COAL COMBUSTION PRODUCTS

By Rustu Kalyoncu

Coal combustion products (CCP's) are the solid residues generated by coal-burning electric utilities in the production of electricity. In 1998, electricity accounted for about 35% of the primary energy use in the United States and was produced by electric power generators designed to convert different fuel types into electricity. More than one-half of the electricity in the United States was generated by burning coal. As a result, approximately 100 million metric tons per year (Mt/yr) of CCP's were generated by the electric utilities.

The lack of information in open literature on flue gas desulfurization (FGD) methods has led to suggestions by some readers to incorporate a somewhat detailed description of some of the prominent FGD methods. The following descriptions are included as background for the commodity data. Future Annual Reviews will include only newly developed methods.

The coal 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 to 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 above products, electric generators equipped with flue gas desulfurization (FGD) units generate what is known as FGD material.

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, require the electric utilities to find ways to reduce SO_2 emissions. Many utilities have switched to low-sulfur coal or fuel oil as partial and/or temporary solutions to the problem. A significant number of those powerplants still using high-sulfur coal have installed FGD equipment.

FGD units help solve the SO_2 problem but, in doing so, generate large quantities of a product called FGD material. These products of the FGD process, produced in large quantities, add to the accumulation of already high levels of CCP's. Of the approximately 23 million metric tons (Mt) of FGD material produced in l998, approximately 10% was used, mostly in wallboard manufacturing and agriculture.

Among the industries directly or indirectly affected by FGD issues are coal, limestone, lime, soda ash, and gypsum producers. Increased commercial use of FGD products represents an economic opportunity for high-sulfur coal producers and the sorbent industry (especially lime and limestone).

In 1998, fly ash represented a major component (58%) of CCP's produced, followed by FGD material (23%), bottom ash (16%), and boiler slag (3%). More than 80% of the boiler slag was profitably used. Among the major CCP components, fly ash had the highest use rate at approximately 33% of the amount produced.

Flue Gas Desulfurization Methods

Passage of the CAAA'90 by the 101st Congress and subsequent FGD requirements for coal-fired powerplants generated much activity in the research and development (R&D) of processes to control SO_2 emissions in flue gas. A significant number of electric powerplants, which continue to use medium- and high-sulfur coal as fuel, have installed FGD equipment.

Almost 200 FGD methods have been identified (Radian Corporation, 1983). Table 1 lists some of the major methods that are either fully developed or being developed. These methods have been divided into two major types, wet and dry systems. Among the numerous methods mentioned, only four have been developed to technically and economically feasible levels. The first three use primarily wet processes; the fourth category uses dry processes.

Lime-Limestone-Based Methods.—In FGD systems using the lime (CaO) process, lime is slaked on site to form a calcium hydroxide slurry (McIlvaine Company, 1996). This slurry reacts with sulfur gases to form calcium sulfite ($CaSO_3$) and calcium sulfate ($CaSO_4$), as illustrated by the following reactions:

$$SO_2(L) + Ca(OH)_2 \rightarrow CaSO_3 \cdot \tfrac{1}{2}H_2O \downarrow + \tfrac{1}{2}H_2O \text{ and}$$
$$SO_2(L) + \tfrac{1}{2}O_2(L) + Ca(OH)_2(L) + H_2O \rightarrow CaSO_4 \cdot 2H_2O \downarrow,$$
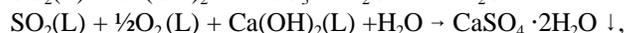
where L, solution or slurry; ↓solid; and ↑, gas.

In limestone ($CaCO_3$) systems, the chemistry is similar. Carbon dioxide, however, is also generated. The process is defined by the following reactions:

$$SO_2(L) + CaCO_3(L) + \tfrac{1}{2}H_2O \rightarrow CaSO_3 \cdot \tfrac{1}{2}H_2O \downarrow + CO_2 \uparrow$$
and
$$SO_2(L) + \tfrac{1}{2}O_2 + CaCO_3(L) + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O \downarrow + CO_2 \uparrow.$$
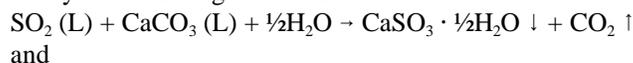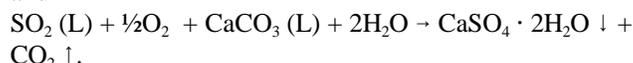
The oxidation of sulfite to sulfate is dependent upon many process variables, such as equipment design, pH, and the O_2-to-SO_2 ratio, and has caused serious operating problems owing to

scale formation in some systems.

A typical method (figure 1) involves the recirculation of the sorbent (lime or limestone) slurry in a scrubber. The flue gas comes in contact with a slurry of calcium salts. The gas may or may not contain fly ash, depending on the absorber design. A larger amount of slurry (relative to the gas volume) is sprayed or dispersed in the contactor, saturating the flue gas and removing the SO_2. The scrubbed gas is then passed through mist eliminators and is often reheated to restore buoyancy before being discharged.

The SO_2-rich fluid typically drains into large tanks where neutralization and precipitation reactions occur. Alkaline reagents are added to these tanks to maintain the desired system pH. When lime is the reagent, the feed liquor pH is typically 8 to 9, and the absorber effluent pH is 5 to 7. In the limestone method, the pH is between 5 and 6. Operating at this lower pH tends to increase the sulfite oxidation rate. As the sulfate concentration rises, the gypsum concentration increases. If a supersaturated condition is reached without adequate gypsum seed crystals present in the slurry, then hard scale can form on the absorber walls, disrupting operation. To obtain scale-free operation, either the reaction tank is sized to maintain the gypsum concentration low enough to prevent scale formation, or forced oxidation is required to generate adequate crystal nucleation sites for gypsum precipitation.

Magnesium-Based Method.—This is a regenerative recovery process, whereby the scrubber captures SO_2 by formation of magnesium sulfite (McIlvaine Company, 1996). The dry material is calcined at the sulfite decomposition temperature to drive off the SO_2 and to regenerate the magnesium oxide (MgO). MgO is recirculated and the SO_2 is recovered. The recovered SO_2 can be used in the production of sulfuric acid or elemental sulfur. This is a much easier application than the lime-limestone method and the intermediate product has immediate utility.

In the MgO method, fly ash and other particulates are removed from the flue gas stream prior to reaction with the sorbent slurry. This reduces the impurities in the regenerated MgO and the solids in the scrubber as well. In this system, reactive MgO is slaked to form magnesium hydroxide slurry, which becomes the absorber. The flue gas enters an SO_2 absorber as shown in figure 2. The SO_2 and small amounts of sulfur trioxide in the exhaust gas react with the MgO slurry to form magnesium sulfite ($MgSO_3$) and magnesium sulfate ($MgSO_4$), respectively. Formation of some magnesium bisulfite $Mg(HSO_3)_2$ is also observed. Addition of excess MgO to the slurry prevents the formation of $Mg(HSO_3)_2$ as the excess MgO reacts with that compound to convert it to $MgSO_3$ which, in turn, is oxidized to $MgSO_4$ in the presence of excess oxygen.

The process chemistry is represented by the following reactions:

$$Mg(OH)_2 + 5H_2O + SO_2 \rightarrow MgSO_3 \cdot 6H_2O,$$
$$Mg(OH)_2 + 2H_2O + SO_2 \rightarrow MgSO_3 \cdot 3H_2O,$$
$$Mg(OH)_2 + 6H_2O + SO_3 \rightarrow MgSO_4 \cdot 7H_2O,$$
$$SO_2 + MgSO_3 \cdot 6H_2O \rightarrow Mg(HSO_3)_2 + 5H_2O,$$
$$SO_2 + MgSO_3 \cdot 3H_2O \rightarrow Mg(HSO_3)_2 + 2H_2O,$$
$$Mg(HSO_3)_2 + MgO + 11H_2O \rightarrow 2\,MgSO_3 \cdot 6H_2O, \text{ and}$$
$$Mg(HSO_3)_2 + MgO + 5H_2O \rightarrow 2\,MgSO_3 \cdot 3H_2O.$$
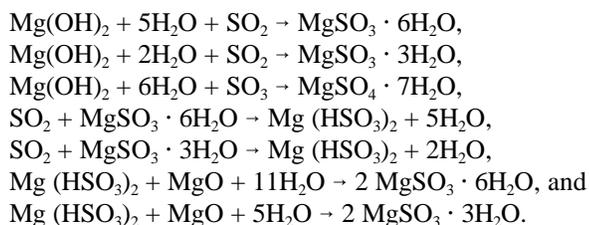
The aqueous sorbent slurry contains hydrated crystals of MgO, $MgSO_3$ and $MgSO_4$, and a solution saturated with these components. A portion of the scrubber stream, theoretically the equivalent (expressed as $MgSO_3$) of the sulfur oxide content being introduced, is constantly diverted to a clarifier/thickener for concentration, and the concentrated slurry is then fed to a continuous centrifuge. A "wet cake" containing crystals of $MgSO_3 \cdot 6H_2O$, $MgSO_3 \cdot 3H_2O$, $MgSO_4 \cdot 7H_2O$, and unreacted MgO is produced.

