiarity with demonstrated applications and that this erroneous perception is responsible for the slow commercialization of CCBs in many industries. The economics of CCB utilization are influenced by the cost and availability of competing materials, transportation charges, and the need for new or modified facilities. Government subsidies for some traditional materials also adversely impact the competitive position of CCBs.

4.2.2 Marketing

Competition between traditional raw materials and CCBs was found to be very important. Most industry representatives indicated that competition is good, but noted that in some cases those interested in the promotion of traditional materials build on negative information regarding CCBs, including the fact that these materials are wastes, that there have been unsuccessful projects performed using CCBs, that CCB composition may not be consistent, that special handling may be required, and similar information. Although these issues can be documented, it is also generally true that most of them can be refuted, but the general lack of familiarity by many potential end users results in a low comfort level with use of CCBs and difficulty in maintaining and expanding current markets and developing new markets.

A specific case of competition is that of portland cement with coal fly ash. Coal fly ash has long been used as a mineral admixture in concrete and has often been termed a cement replacement. Use of fly ash, either pozzolanic or cementitious in nature, in concrete has been shown to be very advantageous, and it is obvious that the replacement of cement with fly ash reduces the amount of cement in a concrete mix. Cement producers and the Portland Cement Association promote cement use, but also have participated in research, development, and commercialization of blended cement containing fly ash, by-product use in cement manufacturing, and use of fly ash as a mineral admixture in concrete. In recent years, the cement industry has come to accept CCBs in the marketplace. Several cement companies sell coal ash and products containing coal ash such as blended cements. It has been speculated that more concrete will be sold because of the economic advantage gained with addition of fly ash and that the cement market may increase because of this. Many cement manufacturers now market CCBs in addition to cement. In some concrete markets, the performance of fly ash concrete cannot be matched by that of portland cement concrete. An example is high-strength concrete used in construction of high-rise buildings. The strengths required for these applications are above 10,000 psi. It is not technically feasible to achieve strengths beyond 10,000 psi using portland cement concrete, but strengths in this range are regularly reached using a combination of cement, fly ash, and superplasticizer. This high-strength concrete is a key example of a specialized product being produced with inclusion of CCBs as a raw material.

While the cement industry is an example of competition for CCBs that appears to be approaching a mutually beneficial resolution in the marketplace, there are still some barriers to CCB use in some applications where cement is well accepted. An example is in CLSM, where environmental testing may be required for coal fly ash used in this application but not for cement. The lack of a level playing field for CCBs as an engineering material is also seen in its competition with other traditional raw materials. Interviews generally indicated a better acceptance of natural aggregates as proven materials for many applications.

One interesting example of materials competition is that between FGD gypsum and natural gypsum for use in wallboard manufacturing. It is indicated that FGD gypsum can generally be substituted for natural gypsum at about 10% without changes in the manufacturing equipment, although some wallboard plants have been designed to use 100% FGD gypsum. In the case where a 10% substitution is made, recycled gypsum from waste wallboard may also be substituted at 10%. With rising costs of disposal for construction materials, more waste wallboard is being reclaimed from construction sites and recycled in wallboard plants, which may reduce the amount of FGD gypsum now being used in this industry. It is also important to note that natural gypsum is subsidized by the federal government through a depletion allowance, which impacts the economic competitiveness of the natural material versus FGD gypsum.

Despite efforts by some groups to educate their customers about the benefits of CCB utilization, customer lack of familiarity and negative perceptions are major barriers. In many instances, customer familiarity and perception are closely tied to acceptance of these materials for specific projects. It is also important to note that in the case of road-building applications, the customer may be federal, state, or local government, and in the area of CCB use in concrete paving and other road-building applications, a high degree of frustration was indicated by some private contractors and engineers at the lack of willingness to try this “new” material or to learn about potential applications for the materials. From this standpoint, the federal and state DOTs are frequently described by private industry CCB users as a key barrier to increased utilization. The lack of familiarity on the part of DOT representatives with CCBs and their uses was noted as a key barrier by many industry contacts as well as by utilities and marketers. It was also indicated that an unwillingness to change or experiment with “new” technologies was commonly found in state DOTs and in the engineering and architectural professions. It was generally indicated that private construction projects and local road-building projects are much more open to CCB utilization, with the stipulation that the end product be equal to or superior in performance to the product not containing CCBs.

Representatives of several trade associations and engineering firms interviewed also indicated that a lack of familiarity with CCBs and their use applications is a major barrier. They indicated that the kind of information that end users and engineers need is not readily available for CCBs. The engineers interviewed stated that their profession is generally unfamiliar with CCB utilization and were particularly candid in their assessment of the engineering profession as one resisting change. They indicated that many variables are used in specifying projects and use of an unproven material is seen as an unnecessary risk when a standard material has been shown to meet project requirements. It was also indicated that CCB marketing efforts are not getting information to end users. A lack of demonstration projects or familiarity with existing demonstrations was also noted as a barrier, consistent with other comments made in the interviews. From the standpoint of engineering and architectural contacts, another related barrier is the potential liability for failed projects.

4.2.3 Environmental and Public Perception

The perception of CCBs as wastes is of itself a barrier to CCB utilization. In some instances, individuals interviewed insisted that they are hazardous wastes, reflecting a lack of information and understanding of these materials. The perception that these materials are generally hazardous in nature may come from an association of the term solid waste with that of hazardous solid wastes; it has been noted in the CCB industry that this is sometimes an automatic, albeit erroneous, association. General acceptance of CCBs as risk-neutral raw materials for manufacturing in place of competing raw materials will be realized only when their nonhazardous characteristics are recognized. Environmental barriers to the utilization of CCBs are driven and maintained primarily on the premise that the residues are wastes. Environmental barriers are tied to regulatory barriers to CCB use as they relate to CCB categorization under RCRA.

Regulatory agencies, the coal-mining industry, the utility industry, and the CCB utilization industry all agree that the environmental issues of maintaining clean air and clean water are of the highest priority when utilization or disposal of coal conversion solid residues and other by-products is considered. It is also agreed within the by-product utilization industry that disposal regulations should not be generically applied to materials in use applications. The ASTM E-50 committee, formed to deal with this issue, has begun to address the definition of CCBs as wastes versus resources. Although regulatory approaches must be adequate to safeguard the environment, it is important that appropriate and comprehensive scientific information be used to make the necessary decisions regarding the disposal or utilization of these highly complex solid materials. The environmental impacts of CCB disposal and utilization have recently been studied, but discussion was limited to soil amendment applications (Carlson and Adriano, 1993). Technical aspects of environmental characterization of CCBs and the characterization requirements were identified as an environmental barrier.

Numerous works in the literature evaluate the potential of CCBs to adversely impact the environment; however, the tests generally used have been designed for wastes codisposed in sanitary landfills. The most commonly used tests are the EPA-approved toxicity characteristics leaching procedure (TCLP) (EPA, 1990a), the ASTM D 3987 leaching procedure (ASTM, 1989), the EPA EP (EPA, 1990b), and the synthetic precipitation leaching procedure (SPLP) (EPA, 1990c). The TCLP is the EPA regulatory leaching procedure, through RCRA, for the identification of wastes as hazardous *when codisposed in a sanitary landfill*. These tests are all short-term tests (generally 18 to 24 hours in duration) and do not allow adequate time for secondary mineralization to occur with the subsequent change in the material controlling long-term behavior (Kumarathasan and others, 1990). The scientific validity of these tests as generally applied to utilized materials or to evaluate materials disposed of in a monofill has been questioned (Hassett, 1991; Hassett and Pflughoeft-Hassett, 1993) . Land disposal of materials identified as hazardous by this leaching procedure is prohibited by EPA. The TCLP has also been adopted by many state regulatory agencies to provide leaching information on solid wastes (not hazardous) that are not federally regulated.

Only a few procedures documented in the literature are appropriate to access the environmental impact of utilized (as opposed to disposed) CCBs. In utilization applications, the CCB is commonly combined with other materials. Leaching tests for CCBs are generally performed on the CCB alone rather than on the final product. For example, coal fly ash is commonly combined with fine aggregate (sand) and cement to produce a CLSM for a broad range of construction applications. While a leaching test may be required on the coal ash prior to use, the final product may not be tested, even though the leachability of the trace elements in the by-products may change as a result of the new matrix. As a result of inappropriate environmental evaluation procedures, misleading or incorrect information on CCBs prevents their proper evaluation for suitability in other applications.

One study on the impact of CCB utilization focused primarily on agriculture and mine soil amendment applications (Carlson and Adriano, 1993). Results in the literature (EPA, 1988; EPRI, 1987) indicate the presence of numerous trace elements in coal ash, and enrichment of some trace elements in CCBs is also documented (EPA, 1988; EPRI, 1987). Although most of the studies reported in the literature indicate very low concentrations of trace elements in leachate (Weber and others, 1993; Hassett, 1991; EPRI, 1987), concern for trace element contamination from placement of products containing CCBs has been raised by numerous state environmental and health agencies as well as by the public. High concentrations of RCRA trace elements (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver) have been reported in leachates from CCBs, but these reports appear to be the exception rather than the rule (EPRI, 1987). Numerous recent reports indicate low toxic leachate concentrations under diverse conditions in applications that involve marine construction (Woodhead and others, 1981; Parker and others, 1982; van der Sloot and others, 1991; Livingston and others, 1991; Price and others, 1991; Baker and others, 1991), agricultural amendments (Beeghly and others, 1993; Bennett and others, 1981; Burnham, 1993), and waste stabilization (EPRI, 1991a; Nonavinakere and Reed, 1993; Baldwin, 1993; Vaquier and others, 1993; Elini and Amodio, 1993; Burnham, 1993; Smith and Yu, 1991; Gray and others, 1991a). Studies have also investigated the impact of CCB use on groundwater and surface water (EPRI, 1991b; Pflughoeft-Hassett and others, 1993). These reports indicate limited-to-negligible impact on groundwater quality as a result of CCB use in various applications, including paving, embankments, and road base. A recent overview of the environmental impacts of CCB use (EPA, 1993) found no justification for the inclusion of CCBs as a hazardous waste. In effect, environmental concern may be based on a perception of a potential problem and not on actual information found in the literature. The prohibition of CCB use based on the perception of potential environmental impact is often unwarranted.

4.2.4 Technical Barriers

The technical barriers included issues related to CCB production, specifications and standards, product demonstration and commercialization, and user-related factors.

The implementation of low-NO_x technologies was commonly mentioned as a concern for CCB utilization; the primary concern was that the low-NO_x strategies would increase the amounts of unburned carbon in the ash, rendering it unsuitable for use as cement replacement in concrete.

Although many of the marketers thought that the limited classification system for fly ash was not a constraint, some believed that it is very important that a new classification system be devised. Various ashes that pass ASTM C 618 may perform quite differently: one may be sulfate-resistant while another is not, or one may be a good water reducer or unaffected by alkali expansion while others do not share these properties. The classification system should take these performance factors into account. Engineering properties should be specified. The Class C and Class F distinction is inadequate.

A constraint indicated by several marketers was that the CCB producers will not allow their by-products to be sold for applications that they do not approve of because of liability. If someone misuses their product, they fear that they will be liable for cleanup costs.

Changes in manufacturing processes or facilities may be required for CCBs to be used in ready-mix and preformed concrete production, gypsum wallboard manufacturing, cement manufacturing, and other applications. Responses from interviewed representatives indicated that businesses may be willing to try replacing standard raw materials with CCBs, but they may not have adequate equipment or facilities to follow through. An example of this problem is a small ready-mix supplier that may not have facilities to store both cement and coal fly ash. Because of the relatively high cost of building additional storage, adding this capability may not be advantageous or economically feasible for a small business. Other changes in normal production procedures may also restrict the use of CCBs, such as longer curing times for concrete block or other preformed concrete products. A necessary incentive to implement changes in procedures must include an equal- or higher-quality end product at an equal or lower cost.

4.2.5 Education and Attitude

Attitude and education were mentioned by virtually all of the utility personnel who provided input to the study, particularly as these factors relate to regulators. Ignorance or unwarranted negative feelings toward CCB utilization was cited by utility personnel as common among other utility personnel and management; end users, such as architects, engineers, contractors, state and local highway personnel; and the general public. There is a strong desire for increased educational efforts. Suggestions were made for educational opportunities for regulators, contractors, utility personnel, and the public. Support was given to increased educational opportunities concerning by-product utilization at the professional, university, and even high school levels.

The overwhelming recommendation to remove barriers to increased utilization of CCBs was to educate the related industrial groups and the public on the benefits of using CCBs. Education of engineers, architects, and other professionals at the college level was most highly recommended to provide a baseline level of comfort in using CCBs. Other recommendations were to adopt the EPA guidelines for fly ash use in concrete as a mandate instead of a guideline, to link mandated use to federal highway funds, and to enforce the mandate. However, mandates can often become counterproductive in the construction industry. Developing additional federal procurement guidelines and standards and performing more demonstration projects, particularly in public works projects, were also widely recommended. Design manuals addressing utilization practices in construction and engineering projects were advocated.

4.3 Regulatory Barriers

4.3.1 Federal Regulations Applying to CCBs

The 1976 RCRA and the 1980 Solid Waste Disposal Act Amendments (SWDAA) provide for comprehensive cradle-to-grave regulation of solid waste generation, collection, transportation, separation, recovery, and disposal (Jagiella, 1993; Findley and Farber, 1992; Butler & 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 coal ash 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, 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 (EPA, 1993). EPA will further evaluate the 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 problem include both 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 law that is 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 may apply to coal ash 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 that is well advanced for CCBs, but requires systematic compilation and refinement to provide the basis for regulatory classification.

4.3.2 State Regulation of CCBs

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). Discussed are barriers to CCB utilization in Maryland, Alabama, Illinois, New York, Pennsylvania, Ohio, Texas, Virginia, and West Virginia (Hudson and others, 1982). Changes in regulations and practices relating to CCB utilization in these states have been noted in more recent works. The TCAUG addressed regulatory issues in Texas in a recent report (TCAUG, 1992). The *Pennsylvania Bulletin* (1992) discusses current regulatory issues in Pennsylvania. These summaries point out that most state regulations of CCBs are 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. Other uses are not commonly specified. States that do specify acceptable use applications for CCBs are the states where the most progress has been made. The following overviews of regulations in Pennsylvania and Texas illustrate innovative strategies that encourage by-product utilization.

4.3.2.1 Pennsylvania

On January 21, 1992, The Pennsylvania Environmental Quality Board (EQB) enacted amendments (*Pennsylvania Bulletin*, 1992) to the 25 Pennsylvania Code concerning residual waste management. Regulations were subsequently promulgated by the Pennsylvania Department of Environmental Resources on July 4, 1992 (*Pennsylvania Bulletin*, 1992). This comprehensive revision of Pennsylvania's residual waste management program, based on more than 8 years of state deliberations, including extensive public participation, illustrates many of the regulatory concepts discussed in this report.

The Commonwealth of Pennsylvania defines residual waste as "most solid waste which results from industrial, mining, and agricultural operations and is not hazardous." The beneficial use of coal ash is addressed separately from the beneficial use of other residual wastes. The amendments set forth beneficial uses of coal ash, to include applications 1) as a structural fill; 2) as a soil substitute or additive; 3) in the manufacture of concrete; 4) for the extraction or recovery of one or more compounds contained within the coal ash; 5) in the use of fly ash as a stabilized product; 6) in the use of bottom ash or slag as an anti-skid material (the use of fly ash as an anti-skid material or road surface preparation material is not deemed a beneficial use); and 7) in the use of coal ash as raw material for a product with commercial value, including the use of bottom ash in construction aggregate. If certain requirements are met, uses of coal ash for mine subsidence control, mine fire control, and mine sealing and for drainage material or pipe bedding are also considered beneficial.

The placement of coal ash as part of a coal refuse disposal operation is not considered beneficial unless certain conditions are met, including that 1) the use complies with coal refuse disposal regulations, 2) the ash makes up less than 50% of the total volume of material, 3) the pH of the ash falls within a certain range that can be further restricted based on interactions between the ash and refuse material, 4) the ash has physical or chemical characteristics that improve compaction within the fill and improve the quality of leachate generated by the coal refuse material, and 5) the coal ash is returned to the coal refuse disposal area used by the related coal preparation activity.

No permit is required for the beneficial use of coal ash, although prior written notice to the Pennsylvania Department of Environmental Resources describing the use is required, and siting and design standards may be required for certain uses. People using coal ash in accordance with designated beneficial uses are required to keep records. The EQB can, at any reasonable time, request all documents and any other information to show whether a person is complying with the necessary requirements. For some beneficial uses, certain analyses (such as pH and bulk chemical data) are required. If the use of coal ash harms or threatens public health, safety, welfare, or the environment, the use is not considered beneficial.

The new Pennsylvania regulations allow certain classes of beneficial use to occur without a permit, subject to general state oversight. The day-to-day oversight of coal ash use is shifted to the user, eliminating some of the regulatory problems and delays caused by case-by-case permitting of CCB use. The public is protected from irresponsible and harmful use of by-products by the recording requirements and the fact that any use causing harm to the public or environment is automatically deemed nonbeneficial. The classification of beneficial uses prevents unpermitted disposal of by-products under the guise of beneficial use.

Most CCBs are not harmful to the public health or environment, and restrictive regulations are not needed. Only in uncommon instances have CCBs been shown to be detrimental. Shifting the burden of responsibility to the user with the necessary regulatory safeguards in place, therefore, seems to be a reasonable strategy for encouraging CCB use. Specific guidelines for beneficial uses of by-products provide the user a clear pathway for making utilization and disposal decisions and avoiding the case-by-case expense and delay for regulatory approval.

4.3.2.2 Texas

In 1991, the Texas state legislature passed SB 1340 to encourage recycling and the use of recycled and recyclable products. The objective was to minimize the landfilling or incineration of solid wastes, including CCBs. The bill also required state, county, and municipal entities to amend their specifications by January 1, 1992, to allow CCBs to be used in road and bridge construction, if technically appropriate and economically justified.

Texas produces about 13 million tons of CCBs per year and uses less than 15% (TCAUG, 1992). The increasing quantities of CCBs that must be landfilled are a major concern. The cost associated with new landfills is adding significantly to the cost of electricity. The TCAUG report (1992) identified environmental constraints, material preferences, and trucking regulations as major reasons why a large fraction of CCBs continue to be landfilled by utilities.

Several barriers were identified to recycling CCBs (TCAUG, 1992). These materials are currently still considered solid wastes by state definition. Regulatory provisions discourage the storage (TAC 335.17) of solid wastes. Other regulations (TAC 335.(D)(I)(1)) state that materials are solid wastes if they are recycled or applied to or placed on the land in a manner that constitutes disposal. This restricts use as a structural fill or any uses involving road building, deicing material for bridges, parking lot construction, or any use that will be covered by soil, highways, or buildings. Coal by-products used to produce products such as asphalt and concrete and placed on the land are considered solid wastes and are regulated by TAC 335.(D)(I)(1).

In 1993, the state of Texas passed SB 1051 to develop and diversify the economy of the state through sustaining and promoting recycling enterprises. The act established the Recycling Market Development Board for the state of Texas to promote and encourage the location and expansion of major industrial, manufacturing, and recycling enterprises within the state. The board coordinates, with the consent of local governments, activities related to these programs. CCBs are specifically listed as part of this recycling development activity. This legislation creates a dialogue among the producers of CCBs, the potential users of recycled products, and the agencies that regulate their use. Although the legislation is designed for several industrial recyclable materials, it specifically mentions CCBs. Different industrial recyclable materials are intended to compete on a level playing field for beneficial reuse. This measure can be interpreted as a step, on a state level, toward National Goal status for CCB recycling, which can point the way to beneficial reuse of industrial by-products nationally.

4.4 Legal Barriers

The key legal barrier to CCB utilization 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 coal ash and FGD products 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 coal ash by very different standards. Some states restrictively control coal ash as a de facto hazardous material, while other states treat recycled ash as an unregulated construction material (Jagiella, 1993). Some states regulate coal ash 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 contained in CERCLA, also known as the Superfund Act. A 1988 summary of state statutes compiled by the USWAG identified forty-three states that exempt coal ash from hazardous waste regulations; seven states—including Kentucky, Tennessee, Oklahoma, Washington, New Jersey, Maine, and California—that require testing to determine if the ash would be regulated as a solid waste or a hazardous material; and one state, Ohio, that exempts coal ash 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 coal ash utilization. The commonly held opinion that semantic reclassification of coal ash 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, and 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 highly significant 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 coal ash because of its importance as the largest-volume recyclable material in the United States and the record of environmental testing that indicates coal ash is not a hazardous substance, pollutant, or contaminant.

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 preapproved classes of by-product use. Although such federal deregulation of preapproved 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 arise 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).

Patents held on various processes, materials, and practices involved in CCB utilization appear to involve broad claims that are difficult to distinguish from common practices normally considered public domain. For example, certain patents involving CLSM would not appear to necessarily represent unique or novel practices, and no known information indicates these patents are being enforced. No judgment is intended here on the validity or enforceability of such patents, but patent searches and legal opinions in selected areas may be useful to remove uncertainties that may constitute de facto legal barriers. Such patent reviews could appropriately be sponsored by trade organizations representing utilities and marketers.

4.5 Recommendations Made to Remove Barriers

4.5.1 Recommendations Made by Industry

The recommendations outlined in Table 12 were refined at the Barriers Workshop held at the DOE Morgantown Energy Technology Center (now FETC) in Morgantown, West Virginia,

TABLE 12

Outline of Action Recommendations for Removing Barriers to CCB Utilization

Action Item	Type of Action	By Whom
1.0 National Goal Status for CCB Recycling Executive Order Congressional Legislation	New legislation CCBs Utilization Act of 1994 Revision of Energy Policy Act of 1992 Revision of the Resource Conservation and Recovery Act Implementation under existing statutes Federal and state pollution prevention laws	Executive Branch, Congress
2.0 Regulatory Classification Defining Preapproved Uses		Congress, DOE, EPA Federal agencies, state agencies, ASTM
2.1 Criteria Environmental compliance criteria Engineering performance specifications	Development of criteria for deregulation	
2.2 Classification for Preapproved Uses	Reclassification of by-products meeting deregulation criteria Removal from RCRA control provisions governing solid wastes (federal and state) DOE advocacy for preapproved uses through federal/state interagency coordination Requests to initiate actions on preapproved uses submitted by private industry and state or federal agencies	
2.3 Technology Base for CCB Classification	Research and data assessment to understand engineering and environmental performance for the purpose of developing predictive capability and streamlining approval and utilization	Joint ventures: DOE, EPA, other federal agencies, state agencies, universities, industry, professional and standards organizations
3.0 Federal Procurement Guidelines		
3.1 Oversight of Existing Federal Guidelines	Republish existing guidelines and provide additional procurement oversight to ensure compliance with guidelines on the use of fly ash in concrete	DOE, EPA
3.2 Extension of Federal Procurement Guidelines to Other Uses/ By-Products	Legislation extending federal procurement guidelines to preapproved products based on environmental, engineering, and economic performance criteria Development of guidelines with the consensual involvement of affected agencies	Congress, DOE, EPA, other federal agencies

TABLE 12 (continued)

Action Item	Type of Action	By Whom
3.3 Technology Base for Guidelines	Development of a matrix of performance specifications: Road base — Fly ash Asphalt paving — Bottom ash Structural fill — Coal ash slags Flowable fill — FBC bed material Waste stabilization — FGD by-products Soil amendment — Other Synthetic aggregate Lightweight block Wallboard Other	Joint ventures: DOE, EPA, other federal agencies, state agencies, universities, industry, professional and standard organizations
4.0 Economic Incentives		
4.1 Deregulation Incentives Regulatory preference for reuse over disposal	Exemption of preapproved uses from RCRA regulation	Congress, DOE, EPA
4.2 Investment Incentives		
Federal tax credits for investment in by-product utilization	Revision of federal tax code	Congress
State sales tax exemption or rebate on sales of CCBs		
Favorable utility rate base treatment	State legislation	State legislatures
	Flexible rules on investment and revenues	State Public Service Commissions
4.3 Federal Funding Incentives Bonus federal highway funding to states for CCB utilization or reduced state matching requirements Bid preference in federal construction procurement where CCBs enhance quality and durability	Legislation targeting users and decision makers (e.g., contracting engineers)	Congress
4.4 Market-Driven Demonstration	Decentralization of demonstration projects Target county and municipal projects, other end users Emphasize joint venture (federal/state/private) projects Establish SBIR grants for recycling projects Technical innovation encouraged by targeted federal funding incentives	Congress, federal DOT, other federal agencies, state agencies

TABLE 12 (continued)

Action Item	Type of Action	By Whom
5.0 Review of Legal Barriers		
5.1 Environmental Liability	Legal review to clarify grounds and remedies and to establish a basis for helpful legislation	Congress, ACAA, EEI, utilities, marketers
Jurisdiction – state and federal Current federal delegation to states under Subsection D of RCRA Proposed exemption from RCRA solid waste provisions for preapproved users Need for "level playing field" with respect to competing products and materials		
Statutory basis of liability Environmental law – strict liability, not fault-based RCRA and related state regulatory law Clean Water Act and related legislation CERCLA – The Superfund Act Tort law product liability for dangerous conditions traceable back to manufacturer		
Legal remedies Statutory exemptions from liability Federal jurisdiction over approved products and uses Regulatory classification defining preapproved uses Technical specifications Background and site studies		
5.2 Commercial and Contract Law A uniform commercial code for CCBs Incorporation of technical and environmental specifications by reference to assist buyers and sellers in writing clear and enforceable contracts for the sale of CCBs	Legal research to develop a uniform commercial code	ACAA, EEI, utilities, marketers
5.3 Broad and Possibly Overlapping Patent Claims Distinction between patent-protected technology and generic use in the public domain	Patent searches in selected areas such as flowable fill	ACAA, utilities, marketers

TABLE 12 (continued)

Action Item	Type of Action	By Whom
6.0 Interagency Coordination		
Federal and state coordination of engineering and environmental specifications, guidelines, and compliance	A DOE lead mission designation for coordinating a federal team effort to increase beneficial use of CCBs DOE–EPA liaison on environmental criteria for deregulation of preapproved uses Federal interagency task force on engineering specifications	Executive Branch, DOE, EPA Federal highway administration Army Corps of Engineers Bureau of Reclamation Department of Agriculture Bureau of Mines Federal Aviation Agency General Services Administration Tennessee Valley Authority State agencies
7.0 Product Specifications		
Future product specifications to address engineering, environmental, and economic considerations together, not as separate issues Special attention devoted to new by-products from clean coal technologies		
7.1 Development and Standardization of Performance-Based Engineering Specifications	Expedited action on performance specifications for all classes of by-products	Joint activities: ASTM, AASHTO, other standards organizations, universities, industry, user/product trade associations, DOE, other federal/state agencies
Ancillary specifications for cement admixtures addressing limitations posed by the ASTM C 618 standard	Characterization based on measures of cementitious behavior and pozzolanic activity Consideration of changes in Class C and F fly ash classifications and of broader ranges on LOI, moisture, alkali, and fineness Addition of appropriate performance criteria for different use regions, considering properties such as strength, permeability, alkali–aggregate reactions, chemical resistance, freeze–thaw, workability, curing time, and water and air requirements	
Additional engineering specifications for high-volume uses	Development of specifications for CLSM (flowable fill), road base, asphalt paving, waste stabilization, synthetic aggregate, and other high-volume uses	
Engineering specifications for manufactured products	Specifications for mineral wool, brick, ceramics, fillers for plastics and cast metal, paint, and other products	

TABLE 12 (continued)

Action Item	Type of Action	By Whom
7.2 Development and Standardization of Environmental Performance Specifications and Criteria for Preapproved Use	Expedited action on environmental specifications and related testing protocols working through standard organizations Test protocols representative of the product use environment Assessment of long-term stability Predictive methods	Joint activities: ASTM, AASHTO, other standards organizations, universities, industry, user/product trade organizations, EPA, DOE, other federal/state agencies
General environmental specifications on by-products for allowing unrestricted use in all applications	Adoption of environmental specifications as criteria for preapproved use exempted from RCRA control	EPA, DOE, other federal/state agencies
Categorical environmental specifications allowing unrestricted use in designated product/use categories defined by regulatory classifications		
8.0 Technical Assistance and Educational Programs		Joint ventures
8.1 Public Education on Benefits and Methods of CCB Utilization	Grants to high schools, trade schools, and colleges linked to federal initiatives in trade education and impact retraining related to NAFTA, military downscaling, and other programs	DOE, EPA, Department of Education, other federal/state agencies, universities, ACAA, EPRI, EEI, utilities, marketers, vendors, professional organizations, environmental organizations
8.2 DOE and EPA Technology Assistance Offices	Assistance and advocacy for preapproved uses Coordination with federal and state agencies to remove roadblocks and to promote adoption of model preapproved use plans	
	Practical education, training, and project assistance by providing engineering standards and handbooks, environmental data, cost data, instruction materials and training programs	
	Technical assistance for market-driven demonstration projects targeted to end uses (e.g., contractors, farmers using FGD gypsum as a soil amendment)	
9.0 By-Product Quality Assurance		
9.1 Source Certification	Designation of sources of by-products for preapproved use based on regulatory classification and appropriate sampling and analysis protocols	DOE, EPA, state agencies, utilities, marketers

TABLE 12 (continued)

Action Item	Type of Action	By Whom
9.2 Quality Improvement		EPRI, utilities, marketing vendors, DOE
In-plant improvement	Modifications of equipment and operating methods to improve combustion and control parameters, including furnace temperatures and excess air; gas-cleaning methods; oxidation of FGD by-products; size classification of particulates; and segregation of off-quality by-products	
Off-plant processing	Investment in facilities for screening, blending, and conditioning by-products, including methods such as sizing or reburning to reduce LOI in fly ash or oxidizing FGD by-products to convert calcium sulfite to gypsum	
Operator training	Training in operating procedures for quality control	
Laboratory analysis	Establishing quality control laboratories and sampling/analysis protocols	
9.3 Utility–User Relations	Communication and resolution of quality control problems Appointment of utility managers to champion by-product quality and utilization	
10.0 Research and Development – Priority R&D Goals		Joint ventures: DOE, EPA, other federal/state agencies, universities, ACAA, EEI, EPRI, utilities, marketers, vendors, trade organizations
10.1 Demonstration Projects Targeted at By-Product Classification for Preapproved Use	Market-driven demonstrations, methods development, engineering and environmental testing, data compilation, and assessment	
10.2 Technical Project Assistance for Troubleshooting Market-Ready Technologies	Problem solving through use of state-of-the-art analytical methods and diagnostic capabilities made available under the coordination of proposed DOE/EPA regional technical assistance centers	
10.3 Applications Research on By-Products from Clean Coal Technologies	Matching new by-product materials with optimum uses	
10.4 Development of New Technology for By-Product Utilization	R&D on processing methods and utilization practices to bring new manufactured or field-implemented uses to the point of readiness for the market, including work on environmental compliance	
10.5 Technical and Economic Assessment	Identification of marketing opportunities by assessment of technical readiness, cost, and profitability	

on September 27–28, 1993. The recommendations presented require a significant reordering of federal priorities; however, federal funding requirements would be minimized by requiring private cost sharing in the proposed actions. The 50% utilization goal contained in the 1990 National Energy Strategy should be adopted as a reasonable first-stage objective in moving from the current 30% utilization of coal ash and 2% of FGD products toward full economic utilization of all CCBs.

