Technical Memo

ARGONNE NATIONAL LABORATORY

ANL/EES-TM-203

A PRELIMINARY ASSESSMENT OF TRANSPORTATION OF SOLID WASTES FROM COAL-FIRED BOILERS

ANL
EES

ARGONNE NATIONAL LABORATORY

Energy and Environmental Systems Division

operated for
U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) among the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

This informal report presents preliminary results of ongoing work or work that is more limited in scope and depth than that described in formal reports issued by the Energy and Environmental Systems Division.

Printed in the United States of America. Available from National Tech
U. S. Department of Commerce, 5285 Port Royal Road, Springfield, V

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

ANL/EES-TM-203

A PRELIMINARY ASSESSMENT OF TRANSPORTATION OF SOLID WASTES FROM COAL-FIRED BOILERS

by

Roger L. Tobin

Energy and Environmental Systems Division
Integrated Assessments and Policy Evaluation Group

February 1982

work sponsored by

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Environmental Protection, Safety,
and Emergency Preparedness
Office of Environmental Assessments

PREFACE

As the nation increases its dependence on coal combustion as a source of electrical power and industrial energy, the amount of coal waste generated will increase significantly. Increasing amounts of this waste will have to be disposed of away from the generating site due to land constraints in urban areas. This report presents a preliminary analysis of the potential transportation problems associated with the disposal of solid wastes from coal-fired boilers.

This project is part of a general program in environmental analysis and assessment, sponsored by the Office of Environmental Assessments, Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness, U.S. Department of Energy, and performed by the Integrated Assessments and Policy Evaluation Group in the Energy and Environmental Systems Division of Argonne National Laboratory.

PREFACE

As the nation increases its dependence on coal combustion as a source of electrical power and industrial energy, the amount of coal waste generated will increase significantly. Increasing amounts of this waste will have to be disposed of away from the generating site due to land constraints in urban areas. This report presents a preliminary analysis of the potential transportation problems associated with the disposal of solid wastes from coal-fired boilers.

This project is part of a general program in environmental analysis and assessment, sponsored by the Office of Environmental Assessments, Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness, U.S. Department of Energy, and performed by the Integrated Assessments and Policy Evaluation Group in the Energy and Environmental Systems Division of Argonne National Laboratory.

CONTENTS

FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)

TABLES

ACKNOWLEDGMENTS

I wish to thank the U.S. Department of Energy (U.S. DOE) Project Officer, Boris Kachura, for his continued support. I am also grateful to Ted Williams and Tom Alexander (formerly of the Office of Environmental Protection) for helpful guidance on this project. Janet Baker and Vera Luner of Argonne National Laboratory (ANL) provided assistance in data gathering and research. David Streets was the ANL Project Manager.

EXECUTIVE SUMMARY

Increased use of coal in utility and industrial boilers will require increased disposal of ash and flue gas desulfurization (FGD) sludge. In many instances, land will not be available on site for disposal; therefore, transportation of the waste to an off-site location for disposal will be required. This transportation will have economic, as well as environmental, implications. The following factors determine the amount and type of transport required: (1) properties of the wastes and methods used for collection and disposal, (2) costs of transportation and handling, (3) location and amount of waste generated, and (4) location of suitable disposal sites.

Waste Properties and Collection and Disposal Methods

The solid waste products from coal-fired boilers are fly ash, bottom ash, and FGD wastes. Fly ash is made up of light ash particles that become entrained in the flue gas. The method used to remove the particles from the flue gas determines the particle-size distribution in the resulting waste -- a characteristic that has a significant effect on the handling and disposal properties of the waste. Bottom ash consists of the heavier ash particles that fall to the bottom of the firebox either in particle or molten form, depending on the boiler design. In both cases, the bottom ash falls into a water-filled hopper and is sluiced to a pond or a dewatering bin. The FGD wastes consist of compounds produced by the reaction of a reagent with the sulfur dioxide in the flue gas. Three types of methods are used to remove the SO_2: (1) those that produce sludge or solids suspended in a liquid, (2) those that produce dry wastes, and (3) those that produce dissolved solids in a liquid waste stream. The methods that produce sludge can be further classified into (1) those producing stabilized sludges, which when dewatered can easily be handled, and (2) those producing thixotropic sludges, which when dewatered and are in an apparently solid form will reliquefy when vibrated or agitated.

Disposal systems for solid wastes from coal-fired boilers can be classified as wet, dry, or combination. Wet systems are designed to dispose of the wastes in slurry form. Due to the difficulties and expense of slurry transport over long distances, wet disposal sites are usually located in the immediate vicinity of power plants. Dry disposal systems involve using the wastes for landfill. These wastes must have enough moisture to facilitate placement. Dry systems may be the only economical disposal alternatives when available disposal sites are not close to the power plant. Combination systems may involve pumping a slurry to a pond close to the plant for dewatering, after which itcould be excavated and transported to a dry site for disposal.

Transportation and Handling Equipment and Costs

For purposes of transportation, a dry waste is one that is sufficiently dewatered so that it no longer exhibits fluid properties; that is, it will maintain its own shape when placed outside a container and is not thixotropic.

Wet wastes are those that can be pumped as slurries. Five basic forms of transportation can be used for coal boiler wastes: belt conveyors, trucks, rail cars, barges, and pipelines.

Belt conveyors can be used only for dry disposal systems. Equipment similar to that used for coal handling is suitable. The initial cost of conveyor systems is higher than the initial cost of trucks, but the conveyor systems have longer lives and lower depreciation rates.

Trucking is probably the most flexible and, therefore, the most widely used mode of transportation for dry sludge and ash. Trucks can also be used to transport wet wastes, but special enclosed trucks must be used. The primary advantage of a trucking system is its flexibility. It can accommodate changes in the quantity of waste produced, and routes can be changed in response to changes in disposal sites. The principal disadvantage of truck transport is its high public visibility. The increased traffic levels and related dust and noise caused by hauling the waste may produce opposition from affected citizens. A 1000-MW plant produces about 110 30-ton truckloads/day of sludge and ash. In addition, trucking is reasonably labor-intensive; as a result, operating costs can be expected to increase appreciably over the life of a coal-fired boiler.

Theoretically, rail cars may be used to transport both wet and dry wastes, but wet sludge rail transport has not been demonstrated. Dry wastes are currently being transported in conventional side-dumping cars, but bottom dumping from hopper cars has not been demonstrated. Because rail cars can handle larger loads, rail traffic is not as continuous as truck traffic. As a result, rail transport may generate less opposition from the general public in sensitive areas.

Transport methods using barges will be limited to (1) stations located on or very close to navigable waterways, (2) stations that are permitted ocean disposal, and/or (3) stations located far from the final disposal site. Except in the case of ocean disposal, barging alone will not move the waste to the disposal site; therefore, additional transport by pipeline, truck or conveyor will be required to move the waste to the disposal area.

Pipelines can be used in a wide variety of wet waste transport systems. Pipeline systems are currently the most-used FGD sludge and ash transport systems because of the predominance of wet waste disposal.

Long-distance transport of ash and sludge can significantly increase disposal costs, which, in turn, will affect the economics of burning coal. Although these increased costs could be an impediment to voluntary conversion to coal, waste transportation costs are relatively small in comparison to the cost of the coal burned. Because many factors affect the economics of conversions, and fuel prices vary significantly, it is unlikely, with all other factors being equal, that the need for long-distance transport of wastes alone would discourage conversion.

Location and Amount of Waste Generated

The amount of solid waste generated by a coal-fired boiler depends on many factors, including (1) size of boiler; (2) boiler capacity factor; (3) type of boiler emission control; (4) type of waste processing; and (5) ash, sulfur, and Btu contents of the coal. The Generating Unit Reference File or GURF, an inventory containing data on utility boiler developed by the Energy Information Administration of the U.S. DOE, was used to estimate the present annual waste generation by utility boilers. At present, the wastes generated in Federal Regions 3, 4, and 5 account for about 80% of the total 36 million tons of ash/year produced by utility coal-fired boilers. Region 4 alone accounts for about half the total sludge production of 2.7 million tons/year.

The waste generation for proposed new utility boilers was estimated using data developed by Teknekron for the U.S. Department of Energy/ Environmental Protection Agency (U.S. DOE/EPA) Acid Rain Mitigation Study on new plants projected to come on line before 2000. These estimates indicate that the largest increases in capacity (and hence ash production) will occur in Regions 4 and 6. These two regions will account for more than 40% of the total ash production of 78 million tons/year when all of the projected plants are on line. Region 5 will contribute an additional 20% of the total. Although Region 5 will not experience the largest increase in new generating capacity, it will have the largest increase in FGD sludge generation due to its proximity to high sulfur coal. Its increase will be about 17 million tons of sludge/year out of a national total of 55 million tons/year from new utility boilers.

The list of 107 power plants at 50 generating stations included in Phase 1 of the proposed Power Plant Petroleum and Natural Gas Displacement Act was used to estimate the magnitude of likely conversions to coal by utilities. These estimates show that increased ash generation due to these plant conversions will be in the neighborhood of 4 million tons/year concentrated in Regions 1, 2, and 3. More than 70% of this ash will require off-site disposal. The largest increase in sludge production will be in Region 2, with about 1.4 million tons/year out of a total of about 2.4 million tons of sludge/year from Phase 1 conversions. Approximately 80% of this sludge will require off-site disposal.

For the industrial sector, the amount of solid waste generated from coal-fired boilers with capacities greater than 99 million Btu/h was estimated using capacity data from the Major Fuel Burning Installation (MFBI) File compiled by U.S. DOE and information about FGD installation from the 1979 first quarter EPA Industrial Boiler FGD Survey. The regional pattern of ash production by industrial boilers is similar to that of existing utility boilers, but the generation rates are an order of magnitude smaller.

An indication of the potential solid waste generation from non-coal-fired boilers likely to convert to coal was obtained by estimating waste generation for those boilers in the MFBI file listed both as coal capable and located on land with space available for coal storage. Conversion of these plants would increase industrial coal boiler wastes by about 50%.

Projections of new industrial coal-fired boiler capacity, developed for U.S. DOE air-quality analyses, were used to estimate solid waste generation from new industrial coal-fired boilers. The projections indicate that the increase in capacity from plants coming on line before the year 2000 will be about 80% of existing capacity with a large shift from Regions 3, 4, and 5 to Region 6.

Location and Availability of Suitable Disposal Sites

Whether transportation of solid wastes from coal-fired boilers will present problems in the future depends mainly on the availability of ash and sludge disposal sites on or near the boiler sites. Because disposal competes with other uses for land, land costs reflect that competition. In densely populated areas, the land cost may be so high or zoning and availability restrictions so severe that the only possible sites for waste disposal will be far from the boiler site.

At the present time, utilities generally avoid the cost of transporting large volumes of wastes over long distances. Approximately 90% of all waste is transported less than 5 mi from the generating plant to the ultimate disposal site, with a mean distance of 3 mi.

If all of the projected utility generating units were on line, their solid waste generation would be 3.5 times that of the existing utility units and 40 times that of large industrial coal-fired boilers. All of these plants that have been sited have been able to obtain large enough quantities of land to accommodate on-site disposal; the assembly of large land areas for siting new coal-burning plants is therefore believed to be within the capabilities of the utilities. This capability indicates that, for new utility generating units, transportation of solid wastes will probably not be a significant problem.

The second largest single group of coal-fired boilers projected to come on line in the future consists of the utility generating units that will convert from oil or gas to coal. The total amount of solid wastes generated by those units included in the Phase 1 list would amount to about 1/6 of that generated by existing boilers and approximately 1.75 times that produced by existing industrial coal-fired boilers. Most of these plants will require off-site disposal and are concentrated in the densely populated northeastern U.S.

The conversion candidates in Connecticut, eastern Massachusetts, and eastern New York do not have disposal sites available nearby and face transport distances of up to 200 mi. The utilities in these regions are considering ocean dumping, backhauling the wastes to the coal mines, and barging wastes to out-of-state sites. However, there are regulatory, economic, environmental, and/or operational problems with all of these alternatives. To mitigate their waste-disposal problems, the utilities are considering the use of beneficiated coal and regenerable scrubbers, which produce salable sulfuric acid.

In general, on-site disposal of ash and sludge will be more limited for industries than for utilities. But, because industrial waste generation rates are an order of magnitude smaller than utility waste generation rates, it is not likely that transportation of solid wastes from coal-fired industrial boilers will be a large-scale problem. However, on a site-specific level, solid waste transportation needs will affect the economics of burning coal and could have localized environmental impacts, especially community disruption impacts.

In the future, industries converting to coal or installing new coal-fired boilers will probably avoid the problems and expenses associated with long-distance waste transport by (1) finding markets for ash and (2) using sodium scrubbing systems, which produce liquid waste streams that can be discharged into a sewer system or a natural watercourse.

are an order of magnitude smaller than utility waste generation rates. It is not likely that transportation of solid wastes from coal-fired industrial boilers will be a large-scale problem. However, on a site-specific level, solid waste transportation needs will affect the transfer-of-burning area and could have localized environmental impacts, especially community disruption impacts.

In the future, industries converting to coal or installing new coal-fired boilers will probably avoid the problems and expenses associated with long-distance waste transport by (1) finding markets for ash and (2) using sodium scrubbing systems, which produce liquid waste streams that can be discharged into a sewer system or a natural watercourse.

A PRELIMINARY ASSESSMENT OF TRANSPORTATION OF SOLID WASTES FROM COAL-FIRED BOILERS

by

Roger L. Tobin

ABSTRACT

Increased use of coal in utility and industrial boilers will require disposal of increased amounts of ash and flue gas desulfurization sludge. In many instances, land will not be available on site for disposal, and transportation of the waste to an off-site location for disposal will be required. The factors that determine the amount and type of transport required are (1) physical and chemical characteristics of the waste, (2) costs of transport and handling, (3) location and amount of waste generated, and (4) location of suitable disposal sites. Both current and future transportation requirements are analyzed with respect to these factors for both industrial and utility boilers.

1 INTRODUCTION

Increased use of coal in utility and industrial boilers will require disposal of increased amounts of ash and flue gas desulfurization (FGD) sludge. In many instances, land will not be available on site for disposal; therefore, transportation of the waste to an off-site location for disposal will be required. This transportation will have both economic and environmental implications. The additional transportation costs will affect the economics of conversion to coal, thereby perhaps decreasing voluntary conversion. These transportation costs will also affect the economics of various disposal alternatives. The environmental effects of transporting the wastes will depend on the distance, mode, and route used to transport the wastes to the disposal site. The following factors determine the amount and type of transport required:

- Characteristics of the waste produced by various collection and disposal methods,
- Costs of transport and handling,
- Location and amount of waste generated, and
- Location of suitable disposal sites.

Section 2 discusses the methods for collection and disposal of wastes as they affect the characteristics of the wastes and, therefore, the handling and transportation requirements. Section 3 discusses (1) the alternative methods for transportation and handling of wastes from coal-fired boilers, (2) the advantages and disadvantages of each method, and (3) the relative costs.

Section 4 provides estimates of the location and amounts of solid wastes for existing and proposed utility boilers and large industrial boilers. These estimates are presented graphically both by Federal Region and by county. Section 5 discusses the availability of disposal sites and the resulting implications for transportion of wastes.

2 METHODS FOR COLLECTION AND DISPOSAL OF WASTES

This section describes (1) the collection methods used to remove the wastes from coal-fired boilers, (2) the properties of these wastes, and (3) the methods used to dispose of these wastes, all of which influence their transportation and handling. Detailed discussions of the collection methods, the physical and chemical properties of wastes, and the disposal methods can be found in many sources.[1-6] In addition, Appendix A contains a discussion of the characteristics of FGD solid wastes.

The solid waste products from coal-fired boilers are fly ash, bottom ash, and FGD wastes. Fly ash is made up of light ash particles that become entrained in the flue gas. Bottom ash consists of the heavier ash particles that fall to the bottom of the firebox either in particle or molten form, depending on the boiler design. Flue gas desulfurization wastes consist of compounds resulting from the reaction of a reagent with sulfur dioxide in the flue gas. For example, scrubbing systems using lime and limestone as reagents produce calcium sulfate and calcium sulfite sludges.

2.1 COLLECTION

The currently available methods for fly ash collection can be classified as follows:

- Mechanical collectors
- Fabric filters
- Wet scrubbers
- Electrostatic precipitators

The collection efficiency for each type of system, which is an important factor in determining the physical properties of the fly ash collected, is shown in Table 2.1. These collection efficiencies for the various particle sizes determine the particle-size distribution for the collected ash, which has an effect on its handling and disposal properties. In general, as can be seen by the relative efficiencies for the various particle sizes, fly ash collected by mechanical collectors will have a larger percentage of coarse particles than will fly ash collected by other methods. Once the fly ash has been separated from the flue gas stream, it must then be moved to temporary storage or to sluice lines. If the ash is collected by one of the dry collection systems, then vacuum, pressure, or a combination of the two are used to move the fly ash. Vacuum systems are limited in the distance they can transport the fly ash; therefore, pressure or combination systems are used for longer distances or at higher altitudes. If the fly ash is removed from the flue gas stream by a wet collection system, it will be sluiced to a pond for dewatering or disposal.

Two boiler types are used for bottom ash collection: wet bottom and dry bottom. In dry-bottom boilers, the bottom of the fire box has an open gate construction through which the bottom ash particles fall into a water-filled hopper. Wet-bottom boilers have a solid base at the bottom of the fire box; the base contains an orifice to allow the molten ash to flow into a

Table 2.1 Several Operating Characteristics of Particulate Collectors

General Class	Specific Type	Typical Capacity	Pressure Loss (Pa)	Power Needed ($W/m^3/min$)	Overall Efficiency (%)	Efficiency (%) for Particle Size Range (mm)				
						0-5	5-10	10-20	20-44	<44
Mechanical collectors	Settling chamber	15-25 ft^3/min per ft^3 of casing volume	50-1,300	1-4	-	-	-	-	-	-
	Baffle	1000-3500 ft^3/min per ft^2 of inlet area	1,300		60	7.5	22	43	80	90
	Conventional cyclone				65	12	35	57	82	91
	High-efficiency cyclones	2500-3500 ft^3/min per ft^2 of inlet area	750-1,250	15-35	85	40	79	92	95	97
Fabric filters	Automatic	1-6 ft^3/min per ft^2 of fabric area	1,000-1,500	35-45	99+	99.5	100	100	100	100
Wet scrubbers	Impingement baffle	400-600 ft^3/min per ft^2 of bed cross-sectional area	500-1,300	7-35	-	-	-	-	-	-
	Packed tower	500-700 ft^3/min per ft^2 of bed cross-sectional area	1,500-2,000		94	90	96	98	100	100
	Venturi	6000-30,000 ft^3/min per ft^2 of throat area	2,500-12,500	140-425	99+	99	99.5	100	100	100
Electrostatic precipitators	Dry (single-field)	2-8 ft^3/min per ft^2 of electrode collection area	50-1,300	15-35	97	72	95	97	99+	100
	Wet (charged-drop scrubber)	5-15 ft^3/min per ft^2 of electrode collection area	0.5-0.7[a]	10-15	-	-	-	-	-	-

[a]The units for this value are inches of water.

Source: Ref. 1.

water-filled hopper. The ash solidifies when it enters the water; it then is crushed, if necessary, to break up any large pieces to aid in the transportation and handling processes. The bottom ash is then sluiced to either a settling pond or dewatering bin. The pond may be either a temporary holding pond or the final disposal site. If the ash is to be sold or disposed of as dry landfill, it is removed from the pond and stacked to drain prior to transport. A dewatering bin allows more rapid dewatering and facilitates the loading of ash for transport.

Three types of FGD systems are used to remove SO_2 from the flue gas stream. The system used determines the physical properties of the wastes and consequently the methods that can be used for its transportation and disposal. These systems are (1) those producing sludge or solids suspended in a liquid, (2) those producing dry wastes, and (3) those producing dissolved solids in a liquid waste stream. Examples of the first type are lime and limestone wet scrubbers. These systems are the most widely used ones for utility boilers, and, therefore, generate most of the sludge. The second type is a spray drying or dry scrubbing system. The dry waste material from this type of FGD system can be handled by conventional fly-ash-handling equipment, thus eliminating the need for a separate sludge-handling system. An example of the third type of system is a sodium scrubber; approximately 75% of all industrial FGD units are sodium scrubbing systems.[7] They produce aqueous waste streams with only 5% dissolved solids; these streams present more of a wastewater treatment problem than a solid waste handling and disposal problem.

The physical property of FGD sludge most influencing its transportability and mode of disposal is crystal morphology; the crystal structure is responsible for dewatering properties. Calcium sulfite scrubber sludges have an open plate-like crystal structure with water filling the voids. The structure is not easily compacted, and, as a result, sulfite-predominant sludges can only be dewatered to approximately 35-50% solids. These sludges are thixotropic (sludges that when dewatered to an apparently solid form will reliquify when vibrated or agitated) and therefore present transportation and disposal difficulties. On the other hand, the blocky, elongated crystalline form of calcium sulfate results in a more easily dewatered sludge, which can be settled and filtered to as much as 85% solids. Because of the superior disposal properties of predominately sulfate sludges, increasing numbers of FGD systems are designed to include an oxidation step to oxidize sulfite to sulfate. The addition of fly ash to scrubber sludges also improves their properties for transportation and disposal.

2.2 DISPOSAL

Disposal systems for solid wastes from coal-fired boilers can be classified as wet, dry, or combination.