The liquor removed from the crystals may be returned to the main recirculating slurry stream or may be used to slake/react with fresh or regenerated MgO, which is then added to the recirculating slurry stream as makeup.

The "wet cake" is conveyed to a dryer where water (including chemically bound water) is removed. Dryer temperatures typically are in the range of 176° to 232° C.

The chemical reactions occur in the dryer as follows:

$$MgSO_3 \cdot 6H_2O \triangleq MgSO_3 \cdot 3H_2O + 3H_2O \uparrow,$$
$$MgSO_3 \cdot 3H_2O \triangleq MgSO_3 + 3H_2O \uparrow,$$
$$MgSO_3 \cdot 6H_2O \triangleq MgSO_3 + 6H_2O \uparrow, \text{ and}$$
$$MgSO_4 \cdot 7H_2O \triangleq MgSO_4 + 7H_2O \uparrow.$$
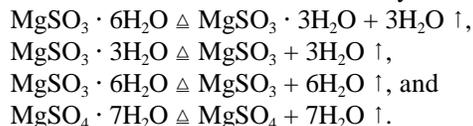
The dry compounds are calcined at 800° to 1,000° C to regenerate the MgO and release SO_2. Regenerated MgO is put in storage for reuse in the scrubber slurry system and SO_2 is used in the manufacture of sulfuric acid or elemental sulfur. A typical MgO method operating at pH 5.5 to 6.5 will remove in excess of 95% of sulfur gases.

Ammonium Sulfate-Based Method.—An FGD method more popular in Europe uses ammonia as sorbent; the final product is ammonium sulfate. A simplified process flow diagram of a particular design, known as the Walther Ammonia method, is shown in figure 3 (McIlvaine Company, 1996). Flue gas containing SO_2 and CO_2 passes through a spray drier and an electrostatic precipitator to separate fly ash and other particulates and finally enters the scrubber containing the ammonia. The following reactions occur:

$$SO_2 + 2\,NH_3 + H_2O \rightleftharpoons (NH_4)_2SO_3 \text{ (L)}$$
$$CO_2 + 2\,NH_3 + H_2O \rightleftharpoons (NH_4)_2CO_3 \text{ (L)}$$
$$(NH_4)_2SO_3 + \tfrac{1}{2}O_2 \rightleftharpoons (NH_4)_2SO_4 \text{ (L)}$$
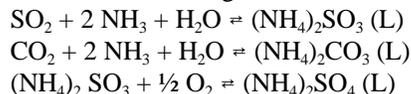
Solution containing the products of the above reactions enters the oxidation chamber where ammonium sulfite is converted to ammonium sulfate. A small amount of sulfite still remains in the oxidized liquor. The oxidized liquor, containing ammonium sulfite and smaller fractions of ammonium carbonate and ammonium sulfate, is then injected into a spray drier where the sulfite and carbonate fractions decompose, leaving behind ammonium sulfate, which is packaged to be sold as nitrogen fertilizer. Meanwhile, the clean flue gas leaving the scrubber is passed through a second wash cycle where the remaining salt is removed. This step helps prevent scaling throughout the FGD unit. Twice-washed flue gas goes through a heat exchanger to recover excess heat prior to being released to atmosphere. Sulfur removal efficiencies of up to 95% are attained.

Ammonium carbonate present in the system serves as a readily available reagent to adjust the pH levels in the various stages of the process, thus eliminating the necessity for an extra step in the cycle to make pH adjustments. The ammonia

system appears to have the added advantage of preventing sulfuric acid formation because ammonia reacts directly with sulfur trioxide to form additional ammonium sulfate, thus eliminating any potential corrosion problems prevalent in other systems.

In the face of mounting agricultural sulfur demand, gradual growth in the status of ammonium sulfate as sulfur blending stock in large-scale chemical fertilizer formulations has led to a significant gap between supply and demand of ammonium sulfate. The current ammonia-based FGD installations portend a substantial increase in world supply and use of byproduct ammonium sulfate as sulfur blending stock. This latest demand is verified by a sustained high market price (compared with an equivalent amount of anhydrous ammonia) commanded by ammonium sulfate. Used as a combined nitrogen and plant-nutrient-sulfur blending stock, ammonium sulfate derived from the ammonia FGD process will help alleviate the increasing worldwide shortage for agricultural applications. Increased world population during the past decades, combined with the loss of valuable arable soil to erosion and urban expansion, has led to overworking of the remaining agricultural land and lowering of the sulfur content in soil. Sulfate is the preferred form of sulfur additive, readily assimilated by crops. Ammonium sulfate is the ideal sulfate compound for soil amendment because it combines sulfate ion with ammonium in the most effective nitrogen fertilizer form.

The estimated worldwide annual shortage of almost 11 Mt of elemental sulfur for agricultural applications is equivalent to 45 Mt of ammonium sulfate. This figure corresponds to approximately 170,000 megawatts (MW) of electricity production using 2.5% to 3.0% sulfur coal as fuel.

Dry Injection Methods.—Dry FGD methods make up the second category of methods developed for use in flue gas cleaning operations. Three major types of dry FGD methods are being developed—spray drying, dry injection, and simultaneous combustion of fuel-sorbent mixtures.

In dry injection methods, a powdered sodium compound is injected into the flue gas with subsequent particulate collection in a fabric filter (McIlvaine Company, 1996). Reactions between reagent and sulfur oxides take place in the duct and on the filter bag surface. Nahcolite and trona appear to be the most promising reagents for this. The injection chamber is heated to the decomposition temperature of the sorbent, 93° C for trona and 135° C for nahcolite. Decomposition increases the reaction rates as it enhances the reactivity by increasing the effective surface area of the sorbent. Decomposition is represented by the following reactions:

$2\ NaHCO_3 \triangle Na_2CO_3 + H_2O\uparrow + CO_2 \uparrow$ and

$2(Na_2CO_3 \cdot NaHCO_3 \cdot 2\ H_2O) \triangle 3\ Na_2CO_3 + CO_2 \uparrow + 5\ H_2O \uparrow$.
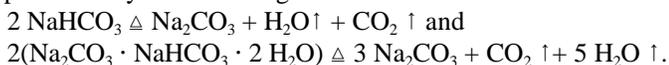
In situ decomposition apparently enhances porosity and reactive surface area. This decomposition reaction seems to occur at significant rates above 93° C for trona and above 135° C for nahcolite. Because of the higher decomposition temperature required, nahcolite may not be applicable for units with operation temperatures below 135° C. The sorption reaction proceeds as follows:

$Na_2CO_3 + SO_2 + \frac{1}{2}\ O_2 \rightarrow Na_2SO_4 + CO_2\uparrow$.
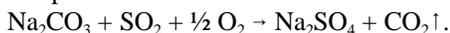
Figure 4 is a schematic flow diagram for the nahcolite-trona

dry injection FGD process. Pulverized sorbent (90% through 325 mesh) is transported pneumatically from the mill to the injection point, where it is injected into the flue gas duct work upstream of the fabric filter. Reagent and fly ash are collected on the fabric filter bags. The reaction occurs as the flue gas passes through the filter cake on the fabric filter. The mixture of ash and spent reagent is removed from the bags and collected in a hopper and pneumatically conveyed to a storage silo.

Dry FGD methods offer a distinct advantage over wet lime-limestone based methods. The end product is a solid that can be handled by conventional fly ash handling systems, eliminating the requirement for wet sludge handling equipment. High water solubility of sodium-based FGD byproducts, however, can lead to leachability and potential environmental problems if not disposed of properly.

In general, dry FGD systems require a higher ratio of sorbent to sulfur to achieve desired efficiencies, as solid-gas reactions proceed at slower rates than liquid-gas reactions. Dry FGD systems, however, cost less to maintain and require less equipment than the wet methods, because thickeners, centrifuges, vacuum filters, and mixers are not needed. In addition, slurry pumping requirements are much lower for spray drying and are completely eliminated in dry injection and direct fuel-sorbent combustion. Finally, dry FGD methods have a distinct advantage over wet methods in terms of energy requirements, mostly owing to savings in reheating and pumping requirements. The above factors make the dry systems more economical in capital and operating costs.

