COAL COMBUSTION PRODUCTS

By Rustu S.Kalyoncu

Domestic survey data and tables were prepared by Rustu S. Kalyoncu, Physical Scientist.

Electricity accounts for more than one-third of the primary energy use in the United States, and more than one-half of the Nation's electricity is generated by burning coal. Coal burning, combined with pollution control technologies, generates enormous quantities of residues, called coal combustion products (CCP's). During 1999, some 860 million metric tons (Mt) of coal were burned and about 100 Mt of CCP's were generated by the electric utilities.

The coal, as fuel for electric utilities, is crushed, pulverized, and blown into a combustion chamber, where it immediately ignites and burns to heat boiler tubes. The inorganic impurities, known as coal ash, either remain in the combustion chamber or are carried away by the flue gas stream. Coarse particles (bottom ash and boiler slag) settle at the bottom of the combustion chamber, and the fine portion (fly ash) remains suspended in the flue gas stream. Unless precautions are taken, fly ash is released into the atmosphere with the flue gases. Prior to leaving the stack, however, fly ash is removed from the flue gas by electrostatic precipitators or other scrubbing systems, such as a mechanical dust collector, often referred to as a cyclone.

In addition to the ash, there is concern about sulfur in flue gases emitted from electricity generating plants. The majority of electric power utilities, especially in the Eastern and the Midwestern States, use high-sulfur bituminous coal. Increased use of high-sulfur coal has contributed to an acid rain problem in North America. To address this problem effectively, the U.S. Congress passed the Clean Air Act Amendments of l990 (CAAA'90; Public Law 101-549) with stringent restrictions on sulfur oxide emissions. The sulfur dioxide (SO_2) reduction provisions of CAAA'90, with a two-phase implementation plan, forced the electric utilities to reduce SO_2 emissions. A number of utilities have switched to alternative fuels, such as low-sulfur coal or fuel oil, as partial and (or) temporary solutions to the problem. A significant number of electric utilities still using high-sulfur coal have installed flue gas desulfurization (FGD) units.

FGD units remove SO_2 from flue gas but, in doing so, generates large quantities of FGD material. The FGD material adds to the accumulation of already high levels of CCP's. About 22 Mt of FGD material were produced in 1999 and about 4 Mt (20%), mostly for wallboard manufacture, were used.

FGD issues affect, directly or indirectly, coal, gypsum, lime, limestone, and soda ash producers. Increased commercial use of FGD products represents an economic opportunity for high-sulfur coal producers and the sorbent industry (especially lime and limestone). FGD material competes directly with gypsum as raw material for wallboard manufacture.

The value of CCP's is well established by research and commercial practice in the United States and abroad as well. As engineering materials, these products can add value while helping conserve the Nation's natural resources.

Fly ash represents a major component (58%) of CCP's produced, followed by FGD material (23%), bottom ash (16%), and boiler slag (3%). Among the major CCP components, fly ash boasts the highest use rate at about 32% of the amount produced.

Legislation and Government Programs

CCP's have been the subject of investigation by the U.S. Environmental Protection Agency (EPA). The agency does not see CCP's so dangerous to the environment to warrant regulation under subtitle C of Resource Conservation and Recovery Act (RCRA), section (b) (3) (C), as hazardous. However, EPA lists the CCP's under subtitle D of RCRA, claiming regulations are warranted for CCP's when they are disposed of in landfills or surface impoundments. Furthermore, possible modifications to existing regulations established under the authority of the Surface Mining Control and Reclamation Act are warranted when they are used to fill surface or underground mines.

Comments on the 1999 Report to Congress submitted by American Coal Ash Association (ACAA), other industry groups, State and Federal agencies, and academic researchers contained numerous data-rich case studies of beneficial mine reclamation projects using CCP's. Those comments included the description of adequately protective State and Federal regulations addressing these practices and provided additional information to demonstrate that these beneficial uses of CCP's do not warrant additional national regulation. ACAA cautioned that simply proceeding with national regulations under Subtitle D rather than Subtitle C would not eliminate adverse impacts on beneficial markets for using CCP's (Sam Tyson, ACAA written commun., 2000). Meanwhile EPA announced that it will pursue regulation under RCRA Subtitle D or under the Surface Mining and Reclamation Act, or a combination of the two, to address its concerns. EPA cites the following reasons for its determination to pursue national regulation:

- The potential to present a danger to human health and the environment under "certain circumstances;" and
- Few States have comprehensive programs that specifically address the unique circumstance of minefilling.

EPA remains particularly critical of State programs however, and it maintains that Federal Government oversight is needed to ensure that minefilling is done appropriately to protect human health and the environment, particularly since minefilling is a recent but rapidly expanding use of coal combustion wastes.

EPA acknowledges that through the course of its 20-year Bevil study it has not found any cases of damage to human health or the environment from any beneficial use of CCP's (Sam Tyson, ACAA, written commun., 2000).

FGD Technologies

A number of commercially viable FGD technologies have been developed (Radian Corporation, 1983). Table 1 presents a list of FGD processes, which are either commercially available or in various developmental stages. Calcium-based wet systems (lime/limestone) are most popular in the United States. Summary descriptions of several FGD technologies were described in the 1998 USGS Minerals Yearbook (Kalyoncu, 2000). Owing to competition in the area of FGD technologies, information on new developments is not published in the open literature.