Wet systems are designed to dispose of the wastes in slurry form. The slurry is pumped to the disposal area where it is contained in ponds, which function as sedimentation basins. In these ponds, the wastes settle leaving a supernatant, which can be treated and discharged, recycled, evaporated, or impounded. As a result of the difficulties and expense of slurry transport over long distances, wet sites are often located in the immediate vicinity of power plants. In general, the advantages and disadvantages of wet disposal systems are as follows:[2]

Advantages

- Wet disposal operations are unaffected by transportation strikes.
- Noise and dust are minimized at the site and along transportation routes.
- Transportation and site operation are simpler and generally less expensive for wet disposal than for dry disposal.

Disadvantages

- The site development costs are high.
- Larger quantities of leachate are generated with wet systems than with dry systems.
- A larger disposal site volume is required for wet methods than for dry methods.
- The value of fly ash for reuse is reduced from the value of the fly ash from dry systems.
- Operation of the system is inflexible with regard to future changes.
- After site closure, the use of land for other purposes may be difficult and costly.
- Spills of slurry are a potential problem.
- Self-hardening fly ash cannot be transported over large distances by this system.

Dry disposal systems involve the landfilling of wastes with enough moisture to facilitate their placement. Ash and some stabilized sludges can be compacted so that the site can then be developed for housing, parks, golf courses, and industry because these compacted wastes are capable of supporting moderate foundation loads. Dry disposal systems may be the only economical disposal alternative when available disposal sites are not close to the power plant. The following are advantages and disadvantages of dry disposal:[2]

Advantages

- Development costs are lower with dry than with wet systems because extensive dams and dikes are not required.
- Efficient use of disposal area and volume is produced by these systems.
- After closure, the site can be reclaimed for a specific land use.
- Operation of the system can be flexible.
- Leachate quantities are decreased.

- Ash can be reclaimed for utilization more easily with wet than with dry systems.

Disadvantages

- Noise and dust have to be controlled.
- The operation is subject to possible transportation strikes.
- The operational costs in most cases are higher for this system than for others.
- There is a visual impact along transportation routes.

Several combinations of wet and dry disposal systems are possible. A combination system could involve pumping a slurry to a pond close to the plant for dewatering, after which it could be excavated and transported to a dry site for disposal. In contrast, a very reactive fly ash could be transported dry to a disposal site, then mixed with water and deposited in ponds to harden. Figures 2.1 and 2.2 summarize collection and disposal alternatives for fly ash and for scrubber sludge, respectively.

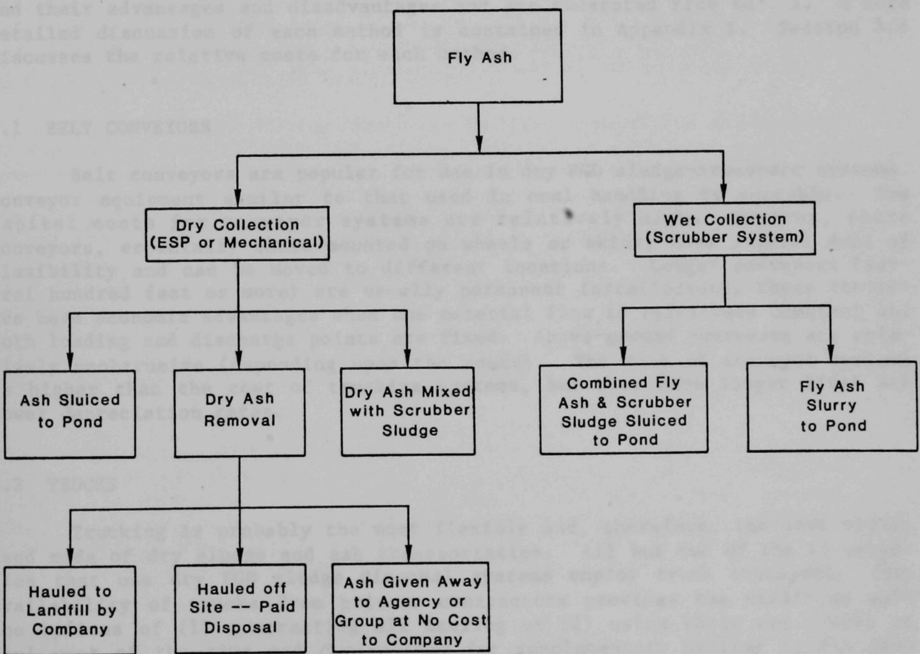

Fig. 2.1 Common Disposal Alternatives for Fly Ash (Separate Collection of Fly Ash and SO_2; ESP means electrostatic precipitation) (Source: Ref. 4.)

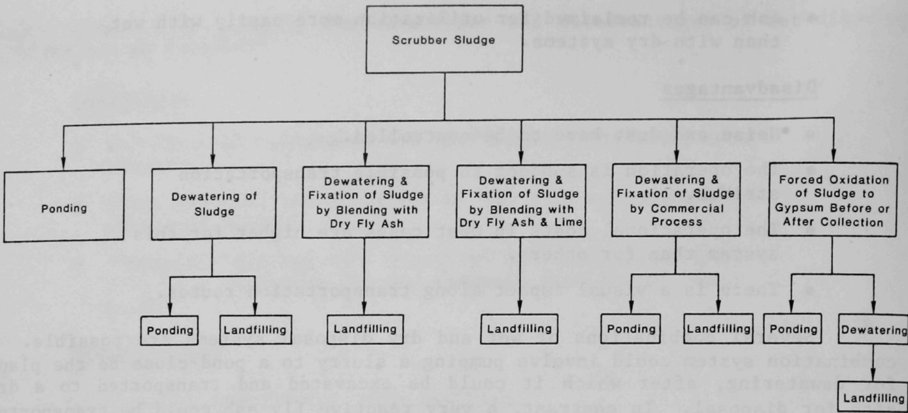

Fig. 2.2 Common Disposal Alternatives for FGD Scrubber Sludge (Source: Ref. 4.)

3 TRANSPORTATION AND HANDLING

Solid wastes from coal-fired boilers can be categorized as wet or dry for the purpose of discussing transportation methods. A dry waste is one that is sufficiently dewatered so that it no longer exhibits fluid properties; that is, it will maintain its own shape when placed outside a container. In most cases, a dry waste will have a solids content greater than 75%. Wet wastes are those that are pumpable as a slurry. The solids content can vary from 30 to 70%. This section discusses methods for handling and transporting both wet and dry wastes from coal-fired boilers.

Five basic conveyances can be used for transporting coal boiler wastes:

- Belt conveyors,
- Trucks,
- Railway cars,
- Barges, and
- Pipelines

Sections 3.1-3.5 contain general descriptions of each of these methods and their advantages and disadvantages and are excerpted from Ref. 1. A more detailed discussion of each method is contained in Appendix B. Section 3.6 discusses the relative costs for each method.

3.1 BELT CONVEYORS

Belt conveyors are popular for use in dry FGD sludge-transport systems. Conveyor equipment similar to that used in coal handling is suitable. The capital costs for conveyor systems are relatively high. However, short conveyors, especially those mounted on wheels or skids, have a great deal of flexibility and can be moved to different locations. Longer conveyors (several hundred feet or more) are usually permanent installations; these conveyors have economic advantages when the material flow is relatively constant and both loading and discharge points are fixed. Above-ground conveyors are relatively unobtrusive (depending upon the route). The cost of conveyor systems is higher than the cost of trucking systems, but they have longer lives and lower depreciation rates.

3.2 TRUCKS

Trucking is probably the most flexible and, therefore, the most widely used mode of dry sludge and ash transportation. All but two of the 13 utilities that use dry FGD sludge disposal systems employ truck transport. The availability of trucks from private contractors provides the utilities with the options of (1) contracting all hauling or (2) using their own fleets to haul most of the time and contracting for supplementary hauling as the need arises.

Truck transportation may be used for either wet or dry waste hauling, but dry hauling is easier. Dry materials may be handled with equipment designed for common earthwork or coal-hauling activities, such as bulldozers, scrapers, or front-end loaders; thus no special equipment is required. Wet materials are difficult to haul and require special enclosed vehicles. Hauling of liquid waste in open vehicles is not feasible because of leaks and spills.

The primary advantage of truck transportation for coal wastes is flexibility. Changes in the quantity of waste can be accomodated fairly easily, and routes can be changed easily when disposal sites are relocated. System reliability is inherent, with standby capabilities provided by additional vehicles. Furthermore, idle vehicles owned by the utility may be used for other hauling purposes at the station. Contract hauling is cost accountable as an operating expenditure and requires little or no capital investment. Except for a basic charge, which may be part of the contract, costs are incurred only when waste is being hauled.

The principal disadvantage of truck transportation is its high public visibility. The proper disposal of the quantity of waste produced by a fully operational station requires a nearly continuous flow of truck traffic in and out of the station site. For example, a 1000-MW plant burning a typical eastern coal would require about 110 30-ton trucks per day to haul sludge and fly ash from the plant. Hauling over public roads may meet with opposition from affected citizens due to the amount of truck traffic and related dust and noise. In addition, trucking is reasonable labor-intensive, and operating costs can be expected to increase appreciably over the life of a coal-fired boiler.

3.3 RAIL CARS

Theoretically, rail cars may be used to transport both wet and dry wastes. However, wet-sludge rail transport has not been demonstrated and may prove difficult. Open cars are not suitable for liquid wastes because of the possibilities of leaks and spills during transit and freezing of the waste upon prolonged exposure to cold. Enclosed cars containing wet wastes could prove difficult to empty due to settling during transit. An alternative would be to maintain mixing in the cars enroute to the disposal site, but this mixing would require specially designed cars, which are not presently available.

The effectiveness of dry disposal using conventional side-dumping cars has been demonstrated at the Martin Lake Plant of the Texas Utilities Generating Company. Bottom dumping from hopper cars and rotary dumping are possible but unproven. There has been speculation that "bridging" of the waste (clogging of the holes in the bottom of the hopper) might make it difficult to unload bottom-dump hopper cars. No specially designed sludge cars have been developed.

Either existing commercial rail-haul routes or captive private haulways (hauling on track and right-of-way owned or controlled by the utility) can be used for the transportation of wastes. The choice depends on both economics and existing trackage. In general, hauling by commercial routes is not economically competitive at distances less than 50 mi. Hauling by captive private line is viable at these distances if the right-of-way exists or can be obtained. Under such conditions, rail transport may be competitive with and preferable to truck transport.

As with other modes of transportation for wastes, there are both advantages and disadvantages to rail transport. System reliability is easily attainable with rail transport because of the surge capacity available from standby rail cars. However, rail cars are not as readily available as trucks on a contract basis with short notice. Also, rail cars are not as versatile as trucks. For instance, an unscheduled shutdown of a scrubber will idle already available rail cars, causing demurrage charges to be incurred. On the other hand, because rail cars haul bigger loads, rail traffic is not as continuous as truck traffic. As a result, rail traffic is less obtrusive than truck traffic to the general public and may be less of a problem in sensitive areas. Dust may be a problem during transit and may need to be controlled by covering the cars or using dust-suppressant sprays.

3.5 BARGES

Barge transport of FGD sludge may be practical for a few cases, but, in general, this mode of transportation has limited applicability. At the present time, no utilities use barging for FGD waste. Barging will be limited to (1) stations located on or very close to navigable waterways, (2) stations that can consider ocean disposal, and/or (3) stations requiring a long transport distance (greater than about 100 mi).

Theoretically, barging provides the advantages of (1) accommodating wet or dry wastes and (2) providing system reliability with very low unit costs. However, the limited number of transport routes and the need for special loading and unloading facilities make the overall economics unfavorable for all but a few selected cases. Barging alone will not get the waste to the disposal site unless that site is the ocean. Therefore, additional transport by pipeline, truck, or conveyor would be required to get the waste to the actual disposal area. Barging is not, therefore, a practical alternative for most cases.

3.5 PIPELINES

Pipelines can be used for a wide range of waste-disposal systems, as long as the systems deal with wet wastes. As a result, pipelines are the most-used of the FGD sludge and ash transport systems because of the predominance of wet disposal. Out of 31 currently operating utility scrubber systems, 18 use wet waste-handling systems, and all of these use pipeline transport of sludge.

A typical pipeline transport facility consists of a single pumping station and two full-size pipelines for redundancy. If long distances and/or up-hill traverses are involved, a second station may be needed. One pipeline can be eliminated if emergency storage capacity is provided in the event the pipeline must be shut down. If supernatant from the waste is to be returned to the station, then supernatant return lines will also be needed.

If the waste pipeline is in use only part of the time, however, it may be available for returning supernatant to the station. Provision should also be included for periodic flushing and cleaning of the lines and for automatic draining following shutdown. Conventional pumping and piping materials are generally suitable if the pH of the sludge is near neutral, but the abrasive character of the sludge and fly ash may lead to failure of these materials from erosion, especially at bends, and must be considered in the design.

3.6 TRANSPORTATION COSTS

Transportation costs in dollars per ton mile for ash and sludge vary greatly. Rail and barge rates are competitive with truck rates for long distances, with trucks being more economical for short hauls. Rates also vary greatly among different regions of the country. Figure 3.1 indicates the relative differences in long-distance transport rates among modes and among regions of the country. Figure 3.2 provides cost estimates for short-distance transport of ash and sludge by truck. No general conclusions can be drawn about the most economical mode for a particular distance because the specific characteristics of the power plant, disposal site, and available transport modes must be taken into account. However, in most cases, because of their flexibility, both operational and economic, trucks will be the chosen means of conveyance for off-site disposal. For on-site disposal, pipelines generally are most economical (\$0.003-\$0.005/dry ton-mi in 1971).[3]

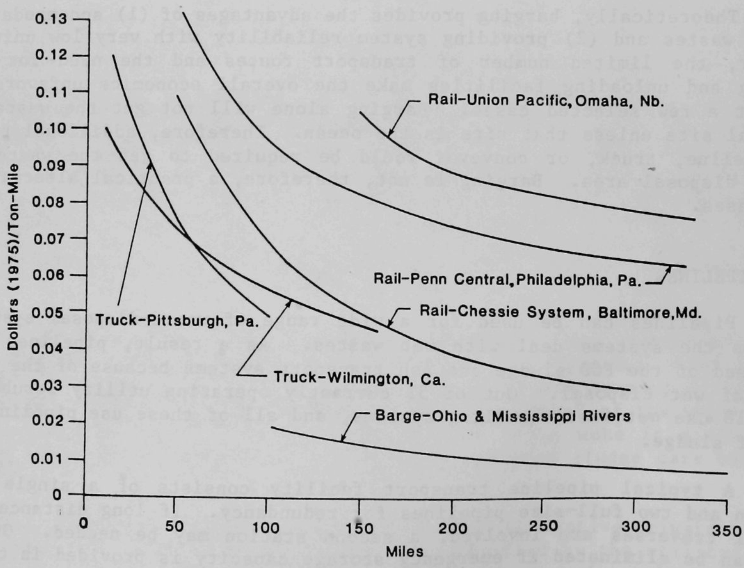

Fig. 3.1 Estimates of Long-Haul Transport Costs (1975) for Coal-Fired Boiler Wastes (Source: Ref. 8.)

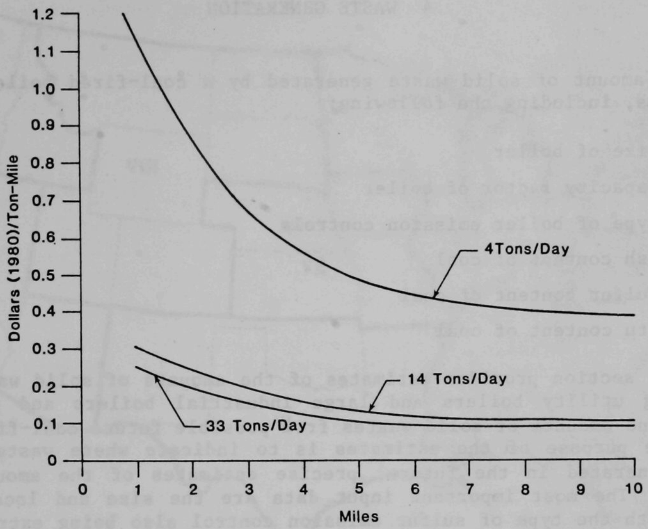

Fig. 3.2 Estimates of Short-Haul Truck Costs (1980) for Coal-Fired Boiler Wastes (Source: Ref. 8.)

Long-distance transport of ash and sludge can significantly increase the disposal costs for these wastes, which, in turn, affects the economics of burning coal. These increased costs could be an impediment to voluntary conversion to coal. However, the waste transportation costs, even for long distances, are relatively small in comparison to the cost of coal. For example, if the cost for transporting coal wastes 200 mi is \$0.05/ton-mi, the total transport cost will be \$10.00/ton of wastes. For a facility with a scrubber, this cost amounts to about \$3.00/ton of coal burned, in comparison with a cost of about \$0.09/ton of coal burned with on-site disposal using trucks. Transporting wastes 200 mi (which is an extremely long distance for waste transport) instead of disposing of the waste on site effectively produces about a 10% increase in the cost of coal. However, as so many other factors are involved in determining the cost of coal, it is unlikely that this increase alone would discourage voluntary conversion to coal.

4 WASTE GENERATION

The amount of solid waste generated by a coal-fired boiler depends on many factors, including the following:

- Size of boiler
- Capacity factor of boiler
- Type of boiler emission controls
- Ash content of coal
- Sulfur content of coal
- Btu content of coal

This section provides estimates of the amounts of solid waste produced by existing utility boilers and large industrial boilers and projects the locations and amounts of solid wastes from possible future coal-fired boilers. Because the purpose of the estimates is to indicate where waste is now and will be generated in the future, precise estimates of the amounts are not necessary. The most important input data are the size and location of the boilers, with the type of sulfur emission control also being extremely important knowledge for estimates involving sludge. General assumptions about ash and sludge production rates have been made to simplify the computation.

4.1 UTILITY BOILERS

The Generating Unit Reference File (GURF) contains information about the capacity of the approximately 1300 coal-fired generating units currently in service in the United States. Figure 4.1 is a map of the United States showing the configuration of Federal Regions; Fig 4.2 indicates the distribution of current coal-fired generating capacity by Federal Region. As can be seen in Fig. 4.2, the coal-fired generating capacity is concentrated in Federal Regions 4 and 5, which contain over 60% of the capacity. An indication of the current capacity with FGD installations is also shown in Fig. 4.2. This information comes from the 1978 Environmental Protection Agency (EPA) survey of utility FGD installations and includes those projected at that time to be on-line by 1981.* Although Region 4 has less total capacity than Region 5, it has more capacity with FGD installations.

In order to estimate the geographical distribution of solid wastes currently being generated, the GURF data and some general assumptions were used to calculate approximate solid waste quantities for each generating unit listed in the GURF. It was assumed that for plants in eastern regions (1-5), the Btu content of the coal is 12,000 Btu/lb and the ash content is 8.8%. For western regions (6-10), the Btu content of the coal was assumed to be 10,000 Btu/lb and the ash content 7.7%.[9]

---

*Work is currently underway to incorporate the 1980 EPA Utility FGD Survey into the GURF data base.

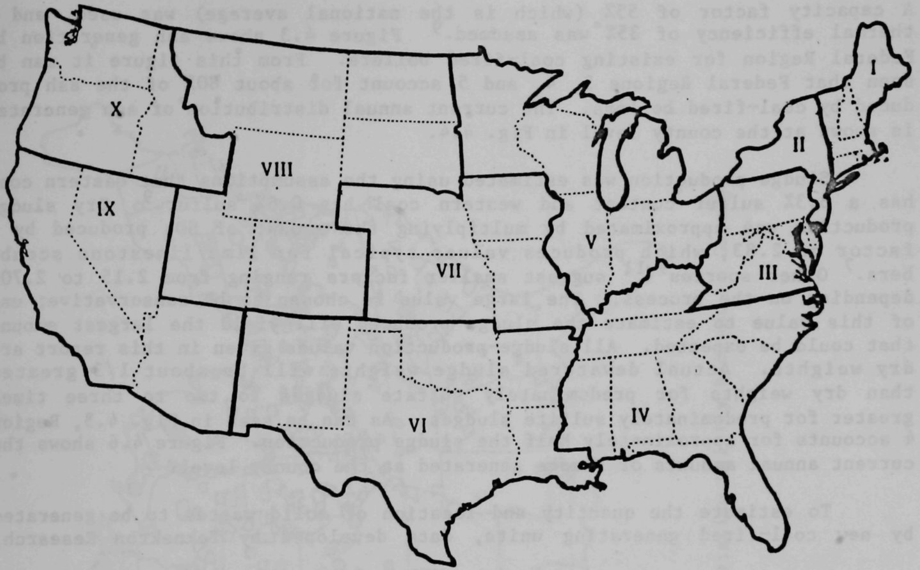

Fig. 4.1 Federal Regions of the United States

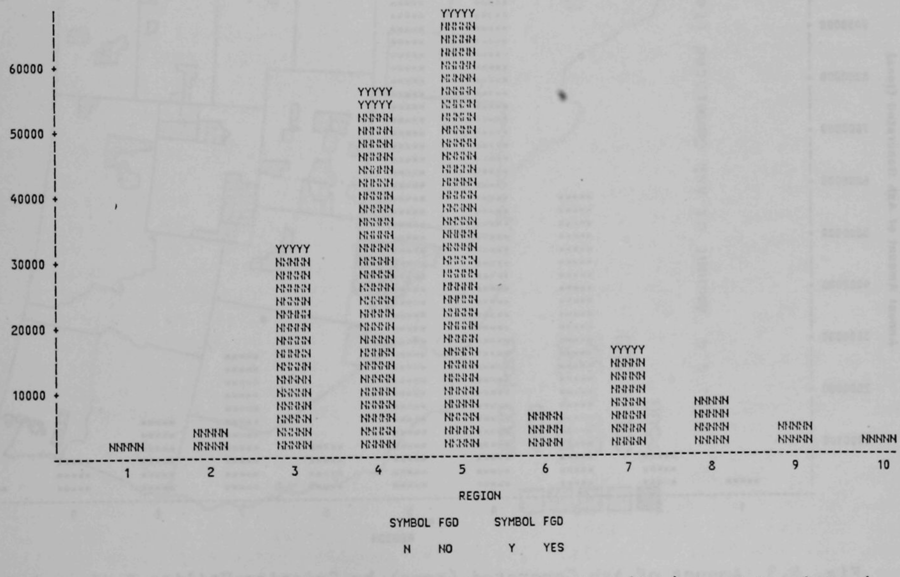

Fig. 4.2 Existing Coal-Fired Utility Boiler Capacity (MWe) by Federal Region

A capacity factor of 55% (which is the national average) was used, and a thermal efficiency of 35% was assumed.[9] Figure 4.3 shows ash generation by Federal Region for existing coal-fired boilers. From this figure it can be seen that Federal Regions 3, 4, and 5 account for about 80% of the ash produced by coal-fired boilers. The current annual distribution of ash generated is shown at the county level in Fig. 4.4.

