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Project Summary

Waste and Water Management for Conventional Coal Combustion: Assessment Report-1980

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The report gives results of a study of sintering and leaching mechanisms of fly ash/spent sodium sorbent mixtures from a dry injection flue gas desulfurization (FGD) process. It includes an estimate of the economics of pelletizing and sintering to handle the fly ash and spent sorbent from a 500 MW power plant burning low sulfur western coal using a dry injection FGD process. The process includes dual disc pelletizing circuits and a furnace with an output of nearly 717 tonnes/day of pellets sintered to a temperature of 950-1000°C. In laboratory tests, pellets with fly ash and either spent nahcolite or spent trona (both reacted with SO_2), when thermally treated at 1000°C and mildly stirred in water for 100 hrs, lost 30-60 percent of the total sulfur in the pellets as SO_2 evolved or SO_4 leached. Under similar conditions, 3-15 percent of the available sodium leached. Encapsulating the dried pellets (or pellets fired at 925°C in concrete or asphalt mixes) did not significantly inhibit the leaching in water of the soluble alkaline sulfates from the pellets. Cured concrete and asphalt samples containing pellets on a 20-percent-by-volume substitution for limestone aggregate exhibited losses in compressive strength of 50 and 75 percent, respectively. Estimated capital cost is $40.55/kW. The levelized annual revenue requirement is nearly 4.92 mills/kWh.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report gives results of the assembly, review, evaluation, and reporting of data from research and development (R&D) as well as commercial activities as of mid-1980 in the areas of (1) flue gas cleaning (FGC) waste disposal/utilization, and (2) power plant water management, including recycle/treatment and reuse.

The purpose of these efforts was to assist EPA in conducting an on-going R&D program in these two areas. The full report on this effort supplements a five-volume 1979 assessment report published early in 1980 [1].

This assessment focuses on:

- Evaluation of the technical, regulatory, economic, and environmental aspects of FGC waste disposal/utilization with emphasis on the effects of these factors on the feasibility and cost of various disposal/utilization options. Recommendations were made on measures to fill information gaps, including research to develop additional data.
- Evaluation of the technical, regulatory, engineering/economic, and environmental aspects of power plant water recycle/treatment/reuse. Again, recommendations were made to cover gaps existing in 1980.

EPA's Waste and Water Program

Since 1974, the EPA has conducted an on-going program of research on waste and water management for coal-fired boilers.

This program, referred to as a Waste and Water Program, has had as its objective the evaluation, development, demonstration, and recommendation of environmentally acceptable, cost-effective technology **for FGC waste disposal/utilization and power plant water recycle/treatment/reuse. EPA's Waste and Water Program included five major areas, three of which are within the scope of this report: FGC waste disposal, FGC waste utilization, water utilization/treatment, cooling technology, and waste heat utilization.**

Waste and Water Program projects ongoing in 1980 are summarized in Table 1. Those pertaining to cooling technology or waste heat utilization, outside the scope of this report, are not listed.

Background on Coal-Fired Boilers

In 1980, more than 340 steam electric plants in the U.S. utilized coal for 80% or more of their power generation and had a nameplate capacity >25 MW. During 1980-1995, 236 more new coal-fired plants with a total generating capacity >125,000 MW are anticipated. In addition, a number of plants are likely to be converted to coal from other fossil fuels (oil and gas).

As coal utilization in utility and large industrial boilers increases, the quantity of FGC wastes (i.e., coal ash and flue gas desulfurization (FGD) wastes) will increase dramatically. Most of these FGC wastes will be disposed of. Over the longer term, utilization is expected to grow but at a slower rate than that of FGC waste generation. Table 2 projects coal ash and FGD wastes through 1995 based on projections of coal utilization, regulatory requirements, and anticipated FGC practice. Several factors will increase the sources and total volume of waste and influence disposal options in the coming year:

- An increase in coal-fired capacity in the U.S. Total U.S. coal-fired electric utility generating capactiy, estimated at >191,000 MW in 1976, is expected to increase to >330,000 MW by 1988 [2,3].