A leading recommendation growing out of the workshop called for embodying actions to remove barriers in a proposed 1994 National CCBs Utilization Act, which would provide leadership at the highest levels of government and give the most comprehensive relief possible, consistent with environmental protection, in the areas of legal and regulatory reform. The key provisions of this proposed act, as contained in the first two of the ten recommendations which follow, are 1) to establish National Goal status for CCB utilization and 2) to provide for a due process addressing environmental safety through regulatory classifications that would progressively define preapproved uses entirely removed from the controls imposed on solid wastes by RCRA, whether administered by federal or state agencies. Coal by-product materials meeting established environmental criteria would effectively be deregulated and become products in interstate commerce. Administration of and advocacy for the required deregulation actions are proposed to be given to DOE, while the proactive involvement of EPA is retained in establishing environmental criteria for deregulation and in encouraging CCB utilization for the purpose of pollution prevention. DOE would provide high-level leadership through the direct involvement of the Assistant Secretary for Fossil Energy for increasing beneficial utilization of deregulated by-products and would enlist the involvement of other affected federal agencies through task force initiatives addressing issues such as federal procurement guidelines and standardization of engineering specifications for CCB use.

The keystone to removing barriers to CCB utilization is federal legislation for accomplishing deregulation, which shapes the first six recommendations in Table 12. However, many of the specific actions proposed under these six initiatives and four additional private initiatives requiring some governmental assistance can and should be undertaken independently before the passage of a comprehensive act. Such independent actions could first and foremost include an Executive Order by the President establishing National Goal status in advance of federal legislation, to be followed by appropriate implementation actions by federal and state agencies and private organizations. Some of the actions that may be appropriately undertaken independently are called out in the discussion of recommendations that follows.

As shown on Table 12, two tiers of action recommendations were identified:

Tier 1 – Recommendations for Governmental Initiatives with Private Participation

1. National Goal status for CCB utilization

2. Regulatory classification defining preapproved uses

3. Federal procurement guidelines

4. Economic incentives, including federal tax and funding preferences
5. Action on legal barriers
6. Federal interagency coordination

Tier 2 – Recommendations for Private Initiatives with Governmental Assistance

7. Product specifications
8. Technical assistance and educational programs
9. By-product quality assurance
10. Research, development, and demonstration

National Goal status for CCB utilization is essential to break the logjam of institutional, legal, regulatory, technical, and economic barriers impeding CCB utilization. Without a clear federal mandate similar to the atmospheric goals established in the CAA of 1970, the other recommendations in this study report will carry little weight in changing customary practices treating CCBs as solid waste. The enactment of a National CCBs Utilization Act in 1994 embodying National Goal status and provisions for accomplishing deregulation with fully adequate environmental safeguards can be the vanguard action needed to move toward a comprehensive national strategy for industrial recycling. Administration of this proposed act should be through the Secretary of the Department of Energy.

Full economic utilization of CCBs provides important public benefits with respect to the conservation of land, energy, and natural resources while reducing CO_2 emissions currently being generated in producing competing materials. Legislation on CCB utilization is overdue as a needed complement to past clean air legislation; to accomplish life-cycle environmental protection of air, soil, and groundwater; and to achieve major pollution prevention goals concerning solid wastes. Important regional benefits are offered by providing manufactured aggregate to areas devoid of sand and gravel and securing gypsum to restore sulfur levels in deficient soils in large areas of the country. The U.S. trade balance can be favorably influenced by reducing imports of cement (currently at 10%) and other construction materials. Opportunities for small business are provided using CCBs in manufactured products. Available environmental data indicate that coal ash is not a hazardous substance, as recognized by the August 2, 1993, ruling by the EPA. The environmental safety of CCBs in various use applications, including waste stabilization, appears to equal or surpass that of competing materials that are not being regulated as solid wastes. Legislation providing for the safe deregulation of CCBs is essential if the high levels of utilization in western Europe are to be achieved in the United States within the foreseeable future.

National Goal status can be implemented by executive order prior to enactment of a comprehensive utilization act. Other legislation approaches that should be alternatively considered include amendments to the Energy Policy Act of 1992 or revision of RCRA. Implementation should also be encouraged under existing statutes, including federal and state pollution prevention laws.

Regulatory classification defining preapproved uses is recommended to deregulate CCBs for beneficial use. The purpose of regulatory classification under the proposed National CCBs Utilization Act will be to certify environmental compliance for restricted classes of by-product use subject to established environmental criteria and to remove the approved-use classes from RCRA controls imposed on solid wastes, including regulations applying to nonhazardous solid waste under RCRA regulatory authority delegated to the states. Regulatory classification should proceed as a series of federal regulatory actions progressively deregulating additional coal combustion products and uses. Initiation of actions should be open to all federal or state agencies and private companies who submit requests to DOE. Certain priority actions should be undertaken apart from such requests on those uses previously addressed under state statutes, including uses such as road base, anti-skid material, structural fill, pipe bedding, soil amendment, waste stabilization, concrete manufacture, other manufacturing raw materials, coal refuse disposal, mine subsidence and fire control, and mine sealing and drainage control.

Actions on regulatory classification are proposed to be under the general administrative control of DOE. However, the environmental criteria to be used for deregulating CCB uses should be approved by EPA, as it draws on environmental specifications developed by ASTM and other standards organizations. Two classes of criteria can be foreseen: 1) a more stringent environmental specification allowing unrestricted use of by-product materials in all beneficial use applications and 2) less stringent categorical specifications allowing restricted use in designated product/use categories. Criteria will address leachability of CCBs or end-use products as appropriate under conditions representative of beneficial use, along with correlative chemical and mineral analyses. The criteria should establish a level playing field by comparing CCBs with competing products used in similar applications.

Regulatory classifications for the purpose of defining preapproved uses can be undertaken by EPA apart from new legislation. However, the effect of new classifications under the current law would be only advisory to state practices under delegated RCRA authority for regulation of solid waste and would, therefore, be expected to accomplish limited deregulation.

Federal procurement guidelines should be addressed in the proposed National CCBs Utilization Act and subsequently developed with the consensual involvement of affected agencies. The 1983 EPA guideline covering the utilization of fly ash in concrete (EPA, 1983) should be republished and additional oversight exercised to encourage utilization compliance. Under the proposed utilization act, the administration of procurement guidelines should be moved from EPA to DOE. Federal procurement guidelines should be extended to cover all preapproved and deregulated products that meet environmental, engineering, and economic performance criteria. Utilization of CCBs as waste stabilization agents in federally funded Superfund cleanup activities and remediation of DOE nuclear weapons sites should be specifically addressed. The federal funding for research and other technology-based activities supporting regulatory classification and product specifications should also support procurement guidelines.

Action on federal procurement guidelines can be addressed either under a comprehensive CCBs utilization act or separately.

Economic incentives, including federal tax and funding preferences, should be offered by the government to encourage CCB utilization activities that are in the long-term interest of the general public. The proposed deregulation of preapproved products will substantially reduce cost and delay, thereby providing an important incentive for utilities to pursue beneficial use rather than solid waste disposal. Targeted tax incentives should be considered at the federal and state level, including investment credits, accelerated depreciation, and reduced or rebated sales taxes. State Public Service Commissions should be encouraged to extend favorable rate base treatment to CCB investments and revenues. Direct federal funding incentives should be considered for selected CCB utilization projects, including possible bonus payments in federal highway funding or a reduction in state matching requirements. Where end-product quality or durability is enhanced by using CCBs, a formula bid selection procedure should provide preference in federal construction procurement. Governmental incentives should be targeted to achieve technical innovation and to demonstrate environmental compliance in a manner analogous to the DOE Clean Coal Technology program. These incentives will require legislation, both as part of a comprehensive CCB utilization act and as separate actions.

Review of legal barriers should be undertaken by industry and government to determine the need for legislation addressing regulatory authority and environmental liability. At a lower level of priority, legal review of contract law and patents should be performed by utilities, marketers, and trade associations to facilitate commercial transactions. One of the most serious legal barriers needing to be addressed concerns the wide divergence in the regulatory law covering beneficial uses of CCBs under state statutes. Whereas EPA confirmed in a ruling on August 2, 1993, that coal ash is not a hazardous material under RCRA Subtitle C, the delegation of regulatory authority under RCRA Subtitle D for solid waste causes various states to treat coal ash in some cases as a de facto toxic substance and in other cases as an unregulated construction material. Uniform regulation of preapproved by-product uses can be achieved by exempting preapproved CCB materials from regulatory control as solid wastes under RCRA Subtitle D, as recommended in the section on regulatory classification above. Legal review on environmental liability would encompass several federal environmental statutes, including RCRA, the CAA, and the CERCLA. Product liability under tort law should also be reviewed in cases where the beneficial use of CCBs could potentially create dangerous conditions that are traceable back to product manufacture. Legal remedies to be considered in review and legislation include statutory exemption from liability, federal deregulation authority for preapproved uses, other regulatory and permitting provisions, and technical specifications having legal standing.

Review of commercial law could be undertaken to address a uniform commercial code for CCB transactions by incorporation of specifications that would assist buyers and sellers in writing clear and enforceable contracts for by-product sales. Summary review of overlapping patent claims in certain areas, such as flowable fills, would clarify the distinction between generic use and specific practices protected by patent. Several of these areas of legal research should appropriately be sponsored by utilities and marketers or the American Coal Ash Association.

The proposed legal review of regulatory authority and environmental liability can proceed independently, but remedial legislation should be considered in conjunction with a comprehensive CCB utilization act.

Federal interagency coordination is urgently needed to encourage beneficial use of CCBs under more uniform environmental and engineering specifications than currently exist among federal agencies and between states. Standardization will become a compelling issue as deregulated CCBs become widely used in interstate commerce under the proposed provisions for regulatory classification. A strong federal leadership role is vital in implementing all of the actions proposed under the National Goal status and the comprehensive CCB utilization act. A DOE lead mission designation is recommended to coordinate the federal team effort needed to address criteria for by-product deregulation and standardization of engineering specifications. DOE would work through the EPA to develop and obtain approval of environmental criteria for deregulation. Advocacy for pollution prevention through the beneficial use of CCBs should also be maintained within EPA.

The DOE lead mission designation proposed here is tied to the need for focused advocacy for deregulated CCB uses exempted from RCRA control under a comprehensive CCB utilization act. In the absence of such legislation, federal leadership would be more diffuse, and coordination would depend on general cooperation among DOE, EPA, and the federal agencies. The lead mission designation is strongly recommended.

Product specifications should continue to evolve in the direction of addressing environmental, engineering, and economic performance criteria together rather than separately. Continuing development of specifications through ASTM and other standards organizations should be expedited by providing governmental joint venture funding to universities for technology-based research. DOE and other federal agencies should provide leadership for the standardization of specifications applying to federal and state construction projects. Current specifications, such as the ASTM C 618 standard for fly ash use in concrete, should not be displaced, but ancillary standards should be developed. Future specifications should provide a better measure of engineering and environmental performance should and be less restrictive in terms of empirical parameters. Specifically, consideration should be given to replacing the Class C and F fly ash designations with appropriately chosen properties indicating cementitious and pozzolanic activity; broader ranges should be allowed on LOI, moisture, alkali, and fineness; appropriate performance criteria should be added for different use regions or categories in light of properties such as strength, permeability, chemical resistance, sulfate resistance, alkali–aggregate reactions, freeze–thaw durability, workability, curing time, and water and air requirements. Additional engineering specifications are needed for high-volume uses and manufactured products, covering uses such as road base, asphalt paving, flowable fill, synthetic aggregate, lightweight block, cast concrete products, wallboard, and fillers in paint, plastic, and metal. New specifications should specifically address CCT by-products.

The development of environmental performance specifications should be coordinated with DOE and EPA actions on criteria for preapproved use and exemption from RCRA solid waste regulations. Environmental specifications may include both more stringent criteria for allowing unrestricted use of a by-product in all applications and less stringent standards permitting restricted use in concrete and other immobilized matrices. In adopting specifications as criteria for regulatory classification, every effort should be made to build upon institutional procedures already in place and to adopt available specifications with minimum modification. For example, the ASTM E 5O standard dealing with environmental criteria for structural fill, which is nearing completion, should be given consideration as the regulatory standard for this type of product.

The development of specifications under ASTM and other standards organizations will not be directly affected by the enactment of a comprehensive CCB utilization act, but the incorporation of these specifications into regulatory classifications will be.

Technical assistance and educational programs should be implemented on a cost-shared basis with high schools, engineering and science departments at universities, and trade organizations such as ready-mix associations and trade unions. The emphasis should be on practical education, training, and project assistance to end users. Regional technical assistance centers should be established under joint funding from industry, DOE, and EPA to provide assistance and advocacy for preapproved uses. Information offered through these centers should include public education on the benefits of CCB recycling, engineering and cost data, short courses on appropriate technical and practical topics, and related educational materials for classroom instruction. Technical information should also be provided to improve by-product quality assurance and to assist market-driven commercial demonstrations.

Action on technical assistance and education can be initiated independently of enactment of a comprehensive CCBs utilization act.

By-product quality assurance is primarily the responsibility of utilities and marketers. The principal roles recommended for federal and state agencies are in source certification of by-products for preapproved uses, development and standardization of sampling and analysis protocols, and, possibly, support for development of on-line quality control instrumentation. Actions that can be taken by utilities and marketers include in-plant equipment modifications, addition of off-plant processing facilities, laboratory quality control analysis, and operator training. In order to be effective, utilities must allocate resources and provide leadership for championing quality by-product utilization. By-product quality assurance is not directly linked to a comprehensive CCB utilization act.

Research, development, and demonstration should involve team efforts with universities, government, and industry in order to bring together the scientific understanding, regulatory approval, and commercial resources needed to achieve significant technological advancement. Highest priority should be given to demonstration projects targeted at regulatory classification defining preapproved uses exempted from RCRA control of solid waste. The second priority should be to provide technical assistance that will make a decisive difference in implementing market-ready technologies. New by-products from clean coal technologies should be investigated to determine their optimal beneficial use. Access to state-of-the-art analytical methods and diagnostic capabilities should be provided by the regional technical assistance centers proposed above under Federal Interagency Coordination. The development of new technologies is a lower priority that should be undertaken through federal or state joint ventures cost-shared by industry to indicate positive commercial interest. RD&D projects should include cost and profitability analyses to identify marketing opportunities. Federal support for RD&D can proceed independently prior to passage of a comprehensive CCB utilization act.

4.5.2 Recommendations Made in DOE's 1994 RTC

4.5.2.1 Criteria for Recommendations

In developing the recommendations for action in this report, several criteria were used.

- Actions recommended should fall within budgetary and personnel resource constraints imposed by today's federal budget and personnel reduction initiatives.

- Recommended actions should attempt to maximize use of existing federal resources and cooperation among federal agencies.

- Any successful effort to promote the increased use of CCBs will require a cooperative effort of federal and state government agencies and the private sector, including industry, environmental interest groups, and private citizenry.

- Recommended actions should promote an environmentally protective and beneficial increase in CCB utilization.

4.5.2.2 Recommendations for Federal Government Actions

Recommendation No. 1. Implement Executive Order No. 12873 with due consideration to use of CCBs. This includes developing affirmative procurement programs in accordance with Section 402(a); revising federal and military specifications, product description, and standards to enhance federal procurement of CCBs in accordance with Section 501; identifying accepted CCBs and possible uses; and reporting progress in increasing procurement of CCBs in accordance with Section 602.

Recommendation No. 2. With industry, DOE will contribute to a database addressing concerns relative to RCRA regarding CCBs derived from advanced coal technologies. If coal technology by-products are to be utilized, determination must be made that they fall under Subtitle D of RCRA. This action removes the "hazardous" tag and potential liability for environmental cleanup and gives responsibility and authority for handling these Subtitle D materials to the states.

Recommendation No. 3. DOE will work with state and local governments to identify issues or concerns regarding CCB use within their respective jurisdictions and factor these results into the DOE RD&D program.

Recommendation No. 4. For identified markets, DOE will work with state and local governments and CCB producers to package and transfer information targeted to these markets that addresses the relevant environmental/health considerations, engineering properties, the range of properties to be expected, and beneficial aspects.

Recommendation No. 5. DOE will work, in cooperation with EPA and other agencies, with state and local governments to review and revise, as necessary, existing specifications and regulations relating to CCB use and develop specifications and regulations where needed.

Recommendation No. 6. Within existing budget levels, consider participation in highly cost-shared demonstrations that would evaluate the viability and environmental acceptability of high-volume CCB utilization applications, such as bridge and highway construction or waste stabilization.

Recommendation No. 7. DOE will work with technology suppliers and utilities early on to explore what might be done within practical limits to make coal residues from plants more useful by-products or more readily disposable wastes.

4.5.2.3 State Government and Private Sector Actions

Although the focus of this report was on federal government actions needed to increase by-product utilization, it will require a cooperative effort between all involved with CCB utilization to achieve the type of results possible and desirable. A few key actions expected to be taken following federal government action are listed below.

4.5.2.3.1 State Government Actions

- The state government procurement agencies should follow the federal lead in specifications and standards in procuring products and services. This includes recovered materials, especially in public projects such as highways.

- State regulatory agencies should revise their regulatory standards based on EPA determinations for environmentally safe preapproved uses for CCBs.

- States should continue to sponsor development of improved CCB utilization technology.

4.5.2.3.2 Private Industry Actions

- Private industry should respond to increased demand for CCBs with adequate by-product quality assurance programs in place. Industry must consider by-product quality in making operational and capital equipment decisions.
- Industry must become more involved in activities of standard-setting organizations such as ASTM. Industry must be able to provide quality information on by-product utilization to federal and state government organizations involved in developing new standards and specifications for by-product use.

- Industry must control its activities with a focus that only environmentally sound utilization technology is to be practiced.

- Industry must continue to support sound RD&D work on utilization of CCBs.

4.6 Responses to Recommendations – 1993 to Present

4.6.1 Industrial Actions

Individual utility, marketing, and end-use companies and individuals have always made an impact through grass roots efforts to encourage CCB utilization, but it is not feasible to mention each separate effort. Most of these types of activities are performed on the state or regional level and involve RD&D and technology transfer. Typically, a single entity or group of entities work with local or state regulating agencies to gain acceptance of a specific application that has high potential in that geographic area. Following state agency approval of one or more projects on a case-by-case basis, these entities frequently work toward obtaining an exemption for the CCB of choice in the specific use application. Most of the actions by individuals or small groups of industry representatives are focused on gaining acceptance of CCBs in a specific application. It is the Phase I Bevill Determination (see Section 4.6.2.1) that makes these efforts most useful, because the states now have final authority over the utilization of CCBs and can use the EPA data in conjunction with data provided locally to understand the nature of the materials and any environmental consequences.

4.6.1.1 Standards Development

One area where industry has consolidated its efforts effectively is in the area of development of consensus standards. Most activity has occurred within the American Society for Testing and Materials. The consensus standard development process is a time-intensive, interactive process. One standard was developed and approved as a provisional standard and several others are currently in the preparation or balloting stages in the ASTM system. These are:

- PS 23-95 Provisional Standard Guide for Use of Coal Combustion Fly Ash in Structural Fills

- E 1861-97 Standard Guide for Use of Coal Combustion Products in Structural Fills

- Proposed Standard Guide for Use of Coal Combustion Products for Low Permeability Barriers, Liners, and Encapsulations

- Proposed Standard Guide for Use of Coal Combustion Products for Mine Reclamation
- Proposed Standard Guide for Use of Coal Combustion Products for Stabilization of Inorganic Wastes

- Proposed standard for a new specification for CCBs used as a mineral admixture in cement based on three ranges of calcium content. This standard is expected to replace ASTM C 618.

- ASTM Committee E-50 agreed to use the term "coal combustion product" (CCP) in standards developed within that committee. Industry has varying opinions on the use of this term.

4.6.1.2 Industry-Sponsored RD&D Efforts

Performance of industry-sponsored RD&D has continued since the DOE RTC. It is important to note that many projects performed or sponsored by industry are not reported in public literature but serve a specific purpose for the interested industrial party. The following list of reports on CCB research performed or sponsored by EPRI provides an overview of some of the topics under consideration.

- *Assessment of Impacts of NO_x Reduction Technologies on Coal Ash Use: Volume 1: North American Perspective*; EPRI Report TR-106747-V1, Nov. 1996.

- *Casting of ASHALLOY Metal Matrix Composites: 1993*; EPRI Report TR-105822, May 1996.

- *Casting of ASHALLOY Metal Matrix Composites: 1994*; EPRI Report TR-106168, May 1996.

- *Demonstration of Ash Utilization in the State of North Dakota;* EPRI Report TR-106516, March 1996.

- *Design, Operation, and Testing of the Fly Ash Carbon Burn-Out Pilot Plant*; EPRI Report TR-1102429, April 1996.

- *Environmental and Physical Properties of Autoclaved Cellular Concrete: Volume 1: Narrative and Radon Exhalation Study and Appendix A*; EPRI Report TR-105821-V1, Oct. 1996.

- *Fluid Placement of Fixated Scrubber Sludge in Abandoned Deep Mines to Abate Surface Subsidence and Reduce Acid Mine Drainage*; EPRI Report TR-107053, Nov. 1996.

- *Use of FGD Gypsum and Bottom Ash in Roadway and Building Construction*; EPRI Report TR-103856, July 1994.

- *Investigation of High-Volume Fly Ash Concrete Systems*; EPRI Report TR-103151, Oct. 1993.

- *Use of FGD Gypsum and Bottom Ash in Roadway and Building Construction*; EPRI Report TR-105236, Aug. 1995.

- *Laboratory Characterization of Atmospheric Fluidized-Bed Combustion By-Products*; EPRI Report TR-105527, Sept. 1995.

- *Land Application of Coal Combustion By-products: Use in Agriculture and Land Reclamation*; EPRI Report TR-103298, June 1995.

- *Land Application Uses for Dry Flue Gas Desulfurization By-Products*; EPRI Report TR-105264, July 1995.

- *Mixtures of a Coal Combustion By-product and Composted Yard*; EPRI Report GS-7059, Nov. 1990.

- *Organic and Inorganic Hazardous Waste Stabilization Using Coal Combustion Byproduct Materials*; EPRI Report No. TR-103958, Sept. 1994.

- *Solidification Processing of Metal Matrix–Fly Ash Particle Composites*; EPRI Report TR-104409, Oct. 1994.

Industry (ACAA) and government (DOE) cosponsored a research effort to develop a database management system to provide improved access to a wide variety of information on CCBs (O'Leary, 1997). The alpha version of the ACAA CCP Database is currently under review by ACAA staff.

4.6.1.3 Industry-Sponsored Technology Transfer Efforts

Numerous technology transfer efforts are performed by the CCB industry. The most notable of these is an ongoing annual effort by ACAA to publish U.S. data on the production and consumption of CCBs. A brief summary of the most recent published data is given in Tables 7 and 9. A more detailed version of this data is included in Appendix C. While this effort is not new, it provides the type of information required for the industry to evaluate trends and set goals.

ACAA has also continued to sponsor the biennial International Ash Utilization Symposium, with one currently scheduled for January 1999. In recent years, ACAA has increased efforts to encourage participation from government agencies and users of CCBs. The symposium proceedings are published by EPRI.

ACAA also sponsors the Educational Program for Managers of Coal Combustion Products on a biennial schedule. Several of the topic areas address specific items discussed earlier in this report such as environmental aspects of CCB use, development of standards, and high-volume uses.

ACAA has also authored and/or published the following reports:

- *Sulfate Resistance of Fly Ash Concrete: An Overview of Selected Publications*; March 1995

- *Solidification and Stabilization of Wastes Using Coal Fly Ash: Current Status and Direction*; April 1995

- *State Solid Waste Regulations Governing the Use of Coal Combustion By-Products (CCBs)*; April 1995

- *Fly Ash Facts for Highway Engineers;* Aug. 1995

- *Coal Combustion Byproduct Production and Use: 1966–1994;* May 1996

- *State Solid Waste Regulations Governing the Use of Coal Combustion Byproducts (CCBs)*; June 1996

- *A Summary of Leaching Methods*; April 1997

- *Analysis of Coal Ash Uses Before and After the EPA's Nitrogen Oxides Emission Reduction Program Goes Into Effect, Using the Life Cycle Assessment Approach*; Sept. 1997

- *Comparison of Coal Combustion Products (CCPs) Used as Structural Fill Material vs. Disposal in a Landfill Using the Life Cycle Assessment Framework;* Sept. 1997

- *State Solid Waste Regulations Governing the Use of Coal Combustion Byproducts (CCBs)*; June 1998

ACAA continues to assemble and publish CCB production and use statistics on an annual basis and has worked to regularly update the status of regulation of CCB utilization by states.

Several technology transfer efforts have been cosponsored by industry and DOE. These include the following:

- EERC Workshops on the Utilization of CCBs

  – October 10–11, 1996 (Bismarck, North Dakota)
  – March 20–21, 1997 (Colorado Springs, Colorado)
  – September 29–30, 1997 (Minneapolis, Minnesota)
  – October 22–23, 1998 (Grand Forks, North Dakota)

- Western Region Ash Group Interactive Forum on Use of CCBs in Public Works – April 16–17, 1998 (Salt Lake City, Utah)

- University of Kentucky International Ash Use Symposium – October 23–25, 1995, and October 20–22, 1997.

4.6.1.4 Lobbying and Review

Industry response to regulatory or legislative issues that have high potential to impact the use of CCBs has been to perform lobbying and/or work with the appropriate agencies to provide the best technical information. Since 1993, several issues have been addressed by industry:

- Procurement guidelines – Industry responded to EPA's notice and request for information on Procedures for Submission of Recycled Content Products. USWAG'S comments recommended adding 1) boiler slag for use as an industrial abrasive and 2) lightweight aggregates containing fly ash.

- Phase II Bevill Wastes – EPA was directed to make a regulatory determination on the Phase II Bevill Wastes (low-volume utility wastes, oil ash, cofire ash, ash from advanced combustion technologies), and industry responded to EPA's request for extensive information on these "wastes" (EPRI, 1997). DOE joined industry by providing information on CCT technologies (Pflughoeft-Hassett, 1997)

- CERCLA – Language was submitted to redefine the definition of "hazardous substance" under CERCLA to exclude CCBs covering both utilization and disposal. At this time, the definition has not been changed as suggested.

- NORM – Industry offered review comments to EPA on a draft report titled *Diffuse NORM Wastes: Waste Characterization and Preliminary Risk Assessment* because the CCB industry noted erroneous assumptions used by the EPA contractor as they relate to common CCB management practices. A response from EPA is expected in 1998.

- FHWA publication titled *Early Distress of Concrete Pavement* – Industry responded to a draft version of this FHWA report. Conclusions indicating that Class C fly ash contributed to early distress of concrete pavement were based on incomplete information. ACAA led an effort to provide information and specific comments that resulted in a change in the wording of the conclusions that better reflected the results typical of technically sound use of Class C fly ash in concrete pavement.

- Transportation legislation – The CCB industry lobbied in favor of federal legislation that will provide funding for state transportation projects. Since CCBs have been incorporated into numerous road-building applications previously funded by industry, this legislation will provide continued opportunities for CCBs to be utilized nationwide.

4.6.2 Government Actions Responding to Recommendations in the 1994 RTC

4.6.2.1 EPA Determination on RCRA Status of CCBs

On August 9, 1993, the EPA released its Final Regulatory Determination of Four Large-Volume Wastes from the Combustion of Coal by Electric Utility Power Plants (EPA 1993a). An EPA fact sheet on this determination is included in Appendix D. The determination indicated that the four large-volume CCBs—fly ash, bottom ash, boiler slag, and FGD emission control waste—were nonhazardous industrial wastes and should therefore be regulated under Subtitle D of RCRA. Regulation of RCRA Subtitle D wastes is left to individual states. This determination was mandated by the Bevill Amendment, and these four pure streams of fossil fuel wastes were called out for a Phase I determination in that amendment.

Determination of the status of other utility fossil fuel combustion (FFC) wastes such as combined high-volume streams, low-volume wastes, wastes from other fossil fuels and blended fuels, wastes from conversion systems other than pulverized coal systems, and industrial FFC wastes was mandated as Phase II of the Bevill Amendment, scheduled to be made in 1999. DOE contracted with the EERC to provide environmental data on by-products from IGCC and PFBC. Information on pilot-scale processes and DOE-sponsored commercial-scale demonstrations was included in a report titled *IGCC and PFBC By-Products: Generation, Characteristics, and Management Practices* (Pflughoeft-Hassett, 1997). This report was provided to the EPA Office of Solid Waste in September 1997 for use in the Phase II Bevill determinations.

4.6.2.2 Department of Energy Report to Congress

As mandated in Section 1334 of the Energy Policy Act of 1992, the Secretary of Energy prepared a report identifying actions that would increase the utilization of coal combustion/ desulfurization by-products in 1) bridge and highway construction, 2) stabilizing wastes, 3) procurement by departments and agencies of the federal government and state and local governments, and 4) federally funded or federally subsidized procurement by the private sector. The information presented in the first part of this report was used by DOE to meet this obligation, and the DOE RTC titled *Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors* was submitted in July 1994. A copy of the Executive Summary of that report is included as Appendix A. DOE recommendations included the following:

- Implementation of affirmative procurement programs for CCBs
- Development of a database of information on advanced coal technology by-products
- Inclusion of state and local government concerns in DOE RD&D program
- Cooperation of DOE, state government, and industry to transfer by-product information relevant to environmental/health considerations, engineering properties, and beneficial aspects of utilization

- Cooperation of federal and state agencies to review, revise, and/or develop specifications and regulations relating to by-product utilization

- Participation of DOE in highly cost-shared high-volume CCB utilization demonstration projects
- Cooperation of DOE and industry to work to make CCBs more useful or more readily disposed, within practical limits

4.6.2.3 DOE Activities Relating to RTC Recommendations

FETC has actively pursued accomplishment of the recommendations set forth in the DOE RTC by sponsoring the following activities:

- Annual Conference on Unburned Carbon in Utility Fly Ash since 1994

- Development of a database of CCB properties and utilizations sponsored jointly with the ACAA

- Biennial Ash Utilization Symposium organized jointly with industry and the University of Kentucky Center for Applied Energy Research

- Research and development projects relating to CCB characteristics and environmental behavior and CCB use in mineland reclamation

- Technology transfer projects related to providing better access to DOE information through Internet access and developing information on CCT by-products such as PFBC and IGCC by-products

- Development of a traveling technology transfer effort focused on providing information on CCT CCBs for state regulatory agencies

- Western Region Ash Group Interactive Forum on the Use of CCBs in Public Works

- EERC Workshops on the Utilization of CCBs

4.6.2.4 Other Government Agency Activities

4.6.2.4.1 Procurement Guidelines

In response to Executive Order 12873 titled “Federal Acquisition, Recycling and Waste Prevention,” signed on October 20, 1993, EPA has been working toward the development of procurement guidelines that encourage the use of recycled or by-product materials as environmentally preferable. In January 1994, EPA developed a concept paper to instigate a dialogue among interested parties. The proposed guidelines would need to meet certain environmental characteristics. A 1983 EPA procurement guideline for cement and concrete containing fly ash was incorporated into a broader procurement program as described in "Comprehensive Guideline for Procurement of Products Containing Recovered Materials – Final Rule" (*Federal Register*, 1995) and "Recovered Materials Advisory Notice" (*Federal Register*, 1995).

EPA officials met with representatives of ACAA in June 1995 to aid industry in providing the appropriate information for development of procurement guidelines for CCBs as environmentally preferable products.

4.6.2.4.2 Technology Transfer Efforts

Following is a list of technology transfer efforts sponsored wholly or in part by government agencies:

- The FWHA and EPA sponsored a symposium in October 1993 titled *Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities*.

- The National Research Council Transportation Research Board published *Synthesis of Highway Practice 199: Recycling and Use of Waste Materials and By-Products in Highway Construction* in 1994.

- FWHA published and distributed a manual authored by the American Coal Ash Association titled *Fly Ash Facts for Highway Engineers*, Aug. 1995.

- FWHA published and distributed a report titled *Early Distress of Concrete Pavement*, Jan. 1997.

- The USGS published a section titled "Coal Combustion Products" in the USGS *Mineral Industry Surveys—Annual Review 1996.* This will be a continuing effort in cooperation with the ACAA.