Production

Production and use data for CCP's are listed in tables 2 through 5. Table 2 lists the five-year historical data on CCP production for 1994 through 1998. Small but steady increases in the total production are apparent. Fly ash production increased to 57.2 Mt from 54.7 Mt in 1997, an increase of 4.6%. Bottom ash and FGD material decreased slightly in 1998 from the 1997 figures. Even though a larger number of utilities produced electric power using FGD units, the amount of FGD material did not increase in 1998 had been designed to produce purer and fewer reaction products. The gradual implementation of the second phase of CAAA'90 is expected to make a noticeable difference in the quantities of FGD material produced. Boiler slag production increased to 2.71 Mt in 1998 from 2.49 Mt in 1997.

The production data for CCP's are listed by various use categories. Figures 5 and 6 show the historical CCP production and use data for the past 5 years. Figure 7 shows the comparative production and use figures for 1998. Figure 8 shows production and use data by geographic regions. Figure 9 shows production by type and region for 1998.

Consumption

The major use of CCP's include cement and concrete production, 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 control and acid mine remediation and as fillers and extenders.

Total CCP use increased to 28.4 Mt in 1998 from 26.5 Mt in 1997 (table 2). The quantities of individual CCP's used were 19.2 Mt for fly ash, 4.76 Mt for bottom ash, 2.17 Mt for boiler slag, and 2.26 Mt for FGD material. The greatest increase was recorded by FGD material, which showed a 14% increase from that of 1997. The use of FGD material reached 10% of production. Most of the use, 1.65 Mt, was recorded in wallboard production (table 3). Tables 4 and 5 show dry and wet CCP production and use data, respectively.

Figures 10 and 11 show the share of each CCP by production and use, respectively, for 1998. Figures 12 through 15 show the leading applications for the four CCP's—fly ash, bottom ash, boiler slag, and FGD product, respectively. Among the CCP's, fly ash is used in the largest quantities and finds the widest applications, followed by bottom ash, FGD material, and boiler slag. Use in cement and concrete production topped the list of leading fly ash applications with approximately 50%, followed by waste stabilization and structural fills (figure 12). Approximately three-quarters of bottom ash was used in road base-subbase, cement and concrete, structural fill, and snow and ice control (figure 13). Other applications, such as mineral fillers and extenders and flowable fill, made up the remaining use categories. Owing to its considerable abrasive properties, the largest use of boiler slag was in the manufacture of blasting grit. Use as roofing granules was also a significant market area. Blasting grit-roofing granules made up almost 90% of boiler slag applications (figure 14). Wallboard manufacture (almost three-quarters of the total), cement-concrete grout, mining applications, and agriculture accounted for the bulk of FGD product uses (figure 15).

U.S. Gypsum Company planned to use 100% FGD gypsum in its new 700-million-square-foot-per-year plant in Bridgeport, AL, which was scheduled to begin production in 1999. The company signed a long-term agreement with Louisville Gas and Electric Co. (LG&E) to receive more than 500,000 metric tons per year of FGD gypsum from four power-generating units at LG&E's Mill Creek Station in Louisville, KY (Drake, 1997). LG&E was modifying its FGD units to produce wallboard-grade gypsum.

Standard Gypsum Corporation was building a wallboard plant near Clarksville, TN, which will use 100% FGD gypsum supplied by the Tennessee Valley Authority's Cumberland generating station; it was expected to begin operations in 1999 (Drake, 1997). Georgia Pacific Corporation and National Gypsum Company also were in the process of building wallboard plants in Wheatfield, IL (Georgia Pacific) and in Shippingport, PA, and St. Louis, MO (National Gypsum), which will use 100% FGD gypsum (Barry Stewart, American Coal Ash Association, oral commun., 1998).

Marsulex Environmental Technologies, Lebanon, PA, was awarded an $85 million contract, believed to be the largest of its kind, to build two FGD systems for the Virginia Power Co. facility in Mount Storm, WV (Canning, 1999). The systems were expected to remove 110,000 metric tons of SO$_2$ from the two coal-fired units. They will be 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 was February 2002.

A subsidiary of Earth Sciences, Inc., ADA Environmental Solutions (ADA-ES), completed a long-term warranty test period of ADA-ES's flue gas conditioning installation at Alliant's 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 that will save Alliant several million dollars annually" (Michael Durham, ADA-ES, oral commun., 1999).

Current Research and Technology

In the past few years, R&D activities have focused on improving FGD methods and finding new applications for CCP's, in the past few years, especially FGD product. Much of the activity in the new FGD technology area has been spearheaded by Japanese and West European researchers. Higher R&D activity levels in these countries have been driven by space limitations—electric utility companies in these countries have no room for the disposal of the products from the current (1998) FGD processes. The countries are, therefore, 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. Consequently, R&D 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

The increase 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. Increase in FGD product, however, may not be limited to a similar growth pattern. Phase one of the CAAA'90 affected only 10% of the coal-burning electric utilities (CAAA'90; Public Law 101-549). In phase two, the remaining 90% of the utilities will be subject to the emissions restrictions set by the law. Currently (1998), more than 10,000 MW of power-generation units support FGD units. More than 6,000 MW of limestone units and nearly 4,000 MW of lime units are being constructed. An additional 7,000 MW of limestone units and 6,000 MW of lime units are in the planning stage. When operational, these units are expected to triple the quantity of FGD product to about 75 Mt/yr from the current level of 23 Mt/yr, making it the largest component of CCP's. When phase two is fully implemented, these quantities may increase by an order of magnitude. This will present a challenge to electric utilities and such industries as construction, agriculture, and certain manufacturing sectors to find increased uses for these additional materials.

To meet the challenge presented, utilities will continue to look for pollution prevention technologies that will yield lesser

quantities, 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 an ammonia-based FGD method is used for SO_2 removal 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, Ellison Associates, Inc., oral commun., 1998).

The wallboard industry is expanding its synthetic gypsum wallboard plant construction significantly. The use of synthetic gypsum eliminates the expense of capital investment in opening or expanding quarries for increased production of natural gypsum. Owing to unprecedented increase in new house construction, wallboard plants operated at full capacity in 1998. The impact of synthetic gypsum on the wallboard industry will be significant. Several wallboard manufacturers announced plans to build 13 plants (Drake, 1997), 10 of which will use FGD gypsum. The new plants are slated to start operation between 1999 and 2001. 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 may add some 8 billion square feet of wallboard capacity during the next 3 years [a 30% increase compared with the current (1998) capacity], 600 million square meters of which will be made from FGD gypsum.

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[1]Prior to 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
SO2 Reduction Systems	8
Combustion Systems	2
Other Dry Systems	5
Flue Gas Desulfurization Subsystems	24

Source: Radian Corporation.

TABLE 2

HISTORICAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons)

	1994	1995	1996	1997	1998
Fly ash:					
Production	49,800	49,200	53,900	54,700	57,200
Use	11,700	12,300	14,700	17,500	19,200
Percent use	23.60	25.00	27.50	32.10	33.60
Bottom ash:					
Production	13,500	13,800	14,600	15,400	15,200
Use	4,610	4,600	4,430	4,600	4,760
Percent use	34.30	33.30	30.40	30.20	31.30
Boiler slag:					
Production	3,440	2,550	2,360	2,490	2,710
Use	2,830	2,440	2,170	2,340	2,170
Percent use	82.30	95.70	92.30	94.10	80.10
FGD 1/ material:					
Production	14,100	18,300	21,700	22,800	22,700
Use	850	1,340	1,500	1,980	2,260
Percent use	6.05	7.41	6.96	8.67	10.00
Total CCP's:					
Production	80,800	83,700	92,400	95,400	97,800
Use	20,000	20,700	22,800	26,500	28,400
Percent use	24.80	24.90	24.90	27.80	29.00

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 3

TOTAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1998 1/

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 2/ material	Total CCP's
Production:					
Disposed	35,900	9,710	580	16,800	63,000
Produced	57,200	15,200	2,710	22,700	97,800
Removed from disposal	600	240	140	70	1,030
Stored onsite	2,680	990	100	3,680	7,450
Use:					
Agriculture	30	10	--	50	90
Blasting grit-roofing granules	--	200	1,940	--	2,140
Cement-concrete-grout	9,400	590	10	190	10,200
Flowable fill	350	20	--	--	360
Mineral filler	310	70	10	--	390
Mining applications	1,740	130	--	100	1,960
Roadbase-subbase	2,540	1,460	--	80	2,850
Snow and ice control	--	640	50	--	700
Structural fills	2,540	1,060	50	20	3,670
Wallboard	--	--	--	1,650	1,650
Waste stabilization-solidification	3,160	130	--	10	3,310
Other	320	450	100	170	1,050
Total use	19,200	4,760	2,170	2,260	28,400
Individual use percentage	33.50	31.30	80.10	10.00	NA
Cumulative use percentage	33.50	33.00	34.70	29.00	29.00

NA Not available.