Table 1. *Ongoing Projects in EPA'S Water and Waste Program (1980)*

Project Title	*Contractor/Agency*	*Environmental & Assessment*	*Technology Assessment & Development*	*Economic Assessment*	*Characterization*
FGC WASTE DISPOSAL					
1. *Characterization and Environmental Monitoring of Full-Scale Utility Waste Disposal Sites*	*Arthur D. Little, Inc.*	X	X	X	X
2. *Assessment of Technology for Control of Waste and Water Pollution*	*Arthur D. Little, Inc.*	X	X	X	X
3. *Disposal of By-Products from Non-Regenerable FGD Systems*	*The Aerospace Corporation*	X	X	X	X
4. *Dewatering of FGC Wastes by Gravity Sedimentation*	*Auburn University*		X	X	
5. *Environmental Assessment of Coal Combustion Waste Disposal in Ocean Waters*	*State University of New York at Stony Brook*	X	X	X	X
6. *Evaluation of FGD Waste Disposal in Mines and Ocean*	*Arthur D. Little, Inc.*	X	X	X	
7. *Toxicity of Leachates*	*Oak Ridge National Laboratory*				X
8. *Ash Characterization and Disposal*	*Tennessee Valley Authority*	X	X	X	X
9. *Shawnee FGC Waste Disposal Field Evaluation*	*TVA and Aerospace*	X	X	X	X
10. *Economics of Ash Disposal at Coal-Fired Power Plants*	*TVA*			X	
11. *Studies of Attenuation of Leachate by Soils*	*U.S. Army - Dugway Proving Ground*	X			
12. *FGC Waste Leachate/Liner Compatibility Studies*	*U.S. Army Corps of Engineers*	X	X	X	
FGC WASTE UTILIZATION					
1. *FGC Waste By-Product Marketing*	*TVA*			X	
WATER UTILIZATION AND TREATMENT					
1. *Pilot-Scale Investigation of Closed-Loop Ash Sluicing*	*Radian Corporation*	X	X		X
2. *Characterization of Effluents from Coal-Fired Power Plants*	*TVA*	X	X		X
3. *Assessment of Various Technologies for Treating Cooling Tower Blowdown*	*Bechtel National, Inc.*		X	X	
4. *Feasibility of Ultrasonic and Other Methods for Direct Measurement of Condenser Biofouling*	*Radian Corporation*		X		

Table 2. *Projections of FGC Waste Generation by Utility Plants in the U.S. (1980-1995)*[a]

Waste Type	*Waste Generation, 10^6 metric tons/yr (10^6 tons/yr)*		
	1980	*1985*	*1995*
Coal Ash[b]	*62.4*	*83.2*	*110.0*
FGD Wastes[c]	*8.6*	*26.9*	*48.6*
TOTAL	*71.0 (78.3)*	*110.1 (121.4)*	*158.6 (174.8)*

[a] *Source: Arthur D. Little, Inc. estimates.*
[b] *Coal ash quantities are on a dry basis.*
[c] *FGD waste quantities are on a wet basis (50% solids).*

- A major increase in the application of FGD technology by utilities and a consequent increase in FGD waste generation. In 1980, > 27,000 MW of generating capacity utilized FGD systems, and > 95,000 MW of gross generating capacity (approx. 72,000 MW scrubbed capacity) was committed (i.e., under construction contract awards, or operating) to FGD systems [4].
- Advances in commercial FGD waste stabilization technology. These wastes can be converted into moist soil-like material by processes that usually involve adding lime and fly ash. This conversion permits landfill disposal of partially dewatered solids. In the future, disposal of wastes in managed landfills (as opposed to ponds) is likely to be encouraged.
- Environmental regulatory developments involving the Clean Air Act Amendments of 1977 and the Resource Conservation and Recovery Act (RCRA).

Regulatory Considerations

Regulatory Overview

The disposal of FGC wastes is subject to regulations at both Federal and state levels. In 1980, FGC wastes were disposed of exclusively on land. In the future, at-sea disposal may be carried out to a limited extent in regions with few available land disposal sites.

Four major environmental issues concern land disposal of wastes: waste stability/consolidation, groundwater contamination, surface water contamination, and fugitive emissions.

These are regulated under the federal legislative framework involving RCRA, the Clean Air Act (CAA), Clean Water Act (CWA), and other laws. RCRA is the major federal environmental legislation aimed at regulating disposal in landfills and impoundments.

Present Regulatory Framework

Since the publication of the 1979 assessment report [1], the basic regulatory framework governing water and waste management for conventional coal combustion has remained intact. However, a number of developments were expected to have significant impact on how the utilities and other industries deal with coal combustion and its waste streams.

The EPA, either directly or by delegation to and oversight of state environmental agencies, continued to have ultimate responsibility for the environmental regulatory aspects of water and waste management. EPA's Effluent Guidelines Division issued revised proposed regulations for the steam electric generating industry late in 1980 [5]. These are particularly important with respect to coal ash handling procedures and a number of water management practices.

In the area of solid waste management, the EPA issued Final Regulations for classifying (non-hazardous) disposal facilities in September 1979; and for generators of hazardous wastes, in May 1980 [6,7]. At least 51% of the solid wastes from conventional coal combustion (i.e., fly ash, bottom ash, and FGD waste) were explicitly deferred from the coverage of the latter regulations pending anticipated Congressional action (Amendments to RCRA) and further studies regarding the need for and nature of appropriate controls. In October 1980, the anticipated Amendments to RCRA were passed and studies (on utility solid waste disposal practice) called for by the RCRA Amendment were underway.