- The USGS published a fact sheet (FS-163-97) titled *Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance*, Oct. 1997.

5.0 STATUS OF BARRIERS TO CCB UTILIZATION

The current status of barriers to the increased utilization of CCBs was reevaluated in less detail in the 1998 than in the 1993 EERC study supporting DOE's RTC. Barriers identified in the 1993 RTC are currently reassessed relative to the actions of industry and DOE and other government agencies. New data and statistics are reviewed in an effort to identify any new barriers. It is evident that industry and DOE have been active in addressing the barriers identified in 1993 and in responding to the recommendations in the RTC. Some other federal agencies have also responded to the recommendations. An increased number of states have addressed CCB utilization through laws, regulations, policies, and/or guidance. What is difficult to assess is the extent to which these activities have reduced the barriers identified previously.

Informal input offered by industry and anecdotal information indicates that the efforts expended have resulted in reduction of some barriers, but the reduction is difficult to quantify. Changes have occurred in 1) the wide variety of CCBs available; 2) use of CCBs and competing materials at different locations; 3) marketing by utilities and vendors; 4) technology options for utilization; and 5) regulation.

5.1 Barriers Perceived as Unchanged

Some barriers that were identified previously appear not to have changed despite directed efforts. These are as follows:

5.1.1 Legal Barriers

- CERCLA – The status of CCBs under CERCLA remains unchanged despite industry efforts. CCBs have not been excluded from CERCLA, and liability for environmental damage assessed at a site where CCBs are present still includes the generator of the CCB. Environmental liability is not fault-based, so the extensive data indicating that CCBs are not hazardous do not provide protection against CERCLA liability.

5.1.2 Institutional Barriers

- Education – Because of continued technical changes in the CCB industry, the need to educate a wide variety of groups and individuals continues. These groups continue to include regulators, engineers, scientists and other professionals, and the public. The diversity of the industry, the CCBs and utilization applications, and the audience makes this a particularly challenging barrier to address. Another challenge in addressing this barrier is presented by continued reports (substantiated and not substantiated) of technical and environmental problems with the utilization of CCBs. These reports require regular efforts to respond with factual and scientifically defensible information in order to defend against poor scientific/engineering information or inappropriate application of CCBs.

- Changes in CCBs due to CAAA – The most frequently cited change to the character of CCBs noted in the EERC study was the impact of NO_x control technologies on fly ash, and the industry is now having to address that concern through implementation of fly ash beneficiation processes or disposal of some fly ash from sources that previously marketed the fly ash. The CCB industry is also currently seeing an increased amount of high-calcium by-products from advanced coal use technologies such as FBC. These by-products are being produced because of the need for more energy production coupled with the CAAA. These high-volume by-products require new technical information to facilitate responsible utilization. At the time of the DOE RTC, the CCB industry had not yet anticipated the potential impact on CCBs from regulations that might require control technologies for air toxics such as mercury. Technologies under development for mercury control will likely use a sorbent, which may impact CCB character. Considering these items, it might be said that the impact to CCBs by the CAAA has only begun to be felt and may become more severe as regulations tighten.

5.2 Summary of Reduction of Barriers

Interpretation of the information presented in this report leads to the conclusion that some previously identified barriers have been reduced, although perception as to the level of reduction likely varies widely in the CCB industry.

5.2.1 Regulatory Barriers

- Federal and state regulation – The EPA *Final Regulatory Determination of Four Large-Volume Wastes from the Combustion of Coal by Electric Utility Power Plants* (EPA, 1993a) stating that fly ash, bottom ash, boiler slag, and FGD emission control waste are nonhazardous industrial wastes and should therefore be regulated under RCRA Subtitle D was a positive step toward reducing the regulatory barriers, also toward reducing the concern of users and the public that these materials are hazardous. The RCRA determination encouraged the utilization of CCBs and supported the issuance of several EPA procurement guidelines indicating preference for products containing CCBs. It is important to note that industry worked hard to provide information for both of these EPA actions and that industry is continuing to work to take advantage of the procurement guidelines. It was stated in the 1993 draft EERC report that industry perceived a lack of federal guidance on the use of CCBs because of their interim status under RCRA Subtitle D prior to the final determination. The final determination provided the federal guidance needed to allow states to reassess their regulations on CCBs, which is occurring (Figure 18). Industry also played a role by working with individual state regulatory agencies.

5.2.2 Institutional Barriers

- Environmental and public perception – The need to reduce CO_2 emissions because of potential global warming has provided an opportunity for the CCB industry to promote the use of fly ash in concrete as an environmental benefit. Utilities have taken credit for their sales of fly ash to the concrete market as part of their contribution to a voluntary program to reduce greenhouse gases. When fly ash is used as part of a concrete mix, the cement content can be reduced. Since cement kilns emit CO_2, it can be shown that reducing the demand for cement by using fly ash reduces overall CO_2 emissions. Since about 90 million tons of CCBs and about 80 million tons of portland cement are produced annually, it may be possible for the use of fly ash in concrete to substantially reduce CO_2 emissions from cement kilns. In order for this to occur, the cement and CCB industries, which historically have seen each other as competitors, are going to need to work together. As a result of changes in both industries, there has been some movement toward cooperative efforts, but this is an area that will need to continue to evolve.

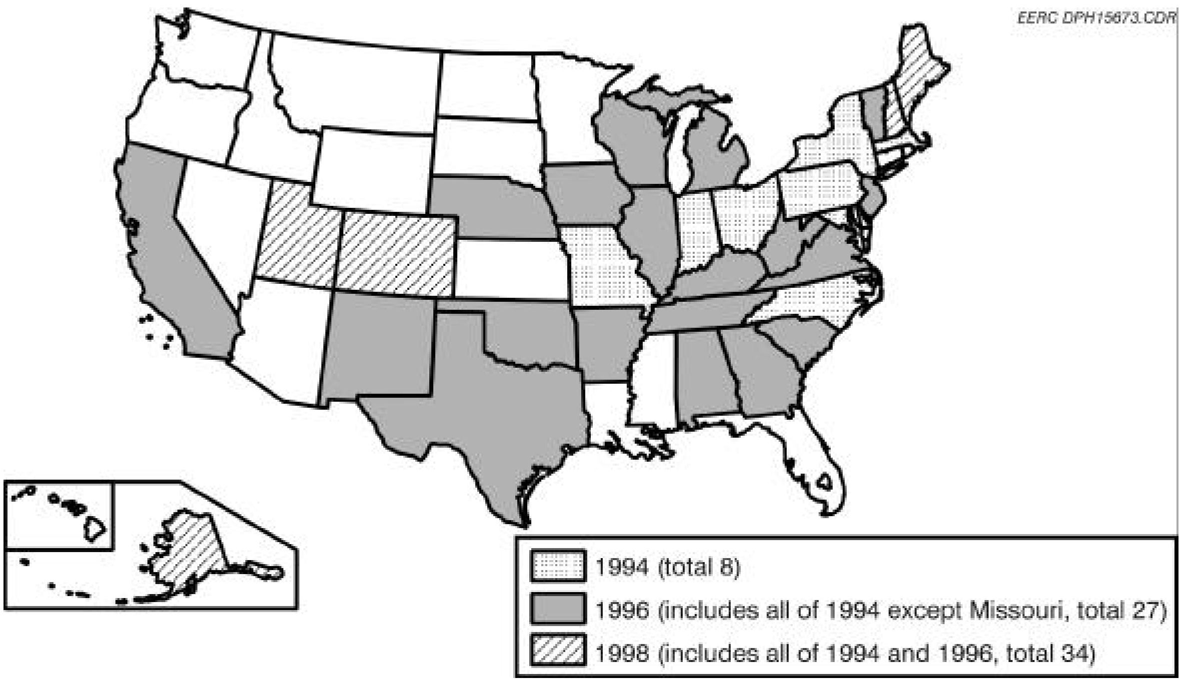

Figure 18. States with laws, regulations, policies, and/or guidance authorizing CCB utilization.

- Economic – The perception that cost avoidance is the only economic advantage to CCB utilization probably remains intact at some utilities. However, the move toward utility deregulation has resulted in a more detailed review of the economics of CCB marketing on the part of some utilities. The results seems to indicate that utilities, at least those active in trade associations, see economic advantage in selecting CCB utilization as a preferred management option. Certainly, the permitting difficulties and cost of new disposal sites have not diminished since the RTC, and these issues are economic drivers for utilities to increase CCB sales.

- Economic – While not a result of any efforts related to the RTC, cement shortages in various parts of the United States have had a significant impact on the demand for fly ash. These shortages and other factors may increase the future price of admixture-grade fly ash. The other factors include 1) several buyouts and mergers that have formed a smaller number of CCB marketing companies, some of which are also cement manufacturers, and 2) the potential for a reduction in the availability of admixture-grade fly ash due to implementation of NO_x control technology. These factors have not yet been reflected in an increase in the price of fly ash. However, if the price for fly ash does increase, it can only have a positive effect on the economics of CCB utilization. It has been suggested that a higher price would help to alleviate the common misperception that fly ash is used in concrete simply to lower the cost.

- Technical – Industry has worked diligently to develop new standards for key CCB utilization applications and to update current standards. Although the standard development process is a slow one by design, several standards have been completed and more are in process. These standards will be used by end users and specifiers to provide assurance that materials and procedures will result in a successful project. Standards are needed by the CCB industry in marketing to guarantee suitable materials and prescribed performance. Working toward the development of performance standards for CCBs in new utilization applications remains a high priority for the industry.

5.3 New Barriers

5.3.1 Institutional and Technical Barriers

- Climate change – The issue of global climate change and the need to reduce greenhouse gas emissions has the potential to impact coal-fired utilities substantially. It is anticipated that coal-fired power plants may be required to reduce CO_2 emissions significantly. One approach is to incorporate biomass as a portion of the fuel. The ashes produced by cofiring biomass will need to be characterized and their performance in utilization applications evaluated. This is an unmet need at this time that can likely be best addressed through cooperation between industry and DOE.

- Opportunity fund – As utilities move toward a more competitive industry, there have been adjustments in fuel selection. Utilities are less likely to enter into long-term coal contracts and are more likely to purchase coal on the spot market and to incorporate alternate fuels, such as petroleum coke, biomass, tires, and other wastes. These decisions can have an impact on the CCBs produced and on their performance in utilization applications. This issue requires the industry and DOE to cooperate in evaluating the impact of the inclusion of alternate fuels on CCB quality and in the development of performance-based standards in place of specifications based on fuel source.

5.3.2 Regulatory Barriers

- NORM – The issue of naturally occurring radioactive material in CCBs has recently become high priority and is both a new regulatory and institutional barrier. It is a regulatory barrier because EPA includes CCBs in a list of eight industrial materials that contain NORM and require some assessment. To date, EPA’s assessment of NORM in CCBs has incorporated faulty assumptions in calculating risk related to NORM exposure. Currently, EPA is reviewing comments to a draft report it released for comment. The final report will provide an indication of the potential risk for humans exposed to the NORM in CCBs, and that will likely impact state regulation of CCB management. This issue is also an institutional barrier because of the potential negative impact to perception of CCBs by users and the public. The level of response that may be needed to address this barrier remains an unknown, but it can best be addressed jointly by industry and government.

- Toxic release inventory (TRI) – TRI reporting has been changed to include utilities in 1998. There are two primary issues: 1) utilized CCBs are excluded from TRI reporting because they are not considered a “release” and 2) utility TRI reports will be included with other industry TRI reports on a publicly accessible Internet site, which has been speculated to cause a level of concern on the part of groups or individuals who have limited technical background. The impact on CCB utilization is unknown, but needs to be followed.

5.4 Next Steps

Industry and government have worked constructively together, but it is apparent that in the short time since the RTC, the progress toward reduction/removal of barriers to the increased utilization of CCBs has been limited. It is important that the cooperation between industry and DOE continue, and DOE has initiated an effort to accomplish that. The DOE Emission Control By-Products Consortium will provide a framework for industry, DOE, and other government agencies to improve cooperation and communication. Using the infrastructure of the consortium, identified barriers, recommendations, and actions can be prioritized and RD&D efforts can be directed to meet identified priorities. The consortium is expected to address primarily technical issues, which are the basis for many of the barriers identified. With input and cooperation from industry, the consortium has the potential to speed the process of barrier reduction.

Industry should continue to take advantage of regulatory policies and guidelines that encourage CCB utilization, including federal procurement guidelines. Industry must continue its efforts to obtain fair legislation and regulation that defines the status of CCBs within sound technical and environmental guidelines to reduce uncertainty and further encourage utilization.

6.0 CONCLUSIONS

The following conclusions are drawn from the information presented in this report:

- Joint efforts by industry and government focused on meeting RTC recommendations for reduction/removal of barriers have met with some success. The most notable of these are the changes in regulations related to CCB utilization by individual states. Regionally or nationally consistent state regulation of CCB utilization would further reduce regulatory barriers.

- Technology changes will continue to be driven by the CAAA, and emission control technologies are expected to continue to impact the type and properties of CCBs generated. As a result, continued RD&D will be needed to learn how to utilize new and changing CCBs in environmentally safe, technically sound, and economically advantageous ways. Clean coal technology CCBs offer a new challenge because of the high volumes expected to be generated and the different characteristics of these CCBs compared to those of conventional CCBs.

- Industry and government have developed the RD&D infrastructure to address the technical aspects of developing and testing new CCB utilization applications, but this work as well as constant quality control/quality assurance testing needs to be continued to address both industrywide issues and issues related to specific materials, regions, or users.

- Concerns raised by environmental groups and the public will continue to provide environmental and technical challenges to the CCB industry. It is anticipated that the use of CCBs in mining applications, agriculture, structural fills, and other land applications will continue to be controversial and will require case-by-case technical and environmental information to be developed. The best use of this information will be in the development of generic regulations specifically addressing the use of CCBs in these different types of CCB applications.

- The development of federal procurement guidelines under Executive Order 12873 titled "Federal Acquisition, Recycling and Waste Prevention," in October 1993 was a positive step toward getting CCBs accepted in the marketplace. Industry needs to continue to work with EPA to develop additional procurement guidelines for products containing CCBs—and to take advantage of existing guidelines to encourage the use of CCBs in high-profile projects.

- Accelerated progress toward increased utilization of CCBs can be made only if there is an increased financial commitment and technical effort by industry and government. The framework for this has been set by the successful cooperation of industry and government under DOE leadership. Cooperation should continue, with DOE fulfilling its lead role established in the RTC. It is clear that the RTC recommendations continue to have validity with respect to increasing CCB utilization and continue to provide guidance to industry and government agencies.

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APPENDIX A

DOE's 1994 REPORT TO CONGRESS – EXECUTIVE SUMMARY

REPORT TO CONGRESS

Barriers to the Increased Utilization of Coal Combustion/Desulfurization Byproducts by Governmental and Commercial Sectors

EXECUTIVE SUMMARY

INTRODUCTION

Increasing cost and heightened regulation are making the disposal of coal byproducts an undesirable option. The increased utilization of coal combustion byproducts could provide numerous environmental and economic benefits to the United States. Positive environmental effects include (1) reduced solid waste, (2) reduced use of natural resources, and (3) reduced energy consumption and $C0_2$ emissions from the reduced use of natural resources and production of cements. Economic benefits of byproduct utilization could include (1) reduced construction costs, (2) savings in energy prices versus disposal, and (3) the creation of new jobs through marketing opportunities from byproduct sales.

For these and other reasons, the Congress of the United States in section 1334 of the Energy Policy Act of 1992 (the Act), charged the Secretary of Energy to "conduct a detailed and comprehensive study on the institutional, legal, and regulatory barriers to increased utilization of coal combustion byproducts by potential governmental and commercial users." Coal combustion byproducts were defined in the Act to be, "the residues from the combustion of coal including ash, slag, and flue gas desulfurization materials."

Following completion of the study, the Act directs that the Secretary prepare a report to the Congress containing the results of the required study. Such report should also contain the Secretary's recommendations for action to be taken to increase the utilization of coal combustion byproducts. The Department of Energy (DOE) has completed the study specified in section 1334 and submits this report to the Congress in fulfillment of its obligation under that section of the Act.

BACKGROUND

Coal is this Nation's largest indigenous fossil fuel resource and its use is expected to remain important well into the 21st century. U.S. coal consumption is approximately one billion tons per year, and is predicted to grow at an annual rate of close to 2 percent. One undesirable feature of the use of coal is the production of large quantities of solid residues from the combustion process. Approximately 80 million tons of ash residues are produced per year. Approximately 20 million additional tons of flue gas desulfurization (FGD) residues are being produced per year. Both of these values are expected to increase as coal usage increases and as utilities adopt flue gas desulfurization technology to control emission of $S0_2$ to the atmosphere in order to meet environmental requirements required by the Clean Air Act Amendments of 1990. Gradual adoption of advanced coal technologies into the commercial marketplace will introduce increased amounts of byproducts differing from the traditional byproducts.

In 1993, the Environmental Protection Agency (EPA) issued its final regulatory determination on fly ash, bottom ash, boiler slag, and flue gas desulfurization residues. They were deemed to be non-hazardous and are to be regulated under subtitle D of the Resource Conservation and Recovery Act (RCRA). As such, individual States have been given the authority under RCRA to regulate them. There is wide variation in the cost to dispose of the byproducts because of the varying State regulation requirements. However, cost of disposal has been rapidly and steadily increasing as more stringent regulations on containment are being implemented in almost all States.

The EPA regulatory determination that coal waste products are not hazardous did not extend to waste products from some advanced coal systems. Therefore, it is important to continue research on these waste products to ensure that data is available to enable EPA to make a future determination if necessary.

The utilization of coal byproducts has remained fairly constant over the last decade at approximately 25 percent overall. No substantial upward movement has been noted since increases associated with the establishment of Federal procurement guidelines for use of fly ash in concrete. Notable is a very low utilization of FGD residues.

Helping industry shift from waste management to resource efficiency and pollution prevention is a major thrust of the Administration. This is reflected in the goals and objectives of the Department of Energy's Strategic Plan and Executive Order 12873. The latter creates an organizational structure in the executive branch agencies to implement a Federal procurement policy favoring utilization of materials that would otherwise be treated as wastes.

The Department's Office of Fossil Energy has a mission to accelerate commercialization of advanced coal using technologies capable of meeting the energy and environmental demands of the 21st century. Environmental demands include dealing with the solid residues (coal byproducts) produced from the advanced coal using systems in an environmentally acceptable manner. Commercialization of these advanced systems hinges on environmental acceptability and cost. Utilization of the coal byproducts for productive purposes would contribute greatly to early market entry of advanced coal using systems. Toward achieving coal byproduct utilization, the Department's Coal Research and Development (R&D) and Clean Coal Technology Demonstration Programs are addressing coal byproduct issues as a part of the cost shared activities with industry to develop advanced power and environmental control system product lines. Coal byproducts are being characterized, and disposal and use scenarios explored. Key participants in these product development activities are equipment vendors, utilities (the end user), State agencies, and industry based research organizations such as the Electric Power Research Institute and the Gas Research Institute.

In parallel with product line development activities, there is an established ongoing support program at the Morgantown Energy Technology Center (METC) charged with integrating the coal byproduct aspects of product development efforts. More specifically, the mission includes characterizing the byproducts and maintaining a data base; identifying information needs; evaluating the adequacy of byproduct disposal methods through field tests, evaluating utilization options through highly cost-shared demonstrations; and addressing market entry issues associated with productive byproduct use.

In pursuing market entry issues, the Federal role, acted out through METC, has been one of interacting with the stakeholders, structuring forums for discussion, and encouraging action on the part of the stakeholders toward achieving market acceptance of coal byproducts. The stakeholders with the greatest interest in seeing coal byproduct utilization include coal producing states, trade organizations such as the American Coal Ash Association (ACAA) and the Edison Electric Institute (EEI) who represent utility and coal producer interests, and the Electric Power Research Institute (EPRI), the utility sector's research arm. All are playing active roles in supporting byproduct utilization. For example, several coal using States have provided funding for relevant studies and tests; the ACAA has gathered and provided needed data and statistics and proactively sought market opportunities; the EEI (representing investor-owned utilities) formed a Utility Solid Waste Advisory Group to conduct studies on both byproduct disposal and utilization issues; and EPRI has supported byproduct utilization demonstrations.

This report is an extension of METC's market oriented activities. The recommendations set forth are not intended to expand the Federal role, but rather serve to focus efforts where they would have the greatest impact. Actions taken to implement the recommendations would remain within the established missions and budgets. The Federal role would remain primarily one of facilitator or catalyst to prompt appropriate action. Clearly, the stakeholders have expressed a desire for a Federal presence not only as a facilitator, but as liaison and independent assessor in accelerating market entry of coal byproducts.

THE STUDY

As directed by the Act, a study was done which identified legal, institutional, and regulatory barriers to increased coal byproduct utilization. The study approach was to first conduct a comprehensive review and assessment of the published literature. Key stakeholder groups were then identified and representatives from those organizations interviewed to determine issues of primary concern to their industry. Notice was placed in the Federal Register that DOE was conducting the study and soliciting public input. Both private and public groups were identified and interviewed in this process. Open forum meetings were held with representatives of two stakeholder groups to further define issues. Finally, a workshop with participants from all stakeholder groups was held to present preliminary study findings and solicit further comment. The most input into the study was provided by the electric utility industry group, which is most affected by barriers to byproduct utilization.

BARRIERS TO INCREASED BYPRODUCT UTILIZATION

The findings of the study suggest that institutional, regulatory, and legal barriers are very much interrelated. The institutional barriers can be summarized into the following major areas:

> *Inadequate Information*. There are shortages of data on certain byproduct use technologies because the data simply was not generated. This includes both engineering and environmental data.
>
> *Inefficient Technology/Information Transfer*. Available information is not transferred or is not transferred in a timely fashion to regulators or potential users of byproduct utilization technology. There is an apparent information or communications gap among the producers of byproducts, end users, and regulators.
>
> *Lack of Coordination/Leadership in Development and Promotion of Coal Byproduct Utilization*. There is a national industry group for promotion of coal byproduct reuse. However, an organization is needed within the Federal Government to support that promotional role within the governmental sector.
>
> *Inadequacies of State Programs to Promote Beneficial Reuse*. Coal byproduct disposal and beneficial reuse are regulated by the States. Across the States there is inconsistency in State regulations for what constitutes beneficial reuse and how it should be regulated. Few State procurement programs support use of recovered materials such as coal byproducts.
>
> *Non-Existent or Inadequate Specifications for Byproduct Use*. There is a lack of recognized technical specifications for use of coal byproducts even in proven technology.
>
> *Existence of Attitudinal Barriers*. Designation of coal byproducts as a solid waste, while fostering public misconception about the risk of these materials, stymies attempts to develop or expand markets for their use.

The lack of discrimination in the Federal and State regulatory systems between coal byproducts for beneficial reuse application and in disposal is central to the regulatory barriers to increased byproduct utilization. Without this discrimination, the "waste" designation can trigger case-by-case approval which makes utilization impractical.

There is also the need in the regulatory field to develop environmental compliance tests which determine realistic environmental impacts.

The chief legal barrier to increased coal byproduct use is the potential for liability associated with use of a material designated as a waste material. It is a concern of producers and users of coal byproducts that their liability is unacceptably extended beyond that normally associated with use of a commercial material.

RECOMMENDATIONS FOR ACTION BY THE FEDERAL GOVERNMENT

In developing the recommendations for action in this Report, several criteria were used.

•Actions recommended should fall within budgetary and personnel resource constraints imposed by today's Federal budget and manpower reduction initiatives.

•Recommended actions should attempt to maximize use of existing Federal resources and cooperation among Federal agencies.

•Any successful effort to promote the increased use of coal byproducts will require a cooperative effort of Federal and State government agencies and the private sector, including industry, environmental interest groups, and private citizenry.

•Recommended actions should promote an environmentally protective and beneficial increase in coal byproduct utilization.

Recommendation No. 1

Implement Executive Order No. 12873 with due consideration to the use of coal byproducts. This includes developing affirmative procurement programs in accordance with section 402(a); revising Federal and military specifications, product description, and standards to enhance Federal procurement of coal byproducts in accordance with section 501, identifying accepted coal byproducts and possible uses, and reporting progress in increasing procurement of coal byproducts in accordance with section 602.

Recommendation No. 2

With industry, DOE will contribute to a data base addressing concerns relative to RCRA regarding coal byproducts derived from advanced coal technologies. If coal technology byproducts are to be utilized, determination must be made that they fall under subtitle D of RCRA. This action removes the "hazardous" tag and potential liability for environmental cleanup, and gives the responsibilities and authorities for handling these subtitle D materials to the States.

Recommendation No. 3

DOE will work with State and local governments to identify issues or concerns regarding coal byproduct use within their respective jurisdictions. Factor these results into the

Department's Research, Development and Demonstration Program (RD&D).

Recommendation No. 4

For identified markets, that DOE work with State and local governments and coal byproduct producers to package and transfer information targeted to these markets that addresses the relevant environmental/health considerations, engineering properties, the range of properties to be expected, and beneficial aspects.

Recommendation No. 5

DOE will work, in cooperation with EPA and other agencies, with State and local governments to review and revise, as necessary, existing specifications and regulations relating to coal byproduct use; and develop specifications and regulations where needed.

Recommendation No. 6

Within existing budget levels, consider participation in highly cost-shared demonstrations that would evaluate the viability and environmental acceptability of high volume coal byproduct utilization applications, such as bridge and highway construction or for stabilizing wastes.

Recommendation No. 7

DOE will work with technology suppliers and utilities early-on to explore what might be done within practical limits to make coal residues from plants more useful byproducts or more readily disposable wastes.

SUMMARY

As identified, it will require the cooperative efforts of State and local governments and the Federal Government to accomplish the goal of increasing coal byproduct utilization. The DOE believes that the implementation of the identified recommendations in such a fashion will lead to significant near- and long-term increased utilization which will enhance our Nation's environment and economic vitality.

APPENDIX B

EERC's 1993 REPORT TO DOE – EXECUTIVE SUMMARY

BARRIERS TO THE INCREASED UTILIZATION OF COAL COMBUSTION/DESULFURIZATION BY-PRODUCTS BY GOVERNMENT AND COMMERCIAL SECTORS

EXECUTIVE SUMMARY

1.0 INTRODUCTION

The nearly 90 million tons of coal combustion by-products produced annually in the United States is a valuable national resource that is vastly under utilized. Current use of about 30% of the coal ash and only 2% of the flue gas desulfurization products represents a failed opportunity when compared to the nearly complete utilization already achieved in some western European countries. Future opportunities can be seized by concerted action to offer substantial benefits to the nation's electric generation, construction, and manufacturing industries; to agriculture; and to the environment, whereas failure to act will create, literally, mountains of solid waste, an unnecessary legacy of future energy production.

The value of coal combustion by-products is well established by research and commercial practice both in the United States and abroad. As engineering construction materials, these products can add value and enhance strength and durability while reducing cost. In agricultural applications, gypsum-rich products can provide plant nutrients and improve the tilth of depleted soils over large areas of the country. In waste stabilization, the cementitious and pozzolanic properties of these products can immobilize hazardous nuclear, organic, and toxic metal wastes for safe and effective environmental disposal. Public benefits of coal combustion by-products utilization are substantial, including conservation of land, energy, and natural resources; reduction in CO_2 emissions generated in the production of competing materials; improvements in the balance of trade (e.g., fewer cement imports); and prevention of solid waste pollution. Increasing cost and heightened regulation are making the disposal of coal by-products an undesirable option.

For the above reasons, in Section 1334 of the Energy Policy Act of 1992, the United States Congress charged the Secretary of Energy to "conduct a detailed and comprehensive survey on the institutional, legal, and regulatory barriers to increased utilization of coal combustion by-products by potential governmental and commercial users." Section 1334 of the Energy Policy Act of 1992 designates that:

> "At a minimum, such report shall identify actions that would increase the utilization of coal combustion by-products in 1) bridge and highway construction, 2) stabilizing wastes, 3) procurement by departments and agencies of the federal government and state and local governments, and 4) federally funded or federally subsidized procurements by the private sector."

Therefore, the goal of this report is to identify the barriers to increased usage of coal combustion by-products and make recommendations for the removal of these barriers in cases where they are unnecessary or detrimental to the economic and environmental well-being of the

United States. To meet this goal, the Morgantown Energy Technology Center contracted the Energy & Environmental Research Center (EERC) to conduct a study to assess the barriers to the increased utilization of coal combustion by-products. The study conducted by the EERC made every attempt to be objective and to base conclusions on data obtained from representatives from all organizations, both public and private, that are involved with coal combustion by-product utilization and disposal. EERC's investigations and comments on barriers to increased by-product utilization were not strictly limited to narrow definitions of the terms "institutional, legal, and regulatory." The study concluded that the real barriers to increased by-product utilization are complex and interrelated, including economic, environmental, attitudinal, and other factors that ultimately manifest themselves in institutional, legal, and regulatory impediments to increased utilization. The information gained from the EERC study was used in the preparation of this report.

The language used in the Energy Policy Act underlines Congressional awareness of under-utilization of coal by-products in the United States. The current utilization of these materials is well below their potential. The concern Congress has shown by including this issue in the Energy Policy Act of 1992 conveys a directive to government and industry to take steps to proceed with the beneficial use of these materials in the interest of the U.S. economy and environment.

Serious barriers are impeding the demonstration, development, and commercialization of utilization applications. An interlocking network of institutional, legal, and regulatory barriers is preventing the forward movement needed to achieve full economic utilization of coal combustion by-products in the foreseeable future. The key to breaking down these barriers lies in changing attitudes that currently consider these materials as wastes. The regulatory classification of a material as a solid waste, even though the material is nonhazardous (as in the case of coal combustion by-products), raises a caution flag and triggers case-by-case approval and permitting procedures that discourage beneficial use because of unreasonable cost and delay. Procedures should be identified and implemented to gain full acceptance of these materials as valuable and environmentally safe products. The environmental safety of coal combustion products is a valid concern that, for the most part, has already been answered. The overwhelming weight of evidence indicates that these products are not hazardous by legal or regulatory definitions and that they pose no greater cause for concern than a host of other common solid materials, including cement, rock, and soil. Nevertheless, current regulatory practice treats coal combustion products as solid waste, requiring environmental validation before allowing their substantially unrestricted use.

The effort to identify barriers and actions to increased utilization of coal by-products that Congress has called for is only the initial step needed to remove or reduce institutional, regulatory, and legal barriers. Governmental agency actions at both the federal and state levels will be pivotal in the efforts that will need to follow. Leadership from government in this effort is anticipated to have a positive and wide-reaching effect on the private sector. Coordinated effort by government and industry is essential to move toward increased utilization in the interest of the national economy and the environment.

2.0 METHODS OF INFORMATION GATHERING

The information contained in the study provided by the EERC was compiled from the following sources: 1) review and assessment of previous works in the literature to assess the current state of understanding and to identify information gaps, 2) identification of the government agencies and private concerns involved with coal by-product utilization, 3) personal interviews conducted to fill knowledge gaps and to assess issues of primary concern, 4) two open forums designed to solicit input from industry, and 5) input from a workshop designed to facilitate comments on a draft version of the EERC report by government and industry experts and to assist in shaping recommendations.

The EERC study solicited a broad range of information, including opinion, from over 130 public and private organizations. Many of those interviewed held conflicting interests and opinions, making a mere compilation of the data useless. Therefore, the EERC study used all of the information gathered to make informed recommendations balancing all interests and opinions.

Numerous interviews and several group meetings were conducted in the effort to identify specific barriers. Participants in the meetings and interviews included representatives from federal and state agencies, utilities, coal by-product marketers, and related industries. An effort was also made to contact and interview national environmental groups. The information-gathering strategy was to compile comments from all of the various groups involved with coal by-product utilization.