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, 1998

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total CCP's
Production:					
Disposed	22,500	6,080	110	11,700	40,400
Produced	40,800	9,250	950	17,000	68,000
Removed from disposal	60	110	--	--	170
Stored onsite	1,440	390	40	3,390	5,260
Use:					
Agriculture	30	10	--	50	90
Blasting grit-roofing granules	--	150	710	--	850
Cement-concrete-grout	8,770	410	--	190	9,370
Flowable fill	300	20	--	--	310
Mineral filler	250	70	10	--	330
Mining applications	1,340	80	--	90	1,510
Roadbase-subbase	1,250	1,090	--	80	2,420
Snow and ice control	--	30	10	--	320
Structural fills	1,670	480	30	20	2,200
Wallboard	--	--	--	1,310	1,310
Waste stabilization-solidification	3,160	130	--	10	3,310
Other	70	170	30	170	430
Total use	16,800	2,900	790	1,930	22,400
Individual use percentage	41.30	31.30	83.80	11.30	NA
Cumulative use percentage	41.30	39.50	40.30	33.00	33.00

NA Not available.

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

TABLE 5
PONDED COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE, 1998

(Thousand metric tons)

	Fly ash	Bottom ash	Boiler slag	FGD 1/ material	Total CCP's
Production:					
Disposed	13,400	3,630	470	5,120	22,600
Produced	16,400	5,960	1,760	5,680	29,800
Removed from disposal	520	130	140	70	870
Stored on-site	1,240	600	60	290	2,190
Use:					
Agriculture	--	--	--	--	--
Blasting grit/roofing granules	--	50	1,230	--	1,290
Cement-concrete-grout	620	180	10	--	810
Flowable fill	50	--	--	--	50
Mineral filler	60	--	--	--	60
Mining applications	400	50	--	--	460
Roadbase-subbase	60	370	--	--	430
Snow and ice control	--	340	40	--	380
Structural fills	870	580	20	--	1,470
Wallboard	--	--	--	330	330
Waste stabilization-solidification	--	--	--	--	--
Other	260	290	70	--	620
Total use	2,320	1,860	1,370	340	5,890
Individual use percentage	14.10	31.20	78.10	6.00	NA
Cumulative use percentage	14.10	18.70	23.00	19.80	19.80

NA Not available.

1/ FGD, flue gas desulfurization.

Source: American Coal Ash Association.

FIGURE 1

LIME/LIMESTONE BASED FGD METHOD FLOW DIAGRAM
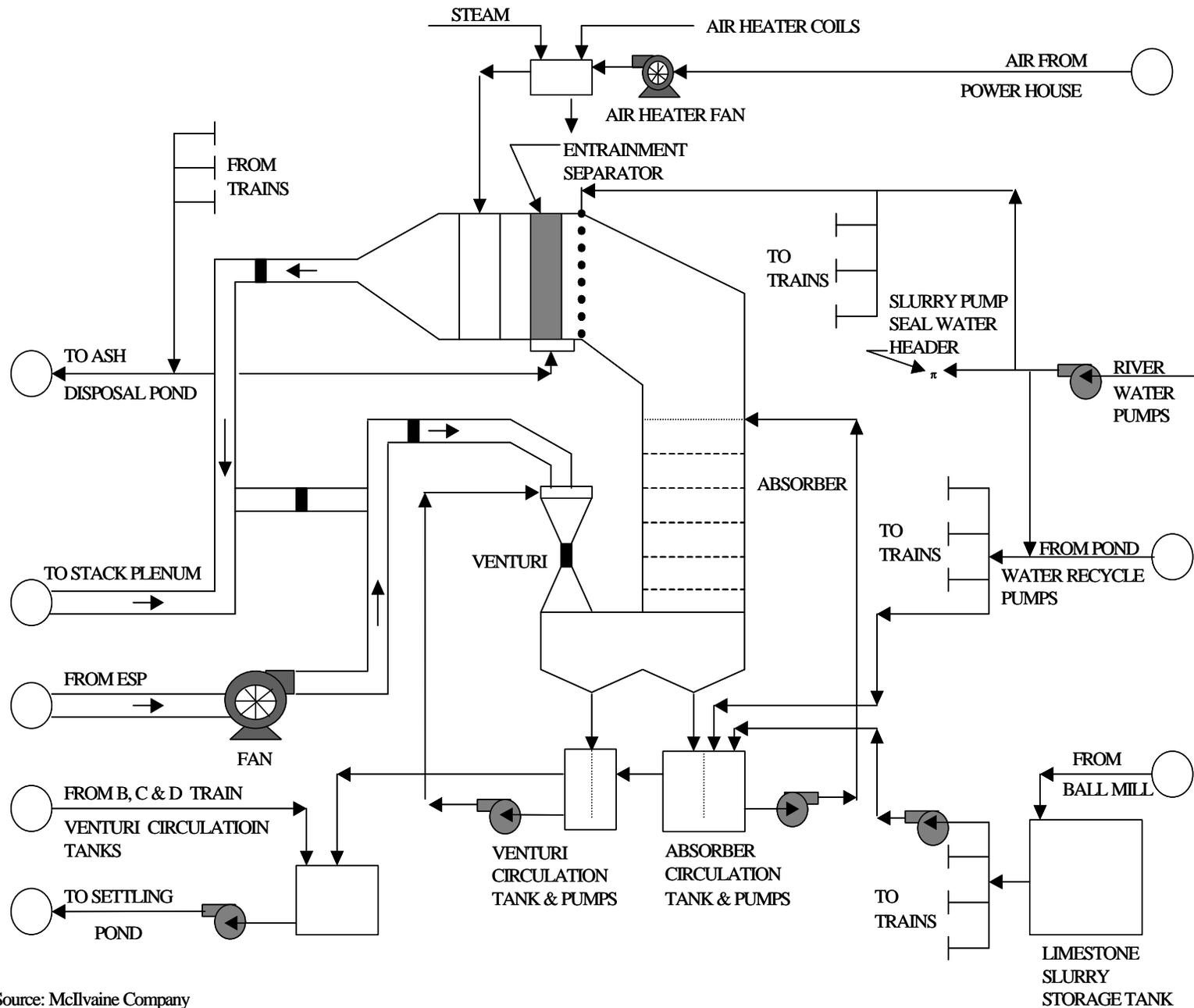
Source: McIlvaine Company