The EPA and other agencies also continued to issue other regulations affecting the extent of generation and management of coal and coal-combustion waste. In 1979-80, there was further work on NSPS for gaseous and particulate emissions [8], and an increasing number of fuel switching (i.e., oil and gas to coal) orders from the Economic Regulatory Administration pursuant to the 1978 Fuel Use Act that can add to FGC waste generation. In addition, the Department of Interior (Office of Surface Mining)--the primary agency concerned with mine disposal of coal-related wastes--further clarified aspects of (1) non-coal waste disposal in surface mines, and (2) its permanent regulatory program for surface mining of coal. Both items are relevant to the subjects covered in this report. Finally, additional activity occurred in EPA's effort to implement Section 6002 of RCRA, which deals with guidelines for federal procurement of products derived from recycled (e.g., waste) materials. Specifically, EPA addressed the use of fly ash in concrete, with promulgation of guidelines on federal procurement expected in late 1980.

Water Management

Steam electric boilers rank second only to agriculture in total water withdrawals from national sources. Since most of this water is for cooling and ash transport, steam-electric power generation is the largest direct discharger of water to surface water bodies of any water-using sector. Several studies on water management were underway, sponsored by EPA, EPRI, and other organizations. The efforts covered by this report focus on: (1) dry handling technologies for FGC waste disposal; (2) changes in cooling tower design, operation, and maintenance practices to minimize water intake and/or blowdown; (3) biofouling control for condensers in once-through cooling systems leading to the reduction of use of some biofouling agents; and (4) use of advanced technologies to prepare wastewaters for recycling and reuse.

The trend toward dry fly ash handling and disposal in new power plants appears to be growing. Dry handling of fly ash eliminates fly ash sluice water as a discharge, and eliminates potentially complex chemical problems connected with closed-loop ash sluicing operations. Reportedly, nearly half of the coal-fired power plants in the U.S. could use dry handling methods [1].

Dry sorbent FGD systems are making very substantial inroads affecting water management by reducing the impact of wet scrubbing FGD methods. As of late 1980, about 11 orders had been placed for utility and industrial boiler applications of dry sorbent systems [4]. Side stream water treatment of ash sluice water was to be investigated on a pilot scale under an EPA-sponsored effort.

The cooling system is by far the largest user and consumer of water in a power plant. Work is underway to limit cooling tower makeup and water pollution by limiting cooling tower blowdown. On the other hand, projections of water shortages, particularly in the West, may encourage dry or wet/dry hybrid systems. Therefore, work is also underway to gain commercial experience on wet/dry and dry cooling towers with a goal of reduced water evaporation per kilowatt hour generated. It appears that wet/dry cooling towers will provide better performance and better overall economics than fully dry cooling systems. While the direct environmental effects of dry and wet/dry systems are low, greater energy requirements may offset this advantage to some extent.

Recycle and reuse of power plant waste streams are generally undertaken to reduce water consumption and meet regulatory requirements. Two approaches to water recycle/treatment reuse continue to be emphasized: (1) coordination or cascading of effluent streams from plant process units; and (2) application of treatment techniques to allow water reuse, (usually through recycle) which may not be otherwise practicable. Method (1) involves the hierarchy of water reuses, with waste from one stream used as a feed to another to utilize the water repeatedly prior to any treatment, recycle, or discharge. Usually, such methods do not require unconventional equipment, but they do require tighter operational controls and place greater demands on skills of the operators. Water treatment techniques may involve additional technologies and can potentially promote utilization of water within a water-use hierarchy. Treatment can vary and may utilize specialized technologies not conventionally part of traditional power plant water management. To minimize raw water consumption, some power plants are using unconventional water sources; e.g., secondary treated waste water from sewage treatment plants.

Work is underway to limit the impact of chlorination by shifting to minimum chlorination practices. Alternative biocides (e.g., bromine chloride and chlorine dioxide) are being investigated. Dechlorination by SO_2 has been studied. Consideration of the potential impacts of physical biofouling systems is also underway. A number of technologies (e.g., distillation, reverse osmosis, and foam evaporation) were also under investigation for treatment of various side streams.

Generation of FGC Wastes

Ash Collection Technology

Coal-fired utility and industrial boilers generate two types of coal ash--fly ash and bottom ash. Fly ash, which accounts for most of the ash generated, is the fine fraction carried out of the boiler in the flue gas. Bottom ash drops to the bottom of the boiler and is collected either as boiler slag or dry bottom ash, depending on the type of boiler.

Collection of bottom ash (or boiler slag) does not involve systems outside the boiler. Fly ash, however, is a major source of particulate emissions and (with regulatory requirements) has required major collection systems. Control of particulate emissions from pulverized-coal-fired steam generators was rapidly becoming a significant factor in the siting and public acceptability of coal-burning power plants.

Typical methods of fly ash collection include mechanical collection, electrostatic precipitation, fabric filtration, and wet scrubbing. However, only electrostatic precipitators (ESPS) and bag filters can meet the requirements in the foreseeable future. A significant development over the past few years has been the growing use of bag filters and associated dry handling methods, although ESPS still represent most of the control equipment.