Sludge production was estimated using the assumptions that eastern coal has a 3.3% sulfur content and western coal has 0.6% sulfur.[9] Dry sludge production was approximated by multiplying the amount of SO_2 produced by a factor of 2.83, which produces values typical for lime/limestone scrubbers.[7] Other sources[9-11] suggest smaller factors ranging from 2.15 to 2.70, depending on the process. The large value is chosen to be conservative; use of this value to estimate the sludge produced will yield the largest amount that could be expected. All sludge-production values given in this report are dry weights. Actual dewatered sludge weights will be about 1/3 greater than dry weights for predominately sulfate sludges to two to three times greater for predominately sulfite sludges. As can be seen in Fig. 4.5, Region 4 accounts for approximately half the sludge production. Figure 4.6 shows the current annual amounts of sludge generated at the county level.

To estimate the quantity and location of solid wastes to be generated by new coal-fired generating units, data developed by Teknekron Research,

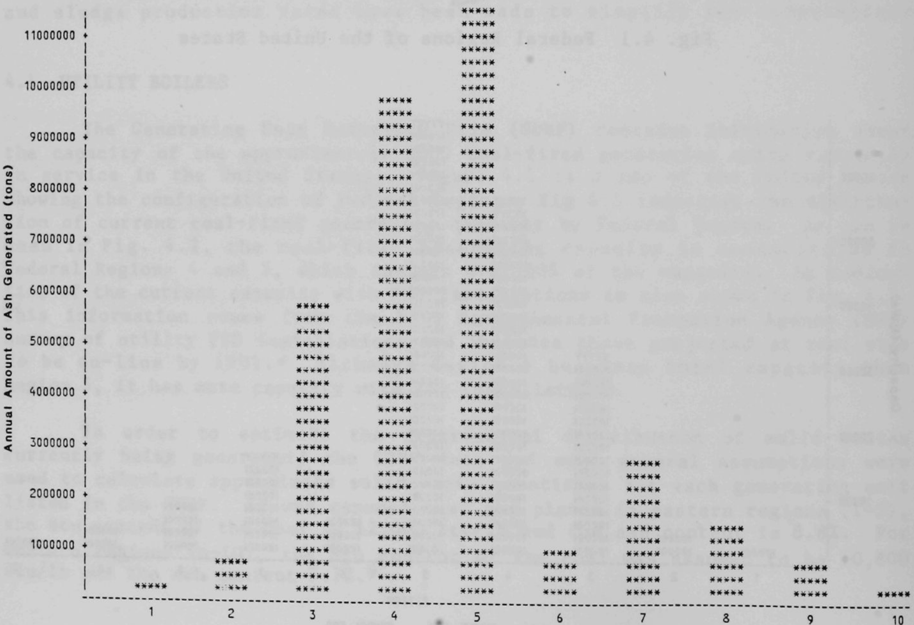

Fig. 4.3 Amount of Ash Generated (tons) by Existing Utility Boilers by Federal Region

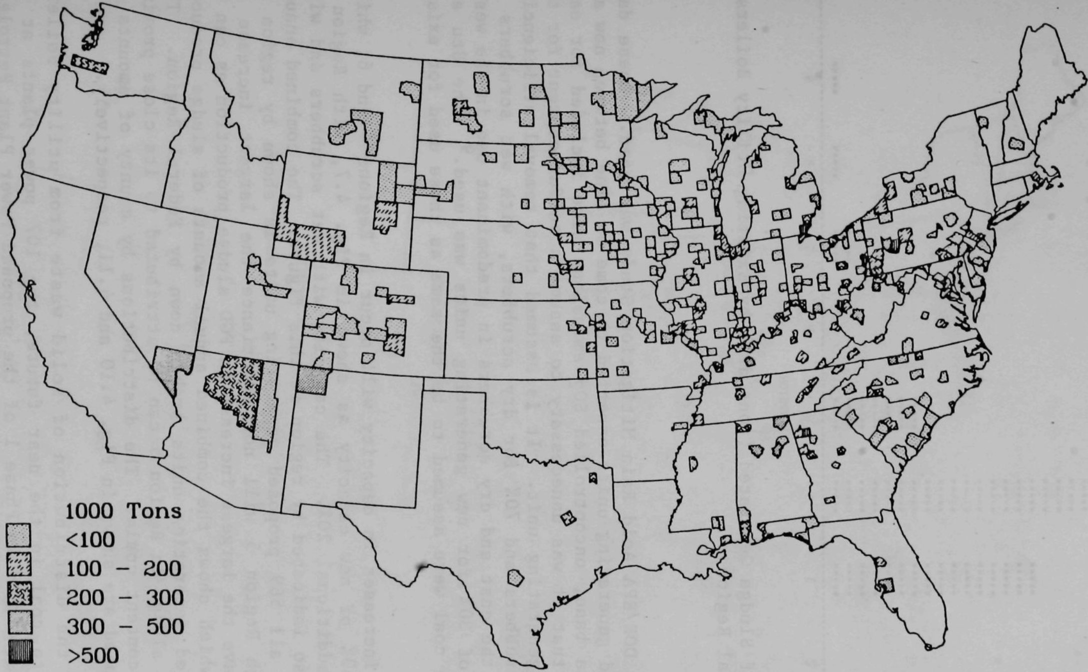

Fig. 4.4 Amount of Ash Generated (tons) by Existing Utility Boilers by County

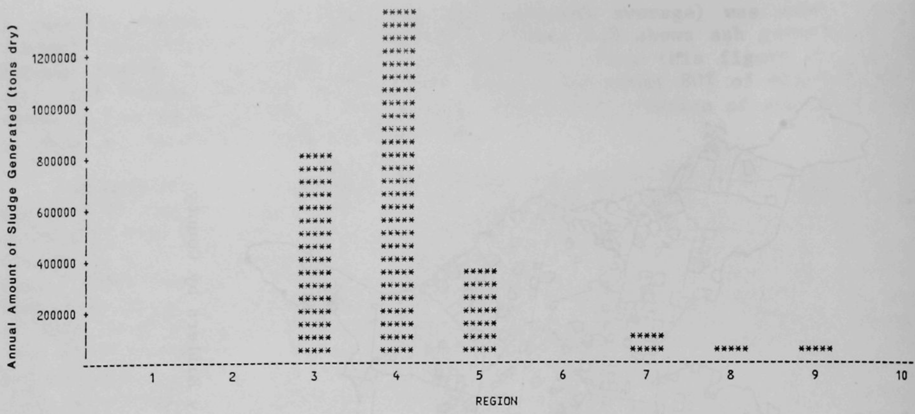

Fig. 4.5 Amount of Sludge Generated (tons dry) by Existing Utility Boilers by Federal Region

Inc., for the U.S. DOE/EPA Acid Rain Mitigation Study was used. These data are for 569 proposed generating units expected to come on line between now and 2000. In this data base, uncontrolled SO_2 emissions were included for each generating unit so that it was unnecessary to assume a sulfur content for the coal used by each generating unit. It is assumed that removal efficiencies are 90% for wet scrubbers and 70% for dry scrubbers, with wet scrubbers in predominant use in the east and dry scrubbers in predominant use in the west. A capacity factor of 80% for new generating units was used.[9] The Btu and ash contents of the coal were assumed to be the same as those used for existing plants.

The largest increases in capacity will occur in Regions 4 and 6, which account for over 43% of new capacity as shown in Fig. 4.7, with Region 5 accounting for an additional 20%. The capacity with wet scrubbers and with dry scrubbers is also indicated by region in this figure. The combined annual ash production for all 569 proposed generating units is shown by region in Fig. 4.8. Although Region 5 will not experience the largest increase in capacity, it will have the largest increase in FGD sludge production as can be seen in Fig. 4.9, which shows the combined annual amounts of sludge produced for all 569 proposed generating units broken down by Federal Region. The large generation of sludge in Region 5 can be attributed to its close proximity to high-sulfur-content coals. The distributions by county of amounts of ash and sludge produced are shown in Fig. 4.10 and 4.11, respectively.

To estimate the distribution of solid waste from utility boilers likely to convert to coal in the near future, the 107 power plants at 50 generating stations included in Phase 1 of the proposed Power Plant Petroleum and Natural Gas Displacement Act[5] were used. These plants were selected by the U.S. DOE from an initial list of 341 separate units that were considered to be coal capable at 117 generating stations totaling approximately 38,000 MW of capacity. From this initial list, all units of 25 MW and larger capacity that went into service in 1953 or later were selected.

Fig. 4.6 Amount of Sludge Generated (tons dry) by Existing Utility Boilers by County

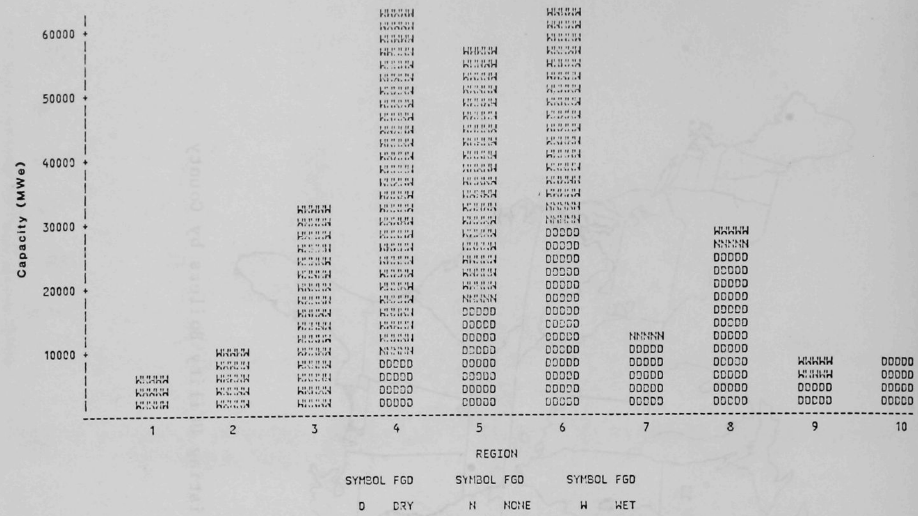

Fig. 4.7 Capacity (MWe) of Proposed Coal-Fired Utility Boilers by Federal Region

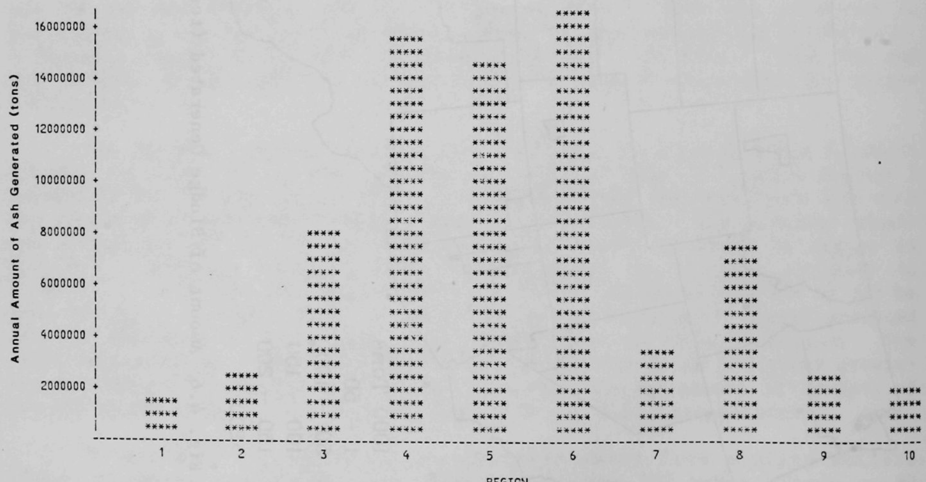

Fig. 4.8 Amount of Ash Generated (tons) for Proposed Utility Boilers by Federal Region

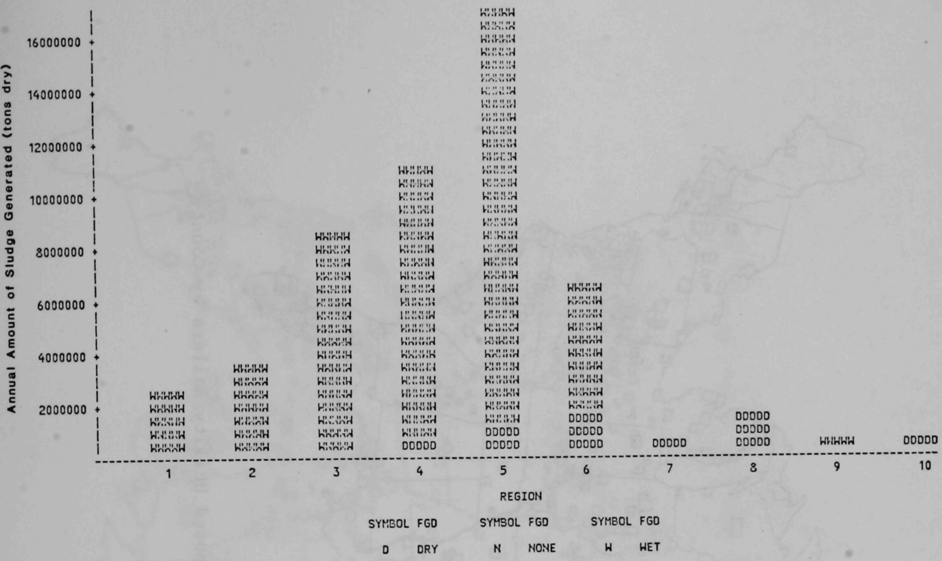

Fig. 4.9 Amount of Sludge Generated (tons dry) for Proposed Utility Boilers by Federal Region

The other units at the generating stations of the selected units were then examined and all those units of 25 MW and larger capacity that were less than 40-y old were added to the list. This selection process produced a list of 181 units at 68 stations with a combined capacity of approximately 30,000 MW. This list was then reduced to 141 units at 62 stations through individual considerations of the technical and environmental viability of conversion. This list was again reduced through an elimination of the more marginal conversion candidates based on technical judgment and analysis of cost effectiveness. This reduction produced a list of 117 units at 55 stations with a combined capacity of approximately 22,000 MW. All of the units that used natural gas as their primary energy source were then removed, producing the final set of 107 units at 50 generating stations with a combined capacity of approximately 21,000 MW. Figure 4.12 shows the distribution of capacity of the 107 Phase 1 plants by Federal Region. These plants are concentrated in Federal Regions 1, 2, and 3. Also shown in Fig. 4.12 is the capacity of plants that will require scrubbers. This information was obtained from the Phase 1 analysis.[5] The distribution of ash generated by the Phase 1 conversion plants is shown in Fig. 4.13 by Federal Region and in Fig. 4.14 by county. Also indicated on Fig. 4.13 is the amount of ash in each Federal Region that will require off-site disposal. The distribution of the amount of sludge generated by the Phase 1 conversions is shown in Fig. 4.15 by Federal Region and in Fig. 4.16 by county. Figure 4.15 also indicates the amount of sludge in each Federal region that will require off-site disposal.

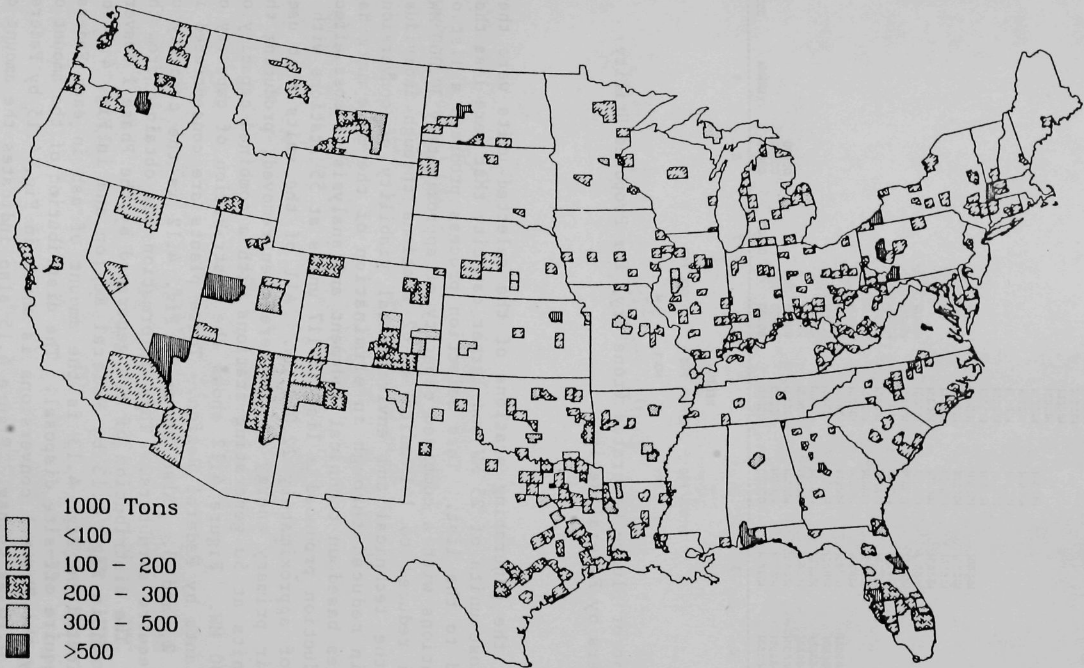

Fig. 4.10 Amount of Ash Generated (tons) for Proposed Utility Boilers by County

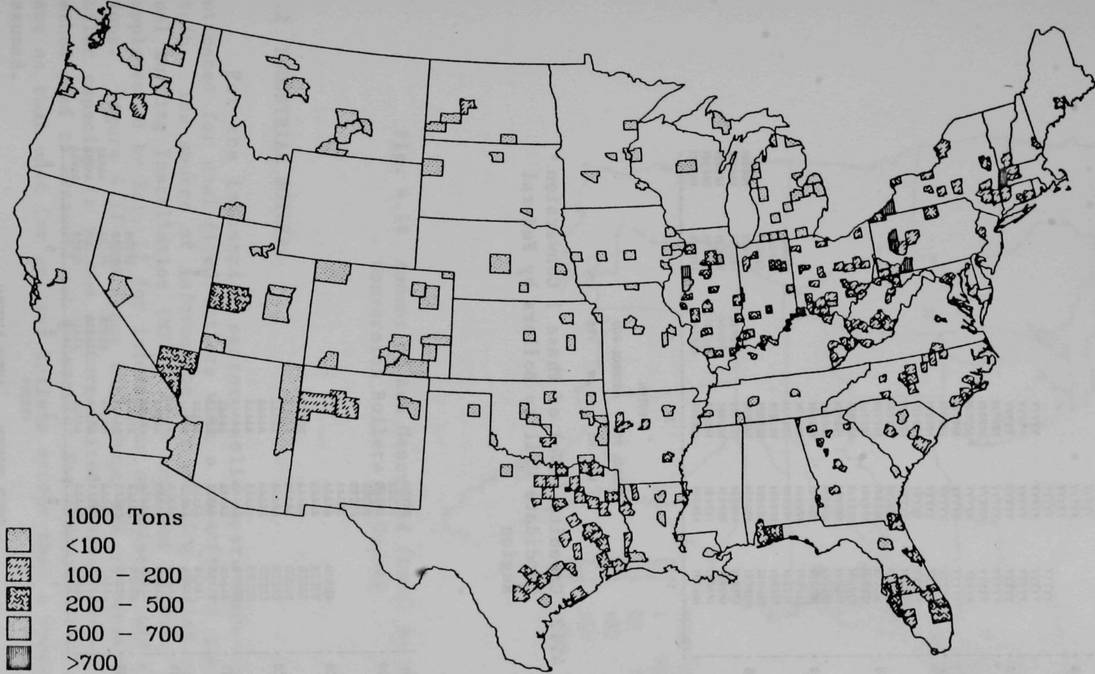

Fig. 4.11 Amount of Sludge Generated (tons dry) for Proposed Utility Boilers by County