FIGURE 2

MAGNESIUM BASED FGD METHOD FLOW DIAGRAM
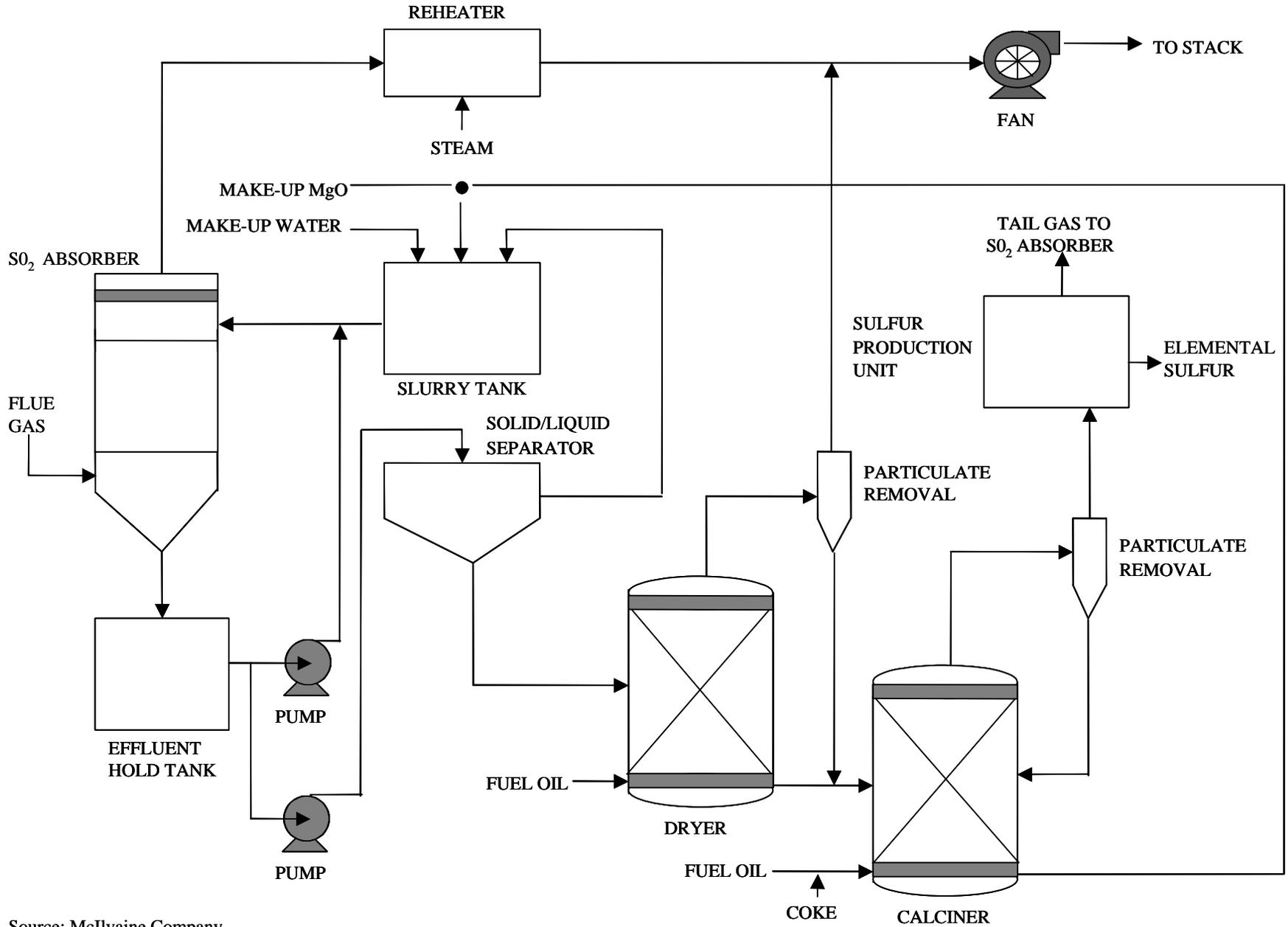
Source: McIlvaine Company