FGD Technology

The implementation of FGD technology on industrial and utility boilers is rapidly growing in the U.S. As of June 1980, FGD systems were in operation on >27,000 MW of utility generating capacity at some 73 different units [4] throughout the U.S., and more than 40 industrial steam plants were equipped with FGD systems. The degree of SO_2 control ranges from < 50% SO_2 removal efficiency to >90%, depending on the type of FGD system, the sulfur content of the fuel, and the applicable SO_2 emission regulations.

The growth in FGD systems over the next 20 years will depend principally on the growth in utility and industrial boiler capacity, current and future SO_2 emissions regulations, and the impact of alternative desulfurization approaches (e.g., existing and enhanced coal-cleaning techniques) on current and developing FGD technology.

In general, FGD processes are designated as either nonrecovery (throwaway) systems, which produce a waste material for disposal; or recovery systems, which produce a saleable byproduct (either sulfur or sulfuric acid) from the recovered SO_2. Nonrecovery processes make up the overwhelming majority of the technology. Of the 11 commercially available processes and process variations, 8 are throwaway systems. These eight constitute more than 95% of the capacity in operation on utility and industrial boilers, a trend which was expected to continue for the foreseeable future.

Disposal/Utilization

One of the most effective ways of managing the FGC waste problem is to utilize the coal ash and FGD wastes. A significant fraction of the total generation of coal ash is utilized. However, through 1980, there had been no utilization of FGD wastes in the U.S.; several studies on utilization opportunities had been sponsored by the EPA [1]. On balance, disposal will continue to be the major option for FGC waste management in the U.S.

Several methods are potentially available for the disposal of FGC wastes both on land and at sea. Disposal options for FGC can be broadly categorized on the basis of the nature of the wastes and the type of disposal. Table 3 lists potentially applicable disposal options.

Disposal Technology for Industrial Boiler FGC Wastes

An important development of the past few years is the growing use of coal in industrial boilers. Thus, management of water and wastes associated with coal-fired industrial boilers is expected to grow in the future. Table 4 provides some estimates on FGC waste generation by industrial boilers.

The sodium throwaway process, used more often than all other FGD systems combined in industrial applications, produces a liquid waste stream. Common practice is to discharge this stream to an evaporation pond or to an existing water treatment plant. The use of evaporation ponds is more prevalent (most of these systems are used on oil-field steam generators in California); however, this approach is restricted to areas with adequate net evaporation. Some sodium scrubbing systems (e.g., in paper mills and textile plants) use a waste process stream containing sodium as the scrubber feed. The waste is then recombined with process waste streams before discharge to a water treatment plant. Similarly, ammonia-containing waste streams are also used as scrubber feed.

FGD sludges from the lime/limestone or dual alkali systems in industrial boilers are disposed of in wet or dry impoundments. Disposal methods include lined and unlined ponding and landfilling. Treatment may include dewatering, adding alkaline ash, and/or applying commercial stabilization technology.

Coal ash which is not combined with other wastes or marketed is usually dis-

Table 3. *Potential Disposal Options*[a]

	Ash	FGD Waste	Ash/FGD Waste Codisposal
Land			
Wet Impoundments - Conventional	C[b]	C	C
Gypsum Stacking	-	P[c]	P
Dry Impoundment	C	C	C
Surface Mine	C	P	C
Underground Mine	C	P	P
At-sea Disposal			
Shallow		P	P
Deep		P	P

[a] *Source: Arthur D. Little, Inc.*
[b] *C = Commercial Practice.*
[c] *P = Reasonable Potential.*

Table 4. *FGC Waste Generation by Industrial Boilers*[a]

	(10⁶ metric tons)		
	1980	1985	2000
Coal Ash	7.5	9.0	14.4
FGD Waste[b]	0.9	1.5	6.1
TOTAL	8.4	10.5	20.5

[a] *Source: Arthur D. Little, Inc. estimates.*
[b] *FGD wastes are estimated on the base of calcium-based wastes as 50% solids and sodium-based solids as 5% dissolved solids by weight.*

posed of in landfills. FGC wastes from dry sorbent FGD systems are also landfilled.

Trends in Industrial Boiler FGD Wastes

The use of coal in industrial boilers is expected to increase due to increasing costs of oil and natural gas and the impact of the Fuel Use Act. Emission standards may also cause an increase in the use of FGD systems and more efficient particulate control devices, which in turn would significantly increase FGC waste generation. Landfill disposal is expected to be encouraged over wet impoundment by regulatory and economic processes.

Waste disposal problems faced by industrial boiler operators differ from those faced by utilities in several ways: (1) industrial plants may be in urban areas where little land is available for waste disposal; (2) industrial operators may have to hire contractors to dispose of FGD waste; and (3) alternatively, emission standards may increase the number of small landfills and ponds, introducing various environmental control and management problems.

As of 1980, most research efforts had concentrated on utility boilers. Information was lacking in such areas as: (1) quantities and properties of FGC wastes that will be generated; (2) costs of treatment and disposal to industries; and (3) environmental effects of waste disposal alternatives.