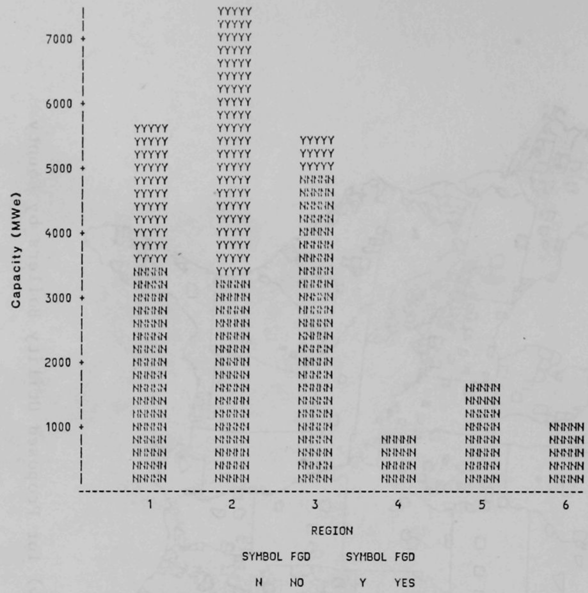

Fig. 4.12 Capacity (MWe) of Phase 1 Conversion Candidate Utility Boilers by Federal Region

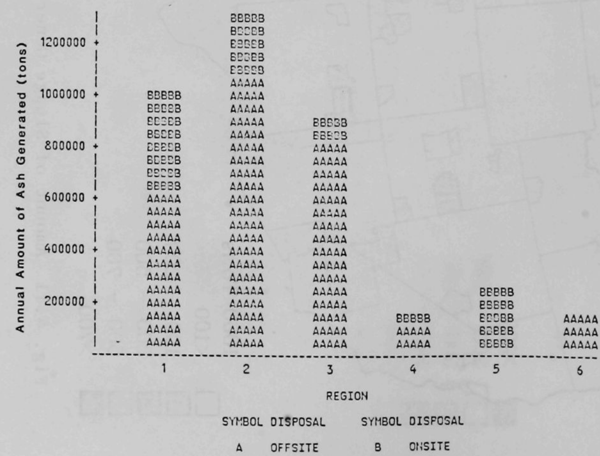

Fig. 4.13 Amount of Ash Generated (tons) by Phase 1 Conversion Boilers by Federal Region

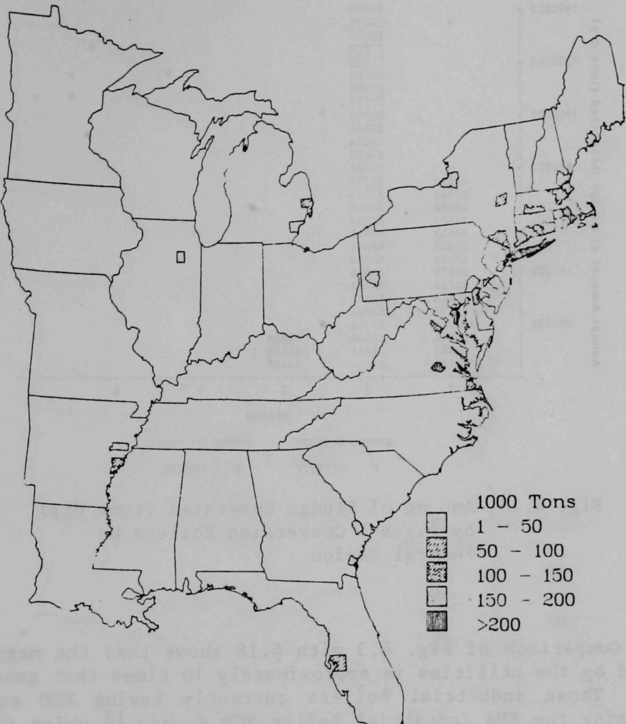

Fig. 4.14 Amount of Ash Generated (tons) by Phase 1 Conversion Boilers by County

4.2 INDUSTRIAL BOILERS

For the industrial sector, solid waste amounts and locations are estimated for coal-fired boilers with a capacity of greater than 99 million Btu/h. The source of information for existing boiler capacity is the Major Fuel Burning Installation (MFBI) File compiled by DOE. This information is supplemented by Ref. 12 for information on existing and planned FGD installations. Figure 4.17 indicates that about 85% of large coal-fired industrial boiler capacity is in the eastern United States (Federal Regions 1-5). The method used to estimate ash generation for industrial boilers is generally the same as that used for utility boilers except that a capacity factor of 50% is assumed.

Figure 4.18 indicates the distribution by Federal Region of ash generated by coal-fired industrial boilers, and Fig. 4.19 indicates the distribution

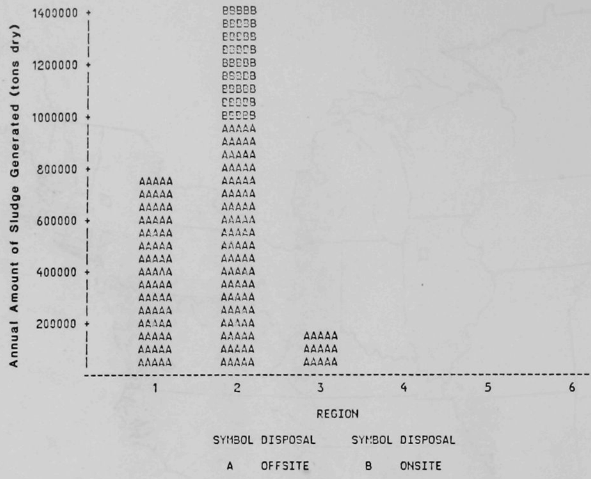

Fig. 4.15 Amount of Sludge Generated (tons dry) by Phase 1 Conversion Boilers by Federal Region

by county. Comparison of Fig. 4.3 with 4.18 shows that the magnitude of the ash generated by the utilities is approximately 10 times that generated by the industries. Those industrial boilers currently having FGD equipment were identified using the EPA Industrial Boiler FGD Survey,[12] which indicates that only 18 industrial boilers were operating at that time with FGD. The capacity of these 18 boilers is shown by Federal Region in Fig. 4.20. Estimates of the amount of dry sludge generated by these boilers are shown in Fig. 4.21 by Federal Region and in Fig. 4.22 by county. Figure 4.21 also indicates the type of disposal being used. Also included in the EPA Industrial Boiler FGD Survey are 11 proposed FGD installations. The capacities of these installations are shown by Federal Region in Fig. 4.23. The amounts of dry sludge estimated to be produced by these installations is shown in Fig. 4.24 along with the proposed disposal method. Fig. 4.25 indicates the amount of dry sludge produced at the county level for these proposed installations. The method used to estimate the amount of sludge generated by industry is the same as that used for the utility boilers. The sulfur content of the coal being used at the existing installations and to be used at the proposed installation is given in the EPA survey and was used in making the estimates.

An indication of the amount of solid waste generated from non-coal-fired boilers likely to convert to coal can be obtained by examining those installations on the MFBI file that are listed as coal capable and that have land available for coal storage. In this category are 520 boilers; Fig. 4.26 shows the distribution of capacity for these boilers by Federal Region. The associated amount of ash generated is shown in Fig. 4.27 by Federal Region and in Fig. 4.28 by county. A comparison of Fig. 4.26 to Fig. 4.17 indicates that if all these coal-capable industrial boilers converted to coal, the industrial coal-fired boiler capacity would be increased by approximately 50%

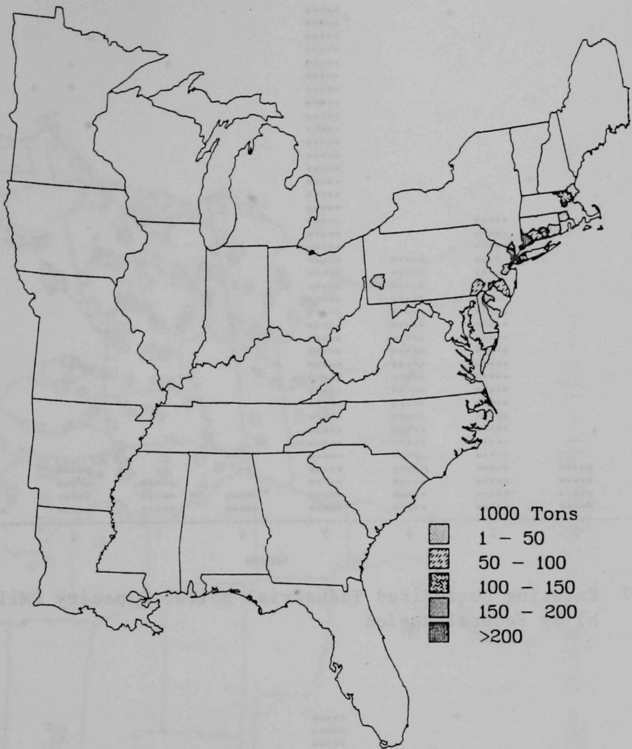

Fig. 4.16 Amount of Sludge Generated (tons dry) by Phase 1 Conversion Boilers by County

Estimates of new industrial coal-fired boiler capacity coming on line between now and the year 2000 were obtained from DOE. These estimates, which were developed by Oak Ridge National Laboratory (ORNL) for air-quality analyses, are based on projections of growth rate in employment by 2000 (Bureau of Economic Analysis projections) and estimates by region of the percentage of total fuel demand that will be filled by coal. These regional coal shares are shown in Table 4.1 and the resulting estimates of new industrial coal-fired capacity are shown in Fig. 4.29 by Federal Region. A comparison of this figure with Fig. 4.17 shows that the new coal-boiler capacity is approximately 80% of the existing MFBI capacity and that there is a large shift to Region 6.

Estimates of annual amount of solid waste generated by new coal-fired industrial boilers were made using (1) these new capacity estimates and (2) the methods used for existing industrial boilers. Figure 4.30 shows the distribution by Federal Region of the ash generated. If it is assumed that

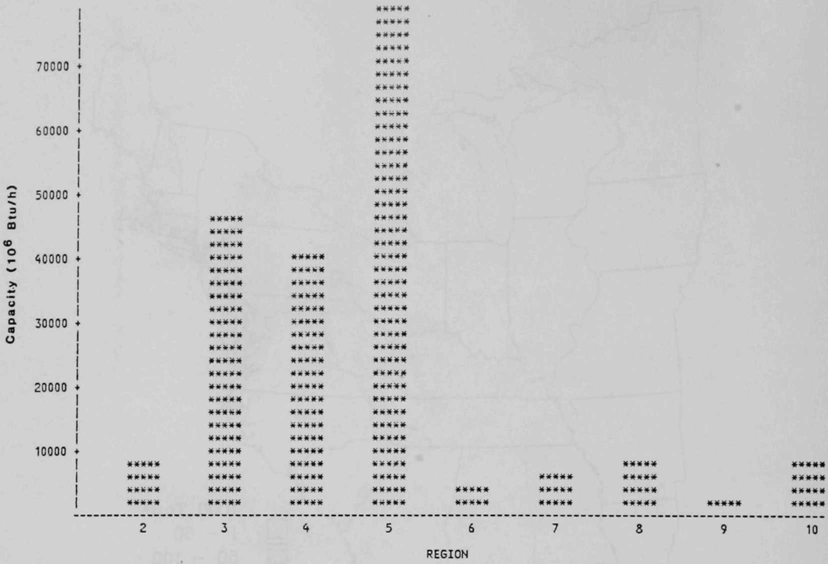

Fig. 4.17 Existing Coal-Fired Industrial Boiler Capacity (Million Btu/h) by Federal Region

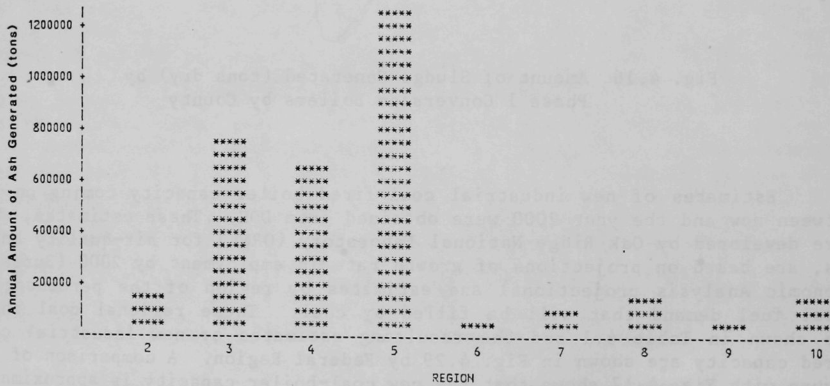

Fig. 4.18 Amount of Ash Generated (tons) by Existing Industrial Boilers by Federal Region

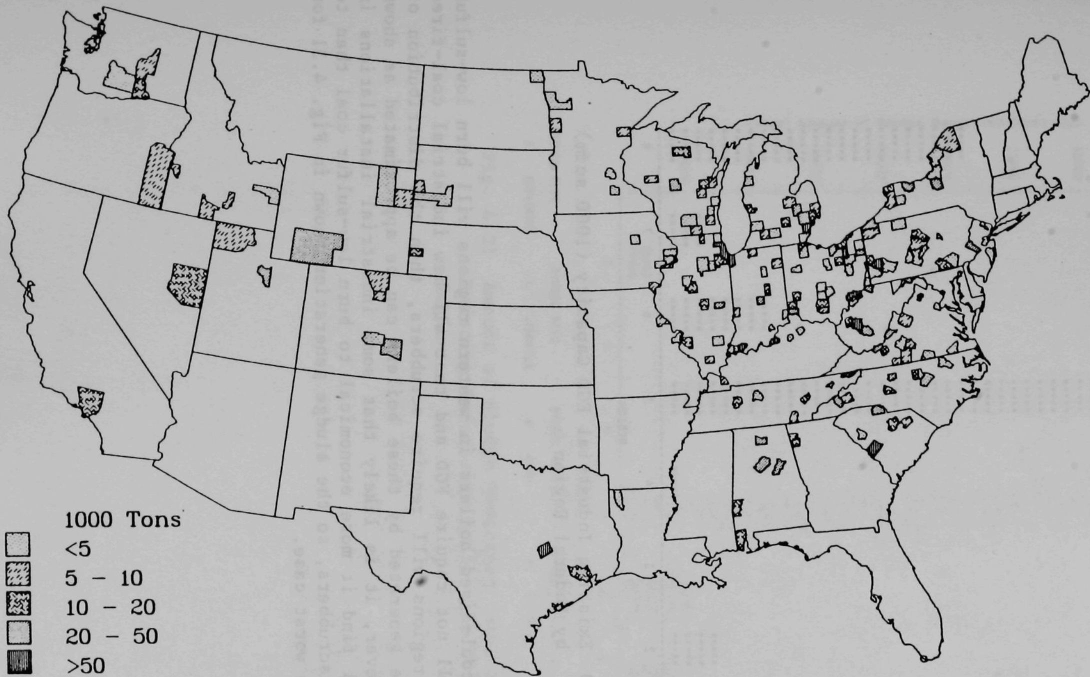

Fig. 4.19 Amount of Ash Generated (tons) by Existing Industrial Boilers by County

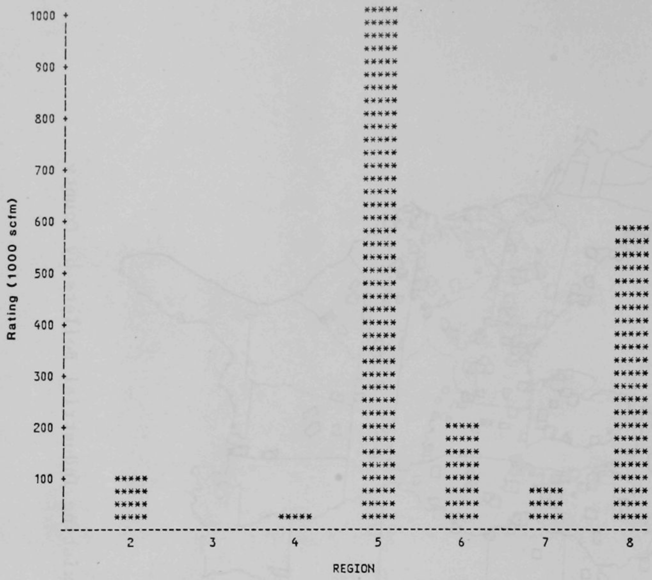

Fig. 4.20 Existing Industrial FGD Capacity (1000 scfm) by Federal Region

all new industrial coal-fired boilers in western regions will burn low-sulfur western coal and will not require FGD and that all new industrial coal-fired boilers in eastern regions will require scrubbers, then the distribution of the amount of sludge generated by these boilers can be approximated as shown in Fig. 4.31. However, it is likely that some industrial installations in eastern regions will find it more economical to burn low-sulfur coal than to install and operate scrubbers, so the sludge generation shown in Fig. 4.31 for eastern regions is a worst case.

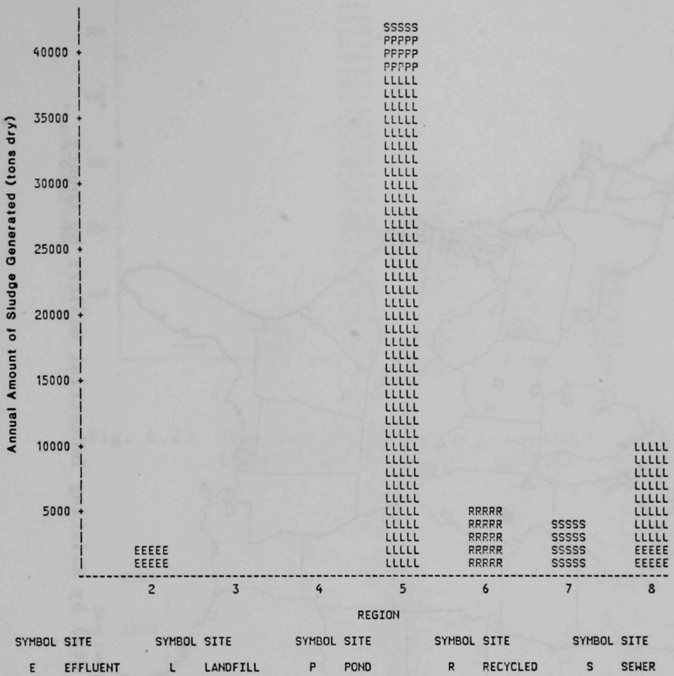

Fig. 4.21 Amount of Sludge Generated (tons dry) by Existing Industrial Boilers by Federal Region

Fig. 4.22 Amount of Sludge Generated (tons dry) by Existing Industrial Boilers by County

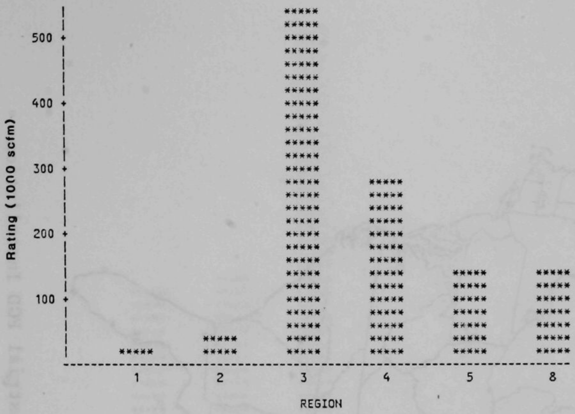

Fig. 4.23 Proposed Industrial FGD Capacity (1000 scfm) by Federal Region

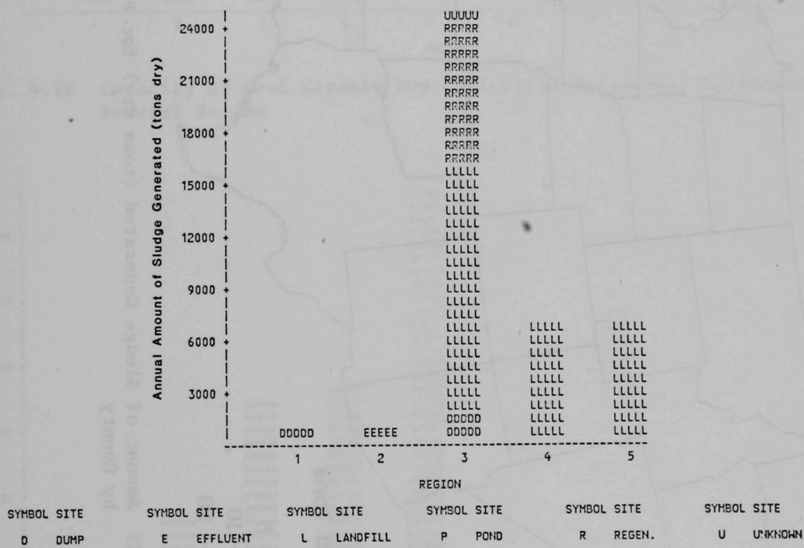

Fig. 4.24 Amount of Sludge Generated (tons dry) for Proposed Industrial FGD Installations by Federal Region

Fig. 4.25 Amount of Sludge Generated (tons dry) for Proposed Industrial FGD Installations by County

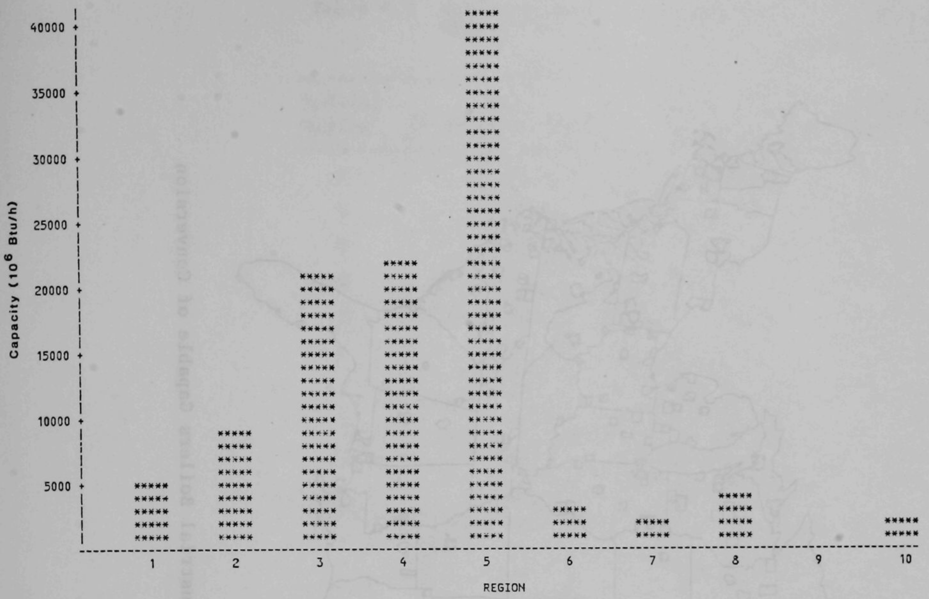

Fig. 4.26 Capacity of Coal Capable Non-Coal-Fired Industrial Boilers by Federal Region