The number of participants from each of the groups involved in the information-gathering phase varied. The level of information was generally appropriate to the evaluation, and the response and cooperation were very good. The two groups with the highest number of respondents were the utilities and marketers. This was expected because of the level of importance the utilization of coal by-products has in these industries. The appropriate individual(s) within each company was usually easily identified and contacted, and the comments were candid and well focused. Many representatives of these groups also participated in open forums to discuss the barriers to coal by-product utilization. Evaluation of the comments from these groups indicated a high degree of agreement. Representatives of related industries in the private sector were also interviewed and attended the open forums. Those interviewed included individuals from coal companies, construction companies, trade associations, engineering firms, and manufacturing companies. This group was extremely diverse, and appropriate individuals from these industries were much more difficult to identify because of the less direct role of coal by-products in their industries. An attempt was made to interview several individuals in each related industry category in order to determine if common barriers existed in these related industries. Their level of familiarity with issues relating to coal by-products ranged from excellent to negligible. This group frequently raised issues from the end-users' perspective. The more common themes emerging from the related industries were often the same as those raised by the utility and marketing groups. In the private sector, three national and five regional environmental groups were also contacted for participation in this effort. Despite numerous calls to various individuals, there was a lack of response from environmental organizations. This is consistent with previous experiences of utility and marketing groups attempting to initiate dialogue on coal by-product utilization with environmental groups.

Federal agencies contacted included the Federal Highway Administration (FHWA), the

Environmental Protection Agency (EPA), the Department of Agriculture (USDA), the Bureau of Mines (BOM), and the Army Corps of Engineers. The U.S. EPA is the federal agency that deals with regulating industrial wastes, including coal by-products. The other federal agencies interviewed are involved with the utilization of coal by-products and may be considered end users in some cases. Only one person was interviewed at most of the federal agencies, but additional representatives of federal agencies participated in the open forums. It was not possible to solicit input from regional offices of federal agencies within the scope of this effort. Many of the individuals interviewed were identified by the EERC with the assistance of the Department of Energy Morgantown Energy Technology Center.

State governmental agencies interviewed included two key groups: Departments of Transportation and Departments of Environmental Protection and Natural Resources. Representatives from over forty state Departments of Transportation were interviewed. These individuals were generally very knowledgeable on the coal by-product utilization practices within their states and cooperative in relaying information. Generally, a conservative attitude was expressed regarding coal by-product utilization from this group.

State environmental protection and natural resources agencies were contacted and interviewed on a more limited basis than the departments of transportation for several reasons. Identification of the appropriate individual for contact was frequently not readily accomplished. Contacts made through input from utility representatives were generally most fruitful. The issues of coal by-product utilization were not usually well addressed by the regulatory mission of the state agencies. Only a few states indicated specific policies on utilization of these materials, whereas many did not have established procedures for addressing utilization apart from waste regulation.

3.0 RECOMMENDATIONS FROM STUDY PARTICIPANTS

Recommendations for increasing the utilization of coal combustion by-products were solicited by the EERC from a broad spectrum of industrial, regulatory, environmental, transportation, and agricultural groups in the course of telephone interviews, open forums, and the study workshop. The proposed actions in this section include some divergent positions presented by the respective groups, which are offered here for consideration by the U.S. Congress. Those positions attributed to particular groups (indicated by notations in parentheses; key is shown in Table ES-1) reflect responses obtained in the study, but they are not official positions taken by those groups. The study workshop was successful in identifying common ground for shaping the consensus positions presented in the study contractor's recommendations in Section 5.0 of the Executive Summary.

Recommendations are categorized in this section as pertaining to legal, regulatory, institutional, technical, and economic barriers, respectively. In reality, all of the recommendations are closely related:

- Action on legal barriers is required as a basis for regulatory reform.

- Regulatory classification is needed before government and private agencies can take actions to increase utilization with assurance of environmental safety.

- Institutional leadership and coordination within prescribed guidelines is needed to implement changes.

TABLE ES-1

Key to Attribution of Recommendations

W	–	Workshop
USWAG/ACAA*	–	USWAG/ACAA Open Forum Meetings
U	–	Utilities
M	–	Marketers
R	–	Related industries
S-E	–	State environmental agencies
F-E	–	Federal environmental agencies
S-T	–	State Departments of Transportation
F-T	–	Federal Department of Transportation
F-USDA	–	Federal Department of Agriculture

*Utility Solid Waste Activities Group/American Coal Ash Association

- An improved technical base is needed to establish both environmental criteria and engineering specifications for safe and effective utilization.

- Economic incentives are needed to establish a level playing field in relation to competing raw materials and to overcome reluctance to adopt new materials and methods.

3.1 Recommendations on Legal Barriers

3.1.1 National Goal Status

- The workshop offered broad endorsement for special legislation addressing national goal status under the title of the 1994 Coal Combustion By-Products Utilization Act. Revision of existing legislation, including the 1992 Energy Policy Act or RCRA, was also supported as a less preferred alternative. Parallel action on national goal status was proposed by executive order. (W, U, R, S-T)

- Legislation addressing national goal status was proposed to include a strategic plan, timetable, and tracking. (W, U, R)

- Congressional action was recommended to exempt federally approved by-product utilization from RCRA Subtitle D regulation currently delegated to the states. (W)

- Specific congressional action was proposed on the approach to be used in assessing the environmental risks involved in by-product utilization. (W, R)

- Recommendations for incorporating percentage goals into legislation were debated from the standpoints of having measurable objectives, avoiding an implied mandate, and not diminishing the interest of the public in striving toward 100% utilization. A consensus position endorsing 50% utilization as an interim goal (proposed in the 1990 National Energy Strategy) was broadly supported. (W, M)

- The public interest in coal by-product utilization should be identified as an integral part of national goal status. Public interests include conservation of land, energy, and natural resources; pollution prevention as defined by multimedia (clean air/clean water/minimum solid waste) life cycle analysis; regional benefits to aggregate-poor and agricultural regions; reduced electric utility rates; reduced costs for building materials; and an improved trade balance, as in the case of reduced U.S. imports of cement use. (W, U, S-T)

3.1.2 Environmental Liability

- Workshop discussion on measures for reducing the environmental liability of by-product producers and users was divided along lines of either advocating exemption from liability (as currently provided for petroleum products under CERCLA) or warning that such exemption would reduce the use of by-products in sensitive-use areas, such as waste stabilization if no one were required to accept responsibility. (W, USWAG/ACAA, U, R)

- If exemption from CERCLA were to be considered, it was proposed that it be addressed by category of application, with special attention given to waste stabilization. (W, U)

- The consensus position taken by the workshop attendees on environmental liability was to advocate general review of grounds and remedies with a view toward future legislative action. (W)

- A proposal to exempt all approved materials used in waste stabilization (e.g., approved ash, lime, cement, etc.) from environmental liability was advanced as a possible legal remedy. (W)

3.1.3 Jurisdiction

- Congressional action should be taken to reconcile extremely divergent treatment of by-product utilization by individual states under RCRA Subtitle D delegated authority. (W, USWAG/ACAA)

3.1.4 Contract Law

- Review of contract law for the purpose of establishing a Universal Commercial Code for by-product sales was given low priority by the workshop. (W, M)

3.1.5 Patent Review

- A proposal for general review of patents covering by-product utilization to clarify the distinction between protected processes and uses in the public domain received only limited support from the workshop. (W, USWAG/ACAA)

3.2 Recommendations on Regulatory Barriers

- The workshop broadly endorsed the development of regulatory classifications for the purpose of preapproving by-products in particular use applications. (W)

- Standardized environmental criteria for approved use should be developed by the U.S. EPA. (W)

- By-products that meet established environmental criteria should not be restricted in use. (W, M)

- Federal approval of guidelines for by-product use should not be on a case-by-case basis but rather by category. (W, U)

- Sufficient agency funding (EPA) should be provided to expedite historically slow approval procedures. (W, S-E)

- The agency setting environmental criteria (EPA) should solicit input on environmental guidelines. (W)

- Use criteria already approved at state levels should be incorporated into the national criteria for preapproved uses. (W, U)

- The deregulation of beneficial uses should be approached through practices that demonstrate reduced risk. (W)

- Environmental criteria should be given highest priority consideration, with particular attention to land applications and contact with groundwater. (W)

- Currently available environmental data should be categorized to be more useful. (W, U)

- Environmental criteria should address long-term stability. (W, S-T)

- Environmental testing as a basis for regulatory testing should be representative of the use environment. (W, U)

- The development of environmental criteria for deregulation should consider intermediate standards for toxic elements between those currently defining toxic waste under RCRA and those applying to drinking water under the Safe Drinking Water Act. (S-E)

- Environmental criteria should emphasize groundwater quality and toxic trace elements. (S-E)

- Questions to be addressed in regulatory classification should include: (W)

  – How real are the identified environmental concerns?
  – How can environmental impact be realistically determined?
  – Who is responsible for determining environmental risk?
  – What level of environmental risk is acceptable?

- Regulatory classification by government should be linked to technical specifications that address environmental, engineering, and economic criteria together. (W, R)

- Federal efforts should be actively focused on eliminating unnecessary environmental barriers. (W, S-T)

- Measures taken to reduce regulatory barriers should be linked to existing pollution prevention laws (state and federal) that encourage recycling. (W, R)

- Regulation of approved beneficial uses should not treat by-products as solid wastes. (W, USWAG/ACAA)

- Environmental performance standards for high-volume uses, such as flowable and structural fill, should be given high priority. (W)

- Initiative for requesting federal action on approved uses should be open to all federal and state agencies and private industry. (W, S-E)

3.3 Recommendations on Institutional Barriers

3.3.1 Need for Coordination

- It was recommended that all affected federal agencies be required to identify opportunities for increasing by-product utilization in their areas of activity and to issue an action report to Congress. (W)

- Cooperation between by-product producers and users should be improved. (W)

- Coordination between producers and users should endeavor to minimize risks (environmental, engineering, economic, and legal liability) and promote quality assurance and product responsibility. (W)

3.3.2 Federal Leadership

- The study workshop generally supported the need to designate a single federal agency charged with the responsibility for leading efforts to increase by-product utilization and for coordinating the activities other participating agencies. (W)

- Some participants proposed that federal leadership should be exercised by those agencies that are most closely affected. (W, S-T)

- The need for an effective team effort involving a large number of federal and state agencies was discussed. Proposals were advanced for including EPA, DOE, DOT, USDA, FHWA, Army Corps of Engineers, Bureau of Federal Aviation Authority, state EPAs, state DOTs, and other agencies. (W)

- The weight of opinion on a recommendation for a lead federal agency appeared to favor DOE, followed by the EPA, the FHWA, and USDA, in that order. (W)

- The responsibility of the U.S. Secretary of Commerce under RCRA (1976) for promoting commercial recovery and use of by-products should also be reviewed. (W)

3.3.3 Federal Procurement Guidelines

- Federal procurement guidelines should be extended to cover additional by-products and uses. (W)

- Federal procurement provisions for increasing the use of by-products should be in the form of guidelines only—not mandates. (W, U, S-T, F-T)

- Procurement guidelines should be developed with the involvement of affected agencies. (W)

- The administration of federal guidelines should involve oversight rather than enforcement. (W)

- Additional oversight was recommended to improve compliance with current guidelines. (W)

- Existing federal procurement guidelines covering the use of fly ash in concrete should be republished and reemphasized. (W, S-T)

- Special emphasis should be given to guidelines for using by-products in federally funded waste stabilization activities under the Superfund. (W, M)

- Agricultural use should be included in federal procurement guidelines. (W)

- Guidelines should include the use of blended cement. (W, R)

3.4 Recommendations on Technical Barriers

3.4.1 Product Specifications

- Standardization of technical specifications should be pursued through established standards organizations such as the American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO). Adoption of uniform specifications across federal and state agencies and user trade associations should be encouraged by increasing the involvement of the affected groups in the standards setting process and by the coordinating efforts of the federal government. (W)

- The development and standardization of performance-based specifications should supplement rather than replace existing specifications, such as the ASTM C 618 standard, for using fly ash in concrete. (W)

- New specifications should address engineering, environmental, and economic criteria together rather than separately. (W)

- New specifications should be developed to cover products produced from technologies demonstrated under the DOE Clean Coal Technology Demonstration Program. (W)

- A high priority should be given to engineering and environmental specifications for high-volume uses such as flowable and structural fill. (W, USWAG/ACAA)

- Specifications should address real-world application properties, such as air entrainment in concrete, rather than an empirically related parameter (e.g., loss on ignition). (M)

- Specifications should address alkali–aggregate reactions, which are a major concern of state Departments of Transportation. (S-T)

- Product performance specifications should include standards for blended cement. (R)

3.4.2 Technical Demonstration, Assistance, and Education

- Joint industry/government funding should be encouraged for regional assistance centers to provide advocacy and technical support for by-product utilization and demonstration. (W)

- Demonstration projects should be targeted to provide practical information to end users such as farmers applying gypsum-rich FGD by-products as soil amendments. (W, R, S-E)

- Education on by-product utilization should be incorporated into established and emerging programs of the Department of Education, professional organizations, environmental advocacy groups, and high schools and colleges as they concern trade and engineering education, job retraining (including training addressing dislocation due to scaledown of the military), and public policy debate. Some workshop participants suggested that educational programs should be given a lower priority than demonstration projects (not a consensus position). (W)

- The federal government should issue a publication on the benefits of coal combustion by-products to lend credibility to the "green" effect of their utilization. (M)

- Design manuals are needed to address the practical application of by-products as engineering materials. (R)

- Demonstration projects should incorporate safeguards to avoid engineering or environmental failures that could pose additional barriers to utilization for a long period thereafter. (S-T)

- The FHWA should provide technology transfer to state Departments of Transportation. (S-T)

- Technical assistance and education on by-product use in agriculture should be provided through the U.S. Soil Conservation Service and the National Association of Conservation Districts. (F-USDA)

- Public education could be advanced through a recycling mission. (R)

3.4.3 R&D Priorities

- It was a consensus recommendation that first priority should be given to demonstration projects that are practical, address environmental issues, and contribute to regulatory classification for preapproved use. (W, F-T)

- Joint government/industry sponsorship of research should be encouraged to help ensure adoption of results. (W)

- Regional technical centers affiliated with universities were suggested as Centers of Excellence for unbiased evaluation of technical and environmental issues concerned with by-product utilization. (M)

- DOE national labs should be involved in R&D on beneficial use. (U)

- More federal funds should be allocated for R&D on by-product utilization. (M)

3.4.4 Quality Assurance

- Standardized protocols should be developed and approved for sampling and analyzing the variable quality of coal combustion by-products. (W, U)

- On-line methods should be developed to analyze by-product quality parameters, such as loss on ignition (LOI), and to integrate these methods into power plant performance monitoring. (W, M)

- States should consider source certification based on sampling protocols as a means of encouraging by-product quality assurance. (W)

3.5 Recommendations on Economic Barriers

3.5.1 Focus of Incentives

- Economic incentives should be targeted toward decision makers, such as the contractors bidding on large construction projects. (W, S-T)

- Incentives should be concentrated on high-volume uses, to include uses in the transportation sector and large commercial construction projects, such as shopping malls. (W)

- Proposals were advanced for targeting federal incentives toward both utility producers and users, but the weight of opinion, including utility representation, favored focusing on users. (W)

3.5.2 Federal Funding Incentives

- States complying with federal procurement guidelines affecting highways should be eligible to receive bonus federal highway funding. (W, U)

- Federal bonus funding for by-product utilization should be linked to the demonstration of technically innovative methods. (U, R)

- Bid incentives on federally funded projects should be provided to recognize the beneficial effects of by-products on strength and durability. (M)

- Federal grants to state environmental agencies should be considered to support efforts designed to reduce environmental barriers to by-product utilization. (S-T)

3.5.3 Tax Incentives

- Tax incentives in the form of credits and accelerated depreciation should be considered to encourage investment. (W)

- Consideration should be given to removing or rebating state sales taxes and/or permitting fees on coal combustion by-products that are sold for beneficial use. (W)

- Measures suggested by the workshop participants for taxing waste disposal or by-product utilization to promote utilization programs did not receive broad endorsement. (W)

3.5.4 Credits

- Consideration should be given to market-driven incentive credits along lines analogous to the tradable SO_2 emission credits provided under the 1990 Clean Air Act Amendments. Credits could be considered in reference to CO_2 emissions and solid waste disposal. (W, R)

- CO_2 emission credits linked to by-product utilization were not supported by utility representatives. (U)

4.0 SUMMARY OF STUDY FINDINGS

An investigation of the barriers to increased coal by-product use reveals that institutional, regulatory, and legal barriers are very much interrelated. While the complex interrelationships of barrier issues can make them difficult to discuss in isolation, for the purposes of this study, each category was considered separately. Institutional barriers are those barriers or constraints that restrict the use of coal combustion by-products through requirements, standards, specifications, policies, procedures, and attitudes of the many various organizations and agencies that are involved in coal by-product use or disposal. Regulatory barriers are those barriers caused by federal and state legislation affecting the beneficial use of coal by-products. Legal barriers include regulatory, contract, patent, and liability issues. The primary legal barrier identified by this study was liability.

Major institutional constraints identified included 1) lack of familiarity with potential ash uses, 2) perceived lack of data on environmental effects and engineering data, 3) the regulation of coal by-products as a solid waste, and 4) the minimal economic incentives provided by current by-product markets. In general, the institutional barriers identified could be considered barriers based on attitude. The stigma of a solid waste is at the heart of many of the constraints listed above. Additional attitudinal barriers stem from the lack of strong economic incentives for by-product producers to utilize more of these materials.

The primary regulatory barrier identified was the lack of a coherent policy among federal and state agencies covering the beneficial use of coal by-products. The existing patchwork of incentives and disincentives and the wide variations in regulations among states results in confusion. This confusion can lead to overly conservative regulatory practices, often involving case-by-case approval. The inadequacy of present environmental and engineering specifications adopted by state and federal agencies for high-volume uses (other than cement replacement) is also a major barrier identified by this study. The need for environmental tests that are more realistic and that provide a level playing field for by-products in competition with other materials was also evidenced. More effective performance-based engineering specifications are needed to expand ash use.

The regulation of by-products as a solid waste is also the major factor underlying legal barriers to increased by-product use. When a by-product is considered a solid waste, the issue of environmental liability becomes a strong disincentive for by-product use and sales. The issue of environmental liability becomes an even more complex issue when by-products are considered for use in waste stabilization applications. Additional legal barriers identified included confusion associated with contract and patent law as applied to coal by-products in utilization applications.

5.0 STUDY CONTRACTORS RECOMMENDATIONS FOR REMOVAL OF BARRIERS TO INCREASED COAL BY-PRODUCTS UTILIZATION

It is the opinion of the study contractors that, at the present time, an interlocking network of institutional, legal, and regulatory barriers is preventing the forward movement needed to achieve full economic utilization of coal combustion by-products in the foreseeable future. The study indicated that the key to untying this Gordian knot lies in the entirely different attitudes and reactions engendered when coal combustion by-products are considered as products rather than as wastes.

The EERC staff who performed the study felt that federal action is needed now to remove barriers to increased by-product utilization. Commitment is needed from both the government and the industrial sectors. Strong federal partnerships with industry and state agencies can ensure the environmental approval and commercial development needed to break down resistant barriers. This coordinated team effort must be championed by the federal government, with a single agency charged with the responsibility of leading the effort and coordinating the activities of the participants. In view of the national importance and benefits of coal by-product utilization, actions to remove barriers should be embodied in a comprehensive act. It was proposed that, in 1994, the U.S. Congress pass the National Coal Combustion By-Products Utilization Act to provide leadership at the highest levels of government and to grant the most comprehensive relief possible, consistent with environmental protection, in the crucial areas of legal and regulatory reform. A 50% utilization goal, as contained in the 1990 National Energy Strategy, should be adopted as a first-stage objective in moving toward full economic utilization.

The keystone to removing barriers to coal by-product utilization is federal legislation for accomplishing deregulation, which shapes the first six recommendations outlined below. However, many of the specific actions proposed under these six initiatives, and four additional private initiatives requiring some governmental assistance, can and should be undertaken independently before the passage of a comprehensive act. Such independent actions could first and foremost include an Executive Order by the President of the United States establishing National Goal Status in advance of federal legislation, to be followed by appropriate implementation actions by federal and state agencies and private organizations. Some of the actions that may be appropriately undertaken independently are called out in the discussion of recommendations that follows. Two tiers of action recommendations have currently been identified:

Tier 1 – Recommendations for Governmental Initiatives with Private Participation

1. National Goal Status for Coal By-Product Utilization

2. Regulatory Classification Defining Preapproved Uses

3. Federal Procurement Guidelines
4. Economic Incentives, Including Federal Tax and Funding Preferences
5. Joint Review of Legal Barriers
6. Federal Interagency Coordination

Tier 2 – Recommendations for Private Initiatives with Governmental Assistance

7. Product Specifications
8. Technical Assistance and Educational Programs
9. By-Product Quality Assurance
10. Research, Development, and Demonstration

1. National Goal Status for Coal By-Product Utilization will present a clear federal mandate similar to the atmospheric goals established in the Clean Air Act of 1970. Enactment of a National Coal Combustion By-Products Utilization Act in 1994 embodying National Goal Status and provisions for accomplishing deregulation with fully adequate environmental safeguards can be the vanguard action urgently needed to move toward a comprehensive national strategy for industrial recycling. Administration of this proposed act should be through the Secretary of the Department of Energy.

The need to elevate the status of coal by-products utilization to that of a national goal is pivotal to the increased use of these materials. The public must be made aware of the importance of this opportunity to reduce the environmental impact of energy production while conserving precious natural resources. The effective implementation of changes recommended in this report requires a strong commitment by the federal government to provide the lead in coordinating efforts by the government and private sectors. Enactment of the National Coal By-Products Utilization Act will provide the strong and public support needed from the highest levels of government for implementing concerted action.

2. Regulatory Classification Defining Preapproved Uses is recommended to deregulate coal by-products for beneficial use. The purpose of regulatory classification will be to certify environmental compliance for restricted classes of by-product use, subject to established environmental criteria, and to remove the approved use classes from RCRA controls imposed on solid wastes. Regulatory classification should proceed as a series of federal regulatory actions progressively deregulating additional coal combustion products and uses. Initiation of actions should be open to all federal or state agencies and private companies that submit requests to the Department of Energy. Certain priority actions should be undertaken apart from such requests on those uses previously addressed under state statutes. Actions on regulatory classification are proposed to be under the general administrative control of the Department of Energy. However,

the environmental criteria to be used for deregulating coal by-product uses should be approved by the EPA as it draws on environmental specifications developed by ASTM and other standards organizations. Two classes of criteria can be foreseen: 1) a more stringent environmental specification allowing unrestricted use of a by-product material in all beneficial use applications and 2) less stringent categorical specifications allowing restricted use in designated product or use categories. The criteria to be used should establish a level playing field for coal by-products and competing products used in similar applications.

3. Federal Procurement Guidelines should be developed with the consensual involvement of affected agencies. The 1983 EPA guideline covering the utilization of fly ash in concrete should be republished and additional oversight exercised to encourage utilization compliance. Under the proposed utilization act, administration of procurement guidelines would be moved from the EPA to DOE. Federal procurement guidelines should be extended to cover all preapproved and deregulated products that meet environmental, engineering, and economic performance criteria. Utilization of coal by-products as waste stabilization agents in federally funded Superfund cleanup activities and remediation of DOE nuclear weapons sites should be specifically addressed.

4. Economic Incentives, Including Federal Tax and Funding Preferences, should be offered by the government to encourage coal by-product utilization activities that are in the interest of the general public. Targeted tax incentives should be considered at federal and state levels, including investment credits, accelerated depreciation, and reduced sales taxes. State Public Service Commissions should be encouraged to extend favorable rate base treatment to coal by-product investments and revenues. Direct federal funding incentives should be considered for selected coal by-product utilization projects, including bonus payments in federal highway funding or reductions in state matching requirements. Where end-product quality and durability are enhanced by using coal combustion products, a formula bid selection procedure should give preference to coal by-product uses in federal construction procurement. Governmental incentives should be targeted to achieve technical innovation and to demonstrate environmental compliance in a manner analogous to the DOE Clean Coal Technology program.

5. Joint Review of Legal Barriers should be undertaken by industry and government to determine the need for legislation addressing regulatory authority and environmental liability. One of the most serious legal barriers is the wide divergence in the regulation of coal by-products under state laws. Whereas the EPA confirmed in a ruling on August 2, 1993, that coal ash is not a hazardous material under RCRA Subtitle C, the delegation of regulatory authority under RCRA Subtitle D for solid waste allows various states to treat coal ash in many cases as a de facto toxic substance and in other cases as an unregulated construction material. Uniform regulation of preapproved by-product uses can be accomplished by exempting approved coal combustion products, such as solid wastes, from regulatory control. Legal remedies to be considered in review and legislation should include statutory exemption from liability, federal deregulation authority for preapproved uses, other regulatory and permitting provisions, and technical specifications having legal standing. Review of commercial law should be undertaken to address a uniform commercial code for coal by-product transactions by the incorporation of specifications that would assist buyers and sellers in writing clear and enforceable contracts for by-product sales. Industry review of overlapping patent claims would clarify the distinction between generic use and

patented processes to assist in both general use and marketing of proprietary technology.

6. Federal Interagency Coordination is urgently needed to encourage the beneficial use of coal by-products under more uniform environmental and engineering specifications than currently exist among federal agencies and states. Standardization will become a compelling issue as deregulated coal by-products become widely used in interstate commerce under proposed provisions for regulatory classification. A strong federal leadership role is vital in implementing all of the actions proposed under the National Goal Status and the comprehensive coal by-products utilization act. A DOE lead mission designation is recommended to coordinate the federal team effort needed to address criteria for by-product deregulation and standardization of engineering specifications. DOE would work through the EPA in obtaining approval of environmental criteria for deregulation. Advocacy for pollution prevention through the beneficial use of coal by-products should be maintained within the EPA.

7. Product Specifications should evolve by environmental, engineering, and economic performance criteria being addressed together rather than separately. Continuing development of specifications through ASTM and other standards organizations should be expedited by providing federal joint venture funding to universities for technology base research. DOE and other federal agencies should provide leadership for the standardization of specifications applying to federal and state construction projects. Future specifications should provide a better measure of engineering and environmental performance and be less restrictive in terms of traditional empirical parameters.

8. Technical Assistance and Educational Programs should emphasize practical education, training, and project assistance to end users. Regional technical centers should be established with joint funding from industry, DOE, and EPA to provide assistance and advocacy for preapproved uses.

9. By-Product Quality Assurance is primarily the responsibility of utilities and marketers. The principal roles recommended for federal and state agencies are in source certification of by-products for preapproved uses, development and standardization of sampling and analysis protocols, and, possibly, support for development of on-line quality control instrumentation. Utilities and marketers should allocate resources and provide leadership to champion quality by-product utilization.

10. Research, Development, and Demonstration priority should be given to demonstration projects targeted at regulatory classification defining preapproved uses exempted from RCRA solid waste controls. Other priority activities include technical assistance for implementing market-ready technologies, optimum use of by-products from clean coal technologies, analytical methods and diagnostic capabilities, and development of new technologies. Research and development projects should include cost and profitability analyses to identify marketing opportunities.

APPENDIX C

COAL COMBUSTION BY-PRODUCT PRODUCTION AND USE: 1966–1994

Coal Combustion Byproduct (CCB) Production & Use: 1966 - 1994

Report for Coal Burning Electric Utilities in the United States

ACAA

American Coal Ash Association, Inc.
2760 Eisenhower Avenue, Suite 304
Alexandria, Virginia 22314-4553 USA
Phone: 703-317-2400 Fax: 703-317-2409
Internet: ACAA@ix.netcom.com

May 1996

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INTRODUCTION

The mission of the American Coal Ash Association (ACAA) is to advance the management and use of coal combustion byproducts (CCBs) in ways that are technically sound, commercially competitive and environmentally safe. ACAA and its members work to gain the recognition and acceptance of specifiers, designers, contractors, legislators, regulators and others for CCBs on par with competing engineering and manufactured materials. ACAA's work in support of its mission also serves the entire "CCB industry" which comprises: producers of CCBs, including coal-burning electric utilities, both within and outside the United States of America (USA), and non-utility producers; marketers of CCBs; and organizations and individuals, including coal companies, allied trade groups, and others with commercial, academic, research and other interests in the management and use of CCBs.

Today, with reliable methods for assessing the quality of CCBs, coal-burning power plants are viewed by marketers and users of CCBs as reliable sources of quality materials. CCBs, including fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material are: produced from the combustion of coal, the principal fuel source for today's energy needs; specified by engineers who rely on the availability of CCBs as mineral resources for today and the 21st century; marketed by companies with knowledge of CCBs as engineering and manufacturing materials; and used in numerous applications.

Annually, the production of CCBs in the USA is nearly 90 million tons [88.994 million short tons in 1994]. The significance of the quantities of CCBs produced annually in the USA becomes apparent by comparison to the quantities of materials produced during similar periods by competing industries. For example, in Table 1, CCBs are shown to rank number three in terms of 1994 production quantities when compared to the four other leading mineral resources produced in the USA during a similar period.

Table 1. Leading Mineral Resources Produced in the USA

[Sources: U.S. Bureau of Mines, *Mineral Commodity Summaries;* and, American Coal Ash Association, *CCB Production & Use Report.]*

Mineral Resources: Annual Production in USA (million tons)	
Crushed Stone	1,200
Sand & Gravel	900
CCBs	**90**
Portland Cement	80
Iron Ore	60

Assuming an average thirty-year life remaining for existing coal-fired power plants, the CCB industry in the USA clearly is an important producer of mineral resources, both for today and for the 21st century.

ACAA's ANNUAL SURVEY OF CCBs

ACAA conducts an annual survey concerning the production and use of CCBs to maintain and enlarge a unique database from which an annual report is issued. The participants in ACAA's survey are coal-burning electric utilities from throughout the USA.

The CCBs included in ACAA's annual survey are: fly ash, bottom ash, boiler slag and FGD material. The CCB applications currently included in ACAA's annual survey report include: cement and concrete products; flowable fill; structural fill; road base/subbase; mineral filler in asphalt; snow and ice control; blasting grit and roofing granules; grouting; coal mining applications; wallboard; waste solidification and stabilization; and miscellaneous/other uses.

There have been several changes in ACAA's survey throughout the years. ACAA was established in 1968, and initiated the collection of data for fly ash, bottom ash and boiler slag produced and used during that calendar-year. Data also was collected for the two preceding calendar-years, 1966 and 1967, however, no distinction between bottom ash and (wet bottom) boiler slag was made in data collected for those two years. Calendar-year 1987 was the first period for which ACAA collected data concerning the production and use of FGD material; and calendar-year 1992 was the first period for which ACAA collected data to distinguish between CCBs that are managed and used in a dry or moisture-conditioned form versus CCBs that are managed and used in a ponded form.

CCB producers other than electric utilities currently are not included in ACAA's survey, however, data available from the U.S. Department of Energy, Energy Information Administration (DOE-EIA) shows that in 1994, electric power plants accounted for some eighty-eight (88) percent of domestic coal consumption. It follows that, even though ACAA's published survey reports do not address CCBs such as those from fluidized bed combustion and other combustion technologies that may be used by electric utilities as well as non-utilities, the four CCBs that are included in ACAA's survey currently account for almost 90 percent of CCBs produced and used in the USA.

Electric utilities in the USA are subject to mandatory annual filing of a report to the DOE-EIA on Form EIA-767, "Steam-Electric Plant Operation and Design Report," which collects information on CCBs that are used on-site and sold. ACAA's survey is unique, however, in that it collects detailed information on CCB market applications as well as CCB production and use. The annual publication and distribution of ACAA's survey results is one of the important services that ACAA provides to the entire CCB industry.

ACAA's series of annual surveys and reports published by ACAA since the late 1960s have been used extensively by producers and marketers of CCBs, federal- and state-level government agencies, engineers and contractors, allied industry groups and others who have an interest in CCB management and use.