Characteristics of FGC Wastes

Chemical Characteristics

Much data on the chemical characteristics of FGC wastes was published in 1979-80. Data were generated on various constituents of FGC wastes, components of leachates, and the relationship of chemical properties to potential environmental impact. Modification of waste properties by stabilization and of environmental impact by soil attenuation were also studied. Results from completed and ongoing studies in this area are discussed below.

Radian studied chemical and physical stability and properties of a variety of FGC waste materials in an EPRI program. Fly ash, unstabilized FGD, and stabilized FGD waste materials were studied. Major and trace elements were evaluated, major crystalline phases identified, and leachability of the elements explored. Estimates of free lime in fly ash, obtained to indicate potential self-hardening characteristics of major crystalline phases in some FGC waste samples using x-ray diffraction, appear to indicate significant amounts of amorphous material. In a slightly different study, Rutgers University completed an evaluation of the pozzolanic properties of fly ash/limestone scrubber mixtures, using solid state analytic techniques including x-ray diffraction, differential scanning colorimetry, and infrared spectrometry. Results suggested that curing of stabilized samples with and without air leads to different products and that sulfite-type waste may produce oxygen-free environments in a disposal site.

TVA conducted laboratory studies on coal ash leaching, examining characteristics of ash, ash sluice water, leaching of metals from various ashes, and effect of pH adjustment on trace metal concentrations in leachate. Ash from four TVA plants was used. The study indicates that the acidity or alkalinity of ash affects trace element levels in ash sluice waters and leachates. In another leaching study, the U.S. Army Corps of Engineers' Waterways Experiment Station (WES) completed a series of column tests on stabilized FGC wastes. In general, it appeared that lower levels of most species occurred in elutriates from stabilized materials.

The University of Notre Dame studied the environmental effects, on groundwater, of fly ash disposal in ponds from a large coal-fired station. In a similar study at two of their plants; TVA studied ash leachate, groundwater, soil, fly ash, and bottom ash to determine contamination by leachate and attenuation by soils. Laboratory studies on attenuation supplemented the effort. WES completed a field study of disposal of unstabilized FGC wastes at three sites. Chemical analyses reportedly indicated elevations of Fe, As, Cr, and Pb in the groundwater from leachates.

The University of North Dakota continued their mine disposal demonstration project (initiated under EPA sponsorship and continuing under DOE sponsorship). The data from this study seem to indicate that North Dakota lignite fly ash produces leachate that has potentially high concentrations of As and Se, exceeding Primary Drinking Water Standards by a maximum factor of 12 and 80, respectively. Leachates from FGD wastes (again, from the same environs), exhibited much lower metals values.

Much data was generated on the application, to FGC wastes, of the proposed EPA extraction procedure (EP); other information on toxicity and radioactivity of FGC wastes was also generated.

Physical Characteristics

Several studies on the physical and engineering characteristics of FGC wastes were underway in 1979-80. Some of the more significant results are described below.

Studies by Radian compared FGC wastes containing fly ash from Eastern bituminous coals to those containing fly ash from bituminous and lignite coals. Unconfined compression strength of some of the mixtures tested reached as high as 5,000 psi, and increased with an increase in the leachable alkalinity of the ashes. The sulfite/sulfate ratio of the sludges used apparently did not influence the value of strength. The permeability of wastes containing high calcium oxide (Western coal) fly ash was 10^{-5} - 10^{-7} cm/sec. In contrast, permeability of mixtures containing low calcium oxide (Eastern coal) fly ash generally was 10^{-4} - 10^{-6} cm/sec.

Research at Northwestern University on waste management from double alkali FGD systems provided information needed for the design of methods of handling and disposal of such FGD wastes in landfills. Laboratory tests on the double alkali wastes from FMC Corp.'s FGD process included grain size analysis, specific gravity determination, Atterburg test limits, compaction tests, compressibility tests, permeability tests, and evaporation tests.

Studies on waste generated from a dry sorbent FGC system at the University of Tennessee included grain size distribution of waste, specific gravity, compaction characteristics of the waste, and unconfined compression strength of the samples. The stabilized wastes were also subject to leaching tests using several techniques. Tests on unconfined compression strength indicate that the strength of the compacted mixture of fly ash and dry FGD wastes depends heavily on the mixed proportions and the amount of unreacted lime present. It appears that, if the proper proportion of lime is present, a relatively high-strength landfill material can be obtained by compaction at optimum moisture content.

Utilization of Wastes

The utilization of fly ash, bottom ash, and boiler slag steadily increased in the 1970s. In 1978, about 16.4 (of an annual generation of 68.1) million metric tons was utilized [9].

The principal uses for fly ash appeared to be in the pozzolan market (in cement and concrete) and accounted for about 2.1 of the 8.4 million tons of fly ash utilized. Other major uses of fly ash include as a filler material for roads and construction, and as a stabilizer for road bases. The largest amount of fly ash was, however, disposed of. Additionally, in recent years a fast growing use for fly ash has been in the stabilization of FGD wastes. This is technically considered to be "disposal;" although, if the stabilized waste is used as a road construction base or in some other analogous application, it may be considered "utilization."