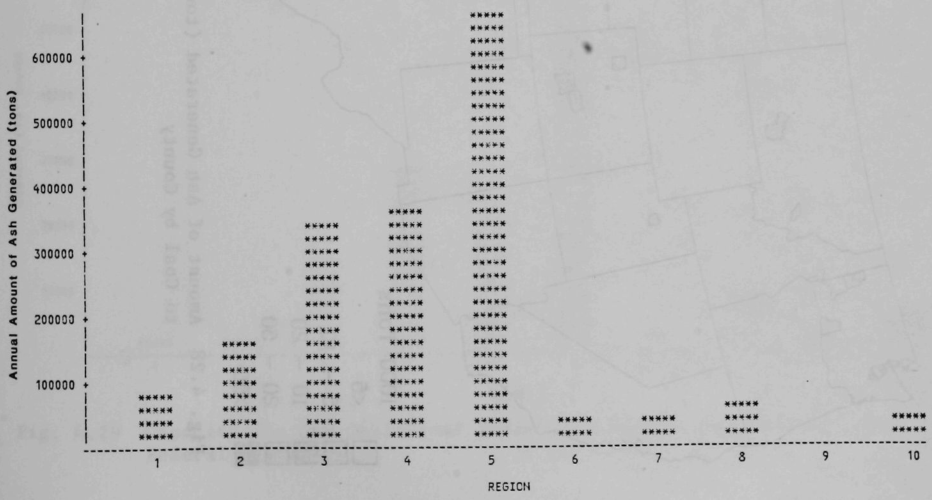

Fig. 4.27 Amount of Ash Generated (tons) for Possible Industrial Conversions by Federal Region

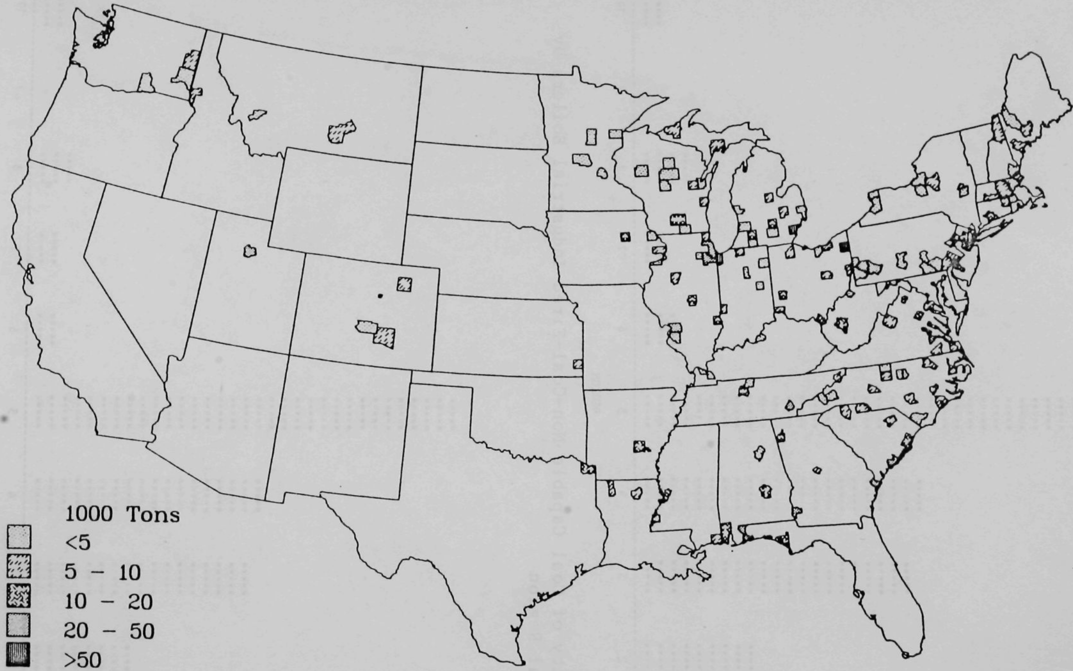

Fig. 4.28 Amount of Ash Generated (tons) by Industrial Boilers Capable of Conversion to Coal by County

Table 4.1 Regional Coal Shares

Federal Region	Coal (% of Total Fuel)
1	34
2	60
3	77
4	78
5	78
6	71
7	80
8	70
9	46
10	49

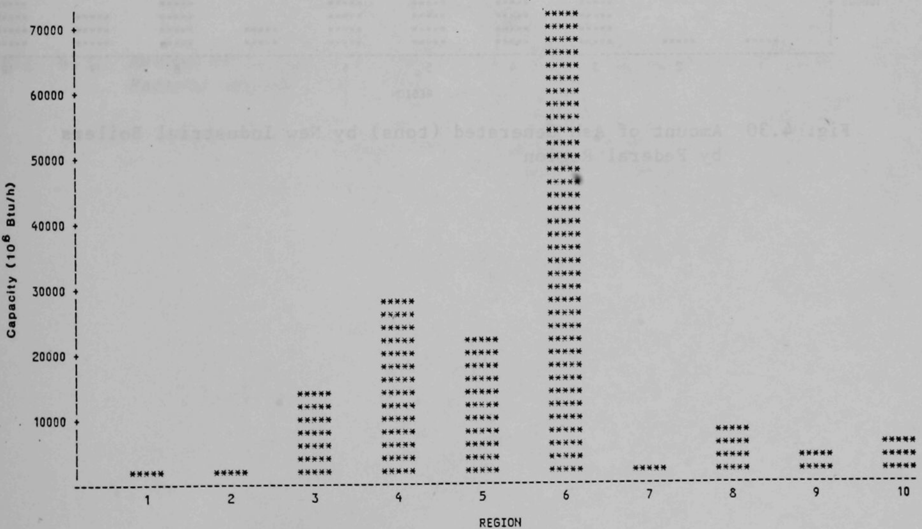

Fig. 4.29 Capacity for New Coal-Fired Industrial Boilers (million Btu/h) by Federal Region

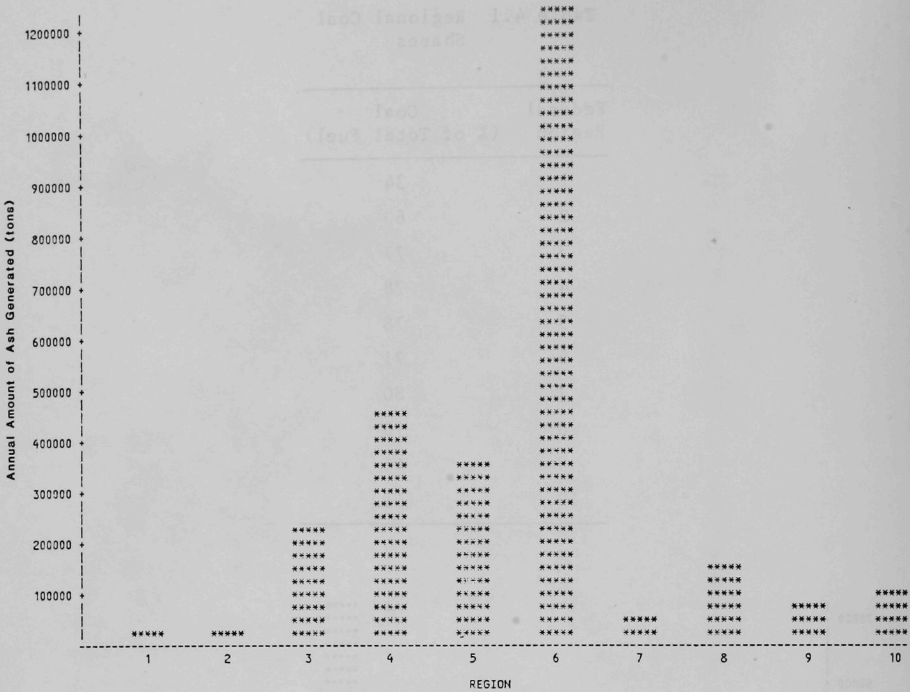

Fig. 4.30 Amount of Ash Generated (tons) by New Industrial Boilers by Federal Region

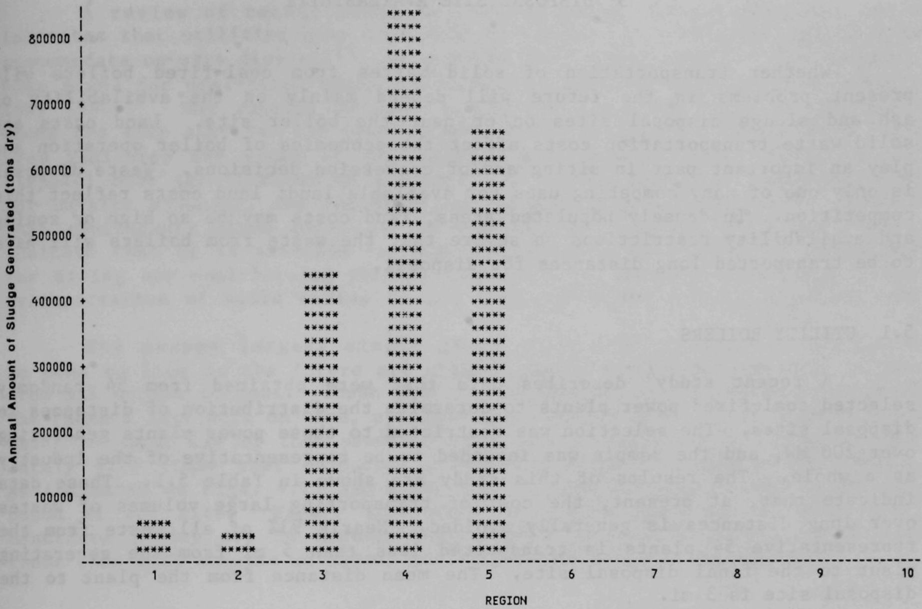

Fig. 4.31 Amount of Sludge Generated (tons dry) by New Industrial Boilers by Federal Region

5 DISPOSAL SITE AVAILABILITY

Whether transportation of solid wastes from coal-fired boilers will present problems in the future will depend mainly on the availability of ash and sludge disposal sites on or near the boiler site. Land costs and solid waste transportation costs affect the economics of boiler operation and play an important part in siting and/or conversion decisions. Waste disposal is only one of many competing uses for available land; land costs reflect this competition. In densely populated areas, land costs may be so high or zoning and availability restrictions so severe that the waste from boilers will have to be transported long distances for disposal.

5.1 UTILITY BOILERS

A recent study[4] describes data that were obtained from 54 randomly selected coal-fired power plants to determine the distribution of distances to disposal sites. The selection was restricted to those power plants generating over 200 MW, and the sample was intended to be representative of the industry as a whole. The results of this study are shown in Table 5.1. These data indicate that, at present, the cost of transporting large volumes of wastes over long distances is generally avoided. Nearly 93% of all waste from the representative 54 plants is transported less than 5 mi from the generating plant to the final disposal site. The mean distance from the plant to the disposal site is 3 mi.

The data presented in Section 4 of this report showed that proposed coal-fired units would generate approximately 127 million tons (dry weight) of solid waste a year if all of them were on line. This amount is approximately 3.5 times the amount of solid wastes currently produced by existing coal-fired generating units and approximately 40 times the amount of the solid wastes currently produced by industrial coal-fired boilers.

Table 5.1 Distance from Plant to Waste Disposal Site

Distance (mi)	Plants (% of Total)	Wastes (% of Total)
Less than 0.4	26.8	7.22
0.4 - 0.8	16.0	24.49
0.9 - 2.5	21.4	36.50
2.6 - 3.8	19.6	24.52
4.3 - 8.6	7.2	4.77
8.7 - 17.2	5.4	1.08
>17.3	3.6	1.42
Total	100.0	100.00

A review of recent planning reports by utilities and power pools indicates that utilities have been able to obtain sites of sufficient size to accommodate on-site disposal[13]. A national survey of utilities that currently have plans for coal-fired units was conducted by Brookhaven National Laboratory (BNL).[7] The results of that survey are displayed in Fig. 5.1, which shows the site size vs. the planned capacity at that site. The cross-hatched area indicates the range of necessary land requirements for sludge and ash disposal over the lifetime of a plant. All of the plants have adequate area for on-site disposal, and engineers for many of the utilities have indicated that contingency plans exist if FGD systems are required.[13] These results indicate that it is possible for the utilities to assemble large land areas for siting new coal-burning plants; therefore for proposed generating units, transportation of solid wastes is not expected to be a significant problem.

The second largest single group of coal-fired boilers projected to come on line in the future are utility generating units that will convert from oil or gas to coal. These units would produce, if all those included in the Phase 1 list were on line, approximately six million tons of waste a year, which is about 1/6 of that produced by existing utility boilers and approximately 1.75 times that produced by existing industrial coal-fired boilers. As indicated in Figs. 4.13 and 4.15, 76% of this waste will need to be disposed of off site. Figure 4.14 shows that almost all of the conversion-candidate plants are in densely populated areas, and Fig. 4.16 shows that those that will require scrubbers are concentrated in the Northeast.

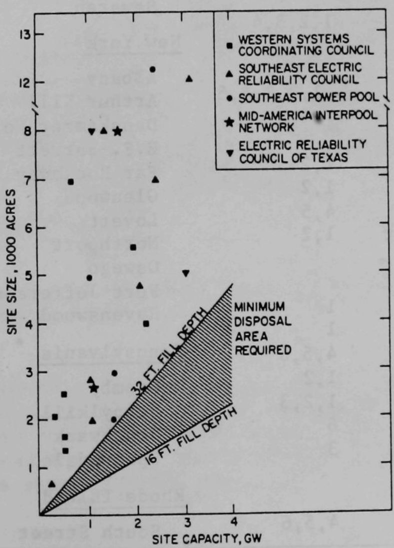

Fig. 5.1 Site Size by Plant Capacity and Reliability Council Region (Source: Ref. 13.)

The generating stations that are in Federal Regions 1, 2, and 3 in the Phase 1 conversion list correspond closely to the 42 generation stations included in the Northeast Regional Environmental Impact Study (NREIS) conducted by the Office of Fuels Conversion, Economic Regulatory Administration, U.S. DOE.[6] The primary purpose of this regional study was to assess the potential for cumulative and interactive environmental impacts associated with the conversion of multiple generating stations in the Northeast. Table 5.2 lists the plants included in the study. These plants are distributed over 10 states in the Northeast, with a majority clustered in the New York, New Jersey, Connecticut tristate region. The locations of the 42 stations are shown in Fig. 5.2.

Table 5.2 Facilities Included in the Northeast Regional Analysis

State/Facility	Unit Number
Connecticut	
Bridgeport Harbor	3
Devon	7,8
Middletown	1,2,3
Montville	5
Norwalk Harbor	1,2
Delaware	
Edge Moor	1,2,3,4
Maine	
Mason	1,2,3,4,5
Maryland	
Brandon Shores	1,2
Crane	1,2
Riverside	4,5
Herbert A. Wagner	1,2
Massachusetts	
Canal	1
Mt. Tom	1
Mystic	4,5,6
New Boston	1,2
Salem Harbor	1,2,3
Somerset	6
West Springfield	3
New Hampshire	
Schiller	4,5,6
New Jersey	
Bergen	1,2
Burlington	7
Deepwater	7,8,9
Hudson	1
Kearny	7,8
Sayreville	4,5
Sewaren	1,2,3,4
New York	
Albany	1,2,3,4
Arthur Kill	2,3
Danskammer Point	1,2,3,4
E.F. Barrett	1,2
Far Rockaway	4
Glenwood	4,5
Lovett	3,4,5
Northport	1,2,3,4
Oswego	1,2,3,4
Port Jefferson	1,2,3,4
Ravenswood	3
Pennsylvania	
Cromby	2
Schuylkill	1
Southwark	1,2
Springdale	7,8
Rhode Island	
South Street	12

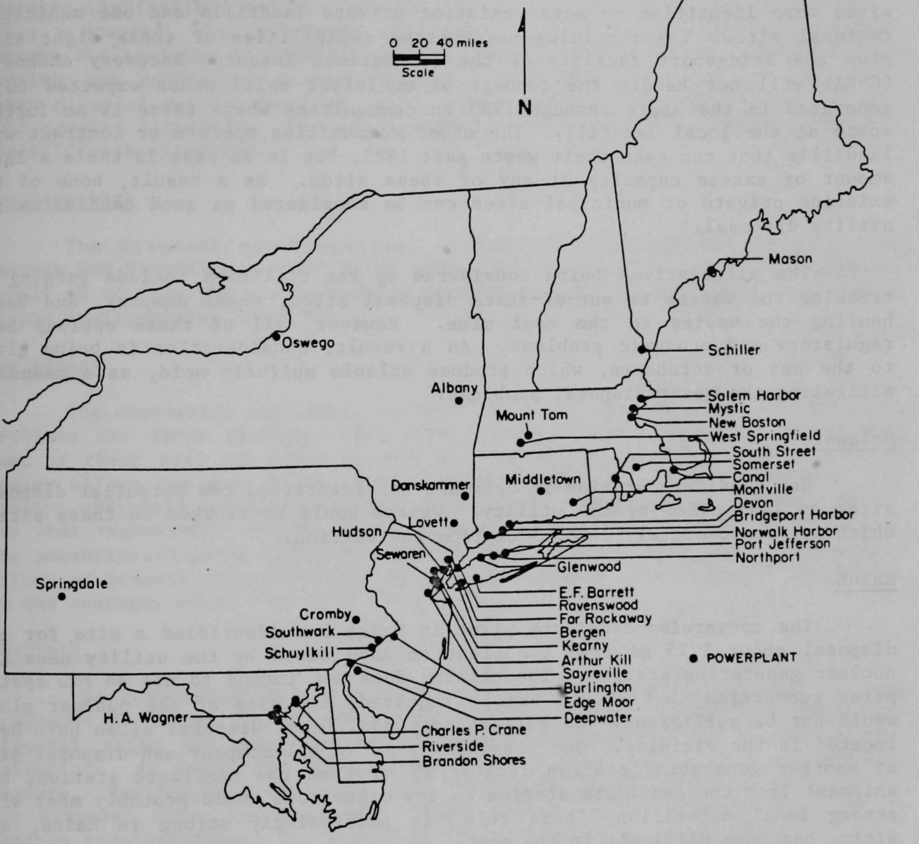

Fig. 5.2 Conversion Candidate Power Plants in the Northeast (Source: Ref. 6.)

The availability of sites for the disposal of ash and FGD sludge from these 42 plants was investigated as part of the NREIS, and the candidate sites are discussed in detail in The Northeast Regional Environmental Impact Study: Waste Disposal Technical Report.[5] The following information is a summary of site availability on a state-by-state basis.

Connecticut

None of the five candidate stations in Connecticut has the option of on-site disposal. Connecticut currently has a shortage of landfill capacity for municipal waste, which includes not only household wastes but also all nonhazardous commercial and industrial wastes generated within the boundary of the municipality. Because of this shortage, the municipal landfills near the power plants are not considered as possible sites. Eight potential disposal sites were identified -- seven existing private landfills and one municipal, regional site. The remaining uncommitted capabilities of these eight sites plus the Bridgeport facility of the Connecticut Resource Recovery Authority (CRRA) will not handle the tonnage of municipal solid waste expected to be generated in the state through 1983 in communities where there is no further space at the local landfill. The other communities operate or contract with landfills that can take their waste past 1983, but in no case is there a large amount of excess capacity at any of these sites. As a result, none of the existing private or municipal sites can be considered as good candidates for utility disposal.

The alternatives being considered by the utilities include barging or trucking the wastes to out-of-state disposal sites, ocean dumping, and back-hauling the wastes to the coal mine. However, all of these options have regulatory and economic problems. As a result, consideration is being given to the use of scrubbers, which produce salable sulfuric acid, as a means of mitigating the waste-disposal problems.

Delaware

One candidate station in Delaware has identified two potential disposal sites on land owned by the utility. Wastes would be trucked to these sites, which are approximately 2 and 5 mi from the station.

Maine

The conversion-candidate plant in Maine has identified a site for ash disposal about 1.25 mi from the plant on land owned by the utility near the nuclear generating station. The utility does not intend to use an FGD system after conversion, but should one be required, the site at the nuclear plant would not be sufficient. No satisfactory additional disposal sites have been located in the vicinity. One possibility is an oil-company ash-disposal site at another generating station located 29 mi from the candidate station, but shipment from the candidate station to any other town would probably meet with strong local opposition; "home rule" is particularly strong in Maine, and siting has been difficult in the past.