REGULATORY STATUS OF CCBs

The U.S. Environmental Protection Agency (EPA) has concluded that CCBs including fly ash, bottom ash, boiler slag and FGD material produced by coal-buming electric utilities do not warrant management as hazardous materials under Subtitle C of the Resource Conservation and Recovery Act [RCRA, 1976 Federal Legislation]. The formal regulatory determination on this matter was issued by EPA in August 1993 through a notice in the Federal Register, and had an effective date of September 2, 1993.

Prior to 1993, CCBs had been granted an exemption from RCRA regulations pending completion of EPA's study which was conducted over a period of some ten years and transmitted in a Report to Congress [EPA, 1988]. Following administrative delays within EPA, there was an additional period of fact-finding and comment [Federal Register, February 1994] which led to EPA's favorable, final regulatory ruling for CCBs. EPA also stated affirmatively that CCBs should be used and not disposed.

FEDERAL AGENCY SUPPORT FOR USING CCBs

Recognition came from EPA more than a decade ago confirming that the use of coal fly ash as a mineral admixture in concrete is environmentally and technically sound; and in 1983 the "*EPA Concrete Procurement Guideline"* clearly endorsed and supported that use. More recently, EPA has published a summary of information pertaining to fly ash use in concrete in an "environmental fact sheet," *Guidelinefor Purchasing Cement and Concrete Containing Fly Ash* [EPA/530-SW-91-086, January 1992]. That fact sheet supports EPA's effort to assure that the intent of the concrete procurement guideline is understood.

The Federal Highway Administration (FHWA) was one of the first federal agencies to remove the experimental label from fly ash use in concrete more than a decade before the EPA took an interest. The FHWA acted in the 1980s to provide educational materials about coal fly ash to highway and transportation departments in each state, and to assist them in implementing the use of fly ash in concrete. The most widely distributed document in this effort by FHWA was titled, *Fly Ash Facts for Highway Engineers* [FHWA-DP-59-8, July 1986, 47 pages]; and was superseded by a recent updated version, *Fly Ash Facts for Highway Engineers*--Concrete, Base, Flowable Fill, Structural Fill, Grout and Paving [FHWA-SA-94-081, August 1995, 70 pages]. The U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation also have long encouraged the use of coal fly ash in concrete.

The U.S. DOE report to Congress, *Barriers to the Increased Utilization of Coal Combustion Desulfurization Byproducts by Governmental and Commercial Sectors* [DOE Office of Fossil Energy, July 1994], is expected to have a significant positive effect on the management and use of CCBs during the remainder of the 1990s. The DOE "barriers report" resulted from Section 1334 of the Energy Policy Act of 1992 *[Public Law No. 102-486]* in which DOE was charged with the task of conducting a detailed and comprehensive study on the "institutional, legal and regulatory barriers to increased utilization of CCBs." The recommendations in the DOE "barriers report" address a network of related barriers which can be overcome only through cooperative efforts among federal and state governments and industry.

ACAA is addressing these and other issues in support of its mission to advance the management and use of coal combustion byproducts (CCBs) in ways that are technically sound, commercially competitive and environmentally safe. As various barriers to the utilization of CCBs are overcome, significant increases in the use of CCBs in existing markets are anticipated. Additionally, new markets for CCBs may be more easily developed as certain barriers are overcome.

CCB PRODUCTION AND USE: 1966 - 1994

This report draws on the database of CCB production and use, collected by ACAA in surveys for calendar-years 1966 through 1994, and summarizes much of that information so that it may be reviewed in a single document without the need for independent analysis.

For example, this report contains information in the form of charts and graphs which convey a useful understanding of the total quantities as well as the simple percentages of CCB materials (fly ash, bottom ash, boiler slag and FGD material) that have been produced and used during the calendar-years, 1966 through 1994, covered by ACAA's annual surveys and reports. Also, the survey data for 1994 is summarized to show the leading applications for each CCB in terms of the quantities used **[see footnote].**

This report presents other useful information, including: a summary of low- and high-calcium coal fly ash production and use in the USA; typical CCB production and use data from twelve (12) representative CCB producers in each of six (6) regions of the USA; and charts showing total CCB production and use by region.

Additionally, this report presents a comparison of calendar-year 1994 production and use data for CCBs which were managed and used as dry or moisture-conditioned materials versus CCBs which were managed and used as ponded materials.

Other information in this report that will assist the reader is an appendix which includes a glossary of technical terms related to ACAA's annual CCB survey and report.

Footnote: This report does not address the relative values of the leading markets for CCBs, nor does it address the value of "other" markets. Neither the data presented in this report nor the statements made concerning that data are intended to convey any information about the value of a particular market for CCBs.

The principal subject areas addressed by the tables and figures which are presented in the subsequent sections of this report are as follows:

- **History of CCB Production and Use for 1966 - 1994**
- **Summary of All CCB Production and Use for 1994**
- **Summary of Leading CCB Applications for 1994**
- **Fly Ash Production and Use for 1994**
- **Regional Information from CCB Survey for 1994**
- **Summary: Category I (Dry or Moisture Conditioned) & Category II (Ponded) CCB Production and Use for 1994**

History of CCB Production and Use for 1966 - 1994

- **CCB Production Quantities: 1966 - 1994 (Table 2 & Figure 1)**
- **CCB Use Quantities: 1966 - 1994 (Table 3 & Figure 2)**
- **Individual and Combined Percentages for CCBs Used: 1966 - 1994 (Figure 3 & Figure 4)**

The summary of historical data resulting from ACAA's annual surveys of CCB production and use for calendar-years 1966 through 1994 is summarized in Tables 2 and 3, and in Figures 1, 2, 3 and 4.

In Table 2, the CCB production quantities for 1966 through 1994 are summarized, and in Figure 1 that same information is presented in graphical form for easier review as a bar chart.

Similarly, in Table 3, the CCB use quantities for 1966 through 1994 are summarized, and in Figure 2 that same information is presented in graphical form for easier review as a bar chart.

As stated previously, ACAA was established in 1968, and initiated the collection of data for fly ash, bottom ash and boiler slag produced and used during that calendar-year. Data also was collected for the two preceding calendar-years, 1966 and 1967, however, no distinction between bottom ash and (wet bottom) boiler slag was made in data collected for those two years. Calendar-year 1987 was the first period for which ACAA collected data concerning the production and use of FGD material.

While the quantities of CCBs produced made a steady increase from 25.2 million tons in 1966 to 88.99 million tons in 1994, the quantities of CCBs used increased at a faster rate during those years, going from 3.1 million tons in 1966 to 22.08 million tons in 1994.

The upward trend for the use of individual CCBs (fly ash, bottom ash and boiler slag) is discernable in Figure 3 where averages for their use are shown throughout the period, 1966 through 1994; however, the upward trend is more clearly seen in Figure 4 where the yearly combined percentages of use for CCBs have been computed.

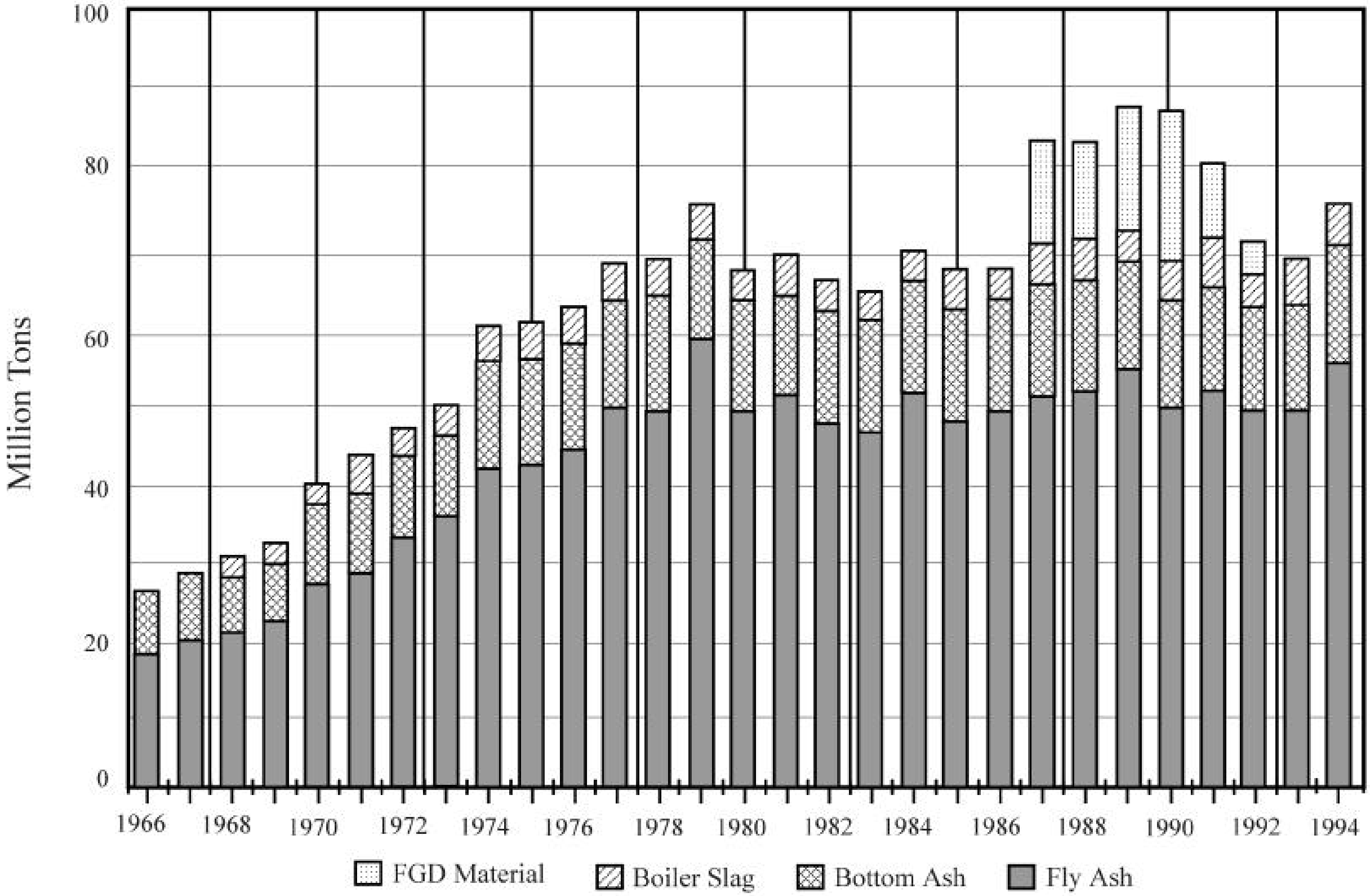
Obviously, when the quantities of FGD material are included, starting in 1987 in Figure 4, the combined percentage of use for all four CCBs (fly ash, bottom ash, boiler slag and FGD material) shifts downward significantly because of the relatively low utilization of FGD material as compared to each of the other three CCBs.

Table 2. Coal Combustion Byproduct (CCB) Production: 1966-1994

[Source: Annual Survey of CCB Production and Use, American Coal Ash Association]

	CCB Production in Millions of Tons				
Year	Fly Ash	Bottom Ash	Boiler Slag	FGD Material	Total CCBs
1966	17.1	8.1			25.2
1967	18.4	9.1			27.5
1968	19.8	7.3	2.6		29.7
1969	21.1	7.6	2.9		31.6
1970	26.5	9.9	2.8		39.2
1971	27.8	10.1	5		42.9
1972	31.8	10.7	3.8		46.3
1973	34.6	10.7	4		49.3
1974	40.4	14.3	4.8		59.5
1975	42.3	13.1	4.6		60
1976	42.8	14.3	4.8		61.9
1977	48.5	14.1	5.2		67.8
1978	48.3	14.7	5.11		68.11
1979	57.5	12.5	5.2		75.2
1980	48.31	14.45	3.64		66.4
1981	50.26	12.87	5.18		68.31
1982	47.91	13.13	4.37		65.41
1983	47.15	12.73	3.94		63.82
1984	51.32	13.62	4.21		69.15
1985	48.31	13.15	3.65		65.11
1986	49.259	13.411	4.13		66.8
1987	50.11	14.72	4.12	14.2	83.15
1988	50.91	14.27	5.03	13.527	83.737
1989	53.38	14.21	4.27	15.6	87.46
1990	48.93	13.71	5.23	18.93	86.8
1991	51.3	13.3	6.05	18.1	88.75
1992	48.06	13.92	4.11	15.88	81.97
1993	47.76	14.21	6.23	20.34	88.54
1994	54.84	14.83	3.79	15.55	88.99

CCB Production: 1966–1994



No Boiler slag data for 1966-1967. No FGD material data prior to 1987.
Source: Annual Survey of CCB Production and Use. American Coal Ash Association

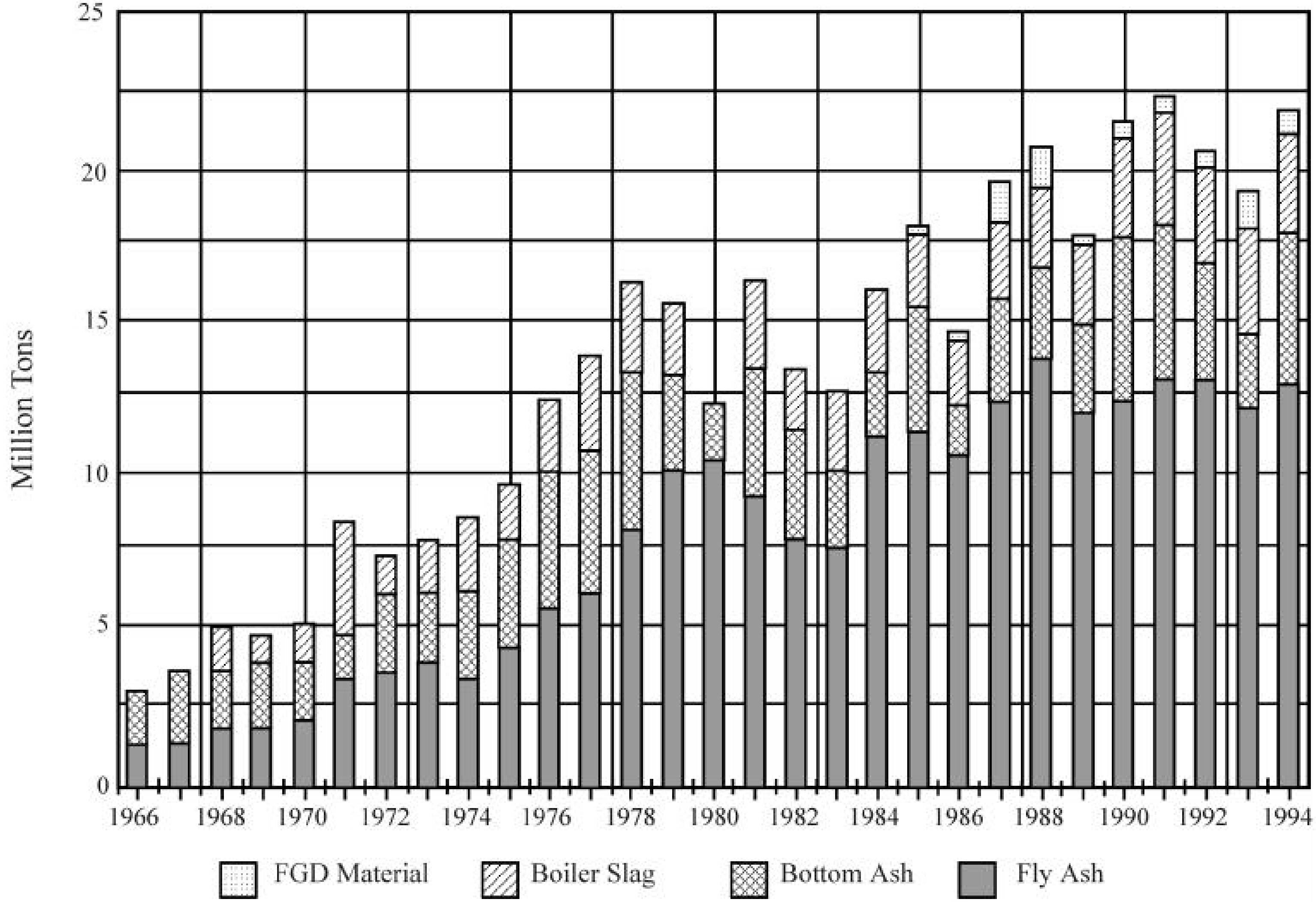
Figure 1

Table 3. Coal Combustion Byproduct (CCB) Use: 1966-1994

[Source: Annual Survey of CCB Production and Use, American Coal Ash Association]

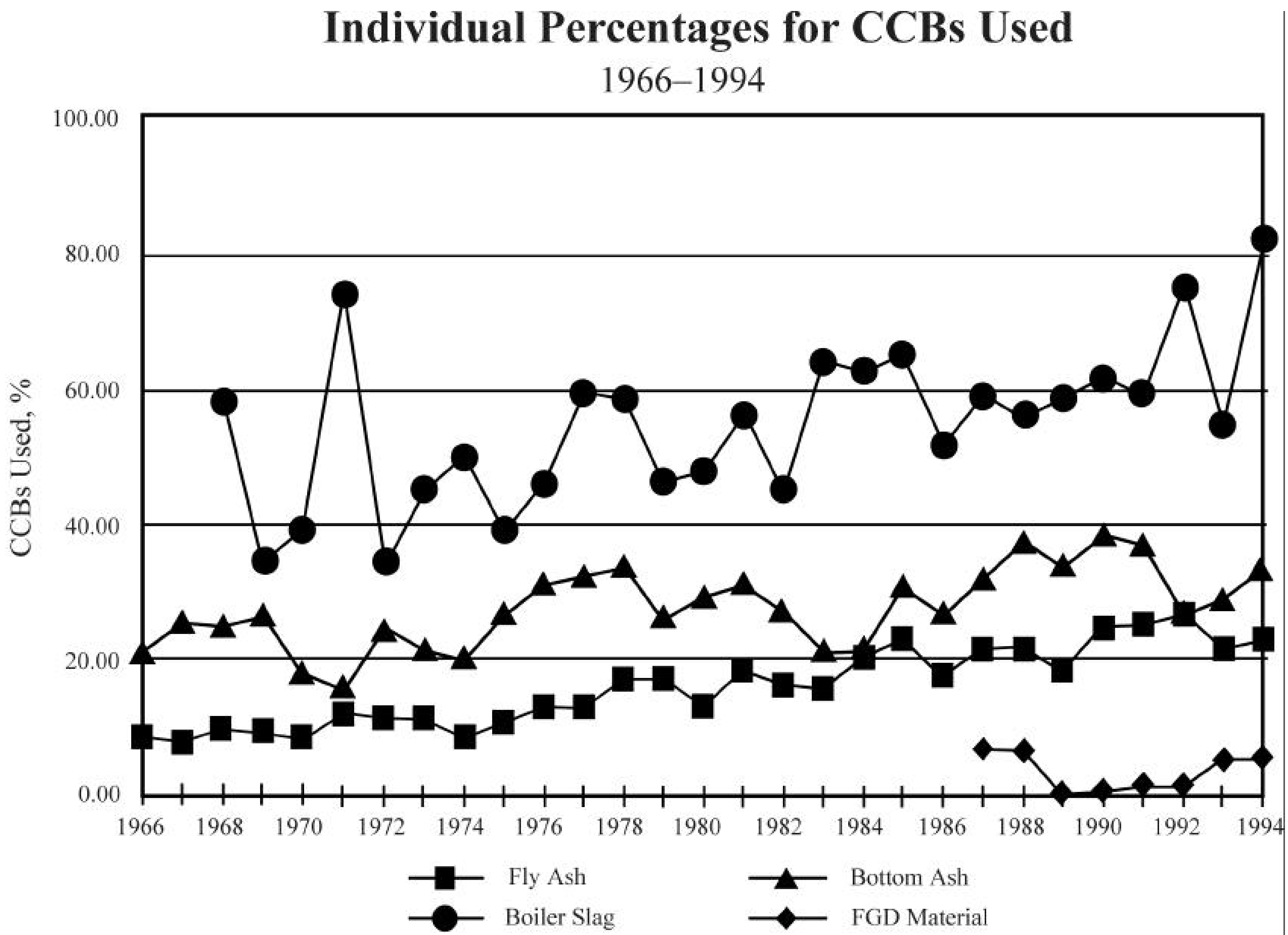
	CCB Use in Millions of Tons				
Year	Fly Ash	Bottom Ash	Boiler Slag	FGD Material	Total CCBs
1966	1.4	1.7			3.1
1967	1.4	2.3			3.7
1968	1.9	1.8	1.5		5.2
1969	1.9	2	1		4.9
1970	2.2	1.8	1.1		5.1
1971	3.3	1.6	3.7		8.6
1972	3.6	2.6	1.3		7.5
1973	3.9	2.3	1.8		8
1974	3.4	2.9	2.4		8.7
1975	4.5	3.5	1.8		9.8
1976	5.7	4.5	2.2		12.4
1977	6.3	4.6	3.1		14
1978	8.4	5	3		16.4
1979	10	3.3	2.4		15.7
1980	6.42	4.26	1.75		12.43
1981	9.41	4.07	2.93		16.41
1982	7.95	3.63	1.97		13.55
1983	7.52	2.76	2.53		12.81
1984	10.43	2.96	2.65		16.04
1985	11.39	4.1	2.38		17.87
1986	8.776	3.585	2.145		14.506
1987	11.05	4.77	2.44	1.02	19.28
1988	11.36	5.43	2.83	0.93	20.55
1989	10.15	4.85	2.52	0.113	17.633
1990	12.42	5.36	3.25	0.216	21.246
1991	13.2	5	3.6	0.35	22.15
1992	13.1	3.87	3.09	0.29	20.35
1993	10.51	4.23	3.43	1.16	19.33
1994	12.93	5.08	3.12	0.94	22.07

CCB Use: 1966–1994



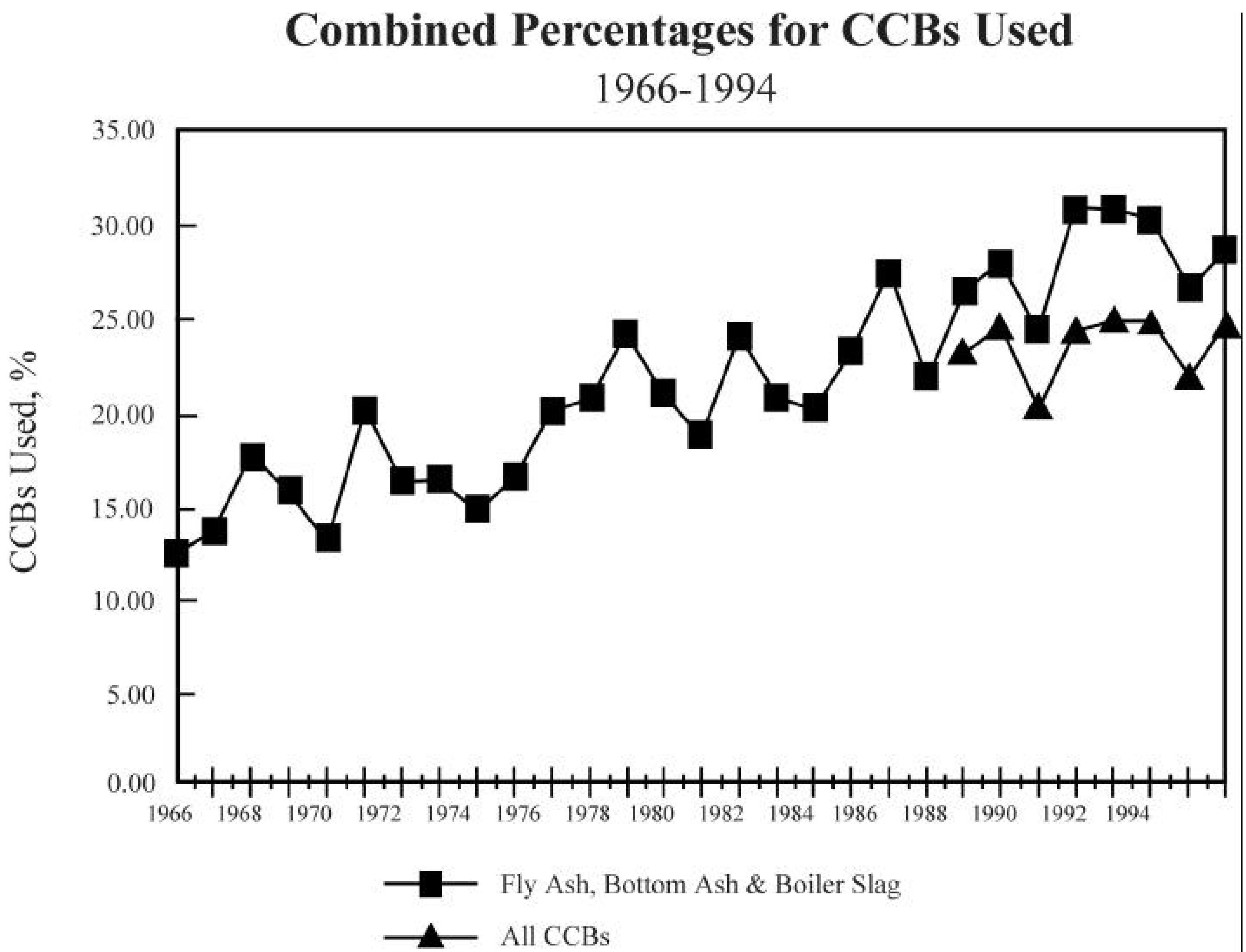
No Boiler slag data for 1966-1967. No FGD material data prior to 1987.
Source: Annual Survey of CCB Production and Use. American Coal Ash Association

Figure 2



No boiler slag data for 1966-1967. No FGD material data prior to 1987.
Source: Annual Survey of CCB Production and Use, American Coal Ash Assocication

Figure 3



No boiler slag data for 1966-1967. No FGD material data prior to 1987.
Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 4

Summary of All CCB Production and Use for 1994

- **CCB Production and Use - Report for 1994 All CCBs (Table 4)**
- **CCB Production and Use Quantities - 1994 (Figure 5)**
- **CCB Production Quantities and Percentages -1994 (Figure 6)**
- **CCB Use Quantities and Percentages - 1994 (Figure** 7)
- **Individual Percentages of Each CCB Used - 1994 (Figure 8)**

The traditional one-page annual report of CCB production and use has been published in the general form of Table 4 (for calendar-year 1994) throughout the history of ACAA's survey with modifications from time to time to modify or add applications, and to include FGD material in 1987.

The overall CCB production and use data for each of the four CCBs (fly ash, bottom ash, boiler slag and FGD material) shown in Table 4 for 1994 can be reviewed quickly in graphical form as shown in the bar chart of Figure 5. Similarly, a good understanding of the overall production and use data for 1994 can be obtained quickly by reviewing the information in graphical form as shown in the pie charts of Figure 6 (CCB production) and of Figure 7 (CCB use).

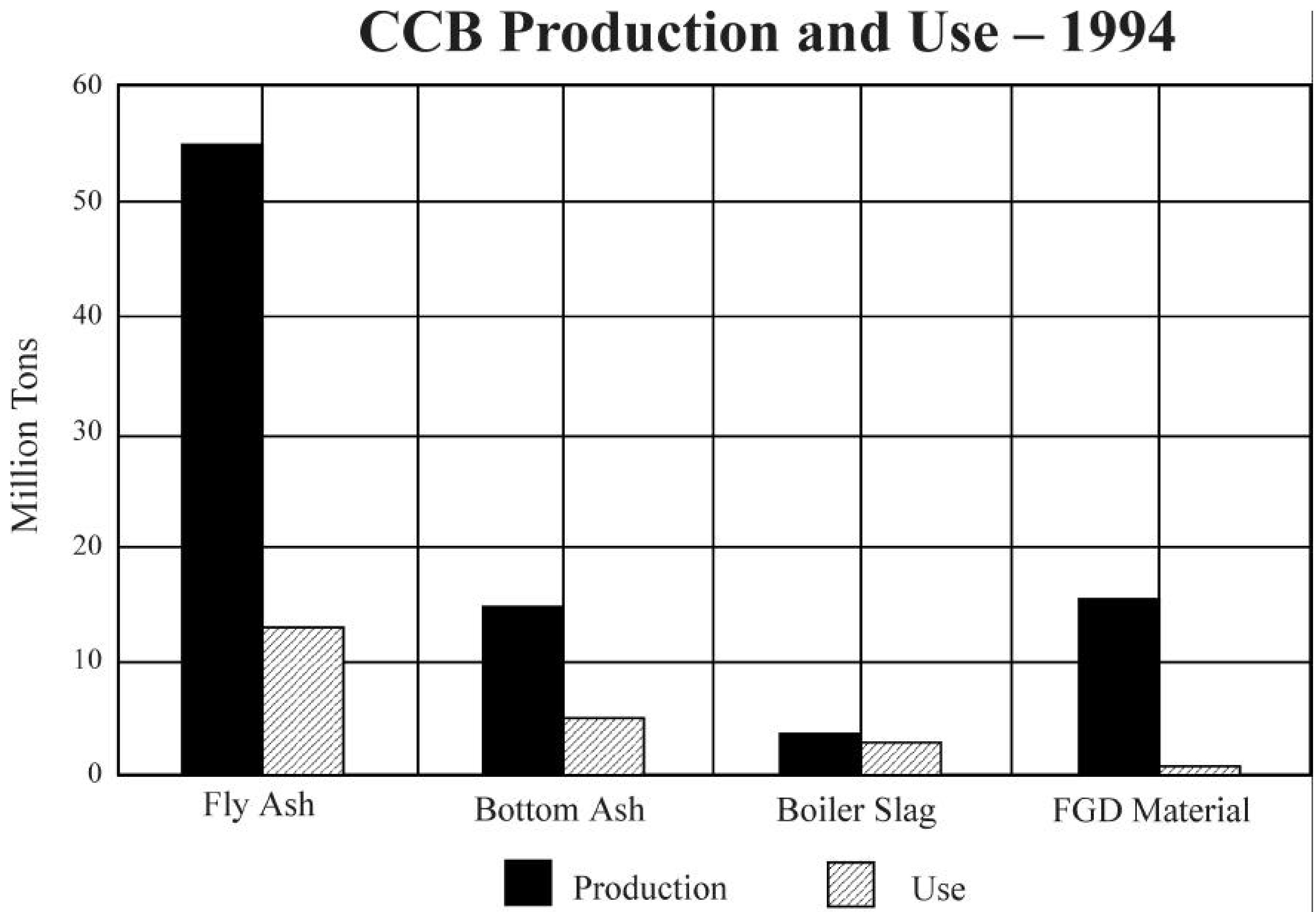
In Figure 8, the overall percentages of each CCB that were used (or not used) in 1994 are shown in the form of four separate pie charts. This format is useful, for example, to illustrate the relative percentages of use and disposal for each of the four CCBs.