FIGURE 3

AMMONIA SULFATE BASED FGD METHOD FLOW DIAGRAM

FLUE

GAS

(NH$_4$)$_2$SO$_4$

LC

LC

DC

LC

LC

PUMP

PUMP

P$_H$C

STACK

AIR

AMMONIA

FRESH WATER

Source: McIlvaine Company
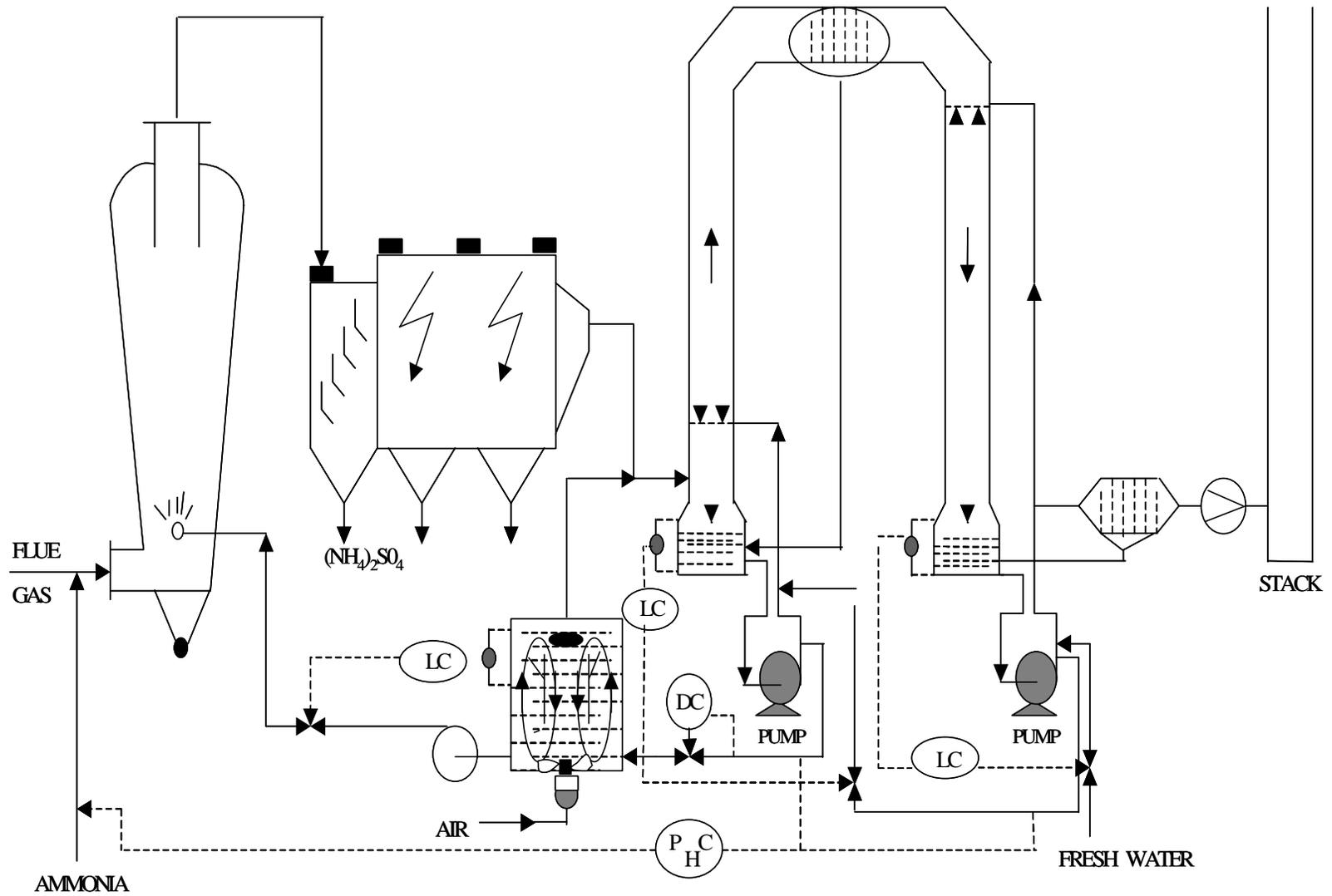
FIGURE 4

NAHCOLITE/TRONA DRY INJECTION FGD METHOD FLOW DIAGRAM

BULK MATERIAL UNLOADING

DRY STORAGE

FABRIC FILTER

FLUE GAS

CONVEYOR AIR BLOWER

BALL MILL PULVERIZER

WASTE DISPOSAL AREA
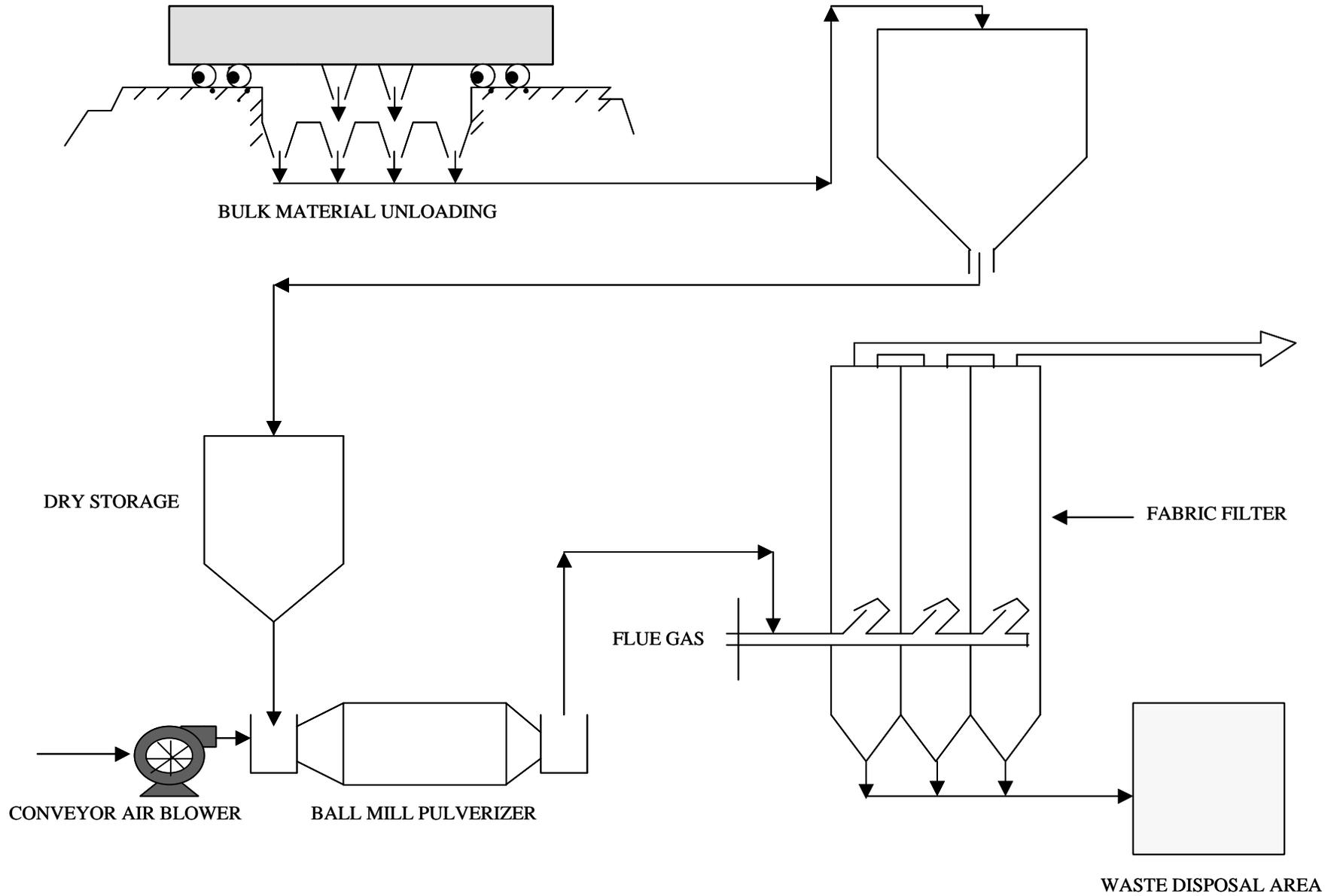
Source: McIlvaine Company

FIGURE 5
HISTORICAL COAL COMBUSTION PRODUCT PRODUCTION DATA, 1994 - 98
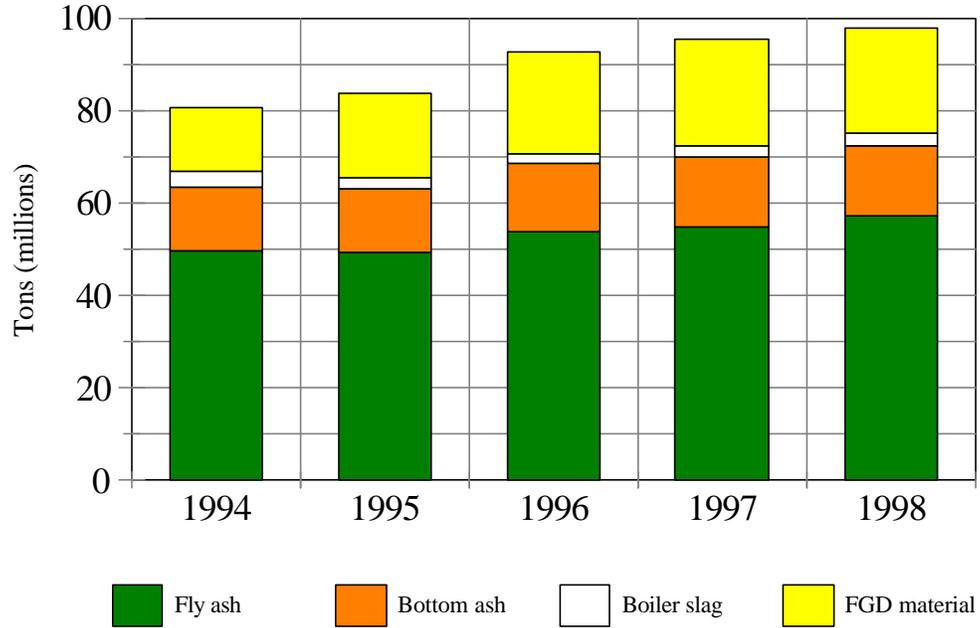
Source: American Coal Ash Association

FIGURE 6
HISTORICAL COAL COMBUSTION PRODUCT USE DATA, 1994 - 98
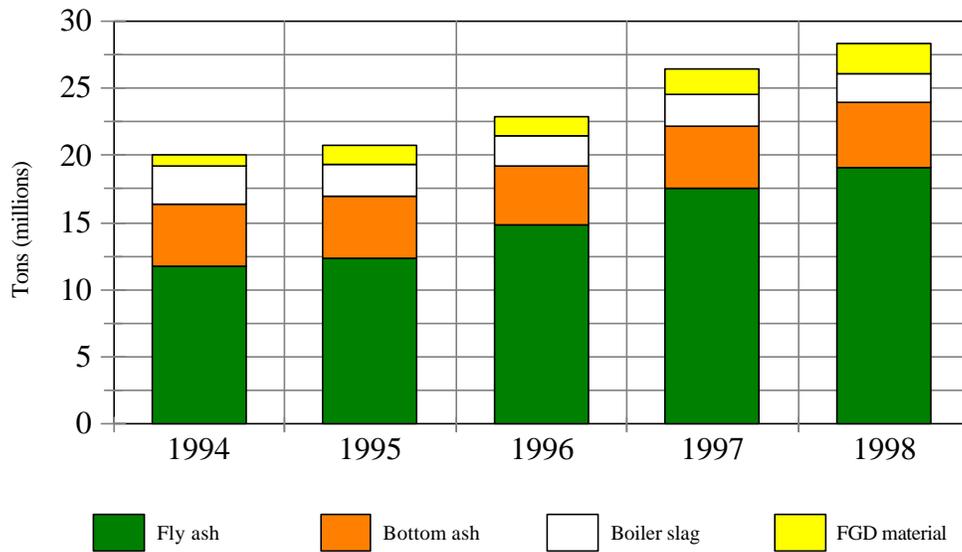

Source: American Coal Ash Association

FIGURE 7
COAL COMBUSTION PRODUCT PRODUCTION AND USE FOR THE UNITED STATES, 1998
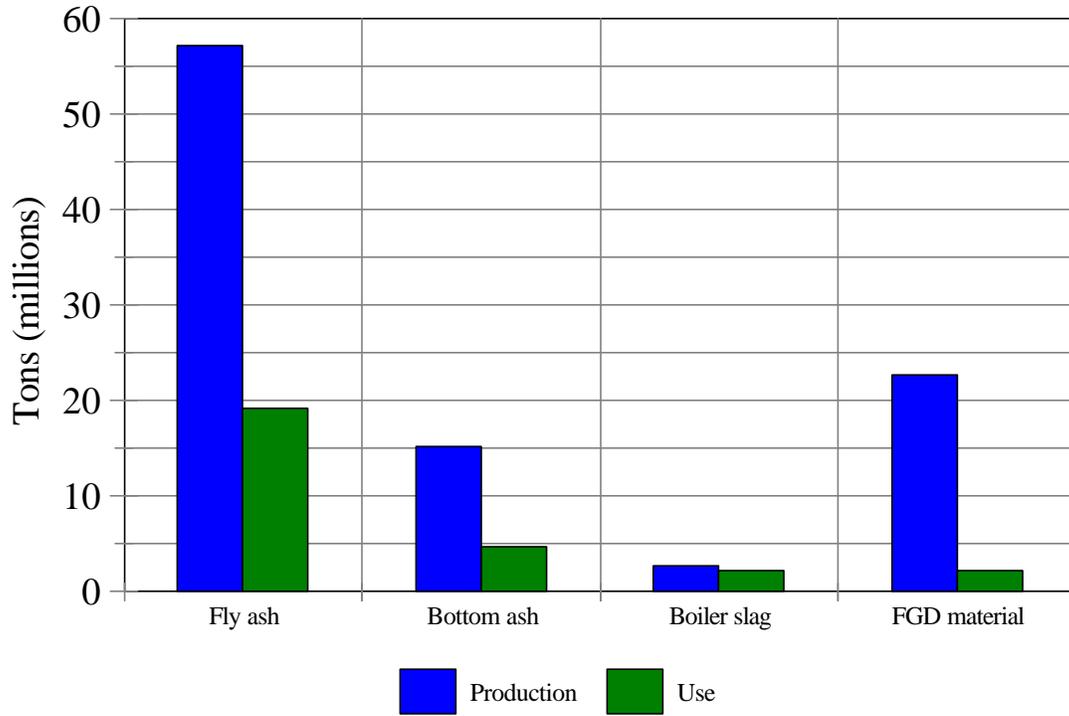
Source: American Coal Ash Association