Production

Production and use data for CCP's are given in tables 2 through 5. Table 2 lists CCP production data for 1995 through 1999. A small, steady increase in CCP production rates through 1998 is apparent. Production in 1999 remained relatively unchanged from that of 1998. Fly ash, bottom ash, and boiler slag production can be expected to remain flat in the near future, as no significant increase in the use of coal is anticipated for electric power generation. However, with the commencement of phase two of CAAA'90 in January 2000, a significant increase in FGD material generation in the years ahead is a distinct possibility.

Thus far, during the phase one implementation, many utilities opted for temporary solutions to CAAA'90 requirements, such as fuel switching, retiring old power generators, and purchase of emissions allowances. This trend has continued to date. Phase two, however, will affect 90% of the remaining utilities that were exempt from the phase one implementation of the act. Options available in phase one, especially emissions allowances, either will no longer be available or will be very costly. This will compel the utilities to find a permanent solution to the emission problems, most likely through the installation of FGD units. With the number of FGD units increasing, a commensurate rise in the quantities of FGD material should be seen. Tables 3 through 5 show the production and consumption data for 1999. Figures 1 and 2 show the historical CCP production and use data respectively, for the past 5 years, and figure 3 shows the comparative production figures for each CCP type in 1999. Figure 4 shows production and use data by geographic region, and figure 5 depicts production by CCP type and region. Figures 6 and 7 show the share of each CCP, by production and use respectively, for 1999. Figure 12 shows six geographic regions of the United States.

Marsulex Environmental Technologies, Inc., Lebanon, PA, has been awarded an $85 million contract to build two FGD systems for the Virginia Power Co. facility in Mount Storm, VA (Canning, 1999). The systems are expected to remove 110,000 tons of SO_2 per year from the two coal-fired units. They are part of Virginia Power's overall strategy to reduce SO_2 emissions under phase two of CAAA'90. The anticipated completion date for the project is February 2002.

Earth Sciences, Inc., subsidiary of ADA Environmental Solutions (ADA-ES), completed a long-term warranty test period of its ADA-ES flue gas conditioning unit at Alliant Columbia powerplant generating unit #1 at Portage, WI. With ADA-ES technology, the Columbia plant will be able to continuously burn a Powder River Basin coal, saving Alliant several million dollars per year (http://biz.yahoo.com/prnews/981215/co_earth_s_1.html).

Consumption

The components of CCP's have different uses as they show distinct chemical and physical properties; each one is suitable for a particular application. CCP's are used in cement and concrete, mine backfill, agriculture, blasting grit, and roofing applications. Other current uses include waste stabilization, road base/subbase, and wallboard production (FGD gypsum). Potential FGD gypsum uses also include applications in subsidence and acid mine drainage control and as fillers and extenders.

Total CCP's use in 1999 increased to 30 Mt from 28.4 Mt in 1998, a 5.6% increase (table 2). The greatest increase in use, once again, was recorded by the FGD material, the use of which increased to more than 18% of production from 10% in 1998. The primary factor in this increase was the construction of new wallboard plants that use only FGD gypsum as raw material. The use of FGD gypsum in wallboard manufacture recorded the largest growth among the CCP's, increasing from 2.26 Mt in 1998 to 4.04 Mt in 1999, an 80% increase.

The use data for CCP's are summarized on a regional basis and in various use categories in figures 1 through 5. Figures 1 and 2 show the historical CCP's use and production data, respectively, for the last 5 years. Figure 3 shows the use for all the United States. Figures 4 and 5 show the use figures on a regional basis and by CCP type, respectively. Figures 6 and 7 present the production and use data by CCP type, respectively. Figures 8 through 11 summarize the use data for individual CCP types.

Among the CCP's, fly ash was used in the largest quantities and found the widest range of applications, with about 60% of the annual consumption in various structural applications. Use in cement and concrete production tops the list of leading fly ash applications with more than 50%, followed by structural fills and waste stabilization (Figure 8). About 65% of bottom ash is used in road base/subbase, structural fill, and snow and ice control (Figure 9). Owing to its considerable abrasive properties, boiler slag is used almost exclusively in the manufacture of blasting grit. Use as roofing granules is also a significant market area. Blasting grit-roofing granules make up almost 90% of boiler slag applications (Figure 10). Wallboard manufacture (more than 2/3 of the total), concrete, mining applications, and structural fill account for the bulk of FGD product uses (Figure 11).

The construction industry is generating an unprecedented demand for wallboard across the United States. Since 1996, nearly all U.S. wallboard plants were running at full capacity and drywall was being imported from Canada to meet the demand. Demand for wallboard has been growing by an average of 5% per year for the past 15 years and has increased significantly during the past several years. U.S. demand for wallboard reached a record level of about 27 billion square feet (2.7 billion square meters) in 1998, and demand continued to be very strong in 1999 (Shannon Bass, Gypsum Association, oral commun., 2000).

A number of factors have contributed to this. While housing industry experts were expecting about 1.45 million housing starts in 1998, there were 1.6 million actual starts. Those 150,000 extra houses created an unanticipated shortage of 100 million square meters of wallboard (Pam Kassner, USG Corporation, oral commun., 2000). Moreover, many of the houses being built today are 18% larger than those built 15 years ago. The size increase accounts for about 240 million square meters per year of wallboard. The repair and remodeling market also has grown markedly during the past several years. Over the past 5 years wallboard demand for repair and remodeling has grown 34%, to 1.03 billion square meters from 770 million square meters.