Table 4. CCB Production and Use - Report for 1994 All CCBs

[Source: Annual Survey of CCB Production and Use, American Coal Ash Association]

Total CCBs - Category I (Dry) & II (Ponded)	Fly Ash	Bottom Ash	Boiler Slag	FGD Material
A. CCB Production	54,835,570	14,827,165	3,785,852	15,545,068
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			73,448,587	
Total All CCB's				88,993,655
B. CCB Use				
External Market Applications				
a. Cement and Concrete Products	7,419,334	736,681	89,694	86,877
b. Flowable Fill	608,023	88,221	0	0
c. Structural Fills	682,053	153,541	3,723	20,071
d. Road Base/Subbase	605,363	272,342	25,529	0
e. Mineral Filler in Asphalt	135,117	15,762	83,316	0
f. Snow and Ice Control	15,298	787,271	216,751	0
g. Blasting Grit/Roofing Granules	0	93,455	2,626,103	0
h. Grouting	17,044	0	0	0
I Mining Applications	80,023	28,769	0	148,932
j. Wallboard	0	0	0	533,941
l. Waste Stabilization	231,028	23,331	0	0
k. Miscellaneous/Other	575,641	183,660	11,985	73,462
Subtotal -- External Market Applications	10,368,924	2,383,032	3,057,102	863,282
Internal Producer Applications				
a. Cement and Concrete	1,003	549	0	0
b. Flowable Fill	26,996	531	0	18,089
c. Structural Fills	529,018	325,455	0	62,688
d. Road Base/Subbase	108,803	694,919	3,028	124
e. Snow and Ice Control	0	493	62	0
f. Miscellaneous/Other	1,895,945	1,677,987	57,645	0
Subtotal -- Internal Producer Applications	2,561,766	2,699,934	60,736	80,901
Total External Market and Internal Producer Applications	12,930,690	5,082,966	3,117,838	944,182
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			21,131,493	
Total -- All CCBs				22,075,675
C. Individual Use Percentage	23.6%	34.3%	82.4%	6.1%
D. Cumulative Use Percentage	23.6%	25.9%	28.8%	24.8%

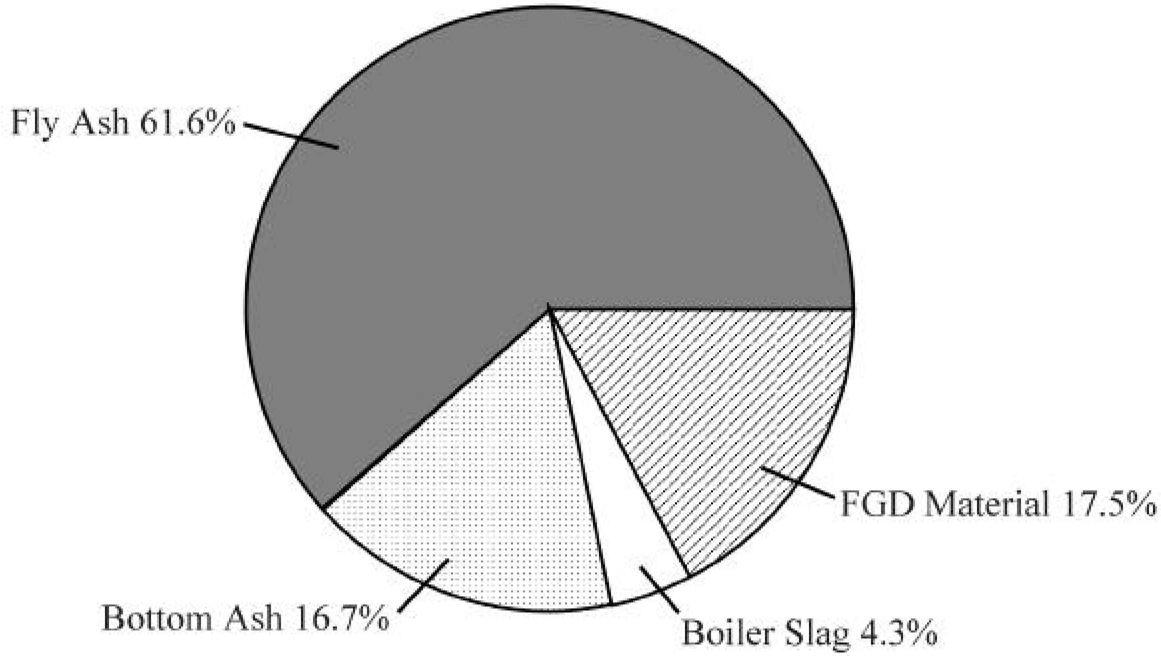
For metric equivalents, multiply tabular values by 0.9078



Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 5

1994 CCB Production

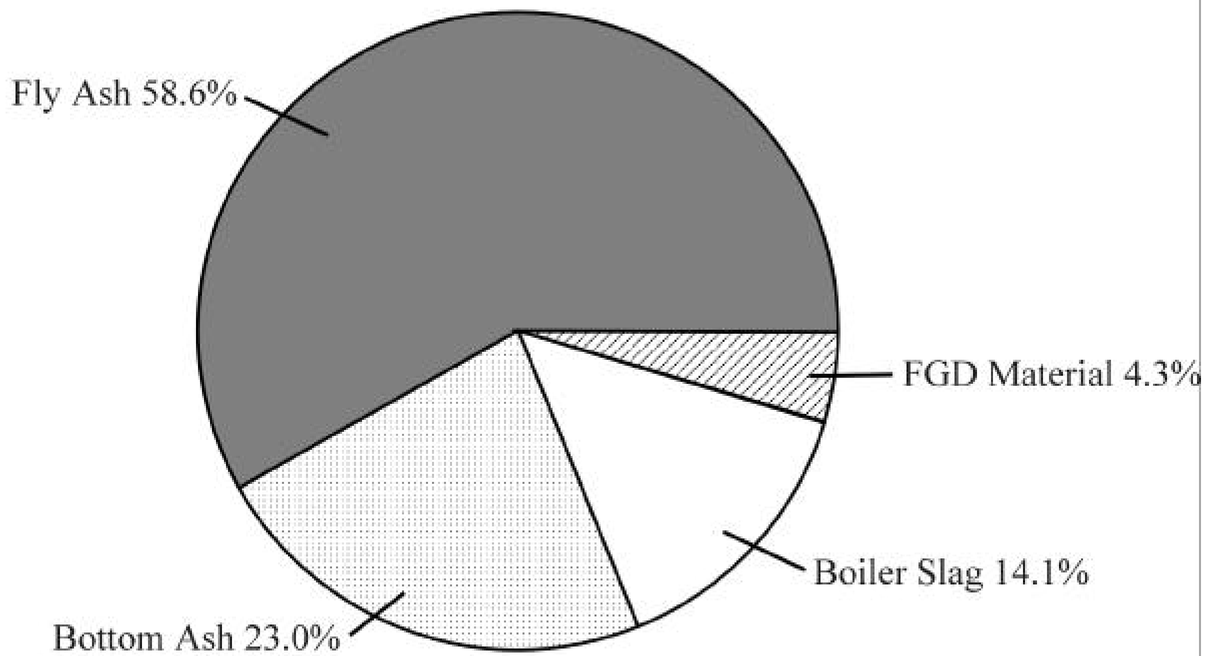


CCB	Total CCB Production, tons
Fly Ash	54,835,570
Bottom Ash	14,827,165
Boiler Slag	3,785,852
FGD Material	15,545,068

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 6

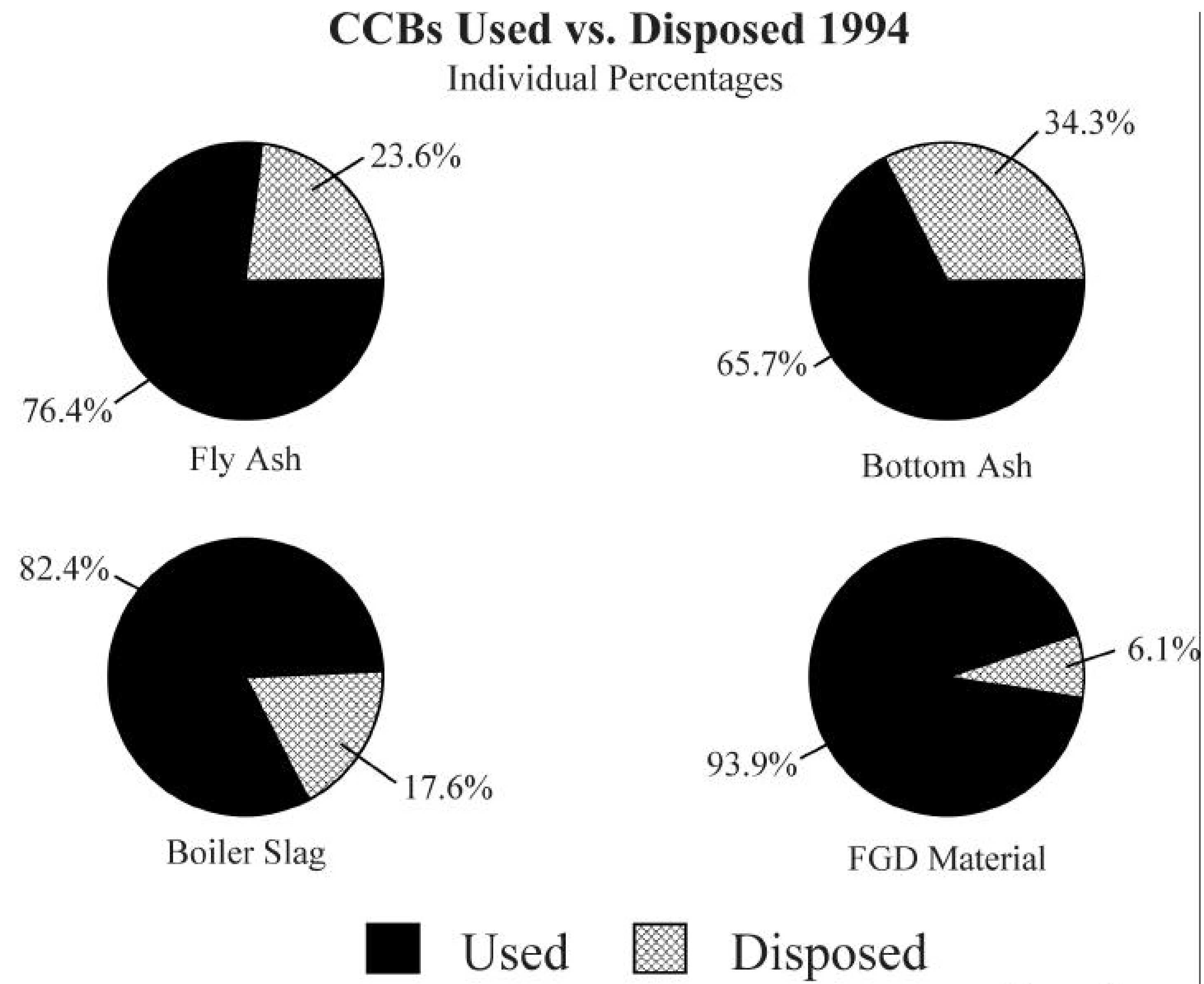
1994 CCB Use



CCB	Total CCB Use, tons
Fly Ash	12,930,690
Bottom Ash	5,082,966
Boiler Slag	3,117,838
FGD Material	994,182

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 7



Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 8

Summary of Leading CCB Applications for 1994

- **Leading Fly Ash Applications - 1994 (Figure 9)**
- **Leading Bottom Ash Applications - 1994 (Figure 10)**
- **Leading Boiler Slag Applications - 1994 (Figure 11)**
- **Leading FGD Material Applications - 1994 (Figure 12)**

The information summarized in the form of pie charts in Figures 9, 10, 11 and 12 readily demonstrates that for each CCB there typically are five or fewer applications which account for most of its use.

In Figure 9, for fly ash used in 1994, cement and concrete applications accounted for 57.38 percent of the total annual use of 12.93 million tons. The next highest percentages of use for fly ash were 9.36, 5.52, 4.91 and 1.79 percent, respectively, for structural fill, road base/subbase, flowable fill and waste stabilization. All other uses of fly ash in 1994 accounted for 21.02 percent of fly ash use.

In Figure 10, for bottom ash used in 1994, road base/subbase accounted for 19.03 percent of the total annual use of 5.08 million tons. The next highest percentages of use for bottom ash were 15.5, 14.5 and 9.42 percent, respectively, for snow/ice control, cement/concrete applications and structural fill. All other applications accounted for 41.54 percent of bottom ash use.

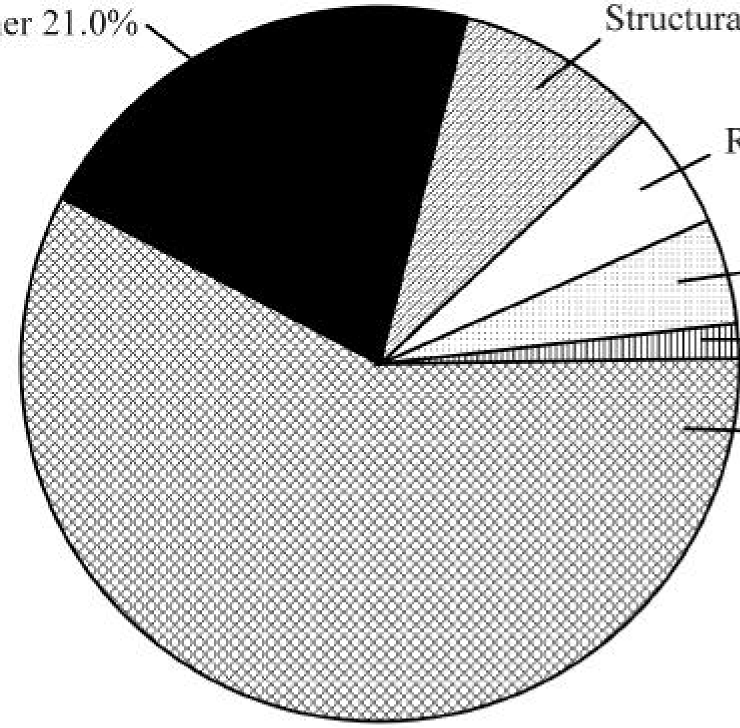
In Figure 11, for boiler slag used in 1994, blasting grit and roofing granules accounted for 84.23 percent of the total annual use of 3.12 million tons. The next highest percentages of use for boiler slag were 6.95, 2.88 and 2.67 percent, respectively, for snow/ice control, cement/concrete applications and mineral filler in asphalt. All other applications accounted for 3.27 percent of boiler slag use.

In Figure 12, for FGD material used in 1994, wallboard accounted for 56.55 percent of the total annual use of 0.944 million tons. The next highest percentages of use for FGD material were 15.77, 9.20, 8.77 and 1.92 percent, respectively, for mining applications, cement/concrete applications, structural fill and flowable fill. All other applications accounted for 7.79 percent of FGD material use.

As stated earlier in this report, this report does not address the relative values of the leading markets for CCBs, nor does it address the value of "other" markets. Neither the data presented in this report nor the statements made concerning that data are intended to convey any information about the value of a particular market for CCBs.

The use of CCBs is affected by numerous local and regional factors including production rates, processing and handling costs, transportation costs, availability of competing materials, seasonal factors, and the experience of materials specifiers, design engineers, purchasing agents, contractors, legislators, regulators, and other professionals.

Leading Fly Ash Applications – 1994

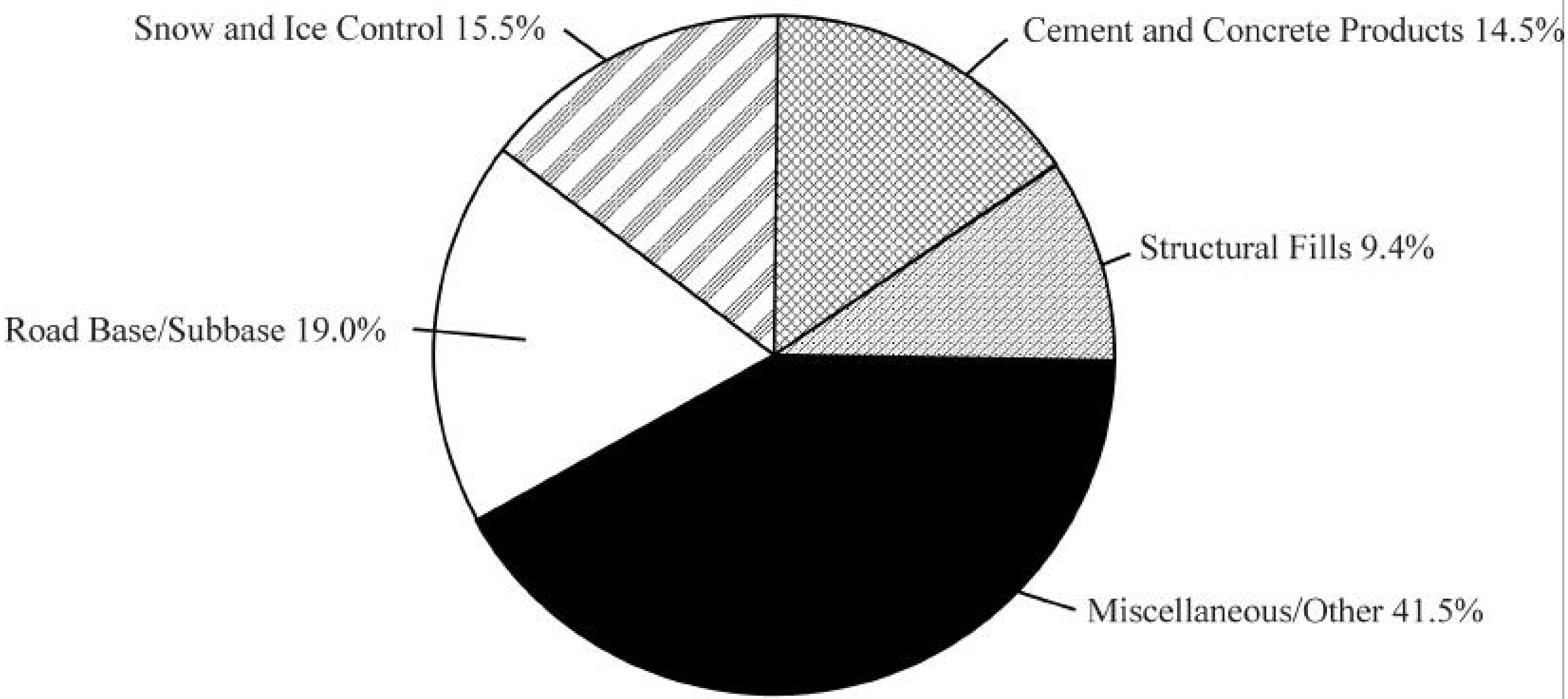


Applications	Fly Ash Use, tons	Percent of Total
Cement and Concrete Products	7,420,337	57.38%
Miscellaneous Other	2,719,069	21.02%
Structural Fills	1,211,072	9.36%
Road Base/Subbase	714,166	5.52%
Flowable Fill	635,019	4.91%
Waste Stabilization	231,028	1.78%
All Applications	12,930,691	100.00%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 9

Leading Bottom Ash Applications – 1994

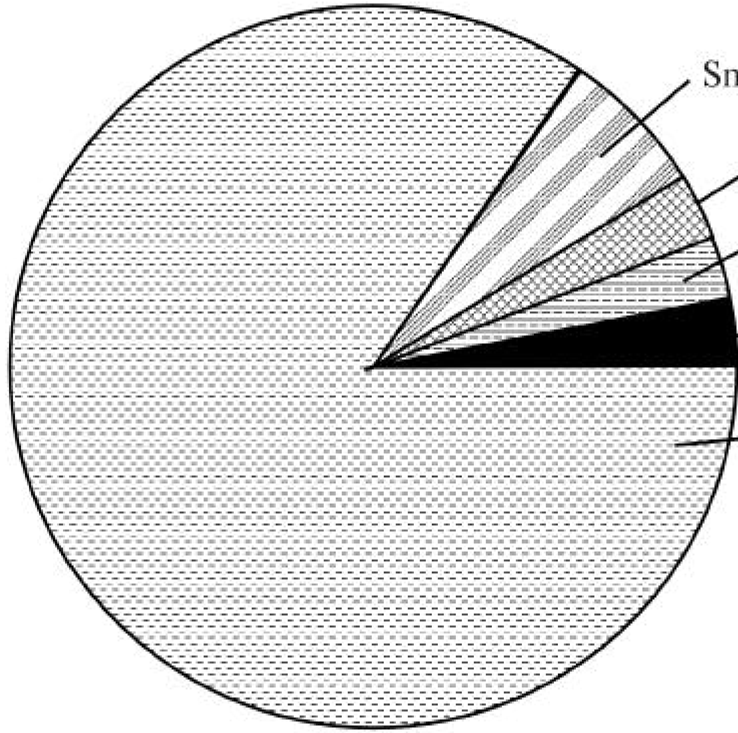


Application	Bottom Ash Use, tons	Percent of Total
Miscellaneous/Other	2,111,715	41.54%
Road Base/Subbase	967,261	19.03%
Snow and Ice Control	787,762	15.50%
Cement and Concrete Products	737,230	14.5%
Structural Fills	478,996	9.42%
Total	5,082,964	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 10

Leading Boiler Slag Applications – 1994

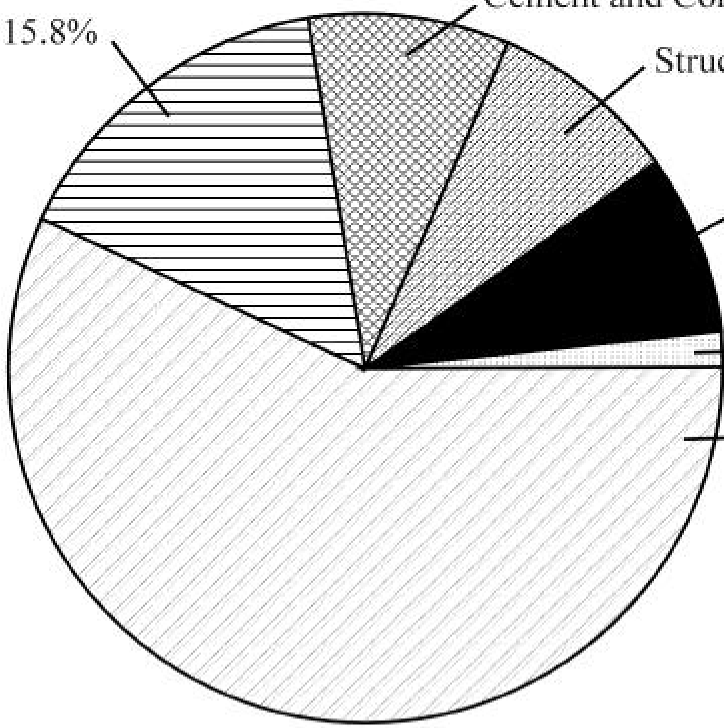


Applications	Boiler Slag Use, tons	Percent of Total
Blasting Grit/Roofing Granules	2,626,103	84.23%
Snow and Ice Control	216,813	6.95%
Miscellaneous/Other	101,911	3.27%
Cement and Concrete Products	89,694	2.88%
Mineral Filler in Asphalt	83,316	2.67%
Total	3,177,837	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 11

Leading FGD Material Applications - 1994



Applications	FGD Material Use, tons	Percent of Total
Wallboard	533,941	56.55%
Mining Applications	148,932	15.77%
Cement and Concrete Products	86,877	9.20%
Structural Fills	82,759	8.77%
Miscellaneous/Other	73,586	7.79%
Flowable Fill	18,089	1.92%
Total	944,184	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 12

Fly Ash Production and Use for 1994

! Comparison of Low- and High-Calcium Fly Ash Production and Use - 1994 (Figure 13)

A characteristic of coal fly ash that is frequently of interest to potential users is the relative calcium oxide, or “calcium”, content. Calcium content may be important in determining the suitability of the fly ash for use in a particular application. Also, as in the case of fly ash that is required to meet specification requirements for use as a mineral admixture in concrete (ASTM C618), the calcium content may have a significant effect on the physical and chemical characteristics of the fly ash.

In general, however, low-calcium fly ash has been assumed to have a calcium oxide content, as a percentage of the total weight of the fly ash, of less than ten percent (< 10.0 %); and high-calcium fly ash has been assumed to have a calcium oxide content of more than twenty percent (> 20.0 %). The primary factor which determines the overall chemical characteristics of coal fly ash produced in modern coal-fired boilers is the source of the coal used to fuel the boiler. The distinction between high-calcium and low-calcium fly ash may have been based on one or more of several criteria including: type of coal burned; CaO content of fly ash; observation of self-hardening of fly ash when mixed with water; and total oxide content ($Si0_2 + Al_20_3 + Fe_20_3$) of fly ash $\geq$50% for high-calcium or $\geq$70% for low-calcium; however, all fly ash would not necessarily meet the requirements of ASTM C 618.

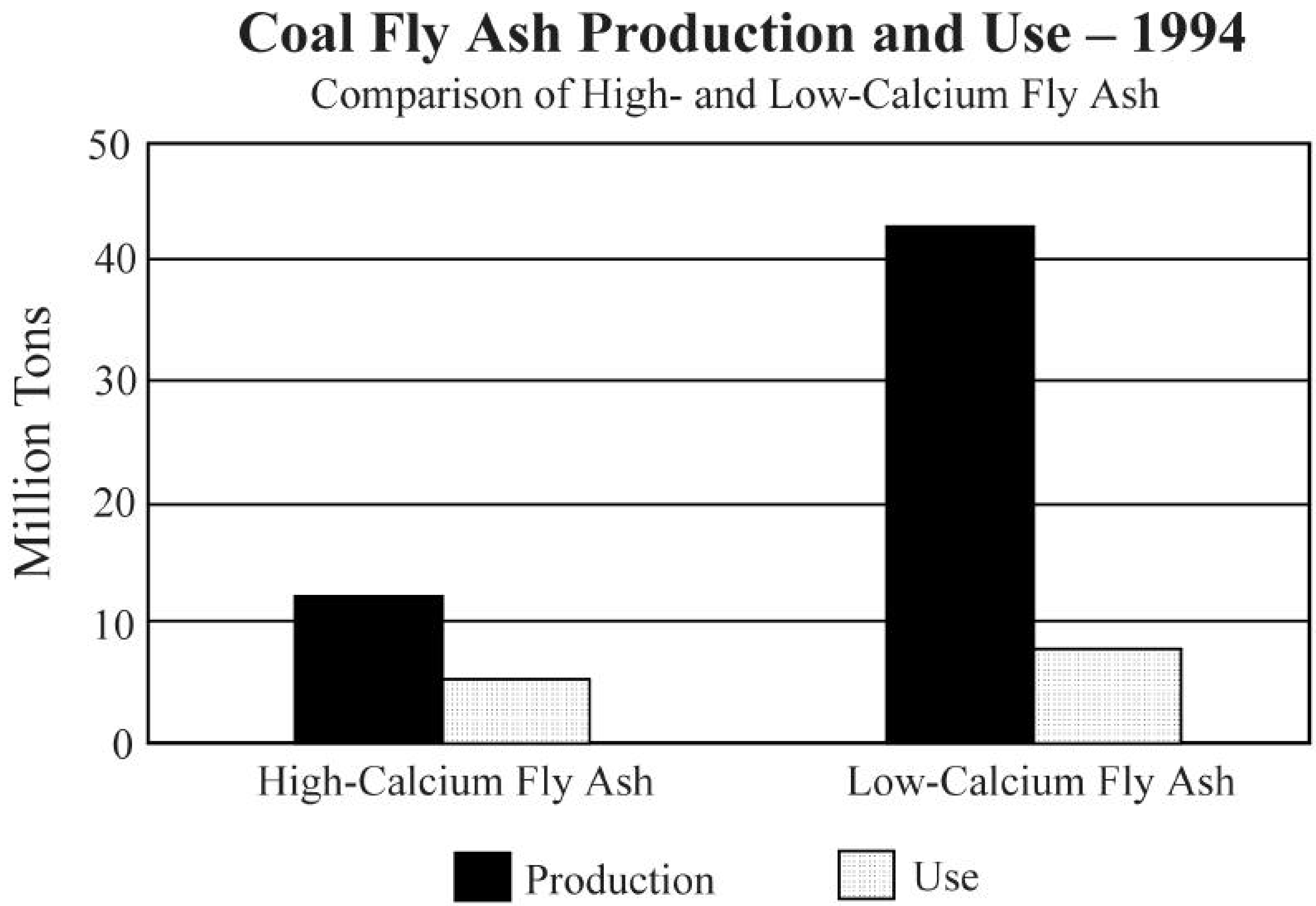
As shown in Table 5, based on responses to ACAA's survey of CCB production and use for 1994, approximately 42.8 million tons of low-calcium fly ash and 12.0 million tons of high-calcium fly ash were produced in the USA in 1994. The low-calcium fly ash amounted to about 78.1 percent of the total fly ash produced in 1994, and the high-calcium fly ash amounted to 21.9 percent of total production.

As shown in Figure 13, approximately 7.73 million tons, or 18.1 percent, of the low-calcium fly ash that was produced in 1994 was used; and approximately 5.20 million tons, or 43.2 percent, of the high-calcium fly ash was used. These percentages, and the quantities depicted in Figure 13, apply to the total production of fly ash and to its use in **all applications,** not only in cement and concrete applications, for 1994.

Table 5. Production and Use of High-Calcium & Low-Calcium Fly Ash by Region
[Source: American Coal Ash Association]

REGION *	Coal Burned	Fly Ash Produced	High-Calcium Produced	Low-Calcium Produced	Fly Ash Used	High-Calcium Used	Low-Calcium Used
1	103,877,279	9,243,154	0	9,243,154	2,359,652	0	2,359,652
2	166,236,772	12,717,925	338,819	12,379,106	3,293,325	0	3,293,325
3	236,571,446	15,420,754	1,980,554	13,440,199	3,078,468	1,399,094	1,679,374
4	98,619,614	3,983,846	3,728,271	255,575	1,038,490	960,385	78,105
5	113,741,357	6,322,644	2,362,074	3,960,571	1,700,095	1,649,053	51,042
6	98,223,532	7,147,247	3,620,255	3,526,992	1,460,660	1,189,583	271,077
Total	817,270,000	54,835,570	12,029,972	42,805,597	12,930,690	5,198,115	7,732,575

* See Figure 14 or Table 6 for states in each survey region.



Source: Annual Survey of CCB Production and Use American Coal Ash Association

Figure 13

Regional Information from CCB Survey for 1994

- **CCB Survey Regions in the USA (Figure 14)**
- **Listing of States in CCB Survey Regions (Table 6)**
- **Region 1: Typical CCB Production & Use Data - 1994 (Table 7)**
- **Region 2: Typical CCB Production & Use Data - 1994 (Table 8)**
- **Region 3: Typical CCB Production & Use Data - 1994 (Table 9)**
- **Region 4: Typical CCB Production & Use Data - 1994 (Table 10)**
- **Region 5: Typical CCB Production & Use Data - 1994 (Table 11)**
- **Region 6: Typical CCB Production & Use Data - 1994 (Table 12)**
- **CCB Production by Region (Figure 15)**
- **CCB Use by Region (Figure 16)**
- **CCB Production and Use by Region (Figure 17)**

The USA has been subdivided into six (6) regions for the purpose of presenting typical CCB production and use data in this report. The regions are shown in Figure 14, and the states within each region are listed in Table 6.

In Tables 7, 8, 9, 10, 11, and 12, respectively, typical CCB production and use data for calendar-year 1994 are shown for CCB producers in Regions 1, 2, 3, 4, 5 and 6. For each of these six (6) regions of the USA, typical data from twelve (12) representative CCB producers is shown. The listed order of the CCB production data in the top portion of each table corresponds to the listed order of the CCB use data in the bottom portion of each table for each of the CCB producers that are represented.

In each of the tables, the data is listed in descending order based on the percentage of CCBs that were used in that region in 1994.

The percentage of CCBs used in each region in 1994 varied within a range from 0 percent to 60, 100, 69, 138, 101, and 60 percent, respectively. Because CCB use may include material produced in previous years, the CCB use as a percentage of 1994 production may exceed 100%.

The total production of fly ash, bottom ash, boiler slag, and FGD material for regions 1 through 6 is represented graphically in Figure 15. Similarly, the total use of each CCB is represented in Figure 16. Figure 17 illustrates production and use by region and includes the percentage of use in each region. There appears to be no regional relationship between the percentages of CCBs used and the total quantity of CCB production.

