United States Environmental Protection Agency

Industrial Environmental Research Laboratory
Research Triangle Park NC 27711

EPA-600/7-80-012a
January 1980

EPA

Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979
Volume I. Executive Summary

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

EPA-600/7-80-012a

January 1980

Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979 Volume I. Executive Summary

by

C. J. Santhanam, R. R. Lunt, C. B. Cooper,
D. E. Kleinschmidt, I. Bodek, and W. A. Tucker (ADL);
and C. R. Ullrich (University of Louisville)

Arthur D. Little, Inc.
20 Acorn Park
Cambridge, Massachusetts 02140

Contract No. 68-02-2654
Program Element No. EHE624A

EPA Project Officer: Julian W. Jones

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

PARTICIPANTS IN THIS STUDY

This First Annual R&D Report is submitted by Arthur D. Little, Inc. to the U. S. Environmental Protection Agency (EPA) under Contract No. 68-02-2654. The Report reflects the work of many members of the Arthur D. Little staff, subcontractors and consultants. Those participating in the study are listed below.

Principal Investigators

Chakra J. Santhanam
Richard R. Lunt
Charles B. Cooper
David E. Kleinschmidt
Itamar Bodek
William A. Tucker

Contributing Staff

Armand A. Balasco
James D. Birkett
Sara E. Bysshe
Diane E. Gilbert
Sandra L. Johnson
Warren J. Lyman
Shashank S. Nadgauda
James E. Oberholtzer
James I. Stevens
James R. Valentine

Subcontractors

D. Joseph Hagerty — University of Louisville
C. Robert Ullrich — University of Louisville

We would like to note the helpful views offered by and discussions with Michael Osborne of EPA-IERL in Research Triangle Park, N. C., and John Lum of EPA-Effluent Guidelines Division in Washington, D. C.

Above all, we thank Julian W. Jones, the EPA Project Officer, for his guidance throughout the course of this work and in the preparation of this report.

ACKNOWLEDGEMENTS

Many other individuals and organizations helped by discussions with the principal investigators. In particular, grateful appreciation is expressed to:

Aerospace Corporation - Paul Leo, Jerome Rossoff

Auburn University - Ray Tarrer and others

Department of Energy - Val E. Weaver

Dravo Corporation - Carl Gilbert, Carl Labovitz, Earl Rothfuss and others

Electric Power Research Institute (EPRI) - John Maulbetsch, Thomas Moraski and Dean Golden

Environmental Protection Agency, Municipal Environmental Research Laboratory - Robert Landreth, Michael Roulier, and Don Sanning

Federal Highway Authority - W. Clayton Ormsby

IU Conversion Systems (IUCS) - Ron Bacskai, Hugh Mullen Beverly Roberts, and others

Louisville Gas and Electric Company - Robert P. Van Ness

National Ash Association - John Faber

National Bureau of Standards - Paul Brown

Southern Services - Reed Edwards, Lamont Larrimore, and Randall Rush

Tennessee Valley Authority (TVA) - James Crowe, T-Y. J. Chu, H. William Elder, Hollis B. Flora, R. James Ruane, Steven K. Seale, and others

CONVERSION FACTORS

English/American Units	Metric Equivalent
Length:	
1 inch	2.540 centimeters
1 foot	0.3048 meters
1 fathom	1.829 meters
1 mile (statute)	1.609 kilometers
1 mile (nautical)	1.852 kilometers
Area:	
1 square foot	0.0929 square meters
1 acre	4,047 square meters
Volume:	
1 cubic foot	28.316 liters
1 cubic yard	0.7641 cubic meters
1 gallon	3.785 liters
1 barrel (42 gals)	0.1589 cu. meters
Weight/Mass:	
1 pound	0.4536 kilograms
1 ton (short)	0.9072 metric tons
Pressure:	
1 atmosphere (Normal)	101,325 pascal
1 pound per square inch	0.07031 kilograms per square centimeter
1 pound per square inch	6894 pascal
Concentration:	
1 part per million (weight)	1 milligram per liter
Speed:	
1 knot	1.853 kilometers per hour
Energy/Power:	
1 British Thermal Unit	1,054.8 joules
1 megawatt	3.600×10^9 joules per hour
1 kilowatt hour	3.60×10^6 joules
Temperature:	
1 degree Fahrenheit	5/9 degree Centigrade

GLOSSARY AND ABBREVIATIONS

GLOSSARY

Cementitious: A chemically precipitated binding of particles resulting in the formation of a solid mass.

Fixation: The process of putting into a stable or unalterable form.