The wallboard industry is expanding its FGD gypsum wallboard plant construction significantly. The use of FGD gypsum eliminates the expense of capital investment in opening or expanding mines for increased production of natural gypsum. The impact of FGD gypsum on the wallboard industry will be significant. Several wallboard manufacturers announced plans to build 13 plants, 10 of which will use FGD gypsum (Drake, 1997). The new plants are slated to start operation 2000 through 2003. The plants using FGD gypsum will be built either adjacent to an electric powerplant or waterways where the FGD gypsum can be economically barged to the wallboard plant. The new lines will add 8 to 10 billion square feet (800 million to 1.0 billion square meters) of wallboard capacity by the year 2003, 6 billion square feet (600 million square meters) of which will be made from FGD gypsum.

National Gypsum Company, in late 1998, announced its plans to build some new wallboard plants and expand its Richmond, CA, wallboard facility in the San Francisco area (John Rappold, National Gypsum Company, oral commun., 2000). Construction on the Richmond expansion was to commence in March 2000 and to be completed late 2000. However, owing to permitting problems encountered, a revised completion date for the project is late 2001.

National Gypsum also broke ground on its new Shippingsport, PA, plant in March 1998 and commenced production 7 months ahead of schedule in March 2000. The new plant, 40 kilometers northwest of Pittsburgh along the Ohio River in Shippingsport, features the latest technology and uses FGD gypsum generated by nearby Pennsylvania Power Company's Bruce Mansfield plant. National Gypsum's expansion plans in the Tampa, FL, area and its new state-of-the- art plant in St. Louis, MO, announced in 1998, are going according to schedule, and the new facility is expected to go into production in January 2001. The Florida facility will increase its capacity by 400 million square feet (40 million square meters) at a cost of $80 million. The St. Louis project will be implemented in two phases. The new plant will be operational late 2001 during phase one, with about 400 million square feet (40 million square meters) capacity. Phase two is expected to take an additional 18 to 24 months to complete and will bring capacity up to 700 million square feet (70 million square meters). Both projects will use FGD gypsum from neighboring electric powerplants. These expansion projects come on the heels of the company's expansion of its Baltimore, MD, wallboard manufacturing capacity, which was completed in late 1998.

U.S. Gypsum Company (USG) announced the construction of a plant in 1997, in Bridgeport, AL. The plant was completed and was put into service in 1999 (Katy Kendall, U.S. Gypsum Company, oral commun., 2000). The 700 million-square-feet-per-year (70 million-square-meter-per-year) plant is using 100% FGD gypsum obtained from Louisville Gas and Electric Company (LG&E). A long-term agreement signed by the two companies calls for LG&E to deliver more than 500,000 tons per year FGD gypsum from four power-generating units at its Mill Creek Station in Louisville.

Standard Gypsum Corp. is building a wallboard plant near Clarksville, TN, that will use only FGD gypsum supplied by the Tennessee Valley Authority's Cumberland generating station. The plant opened for operations in late 1999 according to schedule (Dix Brown, Standard Gypsum Corp., oral commun., 2000).

Georgia Pacific Corp. is building a wallboard plant in Wheatfield, IL, that will use 100% synthetic gypsum obtained from the neighboring electric power utilities (Drake, 1997).

Lafarge Gypsum has officially inaugurated its new $90 million drywall plant in Silver Grove, KY (Global Gypsum, 2000). Silver Grove will have a capacity of 900 million square feet (90 million square meters) of wallboard and will use FGD gypsum shipped down the Ohio River by barge to a custom built loading facility. Lafarge is planning to build another plant in Palatka, FL, in early 2001. The 900 million-square-feet-per-year (90 million-square-meter-per-year) plant is 80 kilometers southwest of Jacksonville and will be the fifth drywall plant that Lafarge has built or purchased in the United States and Canada, since 1996. The plant was built adjacent to two large electric generating units operated by Seminole Electric Cooperative, Inc. and will satisfy its primary raw material requirements by using synthetic gypsum produced by Seminole Electric. The plant is virtually identical to the company's Silver Grove, KY, plant.

USG's first of four new wallboard lines, in Bridgeport, AL, went into operation in May 1999, ahead of schedule. A new line in East Chicago, IN, commenced production in November 1999. A third line was to be completed by early 2000.

Current Research and Technology

Research and development activities have focused on improving FGD processes and finding new applications for CCP's, especially the FGD product. Japanese and West European researchers have spearheaded much of the activity in new FGD technologies area. Higher research and development activity levels in these countries are driven by space limitations. Electric utility companies in these countries have no room for the disposal of the products from the current FGD processes and are forced to find better solutions to flue gas emission problems. Research efforts emphasize the development of technology that requires less space for installation and yields smaller quantities of products than the well established methods using lime or limestone as sorbents.

Research and development efforts in FGD have been directed, for the most part, toward either decreasing the quantities of the reaction products or increasing their economic value to upgrade them from waste products to resources.