As stated earlier, the use of CCBs is affected by numerous local and regional factors including production rates, processing and handling costs, transportation costs, availability of competing materials, seasonal factors, and the experience of materials specifiers, design engineers, purchasing agents, contractors, legislators, regulators, and other professionals.

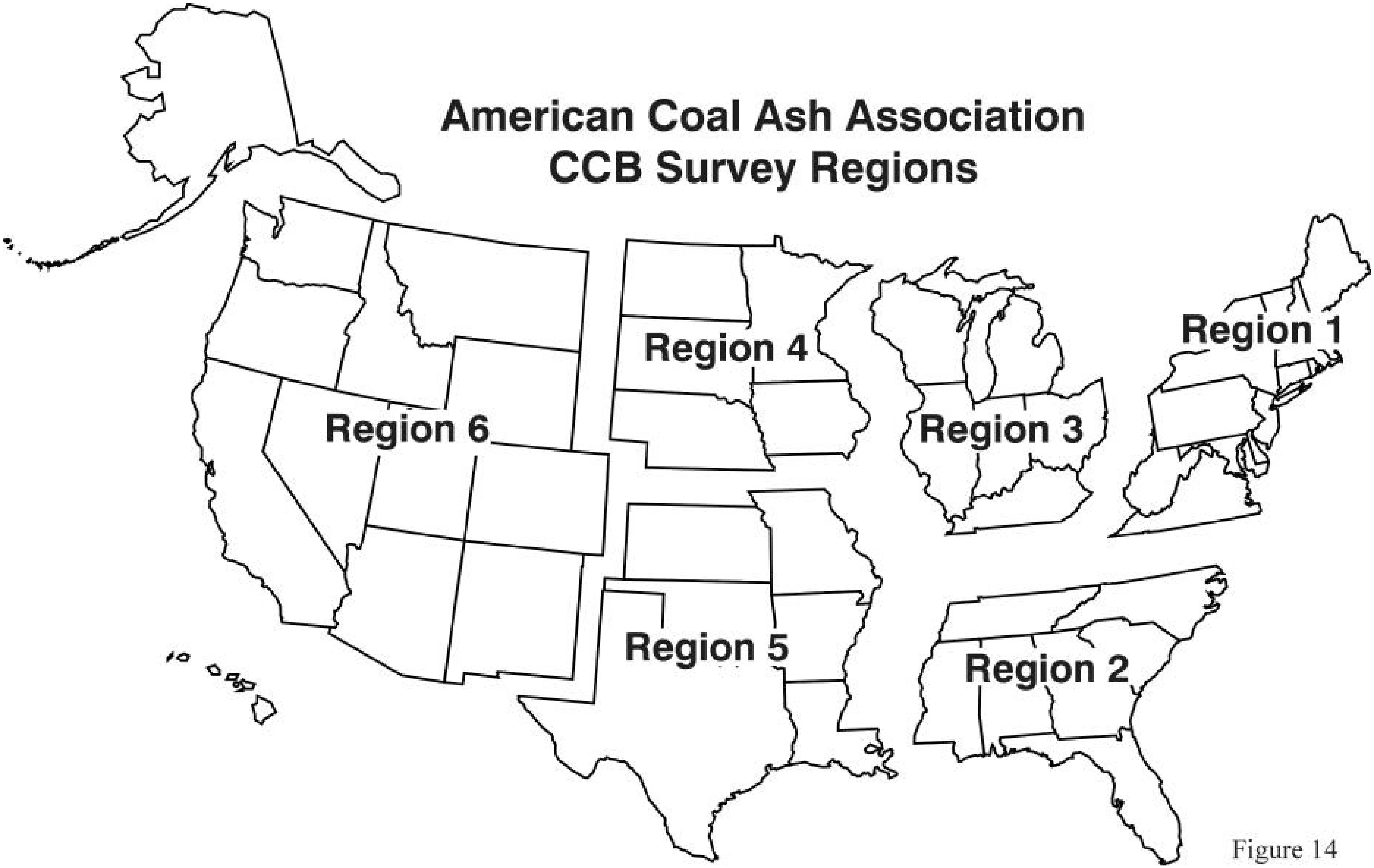

American Coal Ash Association
CCB Survey Regions
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6

Figure 14

Table 6. Listing of States in CCB Survey Regions
[Source: American Coal Ash Association]

CCB SURVEY REGIONS

Region 1

Connecticut
Delaware
District of Columbia
Maine
Maryland
Massachusetts
New Hampshire
New Jersey
New York
Pennsylvania
Rhode Island
Vermont
Virginia
West Virginia

Region 2

Alabama
Florida
Georgia
Mississippi
North Carolina
South Carolina
Tennessee

Region 3

Illinois
Indiana
Kentucky
Michigan
Ohio
Wisconsin

Region 4

Iowa
Minnesota
Nebraska
North Dakota
South Dakota

Region 5

Arkansas
Kansas
Louisiana
Missouri
Oklahoma
Texas

Region 6

Alaska
Arizona
California
Colorado
Hawaii
Idaho
Montana
Nevada
New Mexico
Oregon
Utah
Washington
Wyoming

Table 7 Region 1: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

Typical Regional CCB Data - Region 1

Production	Use	% Use
3,238,987	375,037	11.58%
61,200	16,200	26.47%
605,831	144,910	23.92%
38,900	0	0.00%
308,000	42,900	13.93%
635,890	229,705	36.12%
1,917,686	301,862	15.74%
1,032,198	434,200	42.07%
59,001	0	0.00%
520,772	164,666	31.62%
46,642	6,775	14.53%
1,247,348	744,870	0.5972

Table 8 Region 2: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

Typical Regional CCB Data - Region 2

Production	Use	% Use
195,200	129,800	66.50%
875,655	199,991	22.84%
99,466	0	0.00%
1,321,700	463,320	35.05%
438,261	352,000	80.32%
2,426,000	752,000	31.00%
208,425	94,205	45.20%
454,135	343,506	75.64%
545,271	23,192	4.25%
2,282,275	34,531	1.51%
779,606	779,606	100.00%
4,732,185	1,202,232	0.2541

Table 9 Region 3: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

Typical Regional CCB Data - Region 3

Production	Use	% Use
5,092,476	1,629,733	32.00%
422,824	177,570	42.00%
773,383	530,342	68.57%
1,260,700	241,870	19.19%
620,106	241,376	38.92%
975,200	83,785	8.59%
57,800	14,598	25.26%
10,228	0	0.00%
12,610	0	0.00%
403,384	0	0.00%
11,780	0	0.00%
701,822	337,427	48.08%

Table 10 Region 4: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

Typical Regional CCB Data - Region 4

Production	Use	% Use
762,150	80,000	10.50%
9,901	0	0.00%
10,726	14,796	137.95%
244,516	165,000	67.48%
437,486	133,311	30.47%
292,498	4,900	1.68%
375,400	253,100	67.42%
467,757	16,796	3.59%
74,700	59,293	79.37%
641,553	136,176	21.23%
156,358	102,300	65.43%
98,250	0	0.00%

Table 11 Region 5: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

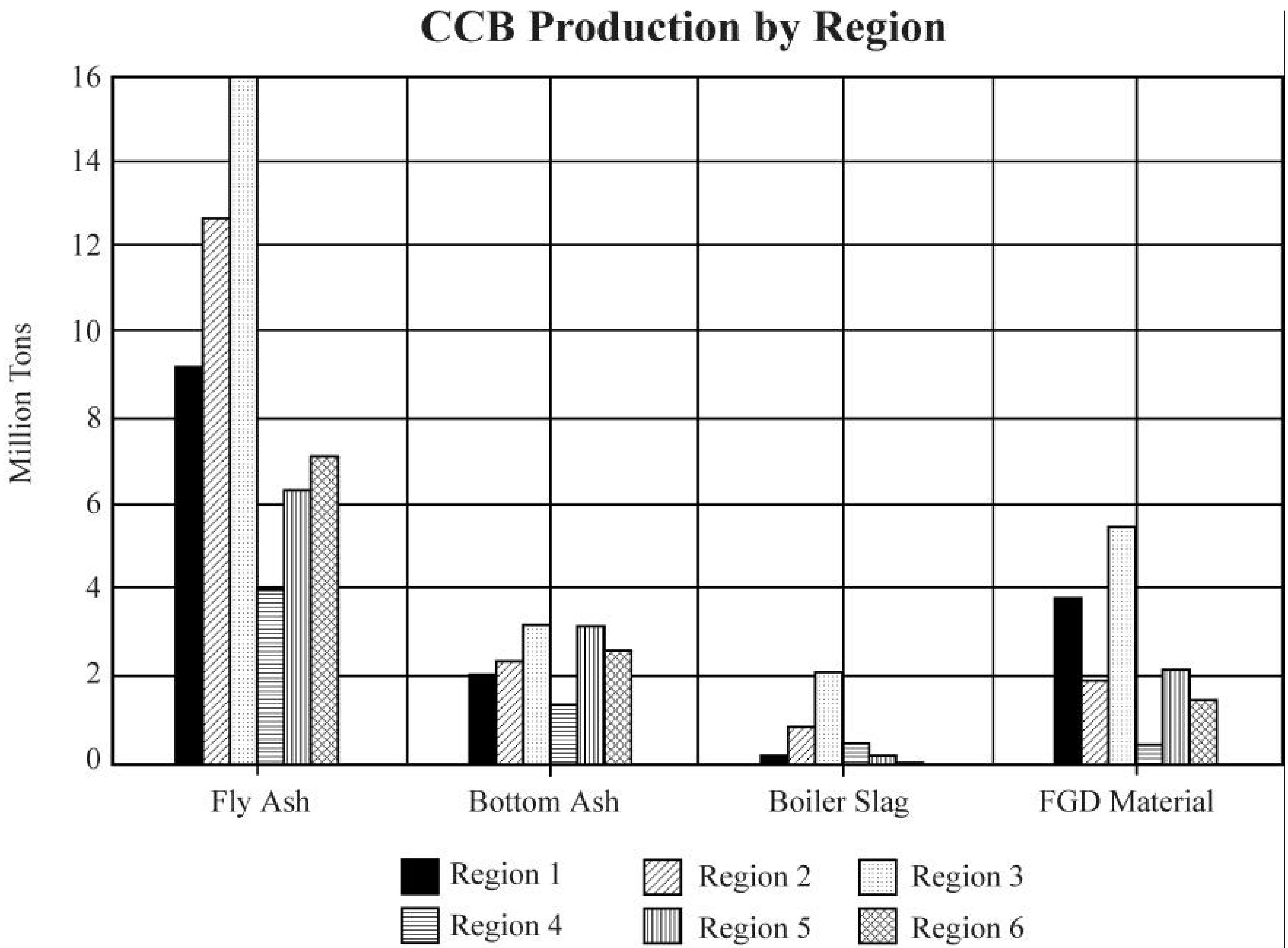
Typical Regional CCB Data - Region 5

Production	Use	% Use
473,474	270,347	57.10%
240,000	70,000	29.17%
13,876	10,706	77.15%
92,000	60,900	66.20%
713,079	228,862	32.09%
328,568	178,561	54.35%
429,700	239,400	55.71%
22,209	22,209	100.00%
1,194,273	0	0.00%
437,756	443,035	101.21%
7,231	6,446	89.14%
5,089,900	489,000	9.61%

Table 12 Region 6: Typical CCB Production and Use Data - 1994
[Source: American Coal Ash Association]

Typical Regional CCB Data - Region 6

Production	Use	% Use
124,000	0	0.00%
107,168	11,856	11.06%
194,600	0	0.00%
14,500	2,400	16.55%
584,900	109,100	18.65%
841,456	0	0.00%
3,816,900	605,300	15.86%
762,388	65,074	8.54%
1,082,259	50,000	4.62%
474,000	284,000	59.92%
404,497	12,279	3.04%
666,970	38,938	5.84%



Source: Annual Survey of CCB Production and Use American Coal Ash Association

Figure 15

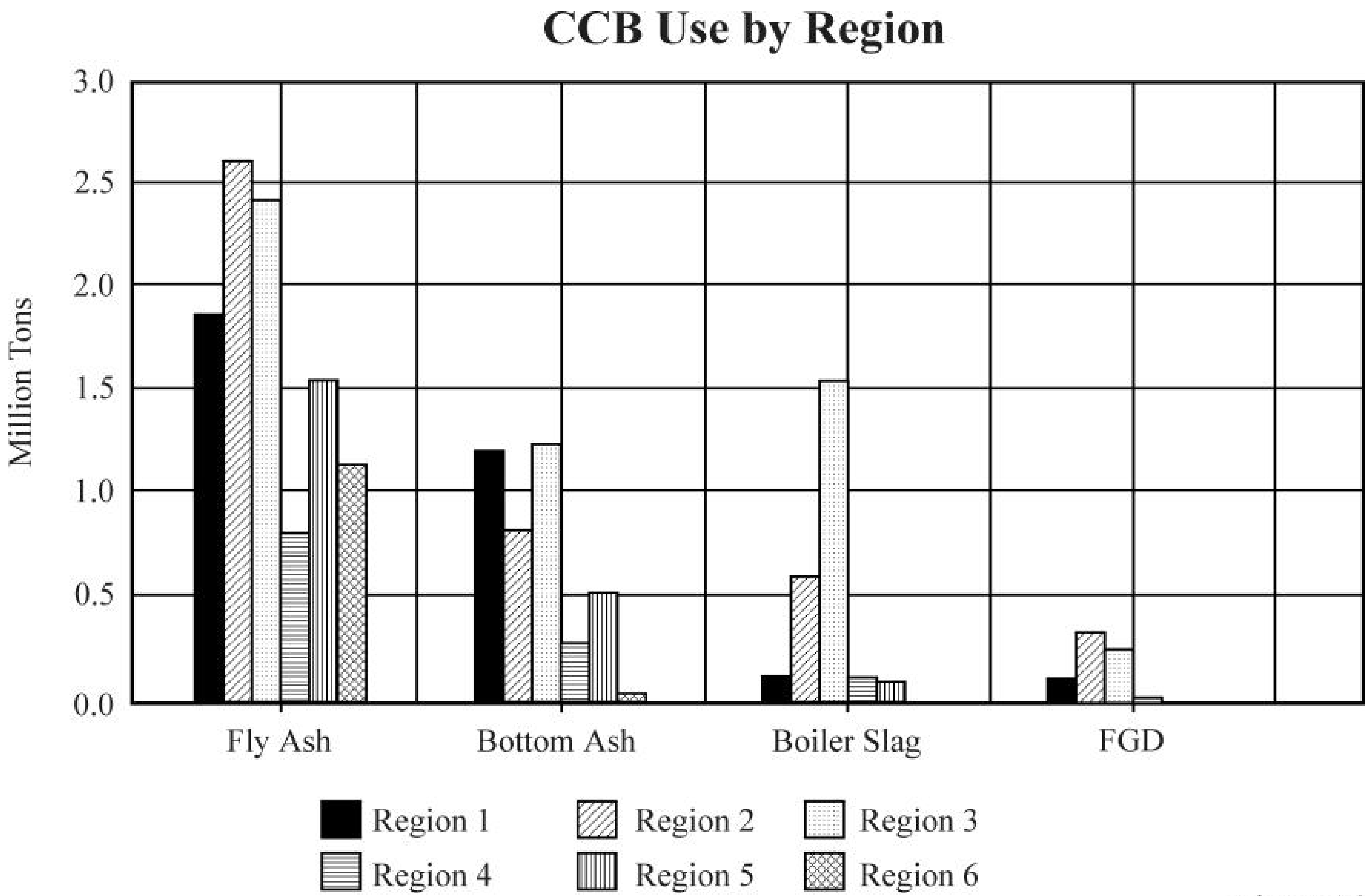
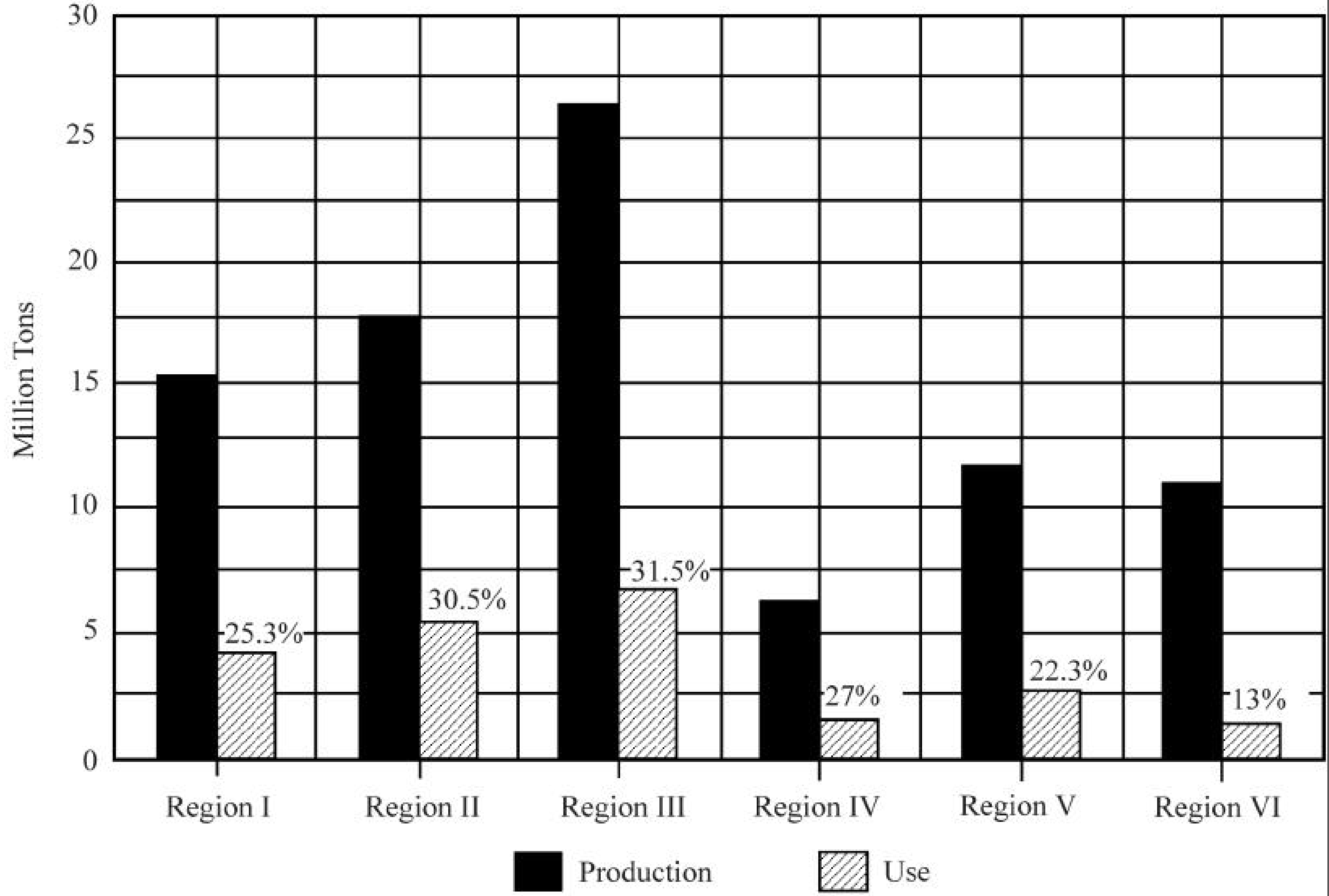


Figure 16

Source: Annual Survey of CCB Production and Use American Coal Ash Association

Combined CCB Production and Use by Region



Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 17

Summary: Category I & Category II CCB Production and Use for 1994

- **CCB Production and Use - Report for 1994**
  Category I: Dry or Moisture-Conditioned CCBs (Table 13)
  Category II: Ponded CCBs (Table 14)

- **Total CCBs Produced in 1994 - Category I & Category II (Figure 18)**

- **Total CCBs Used in 1994 - Category I & Category II (Figure 19)**

- **Category I CCB Production Quantities and Percentages - 1994 (Figure 20)**

- **Category II CCB Production Quantities and Percentages - 1994 (Figure 21)**

- **Comparison of Category I and Category II CCB Production - 1994 (Figure 22)**

- **Comparison of Category I and Category II CCB Use - 1994 (Figure 23)**

- **Category I CCB Use Quantities and Percentages - 1994 (Figure 24)**

- **Category II CCB Use Quantities and Percentages - 1994 (Figure 25)**

ACAA's one-page annual reports of CCB production and use for 1994 document the management of CCBs in two categories: Category I, Dry or Moisture-Conditioned, shown in Table 13; and Category II, Ponded, shown in Table 14. Category I and Category II CCBs accounted for about 68.4 and 31.6 percent, respectively, of total CCB production in 1994, as shown in Figure 18; and, Category I and Category II CCBs accounted for about 76.4 and 23.6 percent, respectively, of total CCB use in 1994, as shown in Figure 19.

The overall CCB production quantities for each of the four CCBs (fly ash, bottom ash, boiler slag and FGD material) shown in Table 13 and Table 14 for 1994 can be reviewed quickly in graphical form as shown in the pie charts of Figure 20 (for Category I) and Figure 21 (for Category II).

The percentage of fly ash being managed in dry or moisture conditioned storage is about 71.4 percent vs. 28.6 percent managed in ponded storage. Similarly, the percentage breakdown of dry or moisture conditioned versus ponded storage for bottom ash, boiler slag and FGD material are 60 vs. 40, 56 vs. 44, and 68 vs. 32, respectively.

Table 13. CCB Production and Use-Report for 1994 Category I-Dry/Moisture-Conditioned CCBs
[Source: Annual Survey of CCB Production and Use, American Coal Ash Association]

Category I - Dry, Moisture Conditioned & Compacted CCBs	Fly Ash	Bottom Ash	Boiler Slag	FGD Material
A. CCB Production	39,147,469	8,975,267	2,106,035	10,621,252
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			50,228,771	
Total All CCBs				60,850,023
B. CCB Use				
External Market Applications				
a. Cement and Concrete Products	6,700,614	185,504	0	86,877
b. Flowable Fill	384,972	57,078	0	0
c. Structural Fills	638,821	92,685	0	20,071
d. Road Base/Subbase	605,363	222,208	25,523	0
e. Mineral Filler in Asphalt	133,511	15,762	56,259	0
f. Snow and Ice Control	15,298	325,450	4,149	0
g. Blasting Grit/Roofing Granules	0	32,144	1,467,890	0
h. Grouting	17,044	0	0	0
I Mining Applications	80,023	28,769	0	0
j. Wallboard	0	0	0	533,941
l. Waste Stabilization	227,816	23,331	0	0
k. Miscellaneous/Other	575,641	77,227	0	73,462
Subtotal -- External Market Applications	9,379,102	1,060,159	1,553,821	714,350
Internal Producer Applications				
a. Cement and Concrete	1,003	549	0	0
b. Flowable Fill	26,996	531	0	18,089
c. Structural Fills	510,941	48,348	0	62,688
d. Road Base/Subbase	103,342	154,072	1,738	124
e. Snow and Ice Control	0	248	62	0
f. Miscellaneous/Other	1,796,658	1,386,576	43,998	0
Subtotal -- Internal Producer Applications	2,438,940	1,590,324	45,798	80,901
Total External Market and Internal Producer Applications	11,818,042	2,650,483	1,599,619	795,251
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			16,068,144	
Total -- All CCBs				16,863,395
C. Individual Use Percentage	30.2%	29.5%	76.0%	7.5%
D. Cumulative Use Percentage	30.2%	30.1%	32.0%	27.7%

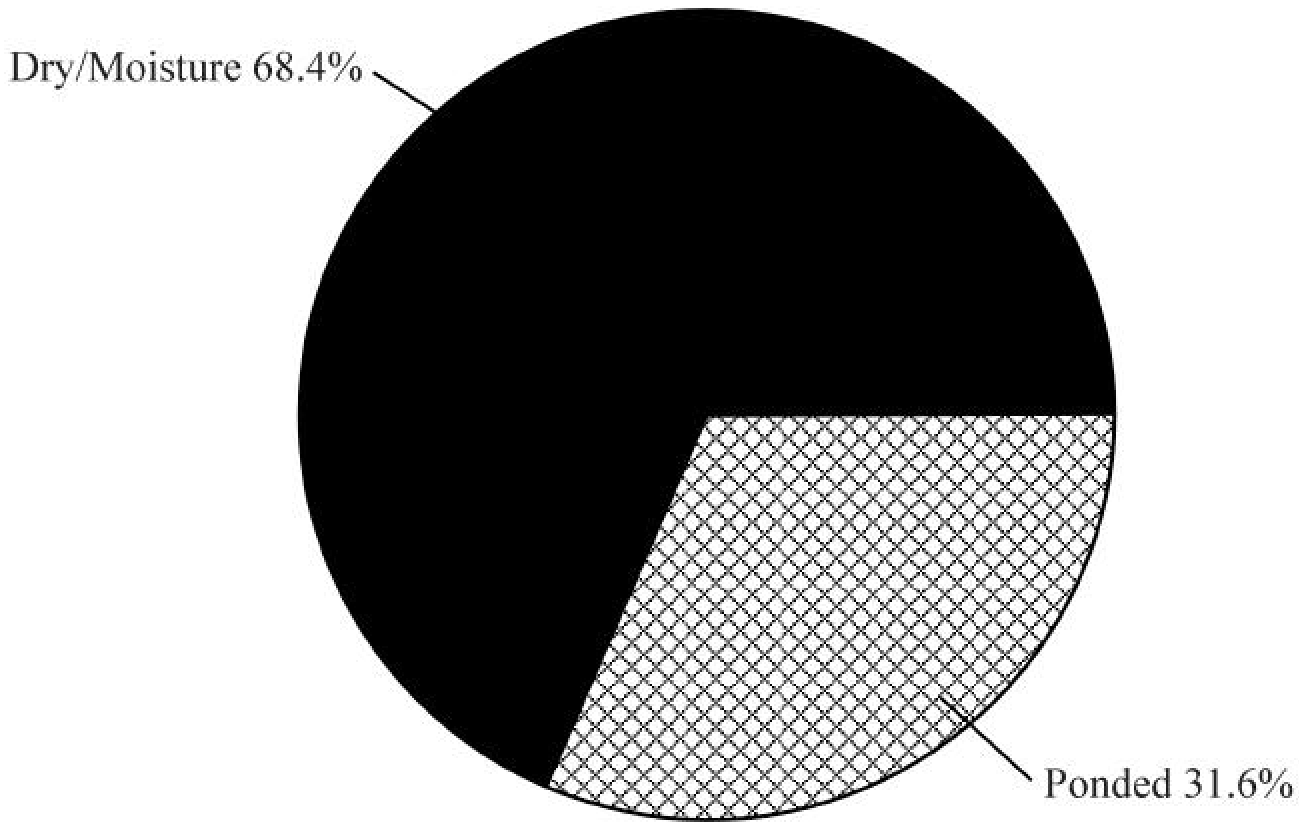
Table 14. CCB Production and Use-Report for 1994 Category II-Ponded CCBs

[Source: Annual Survey of CCB Production and Use, American Coal Ash Association]

Category II - Ponded CCBs	Fly Ash	Bottom Ash	Boiler Slag	FGD Material
A. CCB Production	15,688,101	5,851,898	1,679,818	4,923,816
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			23,219,816	
Total All CCBs				28,143,632
B. CCB Use				
External Market Applications				
a. Cement and Concrete Products	718,720	551,177	89,694	0
b. Flowable Fill	223,051	31,143	0	0
c. Structural Fills	43,232	60,856	3,723	0
d. Road Base/Subbase	0	50,134	6	0
e. Mineral Filler in Asphalt	1,606	0	27,057	0
f. Snow and Ice Control	0	461,820	212,602	0
g. Blasting Grit/Roofing Granules	0	61,310	1,158,213	0
h. Grouting	0	0	0	0
I Mining Applications	0	0	0	148,932
j. Wallboard	0	0	0	0
l. Waste Stabilization	3,212	0	0	0
k. Miscellaneous/Other	0	106,433	11,985	0
Subtotal -- External Market Applications	989,821	1,322,873	1,503,281	148,932
Internal Producer Applications				
a. Cement and Concrete	0	0	0	0
b. Flowable Fill	0	0	0	0
c. Structural Fill	18,078	277,107	0	0
d. Road Base/Subbase	5,461	540,847	1,291	0
e. Snow and Ice Control	0	244	0	0
f. Miscellaneous/Other	99,288	291,411	13,647	0
Subtotal -- Internal Producer Applications	122,826	1,109,609	14,938	0
Total External Market and Internal Producer Applications	1,112,647	2,432,482	1,518,219	148,932
Subtotal -- Fly Ash, Bottom Ash, and Boiler Slag			5,063,349	
Total -- All CCBs				5,212,280
C. Individual Use Percentage	7.1%	41.6%	90.4%	3.0%
D. Cumulative Use Percentage	7.1%	16.5%	21.8%	18.5%