Bottom ash and boiler slag utilization continued at about the same level as in 1977-78. The largest end uses were for bottom ash as a fill material, as a filler in asphalt, for ice control, as a blasting grit, or as roofing granules. Boiler slag was also growing in utilization, although somewhat erratically. The principal use of boiler slag was in deicing roads and bridges.

On balance, these utilization trends are expected to continue, at least through 1985. Total ash collection is increasing dramatically; therefore, the amount of FGC wastes sent to disposal is likely to increase over the next few years.

Disposal of FGC Wastes

Current Practice

In 1980, all FGC wastes were disposed of on land. At-sea disposal may be a future alternative if it can be practiced under environmentally acceptable conditions. The principal methods of disposal are: ponding; landfilling, including mine disposal; and interim ponding followed by landfilling.

At-sea disposal of FGD wastes was not practiced in the U.S. in 1980. However, if it could be practiced under environmentally acceptable conditions, it would represent an important option, particularly along the East Coast, where land for disposal is limited. For this and other reasons, EPA and others have been studying the disposal of FGD wastes at sea.

Wet Ponding

Ponding is more widely used than any other disposal method; it can be used for a wide variety of FGC wastes. Ponds can be designed based on diking or excavation and can even be engineered on slopes.

A special case of wet ponding is FGD gypsum stacking, which was under evaluation in 1980. In this case, if the operation were analogous to that for phos-gypsum, FGD gypsum slurry (typically from forced oxidation systems) would be piped to a pond, allowed to settle, and the supernate recycled. Periodically the gypsum would be dredged and stacked around the embankment, thus building up the embankment.

Dry Impoundment

Dry impoundment may include: (1) interim ponding followed by dewatering (or excavation) and landfilling; (2) mechanical dewatering and landfilling of FGD wastes; (3) blending of FGD waste with fly ash and landfilling of the combined wastes; and (4) stabilization through the use of additives (nonproprietary or otherwise).

Typically, for dry-impoundment disposal, the wastes are thickened and dewatered to a high solids content (FGD waste may also be mixed with fly ash). This material is transported to the disposal site where it is spread on the ground in about 0.3 - 1 m (1 - 3 ft) lifts and compacted by wide track dozers, heavy rollers, or other equipment. A properly designed and operated dry impoundment system can potentially enhance the value of the disposal site after termination or at least permit post-operational use.

Mine Disposal

Ash disposal in mines has been practiced for several years, particularly in the Western U.S. Coal mines, in particular surface area coal mines, are the most likely candidates for waste disposal.

Coal mines offer the greatest capacity for disposal, and they frequently are tied directly to power plants. In fact, many new coal-fired power plants are mine-mouth (located within a few miles of the mine), and the mine provides a dedicated coal supply.

Field Studies

In 1980, several field studies were underway to evaluate various methods of land disposal of FGC wastes. Features of the major studies are described below.

A large EPA-sponsored project on characterization and environmental evaluation of six full-scale utility waste disposal sites by Arthur D. Little, Inc., started in late 1979 and was well underway in 1980. This study is expected to provide substantial information concerning the degree to which disposal of FGC wastes needs to be managed to protect the environment.

A similar EPRI-sponsored study at a single site (Columbus and Southern Ohio Electric's Conesville Plant) with Michael Baker and Battelle-Columbus was continuing in 1980. Interim reports on monitoring of the Conesville site and modeling of associated groundwater had led to some preliminary conclusions on field versus laboratory permeablity of stabilized FGD wastes. EPRI was also funding an eight-site study by Michael Baker to focus on the engineering/economic assessment of FGC waste disposal. This study was expected to provide substantial data by late 1981.

Studies continued at TVA's Shawnee Plant by Aerospace (under EPA sponsorship) concerning disposal methods, impacts of weathering, soil interactions and field operational procedures. Investigators report that, if untreated sludge is properly drained, it can be structurally sound and support significant surface loading. Similarly, properly dewatered gypsum also exhibited significant bearing strength.

Preliminary results from the mine disposal of lignite fly ash and FGD waste in North Dakota seemed to indicate that both wastes can impact the groundwater due to the amounts of soluble sulfate salts. It appears that placing FGD wastes in mined areas can be an effective means of disposing of this waste if careful attention is paid to site selection and design/operation of the FGC disposal systems.

State University of New York (SUNY) at Stony Brook continued a program to assess the feasibility of disposing of blocks of stabilized FGC wastes at sea to produce artificial reefs. Preliminary test results indicated that blocks undergo no appreciable degradation by dissolution during 1.5 years in seawater.

Present Control Technology

The environmental impact of FGC waste disposal (hence, any potential impacts on human health and environment) is influenced by: (1) type of waste generated (i.e., physical and chemical characteristics); (2) disposal method used (e.g., ponding, landfilling); and (3) disposal site characteristics (e.g., soil type, hydrogeology, climate).