Outlook

In the future, increases in the production of fly ash and bottom ash will be proportional to the increase in coal use for electric power production, which may be limited to 5% to 7% per year.

However, a significant rise in the FGD material is expected after the start of the implementation period of phase two of CAAA'90. Only 10% of the utilities were affected by the phase one implementation of the law. Gradual implementation of phase two, covering the remaining 90% of the electric utilities, commenced in January 2000. A noticeable increase in the quantities of FGD material produced will become apparent in the coming years. The majority of the utilities affected by phase one met the restrictions with short-term remedies, such as fuel switching, emission allowance purchases, and reduction of power production where feasible. Such temporary measures, however, will not be available to all. This is apparent by the ongoing and planned construction of FGD units around the country. Currently, over 10,000 megawatts (MW) of power generation systems support FGD units, and more than 6,000 MW of limestone units and nearly 4,000 MW of lime units are under construction. Moreover, the construction of 7,000 MW of limestone systems and 6,000 MW of lime systems are in the planning stage. When operational, these systems are expected to more than triple the quantity of FGD material to about 75 million metric tons per year (Mt/yr), from the current level of 22 Mt/yr. With continued installation of FGD units, FGD material production could double the amount of CCP's currently being generated. This, combined with the potential effect of future EPA rulemaking, presents a formidable challenge to electric utilities and CCP-user industries.

To answer the challenge, utilities will continue to look for pollution-prevention technologies that will yield lesser quantities, but purer and higher value FGD material. An example of such a trend is seen at Basin Electric Cooperative's Dakota Gasification plant, Beulah, ND, where a wet-ammonia-based FGD unit is used to remove SO_2 in combustion of otherwise nonsalable fuels derived from gasification of lignite. The resulting ammonium sulfate is sold and used as a sulfur blending stock in fertilizer production (William Ellison, PE, oral commun., 1999).

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
FLUE GAS DESULFURIZATION PROCESS CATEGORIES

Categories	Number of processes
Calcium-Based Wet Systems	24
Sodium-Based Wet Systems	24
Ammonia-Based Wet Systems	12
Magnesium-Based Wet Systems	9
Potassium-Based Wet Systems	5
Organic-Based Wet Systems	22
Other Wet Systems	34
Wet Reagent Dry Systems	5
Dry Reagent Dry Systems	4
Carbon-Based Sorption Systems	10
Metal Oxide Sorption Systems	9
Other Solid Sorption Systems	5
Catalytic Oxidation Systems	11
SO_2 Reduction Systems	8
Combustion Systems	2
Other Dry Systems	3
Flue Gas Desulfurization Subsystems	24

Source: Radian Corporation.

TABLE 2
HISTORICAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons)

	1995	1996	1997	1998	1999
Fly ash:					
Production	49,200	53,900	54,700	57,200	56,900
Use	12,300	14,700	17,500	19,200	18,900
Percent use	25.00	27.50	32.10	33.60	33.20
Bottom ash:					
Production	13,800	14,600	15,400	15,200	15,300
Use	4,600	4,430	4,600	4,760	4,930
Percent use	33.30	30.40	30.20	31.30	32.10
Boiler slag:					
Production	2,550	2,360	2,490	2,710	2,620
Use	2,440	2,170	2,340	2,170	2,150
Percent use	95.70	92.30	94.10	80.10	81.80
FGD material: 1/					
Production	18,300	21,700	22,800	22,700	22,300
Use	1,340	1,500	1,980	2,260	4,030
Percent use	7.41	6.96	8.67	10.00	18.10
Total CCP's:					
Production	83,700	92,400	95,400	97,800	97,100
Use	20,700	22,800	26,500	28,400	30,000
Percent use	24.90	24.90	27.80	29.00	30.80

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 3
TOTAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1999 1/

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 2/ material	Total CCP's
Production:					
Disposed	35,500	9,360	560	17,400	62,900
Produced	56,900	15,300	2,620	22,300	97,100
Removed from disposal	250	260	240	70	820
Stored on-site	2,760	1,300	150	940	5,150
Use:					
Agriculture	10	40	--	70	120
Blasting grit-roofing granules	--	140	1,940	--	2,080
Cement clinker raw feed	1,150	140	--	--	1,290
Concrete-grout	9,150	640	10	260	10,100
Flowable fill	770	10	--	--	780
Mineral filler	140	60	10	--	210
Mining applications	1,390	140	10	210	1,750
Roadbase-subbase	1,100	1,000	10	20	2,130
Snow and ice control	--	1,010	50	--	1,060
Soil modification	70	20	10	--	100
Structural fills	2,910	1,260	50	520	4,740
Wallboard	--	--	--	2,770	2,770
Waste stabilization-solidification	1,750	60	--	10	1,820
Other	420	410	70	170	1,070
Total	18,900	4,930	2,150	4,030	30,000
Individual use percentage	33.20	32.10	81.80	18.10	NA
Cumulative use percentage	33.20	32.90	34.70	30.80	30.80

NA Not available. -- Zero.
1/ Total CCP's include Categories I and II; Dry and Ponded respectively.
2/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 4
DRY COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1999