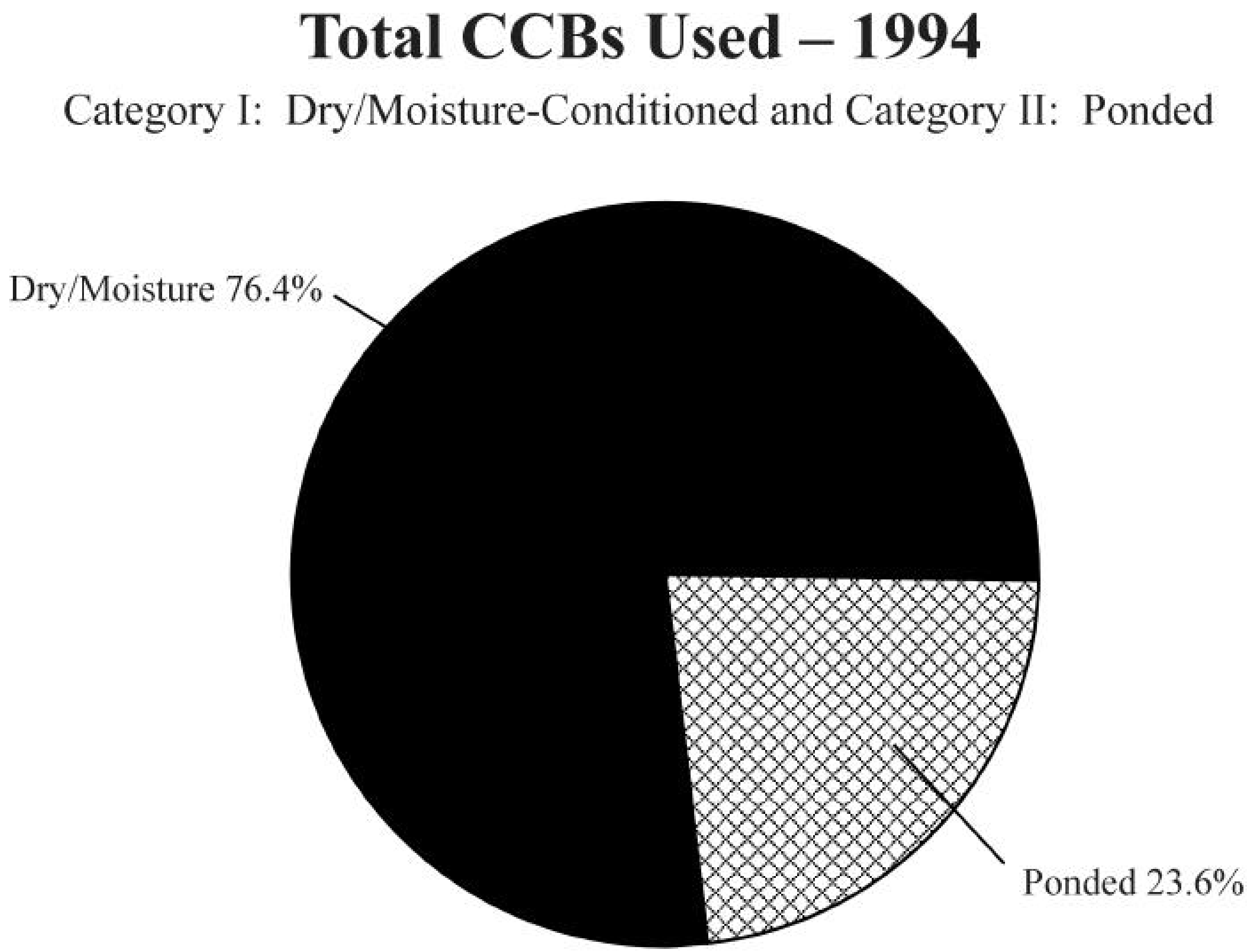
Total CCBs Produced – 1994

Category I: Dry/Moisture-Conditioned and Category II: Ponded



Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 18

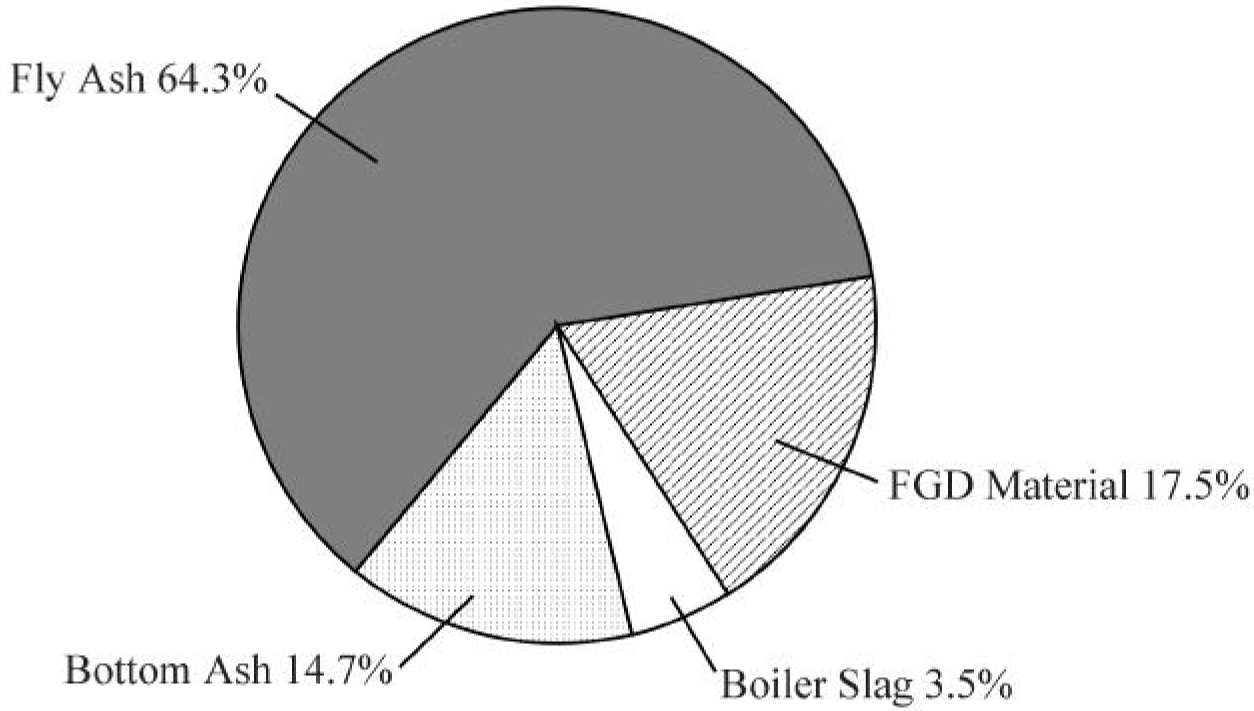


Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 19

CCBs Production - 1994

Category I: Dry/Moisture-Conditioned

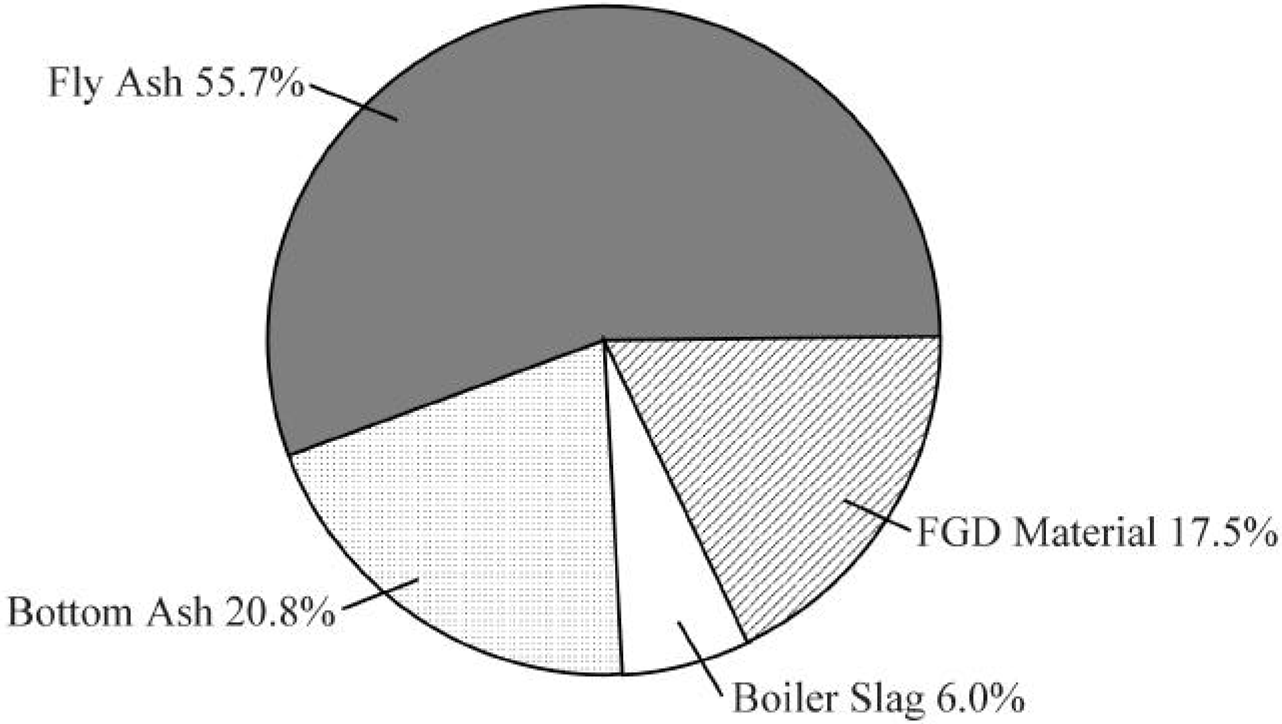


CCB	Category I CCB Production, tons	Percent of Total, %
Fly Ash	39,147,469	64.33%
Bottom Ash	8,975,267	14.75%
Boiler Slag	2,106,035	3.46%
FGD Material	10,621,252	17.45%
Total	60,850,023	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 20

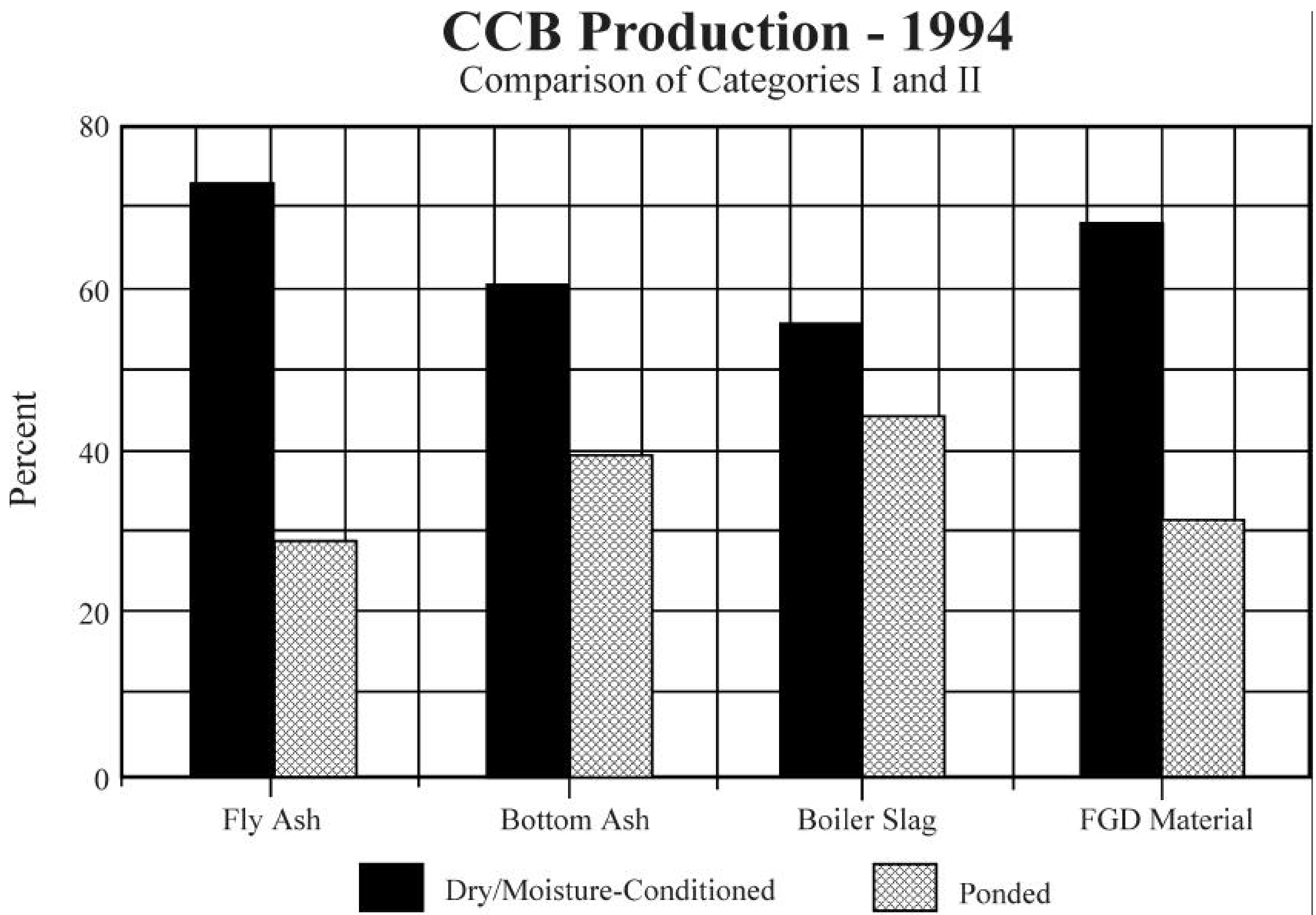
CCBs Production - 1994
Category II: Ponded



CCB	Category II CCB Production, tons	Percent of Total, %
Fly Ash	15,688,101	55.74%
Bottom Ash	5,851,898	20.79%
Boiler Slag	1,679,818	5.97%
FGD Material	4,923,816	17.50%
Total	28,143,633	100%

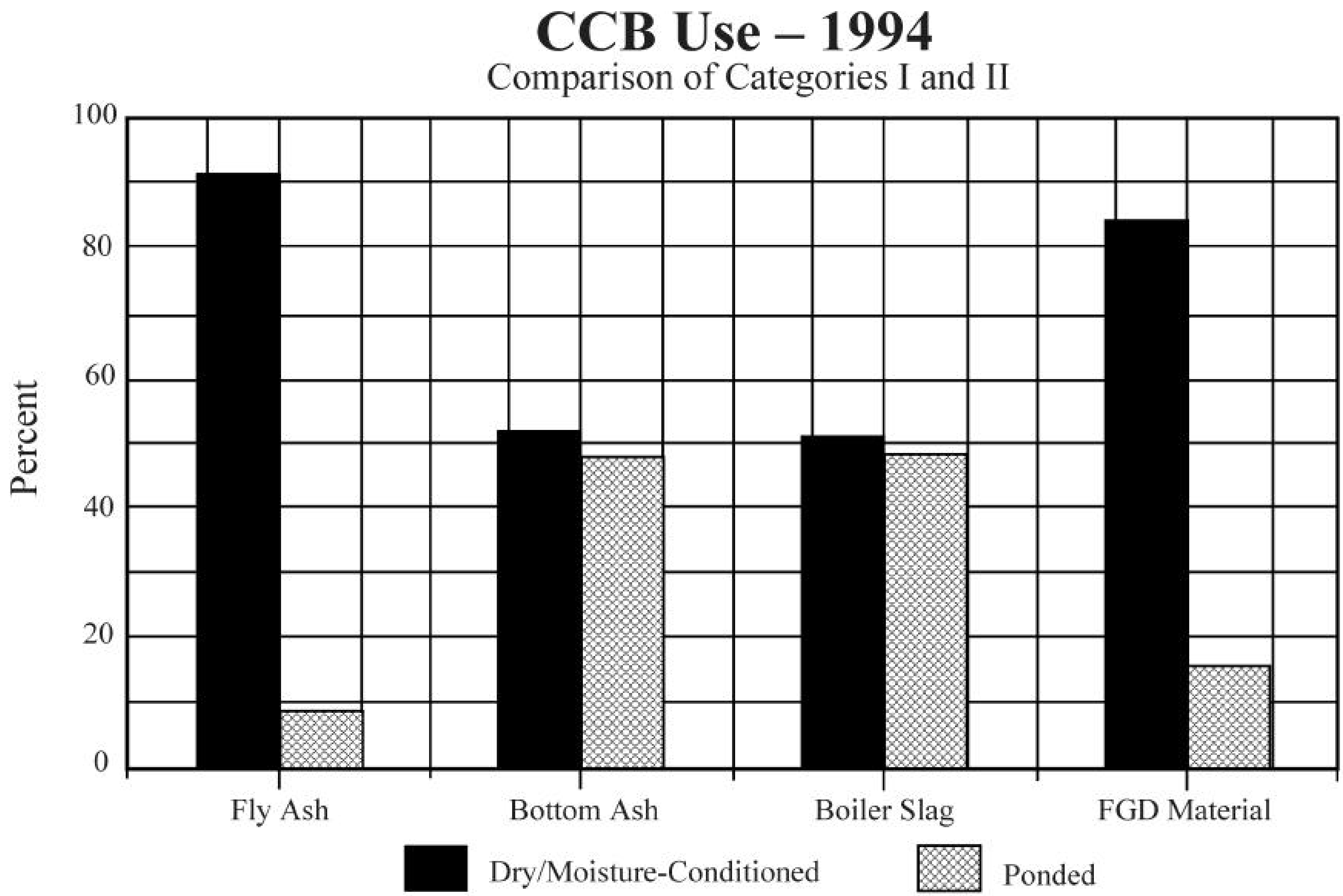
Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 21



Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 22

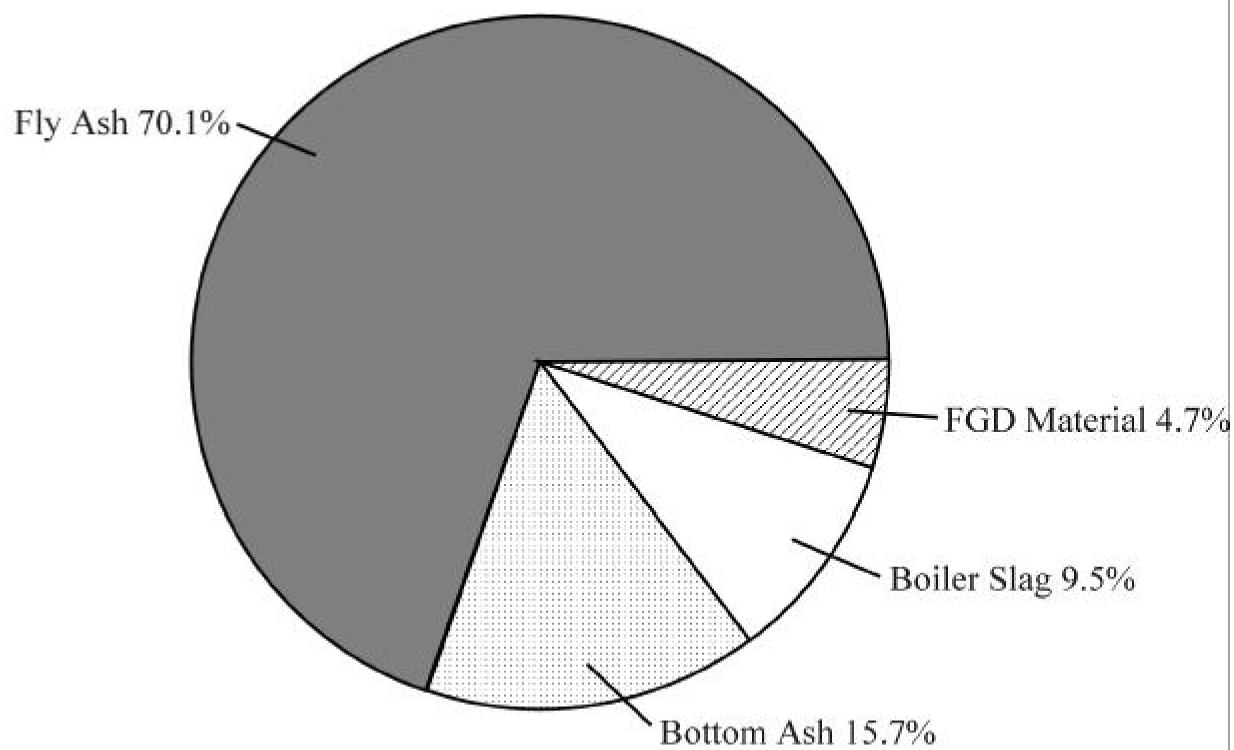


Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 23

CCB Use - 1994

Category I: Dry or Moisture Conditioned



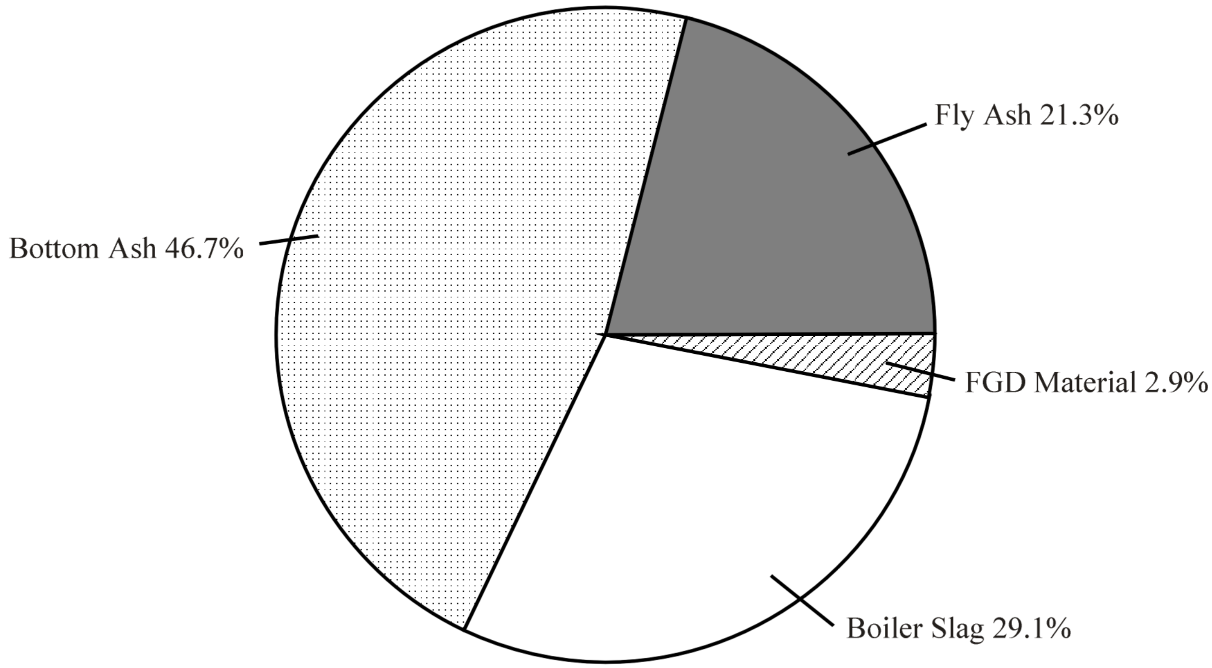
CCB	Category I CCB Use, tons	Percent of Total
Fly Ash	11,818,042	70.08%
Bottom Ash	2,650,483	15.72%
Boiler Slag	1,599,619	9.49%
FGD Material	795,251	4.72%
Total	16,863,395	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 24

CCB Use – 1994

Category II: Ponded



CCB	Category II CCB Use, tons	Percent of Total
Fly Ash	1,112,647	21.35%
Bottom Ash	2,4342,482	46.67%
Boiler Slag	1,518,219	29.16%
FGD Material	148,932	2.86%
Total	5,212,280	100%

Source: Annual Survey of CCB Production and Use, American Coal Ash Association

Figure 25

CONCLUSION

In calendar-year 1994 the use of fly ash, bottom ash and boiler slag reached 21.13 million tons, or nearly 29 percent of production. The advent of FGD material production, which ACAA initially included in its annual survey in 1987, has reduced the overall percentage of CCBs used, but in 1994 with FGD material production at 15.55 million tons, overall CCB use was still an impressive 24.8 percent.

This report summarizes much of ACAA's historical CCB production and use data for the period 1966 through 1994 so it can be reviewed in a single document. Information is presented in charts and graphs showing both quantities and percentages of CCBs produced and used.

Survey results for 1994 are summarized to show: leading applications for each CCB; a summary of low- and high-calcium coal fly ash production and use in all applications; and typical CCB production and use data from twelve (12) representative CCB producers in each of six (6) regions of the USA. Also, this report compares production and use data for CCBs managed and used as dry or moisture-conditioned versus ponded CCBs.

APPENDIX

GLOSSARY OF TERMS **[Revised: January 1995]**

The following terms are related to the annual survey of coal combustion byproduct (CCB) production and use conducted by the American Coal Ash Association (ACAA). These terms are intended to provide guidance in filling out ACAA's survey form, but may not necessarily be applicable for other purposes.

Agriculture -- Soil amendment, other than mine spoil amendment (see also: Mining Industry/Surface Reclamation), for changing physical and/or chemical characteristics of the soil to improve crop yield.

Aggregate -- Lightweight aggregate manufactured from coal fly ash; normal-weight aggregate manufactured from FGD material; and bottom ash or boiler slag.

Backfills -- Use of moisture-conditioned fly ash or bottom ash as an alternative to imported borrow for filling trenches, volumes behind retaining walls, and miscellaneous excavations.

Blasting Grit -- Use of boiler slag as substitute for sand or oxide abrasives in cleaning of castings, paint removal, etc.

Boiler Slag -- Hard, glassy CCB particles collected from wet-bottom or cyclone furnaces when molten CCB materials flowing from the furnace is quenched in water baths.

Bottom Ash -- Solid particles of CCBs which are collected at the bottom of dry-bottom furnaces.

Cement and Concrete Products -- CCBs used the manufacture of portland cement, as a raw feed or in a blended cement; and CCBs used as a mixture ingredient in the production of fresh concrete for a variety of uses (See also: Concrete Block; Ready Mixed Concrete, Precast Concrete and Concrete Pipe; and Portland Cement).

Coal Mining Applications -- See Mining Industry.

Coal Type -- Anthracite, bituminous, subbituminous and lignite.

Concrete Block -- Use of fly ash for a portion of the cementious material, and/or use of bottom ash as a substitute for sand and other fine graded aggregates in the manufacture of building blocks.

Embankments -- Use of CCBs as a structural fill above grade for carrying a roadway, parking lot or building, or for gravity dam construction.

FGD -- Flue gas desulfurization (see Scrubber Material).

FGD Material Solidification -- Use of fly ash interblended with flue gas desulfurization material to produce a soil-like product that can be compacted and which will gain strength over time.

Fillers -- (Applications other than Filler in Asphalt are currently classified as Miscellaneous/Other on ACAA's annual survey of CCB production and use.)

Filler in Asphalt -- (See Mineral Filler in Asphalt.)

Filler in Coatings -- Use of fly ash as a substitute for various minerals in the manufacture of coatings.

Filler in Metals -- Use of fly ash as a substitute for various alloy materials.

Filler in Paints -- Use of fly ash as a substitute for titanium dioxide, calcium carbonate, zinc phosphate, etc., in the manufacture of paints.

Filler in Plastics -- Use of fly ash as a substitute for glass, ceramics, talc, limestone, and sintered clays in the manufacture of plastics.

Elowable Fill -- Use of coal fly ash in a fluid mixture resembling a grout for backfill applications where bearing strengths as well as excavatability are needed comparable to those of compacted soils. The mixture may have a variety of proportions, with typical ingredients including water and fly ash, along with optional fillers such as bottom ash or sand and small, if any, additions of portland cement (See also: Mining Industry /Underground Grouting; Oil & Gas Industry).

Fly Ash Class -- Coal fly ash described by the American Society for Testing and Materials in ASTM C-618, Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use As a Mineral Admixture in Portland Cement Concrete, as Class C or Class F. Also, in common usage, a fly ash may be referred to as a Class C, or high-calcium, fly ash if its lime (CaO) content is greater than about twenty percent by total weight of the fly ash. Similarly, in common usage, fly ash with a lime content less than ten percent by total weight of the fly ash may be referred to as Class F.

Grouting -- Use of coal fly ash in a fluid mixture most frequently placed by pumping to underseal, or mudjack, concrete slabs; and to fill hollow-core concrete walls and other building units.

Mineral Filler in Asphalt -- Use of fly ash in bituminous concrete mixtures to compensate for deficient fines in the aggregate being used, or to impart other physical characteristics.

Mining Industry

Surface Reclamation -- Use of fly ash in landfill applications to restore surface mining areas to original or desirable contours; or to amend mine spoil materials and acid mine drainage.

Underground Grouting -- Use of fly ash in a flowable fill (see above) to control surface subsidence conditions, control mine fires or seal shafts.

Miscellaneous/Other -- Use of CCBs in any application not otherwise described in this glossary of terms.

Moisture-Conditioned CCBs – CCBs to which water has been added to control dusting and/or to allow optimum compacted density to be achieved during placement.

Moisture Adjustment -- A computation to determine the dry weight of CCBs to be reported on ACAA's annual survey of production and use (See also: Zero-Percent Moisture).

Oil & Gas Industry -- Use of fly ash with water and appropriate admixtures for grouting and closing wells (See Grouting).

Pavement Bases -- Use of fly ash with various activators in pozzolanic stabilized mixtures in the construction of highways, airport runways, parking lots and haul-roads on federal lands.

Portland Cement -- Use of fly ash by a cement manufacturer as:

> a raw material feedstock to the kiln in the production of portland cement clinker; or an additive to portland cement for the production of blended cements.

Ready Mixed Concrete, Precast Concrete and Concrete Pipe -- Use of coal fly ash as a mineral admixture to displace portland cement in varying amounts to improve certain fresh and hardened concrete characteristics, such as workability, strength, permeability and durability.

Real Estate Development -- Use of CCBs in an embankment or structural fill application to improve the topography and/or provide foundation support for commercial, residential and other construction.

Reefs -- Use of precast fly ash concrete blocks or other shapes and sizes specifically intended for construction of breakwaters or as habitats for fish and/or oysters.

Road Base/Subbase -- See: Soil Modification; Soil Stabilization.

Roofing Shingles/Granules and Filler -- Use of boiler slag as an inert substitute for fine aggregates, or use of fly ash as an asphalt filler.

Scrubber Material -- Lime or powdered limestone combined with oxides of sulfur, collected from the flue gas stream of coal-fired furnaces by means of scrubbers.

Short Ton -- A unit of weight equal to 2,000 pounds, contrasted with a long ton of 2,240 pounds and a metric ton of 2,205 pounds.

Snow and Ice Control -- Use of bottom ash or other CCB as an alternative to sand for road de-icing operations and skid control.

Soil Amendment -- See Agriculture.

Soil Modification – Any change to in-place soils that results in immediate effects that can expedite highway pavement construction operations. These changes can be measured in terms of moisture reduction, improved California Bearing Ratio (CBR) and/or decrease in plasticity.

Soil Stabilization -- A permanent change to in-place soils that makes significant improvements in the soil mixture characteristics and allows the soil layer to be assigned a structural support value as an integral part of a pavement structure.

Structural Fills -- Use of CCBs in an embankment application to improve the topography and/or provide foundation support for commercial, residential or other construction.

Use of CCBs–External Market Applications -- Employment of CCBs in applications by entities other than the CCB producer.

Use of CCBs--Internal Producer Applications -- Employment of CCBs in applications by the CCB producer or by the producers agent.

Wallboard -- Use of FGD material having a satisfactory gypsum (calcium sulfate) content in the manufacture of building panels.

Waste Solidification and Stabilization -- Use of coal fly ash or CCBs either alone or interblended with lime and/or portland cement or other agents to encapsulate or immobilize municipal sludges, non-toxic and toxic materials, and non-hazardous and hazardous materials (See also: FGD Material Solidification).

Zero-Percent Moisture -- The assumed percentage of moisture in CCBs for the purpose of reporting CCB production and use quantities for ACAA's annual survey of CCB producers throughout the USA. Where applicable, a computation to adjust the weight of moist materials to a dry weight (0% moisture) should be made prior to reporting CCB production and use data to ACAA.

APPENDIX D

ENVIRONMENTAL FACT SHEET

United States Environmental Protection Agency
Solid Waste and Emergency Response (OS-305)
EPA530-F-93-014
August 1993
Office of Solid Waste

EPA

Environmental Fact Sheet

Large-volume Wastes from Coal-fired Electric Utilities Exempt as Hazardous Waste

The Environmental Protection Agency (EPA) has determined that large-volume wastes from coal-fired electric utilities pose minimal risks to human health and the environment. Therefore, it is unnecessary to manage these wastes as hazardous. The Agency believes that industry and the states should continue to review appropriate management methods for these wastes.

Background

In a 1988 Report to Congress, EPA recommended that four large-volume wastes from coal-fired electric utilities—fly ash, bottom ash, boiler slag, and flue gas desulfurization waste—continue to be exempt from regulation as hazardous under Subtitle C of the Resource Conservation and Recovery Act (RCRA). The Report also indicated that the Agency intended to study the "remaining" wastes from coal-fired utilities, noncoal-fired utilities, and nonutility boilers burning any type of fossil fuels. Although the Agency recommended exemption for the large-volume wastes in its Report to Congress, EPA did not make a final regulatory determination on them.

Subsequently, the Agency collected data and information to supplement the 1988 Report to Congress. In February 1993, the Agency presented the new data and solicited public comment for purposes of finalizing the regulatory status of large-volume wastes from the combustion of coal by electric utilities.

Action

This rule continues to exempt four large-volume, fossil fuel combustion wastes from regulation as hazardous waste. Fly ash, bottom ash, boiler slag, and flue gas desulfurization wastes generated from coal-fired utilities pose minimal risks to human health and the environment. EPA recommends that any potential problems associated with the management of these wastes be addressed on a site-specific basis. These waste streams also will be considered for inclusion in the Agency's continuing assessment of industrial solid waste under RCRA, Subtitle D.

Contact

For additional information or to order a copy of the *Federal Register* notice, contact the RCRA Hotline, Monday-Friday, 8:30 a.m. to 7:30 p.m. EST. The national, toll-free number is (800) 424-9346; TDD (800) 553-7672 (hearing impaired); in Washington, D.C., the number is (703) 412-9810, TDD (703) 412-3323.

Copies of documents relevant to this rule may be obtained by writing: RCRA Information Center (RIC), U.S. Environmental Protection Agency, Office of Solid Waste (OS-305), 401 M Street SW, Washington, D.C. 20460.