Maryland

The outlook for solid waste disposal in Maryland is good -- for various reasons. The Crane station may sell most of the boiler slag generated by its cyclone boilers, and it is expected that the Wagner Station will use cleaned coal. These possibilities relieve pressures that could be created by the other stations. Also, a large landfill nearby could accept the bulk of all wastes but is currently closed due to operating violations. This landfill is 18 mi from the Riverside Station, 15 mi from the Brandon Shores Station and the Wagner Station and 27 mi from the Crane Station. In addition, state officials may allow the use of ash as cover in municipal landfills.

Massachusetts

The conversion-candidate plants in the central/western part of Massachusetts (Springfield and Mt. Tom) face no major problems in locating disposal sites. However, the conversion candidates near Boston and on Cape Cod face extreme difficulties in landfill siting. The major constraints are population density and geological characteristics. Transport over long distances or ocean disposal may be required. The Boston stations (New Boston and Mystic) will require scrubbers. Use of regenerable scrubbers would somewhat relieve the difficult situation.

New Hampshire

The disposal opportunities, although limited by the hydrology of eastern New Hampshire, appear to be adequate. A commercial landfill, approximately 18 mi from the one conversion candidate, has the necessary capacity and proper environmental controls.

New Jersey

The conversion candidates in New Jersey will probably not face disposal problems for three reasons: (1) Most stations in New Jersey reported that much of their coal ash could be sold for use by construction firms. (2) New Jersey allows the use of coal ash as cover in general refuse landfills. (3) Utility officials representing five of the seven conversion candidates indicated that regenerable systems would be used if scrubbers were to be required. The potential disposal sites are located in the state, and there is no competition at present from potential out-of-state users. The disposal sites are, on the average, about 6 mi from the plants.

New York

The conversion-candidate plants in New York face the problem of long transport distances for disposal. In addition, many of the proposed quarry disposal sites may prove to be unsound environmentally due to goundwater pollution. At least one utility hopes to use ocean disposal as a temporary measure. The New York utilities have made considerable progress in identifying disposal areas and most have identified two or more disposal sites for serious consideration. The distances to disposal sites vary greatly. Two of the candidate stations, Lovett and Albany, will be able to dispose of waste on site. Two other stations, Oswego and Danskammer, have identified sites at moderate distances. Oswego has identified sites less than 10 mi from the plant, and Danskammer has identified a site less than 5 mi from the plant by barge but 20 mi by truck. The other stations are considering disposal in quarries and sand and gravel pits along the Hudson River up to a distance of 200 mi, with some sites identified at distances of 50 to 70 mi.

Pennsylvania

The disposal options in Pennsylvania are much less definite than those in the states mentioned above, but no fundamental land constraints are evident. The station in western Pennsylvania, Springdale, has a large site 4-5 mi from the station. Coal ash from one of the Philadelphia-area stations, Cromby, will be placed in an existing disposal operation for other coal-fired units at the same station. All Philadelphia plants plan to use regenerable scrubbers to minimize the solid waste problem.

Rhode Island

The one conversion candidate in Rhode Island has two major potential sites for coal ash. These sites are located 10 mi and 15 mi from the plant. A scrubber is not planned due to severe on-site land constraints. If a scrubber were installed, there would not be sufficient room for dewatering equipment. Because the planned disposal sites could not accept liquid waste, the dewatering equipment is essential.

5.2 INDUSTRIAL BOILERS

In general, the ability to dispose of ash and sludge on site will be much more limited for industries than for utilities. An accurate picture of site availability for industrial boilers could only be produced by analyses done at the individual site level, analyses which are beyond the scope of this report. Section 4 indicates that industrial waste-generation rates are an order of magnitude smaller than utility rates. It is, therefore, unlikely that transportation of solid wastes from coal-fired industrial boilers will be a large-scale problem. However, at the site-specific level, the necessity to transport wastes will affect the economics of burning coal and could also have localized environmental impacts, especially community disruption impacts.

About 75% of the industrial coal-fired boilers with FGD use sodium scrubbing systems, which produce dissolved solids in a liquid waste stream (see Section 2.1). The waste stream contains about 5% dissolved solids and is typically discharged into an existing wastewater treatment system, a municipal sewer system, or a natural watercourse. Many industrial coal-burning installations avoid ash disposal problems by finding a market for the ash.

In the future, industries converting to coal or installing new coal-fired boilers will probably avoid the expense of long transport distances and problems with local solid-waste management in two ways.[7] Sodium scrubbing systems are particularly attractive to industry for reasons beyond the avoidance of solid waste disposal. For small-sized boilers, these systems have very low annualized costs and energy demands. They are also tolerant of load changes in the boilers, and they are less likely to become plugged than are other types of scrubbing systems (Appendix A). In densely populated industrial areas where land for disposal is at a premium, the likelihood of a market for ash is high. As coal use is increased, this market could become saturated. This increased use, however, will lead to a more reliable supply of ash; therefore, more industries may rely on ash as a raw material. The potential market for ash utilization has been shown to be quite large.[7]

5.3 OTHER DISPOSAL ALTERNATIVES

Some of the utilities in the Northeast have considered ocean disposal as an alternative method for waste disposal, but most utility officials feel that permits would be difficult to obtain. The principal advantage to ocean dumping is that the method requires no land for disposal. This advantage is particularly important in the Northeast where there is a scarcity of land for solid-waste disposal and where many coal-fired power plants are located close to the ocean. Ocean disposal also reduces the traffic and noise problems related to land transport. The main disadvantage is the potential for adverse environmental impacts.[5,14,15] One method under study of avoiding adverse impacts is to construct artificial marine reefs of blocks of stabilized FGD sludge and fly ash. A reef of 18,000 solid blocks measuring 8 x 8 x 16 in. has been placed in the Atlantic Ocean 3 mi south of Long Island at a depth of 70 ft. The reef, which was placed on September 12, 1980, is now being monitored for a 3- to 4-y period to assess its environmental impacts and its colonization by biological communities.

Another alternative disposal method is back hauling the wastes to the coal mine for disposal in the abandoned portions of the mine. The idea is to make use of the unused transport capacity from the plant to the mine. There are, however, many operational problems. One indication of these problems is the fact that few utility officials, mine operators, or railroad officials have considered using this method of disposal.[5] Coal cars are not well suited for transportation of solid wastes from coal-fired boilers; therefore, some means of preventing excessive dust during transport (such as the use of tarpaulins to cover the ash) would need to be found. Some fly ash is pozzolanic and behaves like cement when it comes in contact with water. Some means of dealing with this problem will also need to be found. A stabilized mixture of FGD sludge and ash can be handled like dirt, and it may be possible that it could be bottom dumped as coal cars are generally designed to be used. However, this possibility has not been tested. The use of rotary car dumpers at the mine would be extremely expensive. The wastes would also be susceptible to freezing, which could make unloading extremely difficult. If, for transportation of the waste from the plant to the mine, special cars would be required, the advantage of this method would be gone. Mine and quarry disposal may be a viable disposal alternative for coal wastes, but most likely the mines or limestone quarries supplying the coal burning plant would not be used; therefore separate transportation facilities would be required. For detailed discussions of mine disposal and related issues, see Refs. 5, 14, and 16.

APPENDIX A: CHARACTERIZATION OF FGD WASTES

Flue gas desulfurization (FGD) scrubber sludge is primarily composed of reaction products (usually calcium sulfate and calcium sulfite), excess scrubbing reagent (unreacted lime or other sorbent), fly ash, and scrubbing liquor. The relative amounts of each of these constituents vary widely depending on the FGD process, sorbent type, coal sulfur content, and numerous operating procedures. Most of the sludge generated in the U.S. is a calcium-based product from utility lime and limestone FGD systems, although sludge from other systems will also be discussed.

A.1 SOLID PHASE

Several physical properties of FGD sludge influence its transportability and mode of disposal. These properties include crystal morphology, bulk density, permeability, compressibility, and viscosity.[3,17] Crystal morphology has possibly the greatest effect on the physical characteristics of the sludge;[17] in particular, the crystal structure is responsible for dewatering properties.

A.1.1 Crystal Morphology

Calcium sulfite scrubber sludges have an open crystal structure with water filling the voids. The structure is not easily compacted, and, as a result, sulfite predominant sludges can only be dewatered to approximately 35-50% solids.[18] Conversely, the blocky, elongated, crystalline form of calcium sulfate results in more easily dewatered sludge. Sulfate sludges can be settled and filtered to as much as 85% solids.[18]

Calcium sulfate sludge, or gypsum, is a higher-quality solid waste than calcium sulfite sludge. Sludge high in calcium sulfate is less thixotropic, has a higher bulk density, and a higher load-bearing strength; thus, it is more suitable for landfill material.[19] (A thixotropic waste, in an apparently solid sludge form, will reliquefy when vibrated or agitated.[18]) Because of these superior disposal properties, increasing numbers of FGD systems are being designed to include an oxidation step in which the sulfite is oxidized to sulfate.[18] Currently, most FGD systems are used with high-sulfur coals, and the resultant sludge has a high sulfite/sulfate ratio.[17] Relatively few systems now generate predominantly sulfate sludges; these systems are either located in the West and burn low-sulfur coals or employ some method of forced oxidation.[17].

A.1.2 Bulk Density

Bulk density is the weight per unit volume of a bulk granular solid material (whereas true density is the density of the individual particles). It is an important parameter of FGD sludge, because it determines disposal-related properties such as compressibility, landfill volume requirements, permeability, and, to some degree, compaction strength.[17] Dewatering increases the bulk density to a certain point. After that point, air fills the voids, causing a decrease in density. The "optimum moisture content" is the point at which maximum bulk density is obtained by compression. Sulfite sludge has a higher optimal moisture content, thus sulfate sludges generally have higher bulk densities.[18] Bulk densities of untreated sulfite sludges range from 1.2 to 1.6 g/cm^3, whereas sulfate sludges vary from 1.4 to 1.8 g/cm^3.[17]

A.1.3 Permeability

The permeability factor of sludge indicates the rate at which water will leach through the material. Settled sulfite sludges, due to their irregular crystalline structure, are generally less permeable than sulfate sludges.[17] Untreated FGD sludges have permeabilities of 10^{-3} to 10^{-4} cm/s (approximately 1000 to 100 ft/y flow rate); slight compaction, however, lowers this value to 10^{-5} cm/s (or 10 ft/y).[17,19]

The addition of fly ash will further decrease sludge permeability. Small particles of fly ash fill the sludge interstices, thereby inhibiting the movement of water through the media. Permeabilities of sulfite sludge mixed with fly ash are about 10^{-6} cm/s -- generally considered the lowest achievable permeability rate for untreated FGD sludge.[17]

A.1.4 Compressibility

The compressibility or compactibility of FGD sludge becomes most important when disposal-site reclamation is under consideration. The degree of compaction achievable depends on both the moisture content and the crystal morphology of the waste material. Sludges with high concentrations of sulfate have relatively high bulk densities, as was previously mentioned. These sludges thus have significantly lower compressibilities.[17] Pure sulfite sludge has been reduced in volume by 25% in laboratory experiments, whereas sulfate sludge, compacted to the same bulk density, was reduced in volume by only 7%.

A.1.5 Viscosity

The viscosity of FGD sludge is an important parameter when pipe flow or load-bearing properties are being considered. It is basically a function of moisture content, crystal morphology, and amount of fly ash present.[17] Wastes are generally pumpable at less than 20 p, which is usually the viscosity of untreated sludges having a solids content between 32 and 70%.[17] A decrease in water content, however, will result in a highly disproportionate increase in viscosity, which is an important consideration in handling FGD sludges.[17]

Because high-sulfite sludges retain so much water, they are efficiently transported by pumping only. Wastes containing high percentages of gypsum and/or fly ash have much lower viscosities, but can still be pumped in concentrations as high as 70% solids.[20] All sludges experience a rapid change in viscosity as they reach their characteristic solids content. Because various power plant and FGD system operational changes can cause variations in the solids content of the sludge, solidification of the sludge in pipes is a potential problem.[17] Addition of fly ash lowers sludge viscosity and causes it to be less thixotropic.[17,19]

A.2 LIQUID PHASE

Although spray drying and fluidized-bed combustion show promise for increasing usage by controlling SO_2 emissions, wet scrubbing FGD processes are currently used almost exclusively by utilities and industry. Water is the most necessary component of these processes, because it is the medium in which the desulfurization reaction occurs.[18] The liquid phase of scrubber waste is also important in transportation and disposal considerations.

The water content of FGD sludge will affect its chemical and physical properties. Generally, an increase in water content above the optimum level will negatively affect the quality of the waste in terms of final disposal. For this reason, and because liquid by-products are recycled to the scrubber, a dewatering step either precedes or accompanies final disposal of all calcium-based sludge.[18] An increase in water content has the following effects on sludge transportation and disposal:[18]

- Lowers disposal efficiency by lowering the amount of solid waste that can be disposed of in a given area.
- Reduces the degree to which the material can be compacted.
- Reduces the shear strength of the waste and thus the load-bearing capacity of the disposal area.
- Improves pumpability by lowering the viscosity.
- Increases the permeability of sludge, causing greater amounts of leachate.
- Increases the total weight and volume of solid waste for disposal.

Scrubbing liquors contain high concentrations of dissolved solids. These concentrations can vary by two orders of magnitude or more, ranging from approximately 2500 mg/L to as much as 1000,000 mg/L.[20] The amount of total dissolved solids in the liquid by-products depends on such factors as the chloride/sulfur ratio of the coal, type of FGD process, and the extent of washing and dewatering of the scrubber solids.[20] The soluble species are primarily calcium, magnesium, sodium, chloride, sulfite, and sulfate.[18] Trace elements, including heavy metals, are also contained in the scrubbing liquor to a minor degree.[3,18,20] Analytical data have indicated that about 1% of the trace elements present in sludge are contained in the liquid phase.[17]

A.3 CODISPOSAL OF SLUDGE AND FLY ASH

Some amount of fly ash is normally present in FGD sludge, ranging in proportion from a trace to more than 50%,[18] depending on several operating parameters. The following factors determine the quantity of fly ash in FGD sludge:[18]

- The site of fly ash removal (upstream, downstream, or in the scrubber).
- The efficiency of upstream removal devices.

- The efficiency of the scrubber in removing fly ash.
- The percentage of ash and sulfur present in the coal.
- The use of alkaline fly ash as a scrubber reagent.
- The use of fly ash as an additive to the sludge for stabilization or dewatering.

Some scrubbers are designed to remove both fly ash and SO_2 from the stack gases in order to eliminate the need for an additional particulate-collection device. However, this design greatly increases the material load to be handled in the scrubbing system. Another disadvantage is that the ash increases the potential for erosion of the scrubber system.[18]

Dry fly ash removed from an electrostatic precipitator or baghouse can be mixed with FGD sludge in order to stabilize the waste for disposal. This is currently the practice at several utility FGD installations and is the practice proposed for eight new utility FGD facilities.[18] The addition of large volumes of dry fly ash serves to decrease the water content of the waste material, thereby creating a higher-quality fill product.

Other advantages of codisposal of scrubber sludge and fly ash include the following:[18]

- The spherical shape of fly ash particles reportedly decreases the viscosity of scrubber sludge, causing it to be more easily pumped.
- Fly ash particles are larger than sulfite/sulfate crystals, and thus improve the drainage properties of the waste material.
- Alkaline fly ash decreases the permeability of the mixture; therefore less leaching occurs.
- A landfill or pond of alkaline fly ash (from western and lignite coals) mixed with sludge will have a greater load-bearing capacity than will a site containing an FGD slurry alone.

A disadvantage of codisposal is the increase in trace-element concentrations in the final waste material. After combustion, most of the trace elements originally present in the coal adhere to small particles of fly ash; only a small fraction of the trace material is trapped in the scrubber.[19] Including the fly ash with sludge for disposal has caused some environmental concern, although agreement has not been reached as to the potential for water-quality deterioration due to polluted leachate. Although the trace elements are known to be contained in the fly ash, it is not yet apparent whether they are soluble in the scrubbing liquor or in leachate from disposed sludge.[18]

A.4 CHARACTERIZATION OF WASTES FROM ALTERNATE FGD PROCESSES

The previous sections on solid and liquid wastes from scrubbers are descriptive of typical calcium-based sludges generated by lime, limestone, and double alkali FGD processes. These processes account for almost 90% of all of utility FGD facilities.[21] Other desulfurization systems are used more commonly by industry or show a potential for more extensive use in the future. The waste materials generated by these systems, which include sodium scrubbing, spray drying, and fluidized-bed combustion, are described in this section.

A.4.1 Sodium Scrubbing

Approximately 75% of all industrial FGD units and 1.7% of utility boilers with FGD capacity[21] use sodium scrubbing for flue gas desulfurization. This technology has been particularly attractive to industry for the following reasons:[19]

- Its use of a clear liquor, rather than a slurry, lowers the potential for plugging and scaling.
- It is tolerant of load changes in the boiler.
- It has very low annualized costs and low energy demand for small-sized boilers.

The sodium scrubbing process results in an aqueous waste stream of only 5% dissolved solids. Process wastes contain sodium sulfite, sulfate, carbonate, hydroxide, and some inert compounds. The high degree of water solubility of these wastes presents disposal problems and eliminates landfills and unlined ponds as disposal options.

A.4.2 Spray Drying

The spray-drying or dry scrubbing FGD process involves a solution of soda ash or lime slurry that is atomized and sprayed into the flue gas. The small amount of water in the mist is evaporated, and the SO_2 in the gas is absorbed by the reactant, producing a dry, free-flowing powder.

The dry waste, consisting of calcium or sodium salts and fly ash, is collected in a baghouse or electrostatic precipitator. The typical composition of desulfurization waste materials from a sodium-based spray-drying system is about 60% sodium sulfite, 20% sodium sulfate, and 20% excess carbonate by weight. Solids from a regenerable lime-based system are expected to contain 55% calcium sulfate, 30% calcium sulfite, and 15% limestone and lime inert compounds.[22]

The dry, solid waste material from spray drying can be handled by conventional fly ash handling equipment, thus eliminating the need for a sludge-handling system. Disposal in either lined and unlined landfills is currently the most common option, although other methods are presently under study. Two industrial applications of spray drying FGD are currently in the planning and construction stages. These industries will transport their solid wastes to off-site landfill areas by truck.[22]

A.4.3 Fluidized-Bed Combustion (FBC)

In a fluidized-bed combustor, a bed of noncombustible sorbent is "fluidized" by a stream of air. The velocity of the air stream is set so that the bed particles are suspended and randomly move about. Fuel is injected into the bed and burned, and the sorbent removes the SO_2 produced during combustion. Spent bed material, consisting of reacted and unreacted sorbent, ash, and other inert materials, is then removed from the bed unit. Smaller particles and fly ash are removed by cyclones and a particulate collection device -- usually an electrostatic precipitator.

As with the waste material from spray drying, FBC solid wastes are dry and consist of both fly ash and products of desulfurization. Between 85 and 95% of the total waste produced is spent bed material, which is composed of $CaSO_4$, CaO, $CaCO_3$, and CaS. The other 5-15% consists of particulates from the precipitator or baghouse.[23]

As is the case with most desulfurization waste material, the chemical quality of FBC waste is determined primarily by the composition of the coal and the sorbent. However, FBCs generally emit fewer gaseous trace elements, due to lower combustion temperatures, and thus more trace elements will be present in the solid waste stream.[24] Experimental evidence has found the leachability of trace elements in FBC wastes to be low, possibly due to inhibition by highly insoluble metal hydroxides and carbonates.[25] In addition, FBC waste material is fully oxidized and thus is not a source of chemical oxygen demand as is wet, partially oxidized, FGD sludge.[19]

Solid waste from FBC can be disposed of in the same manner as conventional fly ash and stabilized scrubber sludge. Landfilling is the common disposal practice, although other uses (such as the manufacturing of cement blocks, road-base material, and other low-grade structural materials) are being developed. In the landfill use, water quality problems may result from the high pH of the waste, as well as from the calcium sulfate and total dissolved solids content of the leachate. Heat release from the material during initial contact with water caused by the hydration of calcium oxide can also present difficulties in handling the waste.[19]

Fluidized-bed combustion and spray drying are both generally considered "innovative" pollution-control technologies. Neither has been utilized in full-scale operation on a power plant. There are, however, two industrial applications of lime spray drying and several pilot-scale FBC operations.[19] Commercial FBC units are also being produced by several vendors.[19] Both of these technologies are suitable for industrial use due to their operating characteristics, and both generate a dry waste product, which has more desirable disposal properties than wet sludge. The use of FBC and spray drying is expected to increase in the future.

APPENDIX B: TRANSPORTATION AND HANDLING OF FGD SLUDGE

This appendix amplifies the information presented in Section 3 and is excerpted from Ref. 1. It describes equipment, methods, and design considerations for transporting both dry wastes and wet wastes. A dry waste is one that is sufficiently dewatered so that it no longer exhibits fluid properties; that is, it will maintain its own slope when placed outside a container. In most cases, a dry waste will have a solids content greater than 75%. Wet wastes are those that are pumpable as a slurry. The solids content can vary from 30 to 70%. See Appendix A for characterization of FGD wastes.