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total CCP's
Production:					
Disposed	22,900	6,000	40	13,800	42,700
Produced	41,400	9,100	800	17,600	68,900
Removed from disposal	180	180	--	--	360
Stored on-site	1,860	460	30	670	3,020
Use:					
Agriculture	10	40	--	70	120
Blasting grit-roofing granules	--	120	640	--	760
Cement clinker raw feed	1,060	130	--	--	1,190
Concrete-grout	8,540	430	--	260	9,230
Flowable fill	720	10	--	--	730
Mineral filler	140	50	10	--	200
Mining applications	920	50	10	210	1,190
Roadbase-subbase	990	620	--	20	1,630
Snow and ice control	--	500	10	--	510
Soil modification	70	20	10	--	100
Structural fills	2,390	400	30	500	3,320
Wallboard	--	--	--	1,910	1,910
Waste stabilization-solidification	1,750	60	--	10	1,820
Other	280	380	30	160	850
Total	16,900	2,810	740	3,140	23,600
Individual use percentage	40.70	30.70	93.00	17.90	NA
Cumulative use percentage	40.70	38.90	39.70	34.20	34.20

NA Not available. -- Zero.
1/ FGD, flue gas desulfurization.

TABLE 5
PONDED COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1999

(Thousand metric tons)

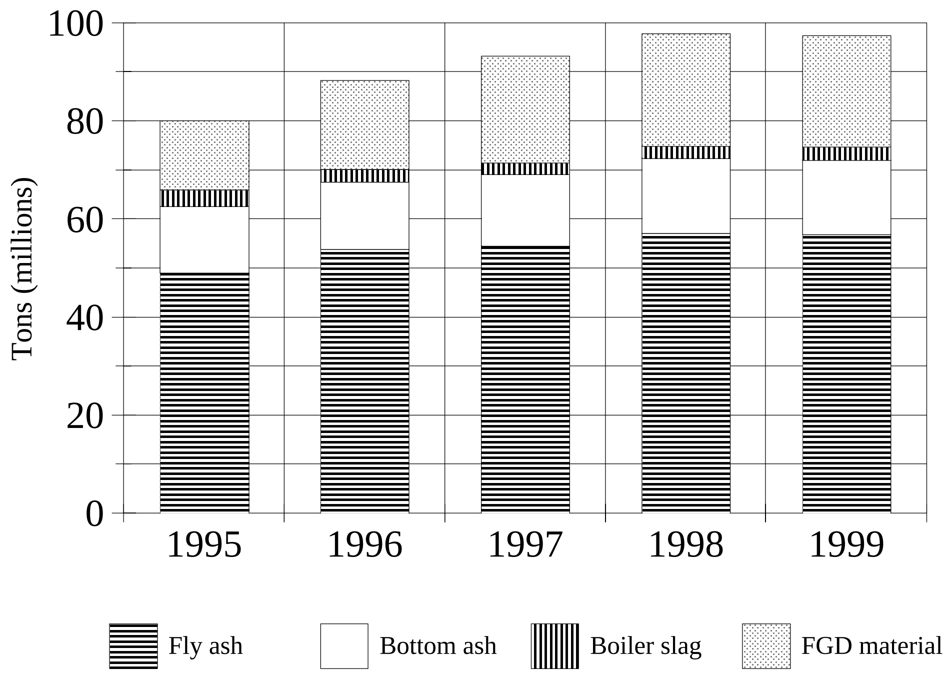
	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total CCP's
Production:					
Disposed	12,700	3,340	540	3,680	20,200
Produced	15,500	6,210	1,820	4,780	28,300
Removed from disposal	70	80	240	70	460
Stored on-site	890	840	120	270	2,120
Use:					
Blasting grit/roofing granules	--	20	1,290	--	1,310
Cement clinker raw feed	90	10	--	--	100
Concrete-grout	620	210	10	--	840
Flowable fill	50	--	--	--	50
Mineral filler	--	10	--	--	10
Mining applications	470	90	--	--	560
Roadbase-subbase	120	380	--	--	500
Snow and ice control	--	510	30	--	540
Structural fills	520	860	20	30	1,430
Wallboard	--	--	--	860	860
Waste stabilization-solidification	--	10	--	--	10
Other	140	30	40	--	210
Total	2,010	2,130	1,400	890	6,430
Individual use percentage	13.00	34.20	76.80	18.10	NA
Cumulative use percentage	13.00	19.10	23.60	22.70	22.70

NA Not available. -- Zero.

1/ FGD, flue gas desulfurization.