It is expected that much of the difference between potential and actual impacts for the FGC waste disposal options discussed above will be determined by the degree to which presently available control technology is incorporated as "good design" and "good practice" in typical disposal operations. Good design and practice could also minimize the potential for adverse impact from abnormal events.

Site Selection

Site selection may or may not be considered control technology. However, there is no question that proper site selection could by itself ameliorate or eliminate most of the potential disposal impacts. The following mitigative combinations of site characteristics and impact issue categories are considered applicable:

Potential Impact Issue	Mitigative Site Characteristics
Land Use	Proper topography, geology, and hydrology; absence of nearby conflicting land uses.
Water Quality	As above for land use, plus absence of nearby sensitive receiving waters (e.g., a small stream or very pure aquifier).
Air Quality	Absence of "non-attainment area" and Class I Prevention of Significant Deterioration designations for total suspended particulates.
Biological Effects	Absence of sensitive biological resources.

Control Options

Control options include dewatering, stabilization, forced oxidation, and use of liners.

As discussed earlier, dewatering of FGC waste prior to processing or land disposal can result in major improvements in physical stability and reduce water quality impacts regardless of the disposal approach used.

Stabilization refers to groups of processes to obtain easy-to-handle materials from difficult-to-handle and difficult-to-dewater FGD wastes. Major processes in use are: (1) processes such as Conversion Systems, Inc.'s, based on adding lime and fly ash to FGD wastes to obtain a moist soil-like waste for land disposal; (2) processes based on proprietary additives, such as Dravo's Calcilox, to obtain a stable waste in water; and (3) inherent stabilization of alkaline fly ash/FGD wastes by the fly ash itself.

In October 1980, at least 25 U.S. utility operators were committed to some type of stabilization process [1].

The intentional production of sulfate-rich wastes or gypsum, rather than sulfite-rich FGC wastes, was subject of considerable interest in 1980. This was primarily due to the relative ease in dewatering gypsum, which alleviates the handling difficulties associated with sulfite-rich wastes.

Liners may not be required for FGC waste disposal except under certain site specific conditions. Field experience with liners for FGC waste disposal was limited in 1980, but ongoing and recently announced programs were expected to close this gap.

Disposal Economics

The economics of FGC waste disposal continued to be an important factor in implementing particulate and SO_2 control. Several conceptual design and cost studies on waste disposal had been undertaken, sponsored by both government agencies and private organizations--notably EPA, EPRI, and DOE. These studies focused on developing comparative economics for various wastes (coal ash and FGD) for various waste disposal options, including current practices and potential alternatives. In addition to these studies, a major ongoing study, sponsored by the EPA, involved a characterization and environmental evaluation program at utility solid waste (coal ash and FGD) disposal sites. Total capital and annual operating costs for waste disposal were to be developed for each site.

As an overview of the individual studies, costs for eight of the more important types of waste disposal are summarized in Table 5. For each process, basic assumptions allowed comparison of the capital and revenue requirements developed.

Figure 1 briefly describes the eight methods.

Even with these waste disposal cost studies, data gaps remained in 1980 on the economics of the disposal of FGC wastes, including both cost information, and knowledge of waste properties and disposal requirements that directly impact disposal costs. The most important of these are:

- A general lack of uniformity in basic cost assumptions in the studies.
- A general lack of reliable cost information from commercial operations of most types of FGC waste disposal. Ongoing and planned EPA projects were expected to at least partially fill this gap.
- No definitive studies on the disposal of wastes from dry sorbent systems and associated costs.
- Inadequate physical and engineering properties data on some types of wastes as a basis for developing design requirements needed for reliable estimates of cost-effective disposal systems.

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Table 5. *Engineering Economics of FGC Waste Disposal*

	Capital Costs (mid-1980 dollars)[a]		*Annual Revenue Requirements (mid-1981 dollars)*[a]	
Disposal Method	*Disposal Only, \$/kW*	*Air Pollution Control and Disposal, \$/kW*	*Disposal Only, \$/dry ton*	*Air Pollution Control and Disposal, \$/dry ton*
Untreated Ponding[b]	38.0	117.0	9.0	41.0
Dravo Calcilox Ponding[b]	53.0	132.0	17.0	47.0
Dravo Calcilox Landfilling[c]	22.0	122.0	13.0	49.0
Lime & Fly Ash Stabilization/ Landfilling (IUCS)[c]	23.0	124.0	14.0	50.0
Untreated FGD Sludge & Fly Ash Blending/Landfilling[c]	19.0	119.0	10.0	47.0
Gypsum (forced oxidation)/ Landfilling[d]	12.0	96.0	9.0	46.0
Alkaline Ash Wastes/Mine Disposal[b]	18.0	97.0	9.0	41.0
Fly Ash/Landfilling[e]	2.0	23.0	6.0	19.0

[a] *Basic Assumptions: Power Plant--500 MW boiler, 9000 Btu/kWh heat rate, Midwestern location, 30-year service life, 80% load factor (1st 10 years), 48% lifetime average load factor, 1 mi from plant to disposal site.*

Coal Properties--3.5% S, 16% ash, 10,500 Btu/lb heating value.