FIGURE 8
COAL COMBUSTION PRODUCT PRODUCTION AND USE BY REGION, 1998
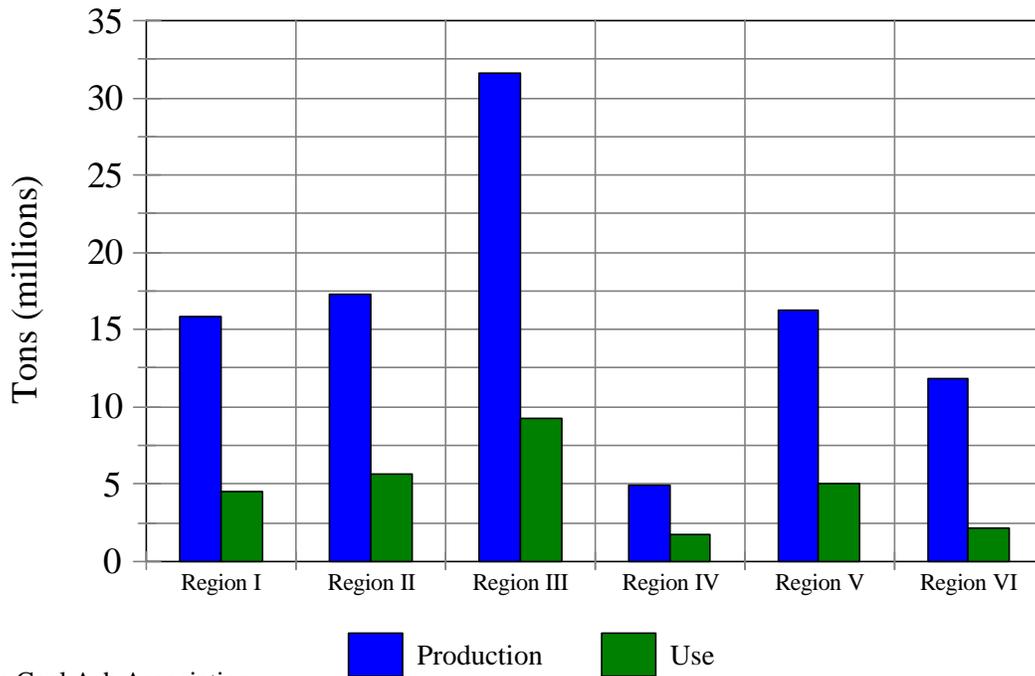
Source: American Coal Ash Association

FIGURE 9
COAL COMBUSTION PRODUCT PRODUCTION BY TYPE AND REGION, 1998
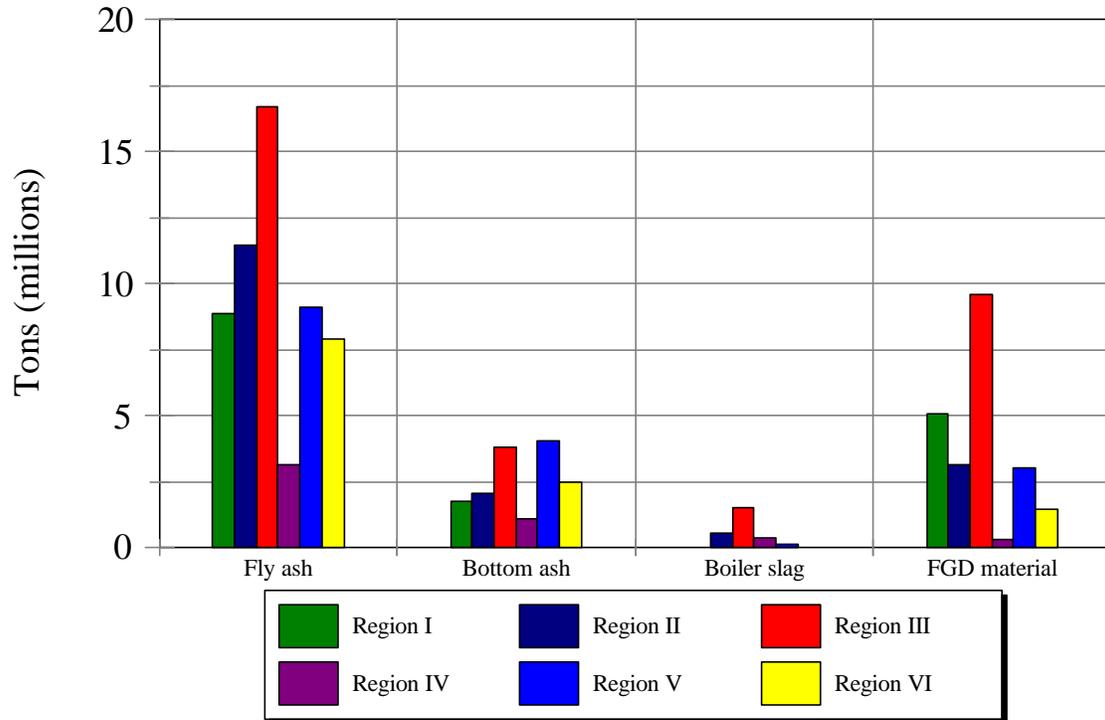
Source: American Coal Ash Association

FIGURE 10
COAL COMBUSTION PRODUCT PRODUCTION BY TYPE, 1998
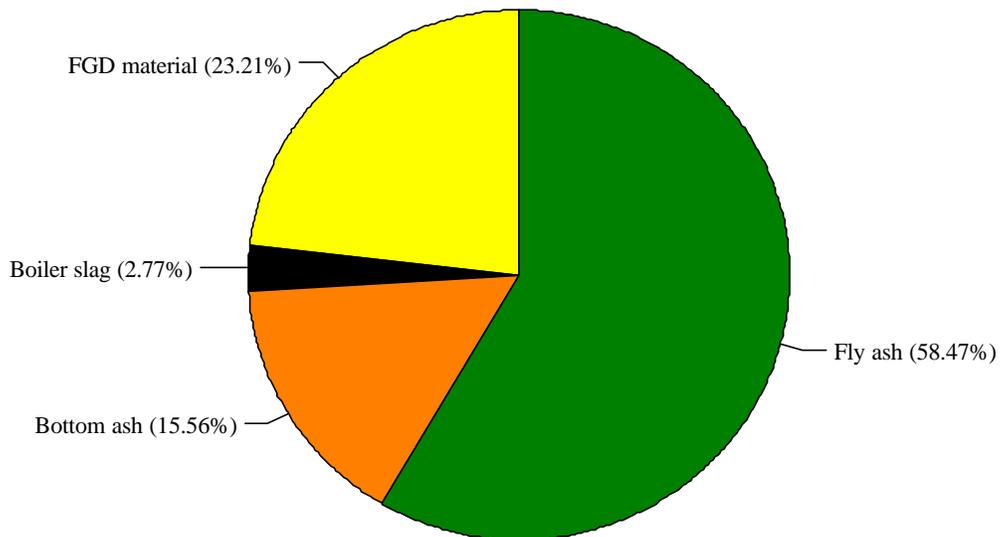
Source: American Coal Ash Association

FIGURE 11
COAL COMBUSTION PRODUCT USE BY TYPE, 1998

FGD material (7.99%)
Boiler slag (7.65%)
Bottom ash (16.78%)
Fly ash (67.59%)
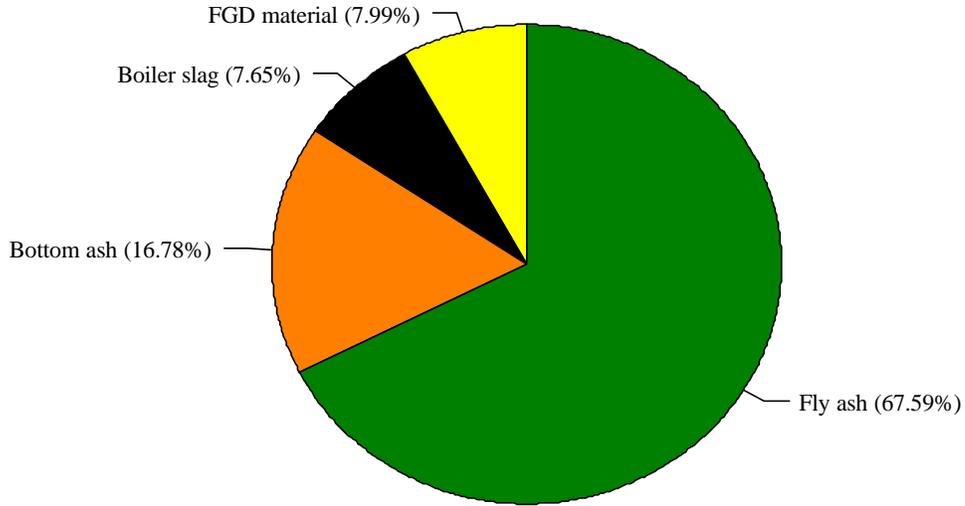
Source: American Coal Ash Association