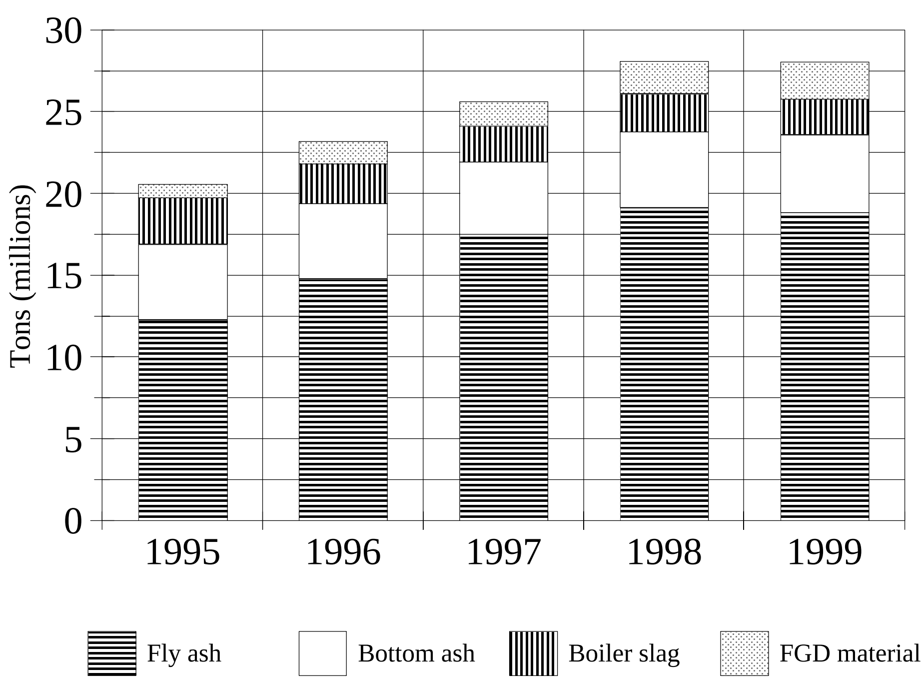
Source: American Coal Ash Association.

FIGURE 1
HISTORICAL COAL COMBUSTION PRODUCT PRODUCTION DATA



Source: American Coal Ash Association.

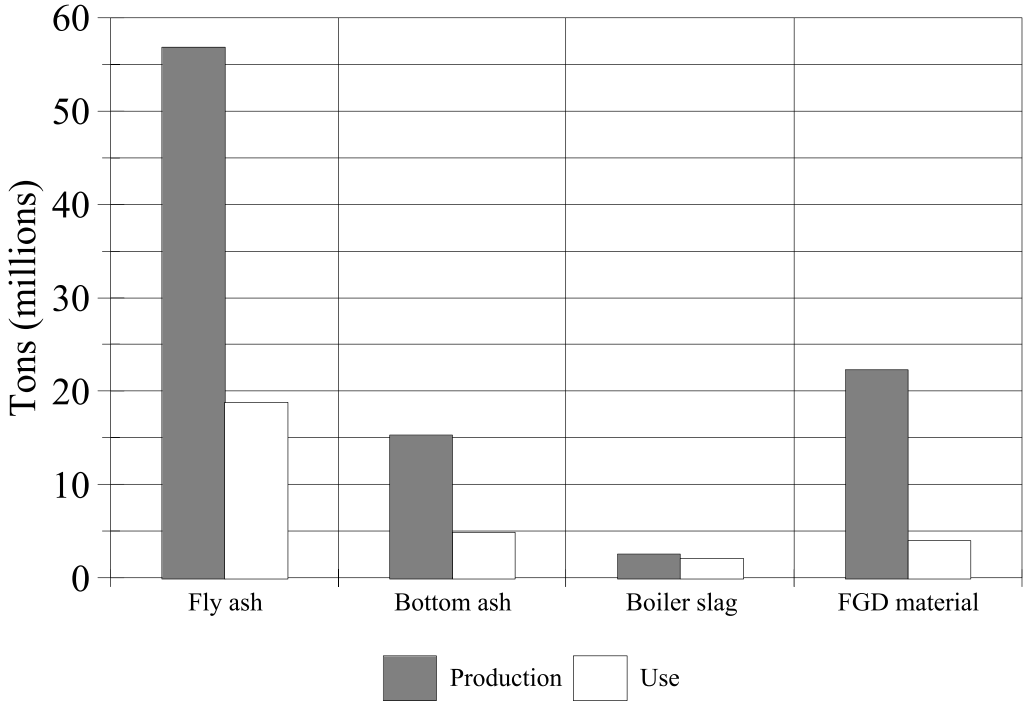
FIGURE 2
HISTORICAL COAL COMBUSTION PRODUCT USE DATA



Source: American Coal Ash Association.

FIGURE 3

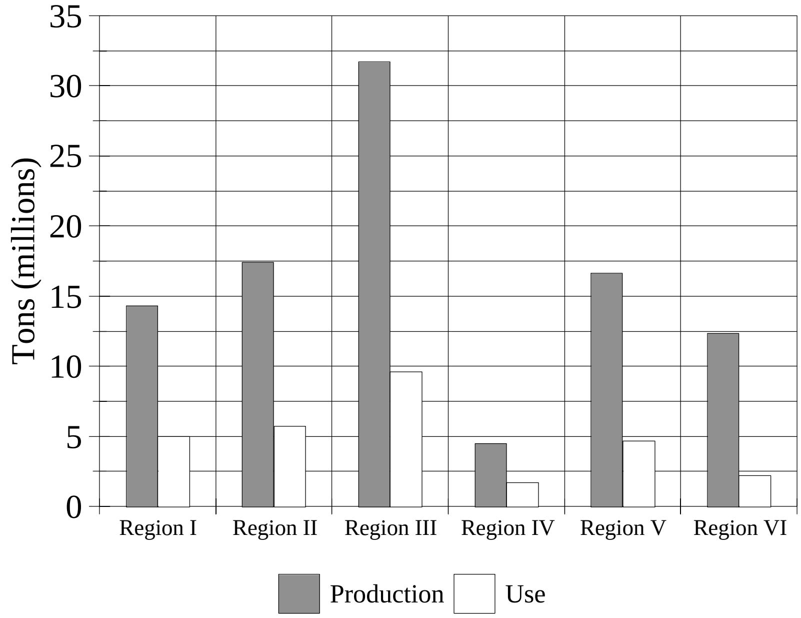
CCP PRODUCTION AND USE FOR THE UNITED STATES, 1999



Source: American Coal Ash Association.