B.1 DRY WASTES

For the transport of dry waste, a variety of conveyance equipment can be used, including belt conveyors, trucks, trains, and marine vessels. For short-distance transfers, chutes, front-end loaders, bulldozers, and scrapers can be used. The physical and chemical properties of the waste play an important part in the actual design of the equipment. The following considerations are important:

- Sludge bulk density governs the conveyance or feeder tonnage rating.
- Maximum lump size may dictate the conveyance or feeder selection and sizing because lumps may require larger conveyance and feeders to transport the desired tonnage.
- The angle of repose (the angle to the horizontal made by the surface of a normal, freely-formed pile) and angle of surcharge (the angle to the horizontal assumed by the surface of the sludge when it is at rest on a conveyance or feeder such as a moving conveyor belt) vary with the sludge flowability, which is determined by the size and shape of fine particles and lumps, proportion of fines and lumps, roughness or smoothness of particles and lump surfaces, and the sludge moisture content. The angle of surcharge is usually maintained between 5-20° less than the angle of repose.
- The sludge temperature is often critical because freezing temperatures can cause severe operating problems with certain conveyance and feeder components.
- Corrosiveness usually is governed by the sludge pH: pHs between 1 and 5 are corrosive, pHs from 5-7 are mildly corrosive, and pHs greater than 7 are generally noncorrosive. High chloride concentration may lead to stress corrosion failure of stainless steel components.
- Abrasiveness of the sludge may be harmful to unprotected (uncoated) metal surfaces, but there is no easy way to determine this. The extent of attack will probably be more severe with increased quantities of fly ash.

Table B.1 shows the major alternative transport modes available and summarizes their limitations and applicability.

B.1.1 Belt Conveyors

Many different types of conveyors are used for material transport including belt, screw, apron, flight, vibrating, and en masse conveyors. Of these conveyor types, the belt conveyor is the only type suitable for the transport of FGD sludge.

A belt conveyor is an endless belt, usually rubber-covered. The belt operates over carrying and return idlers and drive, tail end, and bend pulleys. These components are supported on a frame structure suitable for maintaining accurate alignment of the components and belt. Figure B.1 illustrates the belt conveyor components without the supporting structure.

Belt conveyors are a low-cost method of transporting sludge continuously for both short and long distances when both the loading and discharge points are fixed. These conveyors can be designed for a wide range of capacities by various combinations of belt widths and speeds. Table B.2 provides maximum belt conveyor capacities for various belt widths, idler troughing angles, and surcharge angles. Although the capabilities detailed in Table B.2 are for sludge weighing 100 lb/ft^3 and moving on the belt and 100 ft/min, the capacities can be corrected for other sludge weights and belt speeds.

Belt conveyors require that the sludge be loaded on the conveyor or belt surface from one or more points in a controlled manner -- a process that sometimes requires one or more feeders. Thus, the belt conveyor is provided with a continuous, even flow of sludge to match the flow rate designed for the conveyor. Belt conveyors are arranged in a direct line between terminals and may have an almost unlimited number of elevation profiles or paths of travel. These paths include horizontal, inclined, declined, concave or convex vertical curves, or any combination of these. The inclined or

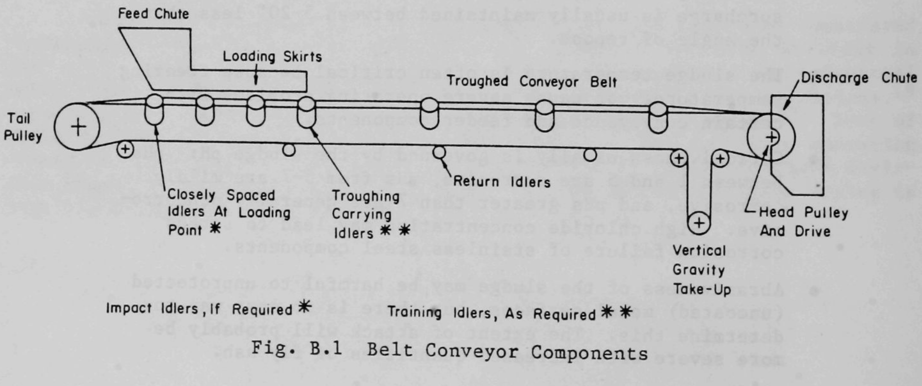

Fig. B.1 Belt Conveyor Components

Table B.1 Alternative Transportation Modes

Conveyance Type	Haul Length (ft) 0-300	300-500	500-1,000	1,000-1,500	1,500-5,000	5,000-10,000	10,000-15,000	15,000 +	Ground Conditions Good	Wet, Soft	Maximum Adverse Grade (%) 3	5	10	15	20	+20	Total Tonnage Sm	Med	Lg
Front-end loader, rubber tires	a	b	a	c	d	d	d	d	b	e	b	b	b	a	e	c	b	b	d
Front-end loader, crawler	b	c	c	d	d	d	d	d	b	b	b	b	b	a	e	c	b	b	d
Bulldozer, rubber tires	b	b	a	d	d	d	d	d	b	c	b	b	a	c	d	d	b	b	d
Bulldozer, crawler	b	c	d	d	d	d	d	d	b	b	b	b	a	a	c	d	d	b	d
Wheeled scraper, conventional	d	a	b	b	b	a	c	c	b	a	b	b	a	c	d	d	a	b	b
Wheeled scraper, tandem powered	d	a	b	b	b	e	c	d	b	b	b	b	b	a	a	c	c	b	b
Wheeled scraper, elevated	a	b	b	b	a	c	d	d	b	e	b	b	a	c	d	d	a	b	d
Truck, rear dump	d	e	b	b	b	b	b	b	b	e	b	b	b	e	c	d	d	b	b
Truck, semi-trailer rear dump	d	e	b	b	b	b	b	b	b	c	b	b	b	c	c	d	d	b	b
Truck, semi-trailer bottom dump	d	d	e	a	b	b	b	b	b	d	b	a	e	c	d	d	d	a	b
Train	d	d	d	d	d	d	c	b	b	d	b	c	d	d	d	d	d	d	b
Conveyor	b	b	b	b	b	b	b	b	b	e	b	b	b	b	b	c	d	d	b

[a]May be considered

[b]Should be considered

[c]May be considered, special situation

[d]Not applicable

[e]May be considered under certain conditions

Table B.2 Belt Conveyor Capacities and Load Cross-Sectional Areas (based on bulk density of 100 lb/ft^3 and belt speed of 100 ft/min)

Idler Troughing Angle	Conveyor Width (in.)	5° Surcharge		20° Surcharge		30° Surcharge	
		ft^2	tons/h	ft^2	tons/h	ft^2	tons/h
20°	14	0.060	18.00	0.093	27.90	0.116	34.80
	16	0.082	24.60	0.127	38.10	0.159	47.70
	18	0.109	32.70	0.168	50.40	0.209	62.70
	20	0.139	41.70	0.213	63.90	0.266	79.80
	24	0.209	62.70	0.321	96.30	0.399	119.70
	30	0.342	102.70	0.523	156.90	0.649	194.70
35°	14	0.088	20.40	0.117	35.10	0.138	41.40
	16	0.122	36.60	0.161	48.30	0.189	56.70
	18	0.161	48.30	0.212	63.60	0.249	74.70
	20	0.205	61.50	0.270	81.00	0.316	94.80
	24	0.309	92.70	0.406	121.80	0.475	142.50
	30	0.506	151.80	0.663	198.90	0.773	231.90
45°	14	0.102	30.60	0.128	38.40	0.146	43.80
	16	0.140	42.00	0.175	52.50	0.200	60.00
	18	0.185	55.50	0.230	69.00	0.262	78.60
	20	0.236	70.80	0.293	87.90	0.333	100.00
	24	0.355	106.50	0.440	132.00	0.499	149.70
	30	0.580	174.00	0.716	214.80	0.812	243.60

declined slope is limited by the properties of the sludge being conveyed but is effectively limited to slopes of up to 25%.

The rubber belt conveyor is rugged and durable and can adaquately handle sludges with variable characteristics. However, freezing conditions may cause operating difficulties with conveyor components.

Belt conveyors are widely used for short transport distances, often for moving sludge from one processing step to the next or from final processing to truck loading. However, no belt conveyors are currently in use to carry sludge from the plant to the ultimate disposal site. Long enclosed belt conveyors are possible but have not yet been used for sludge disposal. Long belt conveyors have high maintenance costs and are inflexible, requiring essentially fixed starting and ending points. They also represent a high capital investment, which may not be justified for the life of the facility.

Proper designing of a conveyor system requires knowledge of the belt conveyor profile, capacity required, sludge characteristics, and operating conditions in order to properly select conveyor idlers, determine belt tension and drive horsepower, and select conveyor belting. The daily hours of operation, ambient temperatures (minimum and maximum), type of operation (reversing or one-directional), enclosed or exposed conditions, seasonal or continuous service, and other significant factors must also be considered.

B.1.2 Trucks

Trucks are highly mobile and can be used to economically transport dry sludge over relatively long distances. Both on-highway and off-highway trucks are available for use and vary primarily in capacity. On-highway trucks are designed for use on public highways. These trucks are subject to width limits and to roadway weight limits and restrictions. Off-highway trucks travel on private highways. In recent years, the off-highway truck has become the major transport vehicle for bulk material that is to be transported between 500 and 15,000 ft.

Trucks are of three types: conventional rear dump, semitrailer rear dump, and semitrailer bottom dump. The conventional rear-dump uses an integrally mounted hydraulic hoist system for dumping. Rear-dump trucks may have two or three axles. Semitrailer bottom-dump drucks also have separate tractor and trailer units. The trailers have either drop bottom or clam-shell doors for material dumping. The bottom-dump truck works well with free-flowing materials being dumped into hoppers. Capacities range from small 13-ton trucks to large 200-ton or more vehicles. All trucks require haul roads with the maximum road grade limited to 10-15%.

For conventional rear-dump trucks, the basic styles are the quarry, standard, and "V." The quarry type has vertically flared sides and a flat bottom. The standard type has vertical sides tapered from front to rear for easy dumping of material. The "V" type has vertical sides with no taper and a bottom that slopes downward from the rear to the front. In colder areas, many truck bodies have exhaust gas heating as a standard feature or have provisions for heating as an option to prevent sludge from freezing to the truck body and eventually building up and reducing the truck payload. Many truck bodies are constructed of low-alloy, high-strength steel, which decreases body weight and correspondingly increases the truck payload. In some cases, bodies are constructed using aluminum and steel to reduce body weight and increase the payload.

B.1.3 Rail Cars

Trains can be used for the transport of dry FGD sludge over long or short distances over a fixed track to the final sludge disposal site. The train may operate as a unit train or as a common carrier. Common-carrier railroads have extensive rail or track networks, which often have existing tracks near both the power plant and the final disposal site. If common carriers do not serve either the origin or the destination, then it may be necessary for the user to obtain a private right-of-way and operate as a private railroad.

Conceptually, it is possible to use empty coal cars to haul FGD sludge back to the mine, thus avoiding "dead-heading" costs (costs of hauling empty cars back to the mine). This idea has been explored at several operating stations, but has not been used. The possibility of using empty coal cars, especially on unit coal trains, may become more attractive with the passage of legislation requiring that strip mines be restored to near-original contour.

Railroad freight cars suitable for the transport of dry FGD sludge are available with capacities of 50, 70, 100, and 125 tons. Until recently, the 50- and 70-ton cars were most common, but the 100-ton car is now becoming more popular. The larger capacity cars require heavier and stronger track, trestle, and dumping facilities. The cars may be of the gondola design with a solid bottom, of hopper design for bottom dumping, or of the side-dumping design. Cars are constructed of steel with car capacity determining the size and strength of wheels, axles, bearings, body side-frames and bolsters, springs, and braking system. Gondola cars may be equipped with a rotary coupler at one end so that the car can be rotary dumped without uncoupling from adjacent cars. However, this system is fairly expensive. Hopper cars may be equipped with either manually operated or power-operated hopper doors. The car configuration, including hoppers and doors, is often designed for specific applications. Side-dump cars, such as those in use at the Martin Lake facility of Texas Utilities, are most cost effective for sludge operations.

A major consideration in using trains to transport dry FGD sludge is car loading and unloading. Cars usually can be loaded with front-end loaders, belt conveyors, or chutes. The front-end loader loads the car from a sludge pile by dumping the sludge directly into the car. The stationary belt conveyor, using a spill-eliminating transfer gate, discharges the sludge into the car with the car being moved and positioned under the discharge for distribution of the sludge in the car. The chute can load directly from the outlet of processing equipment such as centrifuges or mullers operating in an area above the rail car. This type of system is in operation at Martin Lake.

Gondola cars can be unloaded using a rotary car dumper, which rotates the car upside down to dump the sludge. Rotary dumpers are massive equipment and represent a high capital cost. When hopper cars are used, the sludge must be free flowing in order to allow the sludge to be unloaded through the hopper bottom. The side-dump car is self-unloading and uses air cylinders to tip the car body and dump the sludge.

B.1.4 Barges

Barges can be used to ship dry FGD sludge over long distances where the origin and destination are along inland waterways or are separated by large bodies of open water. When power plants are located near waterways, these waterways can sometimes serve as economic transport routes. Although barge transport is inexpensive when measured in terms of cost/ton-mi, it is not usually justified except under special circumstances. The cost of loading and unloading and the associated double handling of the sludge will usually rule out the use of barges as an economical alternative except for very long transport distances (which are rarely anticipated) or for ocean disposal, which is only available for tidewater utilities.

If the ultimate disposal site is an ocean dump site, the sludge would be transported using ocean barges. If the ultimate disposal site is on land and both the disposal site and power plant are adjacent to waterways, conventional river barges would be used to transport the sludge.

Inland waterway barges are constructed to take maximum advantage of the width and length of the lock chambers through which they pass. The standard open-hopper barge is 175-ft long x 26-ft wide x 10 ft, 8 in. deep. The standard barge has a cargo compartment capacity of 26,191 ft^3 and an 8 ft, 9 in. draft when loaded with 1,000 net tons. Barges used on the Gulf of Mexico, Great Lakes, and oceans are covered with doors having a seal and a locking device to prevent water from entering the cargo compartment when the barges encounter swells.

A major consideration when barges are used to transport dry FGD sludge is barge loading and unloading. Standard barges usually are loaded and unloaded by stationary equipment with the barge moved and positioned under the stationary equipment. Traveling loading/unloading equipment usually requires very large vessels for economic justification.

Belt conveyors often are used to load standard barges with the barge moved under the discharge. The belt conveyor loader must be designed so that (1) discharge height can be adjusted to allow for changes of water level and barge draft as the barge is loaded and (2) the barge cargo can be trimmed to either side to keep the vessel on even keel. Often it is necessary to use a revolving spout or slinger attached to a conveyor discharge to properly distribute the sludge in the barge.

B.1.5 Short-Distance Transfer

Equipment for this purpose is used for feeding sludge at a controlled rate, for vertical short transfer from one processing step to another, or for sludge stocking or reclamation. The various types of short-distance-transfer equipment are discussed next.

Feeders

Feeders have very limited application in the transport of FGD sludges. The primary purpose of a feeder is to meter or control sludge feed rate within predetermined limits. In most cases, the conveyance is removing the dry sludge from process equipment as quickly as the sludge is discharged. Thus, there is no need for a feeder. However, if a feeder is necessary in certain instances, a belt feeder is the only type suitable for FGD sludges. Belt feeders are similar to belt conveyors with flat idlers and skirt plates to contain the sludge. The belt feeder should have belt scales to weigh the sludge on the belt and determine the rate of sludge discharge from the feeder. The discharge from the belt feeder usually is controlled by a gate or by varying the belt speed or travel rate.

Chutes

Chutes are vertical or inclined enclosures that guide and direct the sludge flow as the sludge is transported from a higher to a lower elevation by the force of gravity. Chutes usually are designed with a rectangular cross section with an open top or a removable cover for easy access to the chute interior to clean it out in case of plugging and to replace worn linings or protective coatings. A freely flowing chute that has little downtime due to plugging.

The rectangular chute is easy to fabricate from flat-plate steel. The chute should be of welded construction with a stiffening flange along the top edge of the side plates. This type of construction will provide the chute with some structural rigidity and facilitate the addition of a removable cover plate. If the sludge is abrasive or corrosive, the chute can be constructed of special steel or lined with rubber, plastic, or ceramic materials. If the sludge tends to stick to the surface and plug the chute, lining the chute with stainless steel or Teflon may be effective. If the chute is exposed to below-freezing temperatures, it may be necessary to insulate it or provide a means of heating it to prevent the sludge from freezing.

Front-End Loader

The front-end loader is available in a wide range of sizes, either mounted on crawler tracks or rubber-tired wheels. The front-end loader can be used as a loader for other transport vehicles or as a load-haul-dump vehicle. A typical application is reclaiming or loading sludge from a sludge pile into a truck. When used as a haulage vehicle, the front-end loader is usually limited to a maximum haul distance of 1,000 ft. The inherent characteristics of the crawler-mounted or track type front-end loader are (1) relatively slow travel speeds, (2) relatively high maintenance cost for abrasive materials, (3) relatively low ground-bearing pressure, (4) good steep slope capability, (5) strong digging ability, (6) relatively good maneuverability, and (7) good stability. In comparison, the inherent characteristics of the rubber-tired front-end loader are (1) high degree of mobility, (2) relatively low maintenance cost, (3) relatively high ground-bearing pressure, (4) good performance on gentle slopes, (5) ability to dig and transport its own load, and (6) need for maneuvering. Information on equipment specifications and proper sizing can be obtained from equipment manufacturers.

Bulldozers

Bulldozers are available in a wide range of sizes with both crawler tracks and rubber-tires and two- and all-wheel drives. Rubber-tired units are highly mobile with relatively low operating costs. Crawler units are used principally where ground conditions require units with low ground-bearing pressure with high stability. Bulldozers can be used for a variety of applications. These include transporting sludge over distances usually less than 400 ft by pushing the sludge and by assisting wheeled scrapers during loading. The bulldozer can be used for other construction purposes at the power station, so it is a popular, flexible tool. The inherent characteristics of the crawler and rubber-tired bulldozers are similar to those for crawler-mounted and rubber-tired front-end loaders.

A variety of bulldozer blade types are available, depending on the specific application. However, the straight blade and universal blade are the most common. The straight blade is the most versatile bulldozer blade and is excellent for land clearing, fill spreading, and final grading. The universal blade with its large wings is efficient for pushing sludge over longer distances as in stockpiling, charging hoppers, spreading fill, and reclaiming land.

Scraper

The wheeled or rubber-tired scraper digs its own load, transports, then dumps and spreads at the dump site. Wheeled scrapers can be used economically to transport sludge when haul distances are less than 4,000 ft. The use of scrapers eliminates the need for front-end loaders to load the transport vehicle. However, a bulldozer is usually needed to push the scraper for efficient loading. In addition, because scrapers operate on the surface of the sludge being removed during digging, the sludge surface must have adequate bearing pressure. At the present time, there is very little experience in transporting FGD sludge with scrapers, and additional experience is necessary before specific use recommendations can be developed.

The three basic types of wheeled-scrapers are conventional, tandem powered, and elevated scrapers. The conventional scraper is powered by the tractor and scraper wheels. The conventional and tandem scrapers usually require a bulldozer for assistance during loading, whereas the elevated scrapers are designed for self-loading. Elevated scrapers may be powered by the tractor wheels or both tractor and scraper wheels. Scraper capacities range from 10 to more than 50 yd^3. Equipment specifications for a particular application can be obtained from the equipment manufacturer.

B.2 WET WASTES

Conceptually, slurries can be transported by front-end loaders, trucks, railcars, barges, or pipelines. Of these, pipeline transport is the most practical means of slurry transport and the only system in current use. Of the 30 utility scrubber systems in operation on April 1, 1978, 18 employed pipeline transport of sludge. In this section, the only transport method considered for slurries is pipelines.

Slurries flowing in pipes may behave as homogeneous or heterogeneous suspensions. Homogeneous slurries are nonsettling slurries characterized by the uniform distribution of solid particles in the liquid medium. Homogeneous slurries usually require fine solid particles of low specific gravity and have a high percentage of solids.

Two distinct flow regimes may occur with homogeneous slurries: turbulent flow and laminar flow. Heterogeneous slurries are slurries characterized by coarse solid particles settling to the pipe bottom. Heterogeneous slurries usually contain coarse, poorly graded particles of a high specific gravity and a low percentage of solids. In heterogeneous slurries, concentration gradients exist with a higher percent solids at the pipe bottom. Three distinct flow regimes may occur with heterogeneous slurries. At high velocities, all the solids may be suspended with pseudohomogeneous flow. At a lower velocity, saltation or moving-bed flow occurs with larger particles bouncing along the pipe bottom. Moving-bed flow occurs over a narrow velocity range and friction losses are at a minimum. At a still-lower velocity, fixed-bed flow occurs with the finer particles moving over a stationary bed on the pipe bottom. Slight decreases in slurry velocity during fixed-bed flow may result in plugging. Slurry velocity should be about 1 ft/s higher than the particle-deposition velocity for heterogeneous slurries, whereas the minimum Reynolds number of 2100 to 4000 usually is the governing factor for homogeneous slurries. Most slurry pipelines are designed to operate with velocities between 4-10 ft/s.

Particle shape, size, and size distribution, and percentage of solids all affect viscosity, which, in turn, determines pumpability. A knowledge of viscosity is essential in determining system design and cost. Variation in temperature of the slurry will affect the slurry viscosity. In cold climates, it may be necessary to insulate storage tanks or heat the slurry lines to prevent freezing. Figure B.2 illustrates typical sludge viscosities as affected by the solids content.

The energy required to overcome the friction losses caused by the slurry flowing in the pipe and the elevation difference between intake and discharge usually is supplied by pumps. In some cases, pumps may not be required if the elevation of the slurry is lowered and gravitational force is adequate to overcome pipe friction losses.

A layout for FGD sludge disposal facilities establishes pipeline routes, including distances, elevations, and physical constraints. Pump overflows and pipeline drains should have controlled drainage to reduce clean-up costs. When the breakdown or plugging of a single pump or pipeline could reduce the power plant capacity and/or scrubber operation, standby pumps and pipelines are desirable.