FIGURE 12
LEADING COAL FLY ASH USES, 1998

Miscellaneous (5.27%)
Road base - subbase (6.84%)
Mining applications (9.08%)
Structural fill (13.26%)
Concrete (49.06%)
Waste stabilization (16.49%)
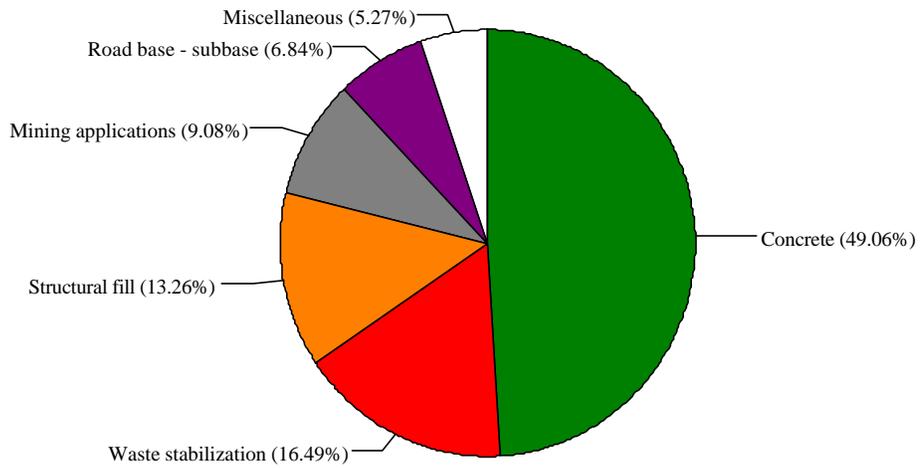
Source: American Coal Ash Association

FIGURE 13
LEADING BOTTOM ASH USES, 1998

Waste stabilization (2.71%)
Blasting grit - Roofing granules (4.18%)
Concrete (12.32%)
Road base - subbase (30.48%)
Miscellaneous (14.82%)
Snow - Ice control (13.36%)
Structural fill (22.13%)
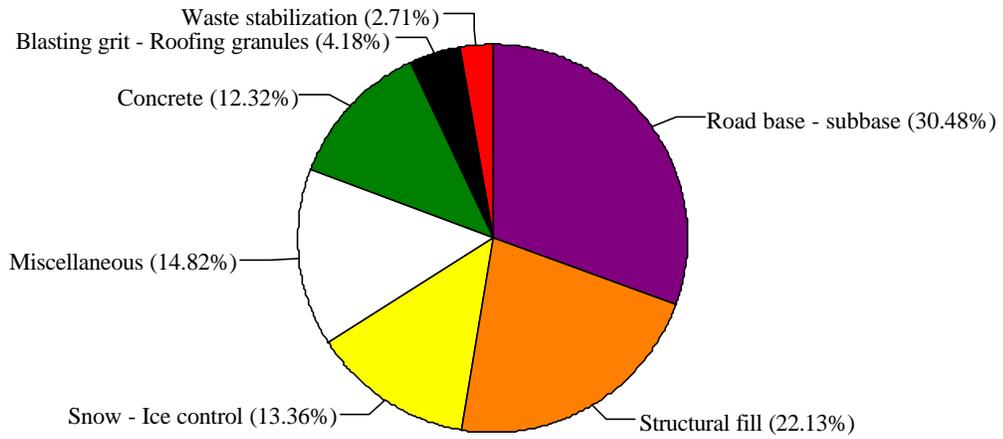
Source: American Coal Ash Association

FIGURE 14
LEADING BOILER SLAG USES, 1998

Structural fill (2.30%)
Snow/Ice control (2.30%)
Miscellaneous (5.99%)
Blasting grit - Roofing granules (89.40%)
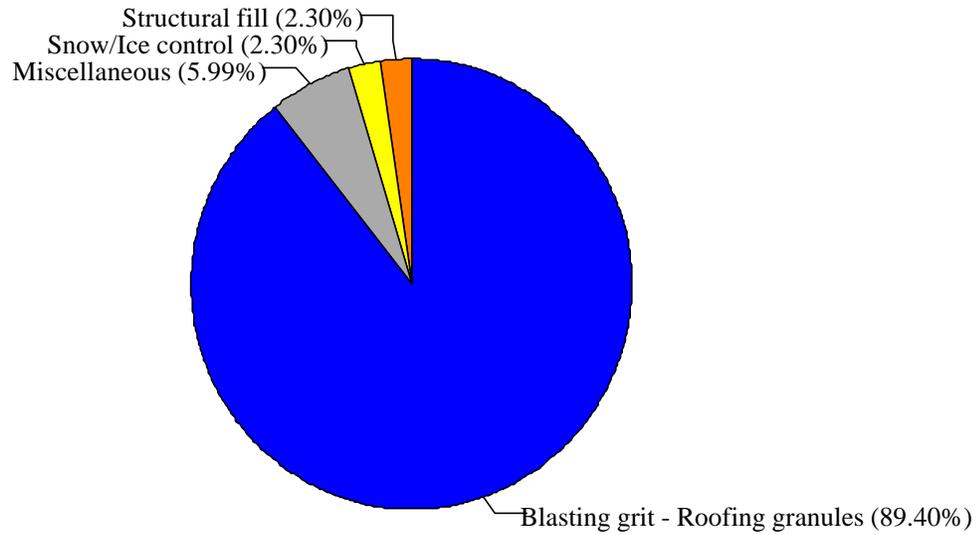
Source: American Coal Ash Association

FIGURE 15
LEADING FGD MATERIAL USES, 1998
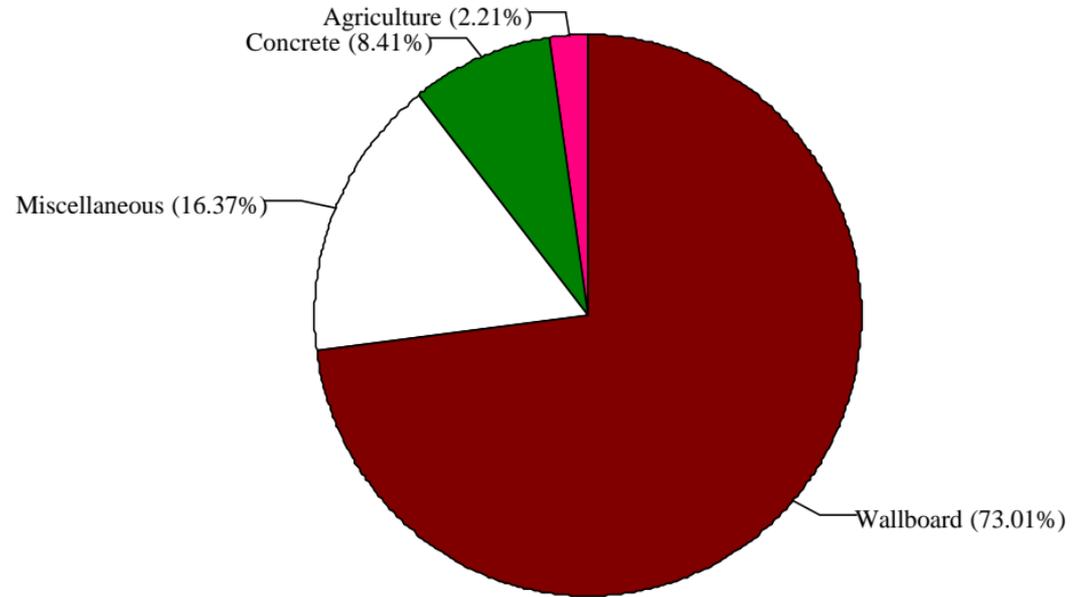
Source: American Coal Ash Association

FIGURE 16
REGIONS OF THE UNITED STATES

Region IV

Region III

Region I

Region VI

Region V

Region II