FIGURE 4

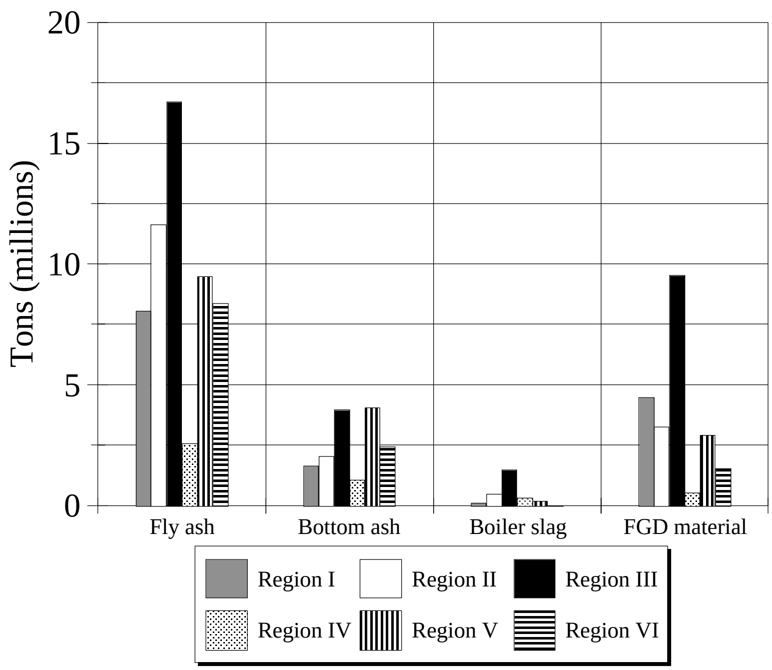
COAL COMBUSTION PRODUCT PRODUCTION AND USE BY REGION, 1999



Source: American Coal Ash Association.

FIGURE 5

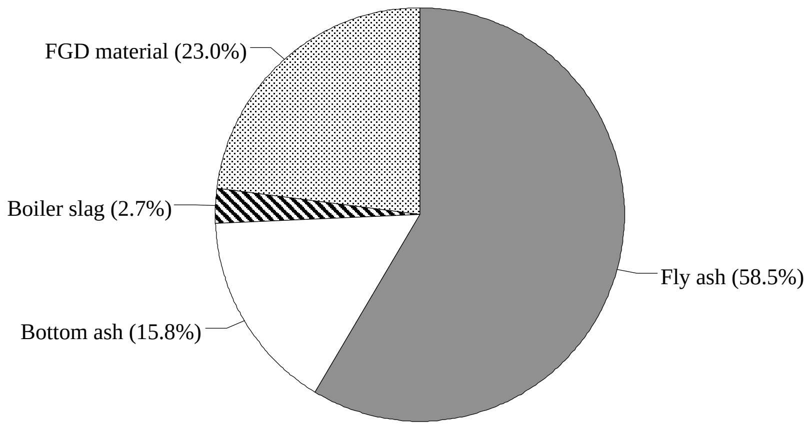
COAL COMBUSTION PRODUCT PRODUCTION BY TYPE AND REGION, 1999



Source: American Coal Ash Association.

FIGURE 6

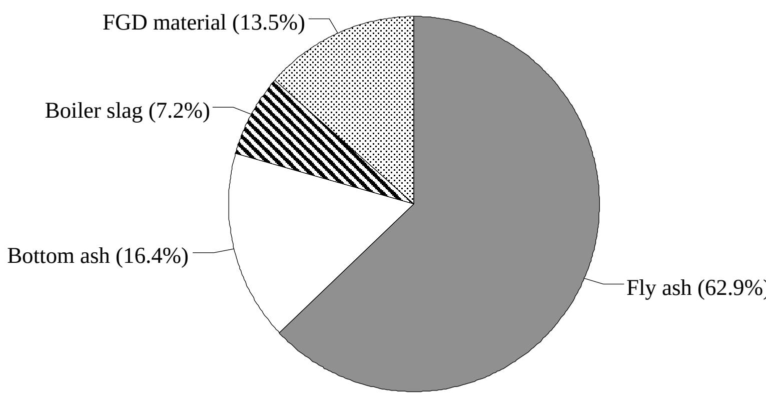
COAL COMBUSTION PRODUCT PRODUCTION BY TYPE, 1999



Source: American Coal Ash Association.