Scrubber System--limestone (except for alkaline ash/mine disposal), 1.5 stoichiometry for conventional limestone, 1.1 stoichiometry for forced oxidation, SO_2 emissions controlled to 1.2 lb/10^6 Btu.

Capital Charge Factor--0.164.

[b] *Includes costs of scrubber (simultaneous fly ash and SO_2 removal).*

[c] *Includes costs of scrubber and ESP (for separate fly ash collection).*

[d] *Includes costs of scrubber (simultaneous fly ash and SO_2 removal) and air oxidation modifications.*

[e] *Includes costs of ESP.*

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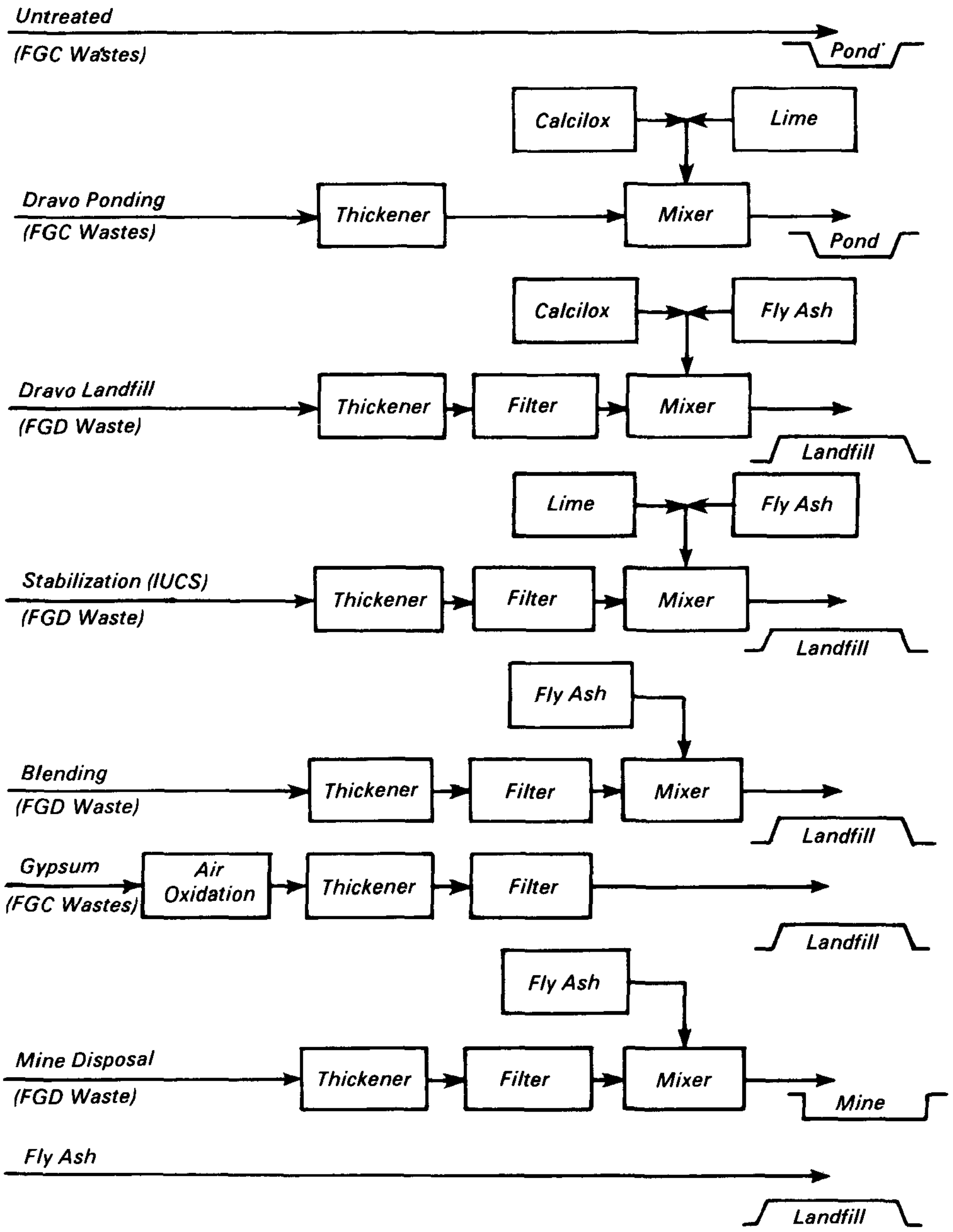

Figure 1. *FGC waste disposal methods.*

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The complete report, entitled "Waste and Water Management for Conventional Coal Combustion: Assessment Report - 1980," (Order No. PB 83-163 154; Cost: $55.00, subject to change) will be available only from:

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