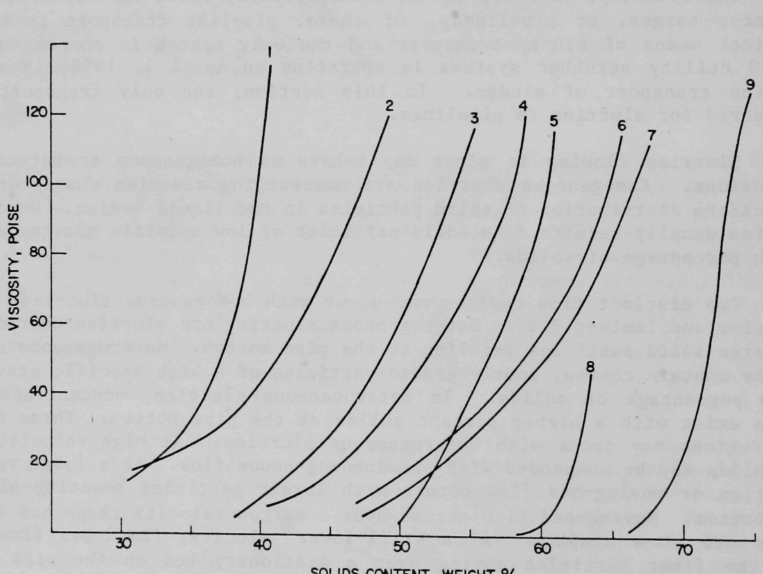

Fig. B.2 Viscosity of Typical Sludges (Source: Ref. 9)

B.2.1 Pumps

Pumps suitable for FGD sludge slurries are of two principal types: positive displacement and centrifugal. Both pump types have specific applications. In general, the positive displacement pump is used for long-distance pipelines, which have very high pressures or heads. The centrifugal pump is used for high flow rates and relatively low pressures.

Positive displacement pumps normally are considered for pressure above 500 lb/in.^{2} and can generate pressures of up to 2400 lb/in.^{2} Only positive displacement pumps can be utilized in high-pressure slurry applications because of casing pressure limitations of about 650 lb/in.^{2} for centrifugal pumps. The principal types of positive displacement pumps suitable for pumping FGD sludge slurries are (1) direct acting plunger or piston, (2) reciprocating oil-pressure transfer, and (3) direct-pressure transfer.

Direct-acting-plunger or piston-type pumps are the most common for pumping slurries. The plunger type is preferred over the piston type for abrasive slurries because the plunger can be flushed synchronously with clear water during the function stroke. For direct-acting plunger and piston-type pumps, the slurry is in direct contact with the pump's plunger or piston, cylinder, and valves. Thus, these parts are subject to wear, requiring replacement and resulting in high maintenance costs. However, flushing of the plunger-type pump during the suction stroke will prevent excessive wear.

For the reciprocating oil-pressure transfer-type pump, the plungers are operated in oil and pressure is transferred from the oil to the slurry in intermediate pressure chambers. This arrangement eliminates slurry wear on the pump's plungers and cylinder because only the valves are in contact with the slurry.

The advantage of positive-displacement pumps is the ability to produce high pumping pressures with relatively high efficiency. The disadvantages are the high capital cost; the need for high power, low-speed drive and speed reducers; the high wear rate for plungers or pistons, cylinders and valves; the limitation of a maximum particle size of about 1/8 in.; and limited volumetric capacity. Because positive-displacement pumps have limited volumetric capacity, several pumps usually are required to operate in parallel. Manufacturers should be consulted for additional information.

Centrifugal slurry pumps are suitable for pressures or heads in excess of 100 lb/in.^{2} per pumping stage; these pumps can be operated in series to produce pressures up to 600-800 lb/in.^{2} Characteristically, a slurry pump is larger than a conventional water pump of comparable pressure and capacity.

The wetted parts of the slurry pump usually are made of an alloy with hardness of approximately 600 Brinell. To reduce wear, the wetted parts are often lined with elastomeric materials such as natural rubber, neoprene, butyl rubber, or other synthetics. Rubber has the ability to withstand the most abrasion and will outlast the hardest allowy. However, rubber lacks mechanical strength and must be fully supported or reinforced. Thus, the use of rubber in high head centrifugal pumps is limited, and special design and pump construction are needed to avoid rubber breakdown at points of high energy dissipation. Suitable elastomer liners reduce direct impact wear, which is the most serious problem in pump maintenance.

Centrifugal slurry pump design requires balancing between pump efficiency or hydraulic performance and the wear life of the wetted parts. Large diameter impellers are operated at lower speeds and, therefore, reduce wear at the vane inlet. However, larger impellers result in lower pump efficiency.

Because centrifugal slurry pumps are limited in pumping pressure, centrifugal pumps are operated in series for high pumping pressure applications, such as long-distance pipelines. Centrifugal slurry pumps may be installed in series by placing several closely coupled pumps in one pumping station or placing single pumps at spaced intervals along the pipeline. The advantages of placing closely coupled pumps in one station are (1) simplicity of control, inspection, and operation; (2) a single electrical-distribution system; (3) centralized electrical controls and instrumentation; and (4) centralized maintenance and spare-parts handling. The principal disadvantage is the negative effect of the high slurry pressure on pump glands, bearings and casing, and on the pipeline.

Centrifugal slurry pumps can be operated in parallel to multiply pumping capacity. Pumps also are installed in parallel so that pumping can continue while a pump is down for maintenance.

Interlocked controls for pumps are necessary to assure continuous sludge slurry pumping and plant operation and to insure that startup and shutdown of the entire process and pipeline occur in proper sequence. The interlock should provide for emergency shutdown in case of equipment failure or an accident requiring immediate shutdown of a specific pumping station.

B.2.2 Pipelines

The principal materials used for pipelines are steel, rubber-lined steel, rubber hose, and plastic. Steel is the most common pipeline material. Steel pipes are easy to install, are relatively easy to support because of the rigidity of the pipe, and have reasonable wear resistance.

Rubber-lined steel pipe usually consists of a 50-100 mm rubber lining cemented inside standard or thin-wall steel pipe. The wear resistance of rubber-lined pipe is many times greater than the wear resistance of plain steel pipe. Thus, rubber-lined steel pipe should be considered if the FGD sludge is highly abrasive.

Rubber hoses commonly are used for short piping applications and for easy disassembly where plugging may occur. The rubber hose is flexible and easy to install. It has high wear resistance and often is used for high wear points such as bends in piping systems. The rubber hose is available in diameters up to 30 in. for use with pressures up to 250 $lb/in.^2$ The rubber hose consists of a lining, carcass, and cover. The lining usually is 25- to 50-mm-thick rubber. Rubber hose in smaller sizes has been used to facilitate scale removal in locations where buildups may be encountered.

Plastic-lined steel pipe is comparable in erosion resistance to rubber-lined steel pipe. Polyurethane linings are used steel pipes to increase pipe life for abrasive materials. Some difficulty has been experienced with loosening of the lining. Plastic pipe is made entirely of plastic in diameters up to 40 in. High-density polyethylene- or fiberglass-reinforced plastics have been used in some cases. Results have been varied; a number of failures have occurred at flanged joints. Polyethylene has a limited high-temperature range up to about 120°F and a high thermal expansion. Plastic pipe usually must be fully supported, either by support structures or the ground.

Slurry pipelines require valves to control the slurry flow. The valve types used for slurry applications are pinch, diaphragm, plug, ball, and gate valves.

- The pinch valve consists of a length of rubber-lined hose with an external clamp with no wetted parts. Pinch valves can be operated manually or hydraulically and are used as process control valves. Pinch valves are available for pipe diameters up to 20 in. and for pressures up to 85 $lb/in.^2$
- Diaphragm valves operate similarly to pinch valves but with a moving diaphragm closing against a fixed valve body. The diaphragm valve also can be operated manually or hydraulically and is used frequently as a process control valve.
- A plug valve consists of the plug and valve body. The plug valve is suitable for relatively high pressures and fine slurries. The plug valve can be operated manually or mechanically.
- Ball valves are similar to plug valves. Ball valves are not as abrasion-resistant to slurries as plug valves and generally are not recommended for slurry applications.
- Gate valves consist of gate, seal, and valve body. Gate valves are not recommended for abrasive slurries but are suitable for nonabrasive slurries and for supernatant.

Slurry pipes must have "cleanouts" to clear plugged lines and to drain lines when they are shut down. Cleanouts should be readily accessible and have space for the use of tools and equipment. Cleanouts are located at tees, elbows, and line low points with removable plugs installed in the fitting or pipe. Pipe drainage from cleanouts should be controlled for convenient cleanup. Facilities for back flushing with clean water may be advisable at some locations.

In cold climates, freezing of the slurry in the pipe can cause serious operating difficulties. Except in long-distance pipelines, the slurry will not freeze as long as the slurry is kept in motion. However, if the pipeline is shut down and all the slurry is not drained quickly from the pipes, freezing can occur. To provide a longer possible downtime without draining the pipeline, the pipes can be insulated or equipped with heating equipment. In some instances, the pipeline can be buried below the frost line, but this option will increase both installation and maintenance costs. Below-ground installation was used for part of the pipeline runs at the Bruce Mansfield Plant of the Pennsylvania Power Company.

REFERENCES

1. *FGD Sludge Disposal Manual*, prepared by Michael Baker, Jr., Inc., Electric Power Research Institute Report EPRI FP-977 (Jan. 1979).

2. *Coal Ash Disposal Manual*, Electric Power Research Institute Report EPRI FP-1257 (Dec. 1979).

3. Rossoff, J., et al., *Disposal of By-Products from Nonregenerable Gas Desulfurization Systems: Second Progress Report*, prepared by the Aerospace Corp., U.S. Environmental Protection Agency Report EPA-600/7-77-052 (May 1977).

4. *Study of Non-Hazardous Wastes from Coal-Fired Electric Utilities*, Radian Corp. Report DCN 80-202-187-41-20 (May 1980).

5. *The Northeast Regional Environmental Impact Study: Waste Disposal Technical Report*, U.S. Department of Energy Report DOE/RG-0058 (April 1981).

6. *Environmental Impact Statement of the Cumulative and Interactive Impacts of Coal Conversion in the Northeast*, U.S. Department of Energy Report Final Draft (Sept. 1981).

7. Meier, P., et al., *An Assessment of the Solid Waste Impact of the National Energy Plan*, Brookhaven National Laboratory Report BNL-50708 (Feb. 1978).

8. *New Source Performance Standards Analysis of Solid Waste Impacts for Industrial Boilers, Vol. 5*, Argonne National Laboratory Report ANL/EES-TM-107 (1980).

9. *Technology Characterizations Environmental Information Handbook*, U.S. Department of Energy Report DOE/EV-002 (June 1980).

10. *Simplified Procedures for Estimating Flue Gas Desulfurization Costs*, U.S. Environmental Protection Agency Report EPA-600/2-76-150, (1976).

11. *Electric Utility Steam Generating Units: Background Information for Proposed Particulate Matter Emission Standards*, U.S. Environmental Protection Agency Report EPA-450/2-78/006A, (1978).

12. *EPA Industrial Boiler FGD Survey: First Quarter 1979*, U.S. Environmental Protection Agency Report EPA/600/7-79/067B, (1979).

13. Le, Tien, et al., *The Solid Waste Impacts of Increased Coal Utilization*, Draft, Brookhaven National Laboratory Report BNL-24786 (Aug. 1978).

14. *An Evaluation of the Disposal of Flue Gas Desulfurization Wastes in Mines and the Ocean: Initial Assessment*, U.S. Environmental Protection Agency Report EPA/600/7-77/051, (May 1977).

15. *Environmental Outlook 1980*, U.S. Environmental Protection Agency Report EPA-600/8-80/003 (July 1980).

16. *Control Technology and Waste Management*, U.S. Environmental Protection Agency Report EPA 600/9-79-019 (May 1979).

17. Weaver, D.E., C.J. Schmidt, and J.P. Woodyard, *Data Base for Standards/Regulations Development for Land Disposal of Flue Gas Cleaning Sludges*, prepared by SCS Engineers, Long Beach, Calif., U.S. Environmental Protection Agency Report EPA-600/7-77-118 (Dec. 1977).

18. Knight, R.G., E.H. Rothfuss, and K.D. Yard, *FGD Sludge Disposal Manual*, Second Ed., prepared by Michael Baker, Jr., Inc., Electric Power Research Institute Report CS-1515 (Sept. 1980).

19. Baker, J.E., and D.G. Streets, *New Source Performance Standards for Industrial Boilers: Vol. 4, Control Technology Overview*, Argonne National Laboratory Report ANL/EES-TM-106 (Dec. 1980).

20. Johnson, S.L., and R.R. Lunt, *Mine Disposal of FGD Waste*, Symp. on Flue Gas Desulfurization, Vol. II, Hollywood, Fla., U.S. Environmental Protection Agency Report EPA-600/7-78-058B (Nov. 1977).

21. DeVitt, T.W., and B.A. Laseke, *Utility Flue Gas Desulfurization in the U.S.*, Chemical Engineering Progress, pp. 45-57 (May 1980).

22. Dickerman, J.C., and K.L. Johnson, *Technology Assessment Report for Industrial Boiler Applications: Flue Gas Desulfurization*, prepared by Radian Corp., U.S. Environmental Protection Agency Report EPA-600/7-79-1781 (Nov. 1979).

23. Young, C.W., et al., *Technology Assessment Report for Industrial Boiler Applications: Fluidized-Bed Combustion*, prepared by GCA/Technology Division, U.S. Environmental Protection Agency Report EPA-600/7-79-178E (Nov. 1979).

24. Ehrenfeld, J.R., Energy Resources Company, Inc., personal communication (Feb. 1978).

25. Sun, C.C., C.H. Peterson, and D.L. Keairns, *Environmental Impact of the Disposal of Processed and Unprocessed FBC Bed Material and Carry-Over*, Proc. Fifth International Conf. on Fluidized-Bed Combustion, Vol. II, pp. 846-871 (Dec. 1977).

BIBLIOGRAPHY

An Assessment of National Consequences of Increased Coal Utilization: Executive Summary, Vol. II, U.S. Department of Energy Report TID29425 (Feb. 1979).

Annual Report of the ABA Coal Committee 1979 Developments, Natural Resources Lawyer V. 3n2, p. 299 (1980).

Anoau, A.H., J.E. Oven, and L.H. Haynes, *1979 Utility Wastes Proposal Options: A Comparative Study*, pp. 265-290, In Coal Technology, 1979, Proc. of the Second International Coal Utilization Conf. and Exhibition, Houston, Tex. (Nov. 1979).

Bern, J., R. Neufeld, and M. Shapiro, *Solid Waste Management of Coal Conversion Residuals from a Commercial-size Facility and Environmental Engineering Aspects*, prepared by the University of Pittsburgh, U.S. Department of Energy Report DOE/ET/20023-5 (Nov. 1980).

Braunstein, H.M., *Environmental and Health Aspects of Disposal of Solid Wastes from Coal Conversion*, Oak Ridge National Laboratory Report ORNL-5361 (Sept. 1978).

Chiu, S.H., et al., *Problems Associated with Solid Wastes from Energy Systems*, Argonne National Laboratory Report ANL/EES-TM-118 (Sept. 1980).

Christman, R.C., et al., *Activities, Effects and Impacts of the Coal Fuel Cycle for a 1,000 MWe Electric Power Generating Plant*, Final Report, prepared by the Teknekron Research Company, U.S. Nuclear Regulatory Commission Report NUREG/CR-1060 (Feb. 1980).

Destefanis, R., *The Handling and Transport of Power Plant Scrubber Sludge Wastes*, Proc. of the American Power Conf. Report No. 718-731, Vol. 38 (1976).

Devitt, T., P. Spaite, and L. Gibbs, *Population and Characteristics of Industrial/Commercial Boilers in the U.S.*, prepared by PEDCo Environmental, Inc., U.S. Environmental Protection Agency Report EPA-600/7-79-178A (Aug. 1979).

Dvorak, A.J., et al., *Impacts of Coal-Fired Power Plants on Fish, Wildlife, and Their Habitats*, prepared by Argonne National Laboratory, U.S. Fish and Wildlife Service, Office of Biological Service Report FWS/OBS-7/29 (Mar. 1978).

Economics of Disposal of Lime/Limestone Scrubbing Wastes: Untreated and Chemically Treated Wastes, U.S. Environmental Protection Agency Report EPA-600/7-78-023A (1978).

Ehlich, W.F., (1977) *Transport of Sewage Sludge*, prepared by Culp/Wesner/Culp, U.S. Environmental Protection Agency Report EPA-600/2-77-216 (Dec. 1977).

Environmental Control Implications of Generating Electric Power from Coal, Technology Status Report, Vol. II, Argonne National Laboratory Report ANL/ECT-1 (1976).

Lacombe, D.M., *An Overview of Solid Waste Generation in the United States*, Los Alamos Scientific Laboratory Report LA-8172-[illegible]

Leo, P.P., and J. Rossoff, *Controlling SO_2 Emissions from Coal-Fired Steam Electric Generators: Solid Waste Impact*, Vol. II, Technical Discussion, prepared by the Aerospace Corp., U.S. Environmental Protection Agency Report EPA-600/7-78-0448 (Mar. 1978).

Phillips, N.P., and R.M. Wells, *Solid Waste Disposal, Final Report*, prepared by the Radian Corp., U.S. Environmental Protection Agency, EPA-65072-74-033 (May 1974).

Power from Coal, a special report, Power (Feb. 1974).

Ray, S.S., and F.G. Parker, *Characterization of Ash from Coal-Fired Power Plants*, prepared by the Tennessee Valley Authority, U.S. Environmental Protection Agency Report EPA-600/7-77-010 (Jan. 1977).

Rogers, S.E., et al., *Environmental Assessment of Coal Cleaning Processes: Homer City Power Complex Testing*, prepared by Batelle Columbus Laboratories U.S. Environmental Protection Agency Report EPA-600/7-79-0737 (Sept. 1979).

Rossoff, J., et al., *Control of Waste and Water Pollution from Coal-Fired Power Plants*, Second R&D Report, prepared by the Aerospace Corp., U.S. Environmental Protection Agency Report EPA-600/7-78-224 (Nov. 1978).

Santhanam, C.J., et al., *Health and Environmental Impact of Increased Generation of Coal Ash and FGD Sludges*, Environmental Perspective, Vol. 33 (Dec. 1979).

Santhanam, C.J., et al., *Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979*, Vol. II, Executive Summary, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7-80-012 (Jan. 1980).

Santhanam, C.J., et al., *Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979*, Vol. III, Generation and Characterization of *FGD Wastes*, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7-80-012C (March 1980).

Santhanam, C.J., et al., *Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979*, Vol. V, Disposal, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7/80-012E (March 1980).

Scholt, L.F., et al., *Handling of Combustion and Emission Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources*, U.S. Fish and Wildlife Service, Office of Biological Services Report FWS/OBS-80/33, p. 184 (1980).

Streets, D., et al., *An Environmental Assessment of a Program to Reduce Oil and Gas Consumption by Electric Utilities*, Argonne National Laboratory Report ANL/EES-TM-97 (Mar. 1980).

Utility Analysis of Coal Transportation Availability, Final Report, prepared by the Energy Resources Company, Inc., U.S. Department of Energy Report HCP/B60573-01 (Sept. 1976).

Leo, P.P., and J. Rossoff, Controlling SO_2 Emissions from Coal-Fired Steam Electric Generators: Solid Waste Impact, Vol. II, Technical Discussion, prepared by the Aerospace Corp., U.S. Environmental Protection Agency Report EPA-600/7-78-044b (Mar. 1978).

Phillips, N.P., and R.M. Wells, Solid Waste Disposal, Final Report, prepared by the Radian Corp., U.S. Environmental Protection Agency, EPA-650/2-74-033 (May 1974).

Power from Coal, a special report, Power (Feb. 1974).

Ray, S.S., and F.G. Parker, Characterization of Ash from Coal-Fired Power Plants, prepared by the Tennessee Valley Authority, U.S. Environmental Protection Agency Report EPA-600/7-77-010 (Jan. 1977).

Rogers, S.E., et al., Environmental Assessment of Coal Cleaning Processes: Homer City Power Complex Testing, prepared by Battelle Columbus Laboratories, U.S. Environmental Protection Agency Report EPA-600/7-79-0127 (Sept. 1979).

Rossoff, J., et al., Control of Waste and Water Pollution from Coal-Fired Power Plants, Second R&D Report, prepared by the Aerospace Corp., U.S. Environmental Protection Agency Report EPA-600/7-78-224 (Nov. 1978).

Santhanam, C.J., et al., Health and Environmental Impacts of Increased Generation of Coal Ash and FGD Sludges, Environmental Health Perspectives, Vol. 33 (Dec. 1979).

Santhanam, C.J., et al., Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979, Vol. II, Executive Summary, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7-80-012 (Jan. 1980).

Santhanam, C.J., et al., Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979, Vol. III, Generation and Characterization of FGC Wastes, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7-80-012c (March 1980).

Santhanam, C.J., et al., Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979, Vol. V, Disposal, prepared by A.D. Little, U.S. Environmental Protection Agency Report EPA-600/7-80-012e (March 1980).

Schmitt, D.T., et al., [illegible] of Combustion and Emission Pollutants from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources, U.S. Fish and Wildlife Service, Office of Biological Services Report FWS/OBS-80/53, p. 189 (1980).

Streets, D., et al., An Environmental Assessment of a Program to Reduce Oil and Gas Consumption by Electric Utilities, Argonne National Laboratory Report ANL/EES-TM-97 (Mar. 1980).

[illegible] Analysis of Coal Transportation Capability, Final Report, prepared by the Energy Resources Company, Inc., U.S. Department of Energy Report HCP/R6-0523-01 (Sept. 1978).