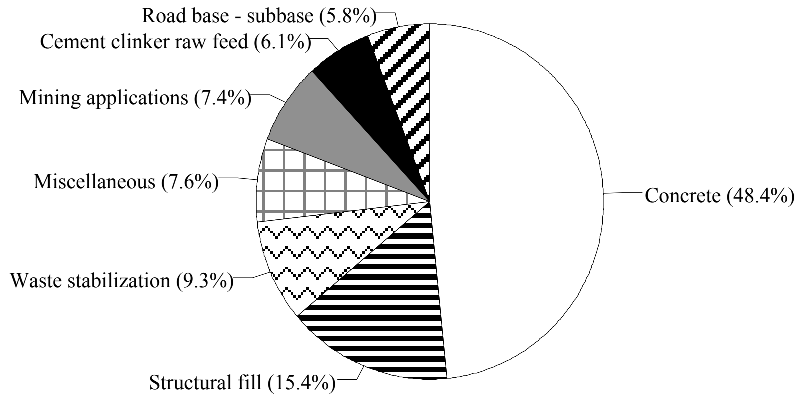
FIGURE 7

COAL COMBUSTION PRODUCT USE BY TYPE, 1999



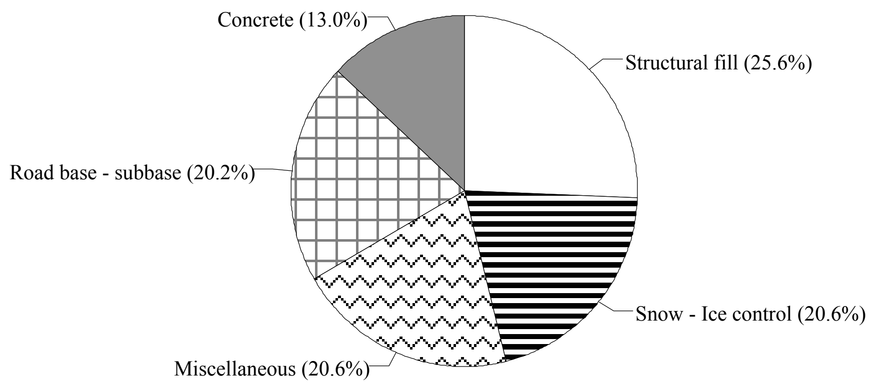
Source: American Coal Ash Association.

FIGURE 8
LEADING COAL FLY ASH USES, 1999



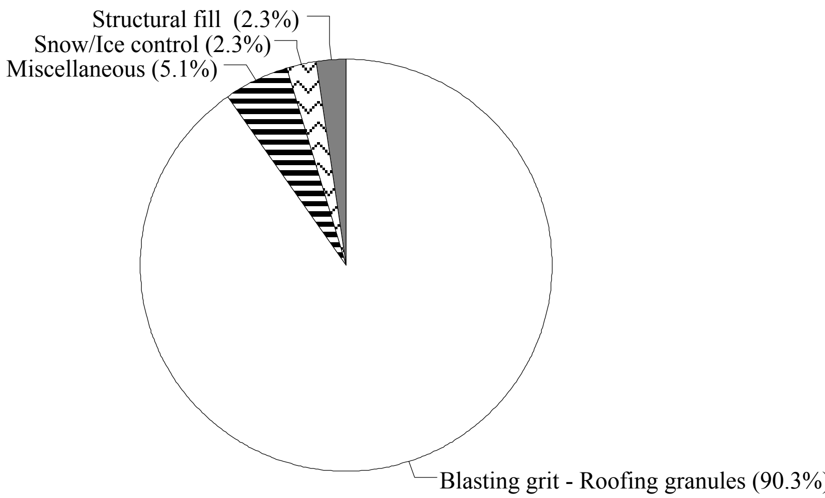
Source: American Coal Ash Association.

FIGURE 9
LEADING BOTTOM ASH USES , 1999



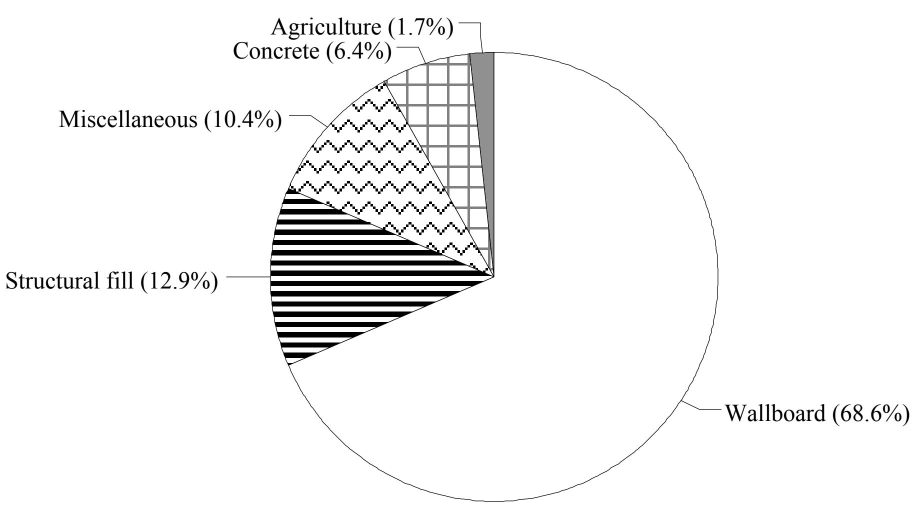
Source: American Coal Ash Association.

FIGURE 10
LEADING BOILER SLAG USES, 1999



Source: American Coal Ash Association.

FIGURE 11
LEADING FGD MATERIAL USES, 1999



Source: American Coal Ash Association.

FIGURE 12
REGIONS OF THE UNITED STATES