Impoundment: Reservoir, pond, or area used to retain, confine, or accumulate a fluid material.

Leachate: Soluble constituents removed from a substance by the action of a percolating liquid.

Leaching Agent: A material used to percolate through something that results in the leaching of soluble constituents.

Pozzolan: A siliceous or aluminosiliceous material that in itself possess little or no cementitious value but that in finely divided form and in the presence of moisture will react with alkali or alkaline earth hydroxide to form compounds possessing cementitious properties.

Pozzolanic Reaction: A reaction producing a pozzolanic product.

Stabilization: Making stable by physical or chemical treatment.

ABBREVIATIONS

Btu	British thermal unit
cm	centimeter
cm/sec	centimeter per second
^{o}C	degrees Centigrade
^{o}F	degrees Fahrenheit
ESP	electrostatic precipitator
FGC	flue gas cleaning
FGD	flue gas desulfurization
ft	feet
ft/sec	feet per second
g	gram
gal	gallon
gpm	gallons per minute
hp	horsepower
hr	hour
in.	inch
j	joule
j/s	joule per second
k	thousand
kg	kilogram
km	kilometer
kW	kilowatt
kWh	kilowatthour
l	liter
lb	pound
M	million
m^2	square meter
m^3	cubic meter
MW	megawatt
ppm	parts per million
psi	pounds per square inch
sec	second
TDS	total dissolved solids

Note: For conversion units, see page v.

VOLUME 1: EXECUTIVE SUMMARY

TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		iii
CONVERSION TABLE		v
GLOSSARY AND ABBREVIATIONS		vi
LIST OF TABLES		x
LIST OF FIGURES		xi
1.0	INTRODUCTION	1-1
2.0	EPA's WATER AND WASTE PROGRAM	2-1
3.0	PURPOSE AND ORGANIZATION OF THIS REPORT	3-1
	3.1 Scope of Contract	3-1
	3.2 Purpose	3-2
	3.3 Organization of this Report	3-3
4.0	SUMMARY AND CONCLUSIONS	4-1
	4.1 Overview	4-1
	4.2 Regulatory Considerations	4-3
	4.3 Water Recycle/Treatment/Reuse	4-12
	4.3.1 Effluent Streams	4-14
	4.3.2 Water Management	4-15
	4.3.3 Data Gaps and Future Research Needs	4-18
	4.4 FGC Wastes Overview	4-19
	4.5 Characterization of FGC Wastes	4-21
	4.5.1 Chemical Characteristics	4-21
	4.5.2 Physical Properties	4-31
	4.5.3 Research Needs in Characterization	4-35
	4.6 FGC Waste Disposal	4-35
	4.6.1 Impact Issues	4-35
	4.6.2 Disposal Options and Potential Impacts	4-36
	4.6.2.1 Land Disposal	4-38
	4.6.2.2 Ocean Disposal	4-44
	4.6.3 Potential Impacts	4-45
	4.6.4 Impact Control Measures	4-47

VOLUME 1: TABLE OF CONTENTS

	Page
4.6.5 Future Research Needs	4-50
4.6.6 Economics of FGC Waste Disposal	4-53
4.6.6.1 Costs of Waste Disposal Alternatives	4-54
4.6.6.2 Economic (Cost) Impact Studies	4-61
4.6.6.3 Economic Uncertainties and Data Gaps	4-62
4.7 FGC Waste Utilization	4-63
4.8 Emerging Technologies and the Future	4-66
References	R-1

LIST OF TABLES

Table		Page
S.1	Projects in the Waste and Water Program	2-2
S.2	Federal Regulatory Framework for Disposal of FGC Wastes and Water Effluents	4-4
S.3	Discharge Limits for the Utility Industry	4-6
S.4	Water Used for Electric Utility Generation of Thermoelectric Power in Million Gallons Per Day, By Regions, 1975	4-13
S.5	Projected Generation of Coal Ash and FGC Wastes	4-20
S.6	Composition of Coal Ash According to Coal Rank	4-22
S.7	Major Components in FGC Waste Solids	4-24
S.8	Range of Trace Species Present in Coal Ash	4-26
S.9	Total Concentration of Trace Constituents in FGC Waste and Coal	4-28
S.10	Typical Concentration Ranges of Chemical Species in FGC Waste Liquors and Elutriates	4-29
S.11	Physical and Engineering Properties of Fly Ash	4-32
S.12	Physical and Engineering Properties of FGC Waste	4-33
S.13	Potential Disposal Options	4-37
S.14	Present Disposal Practices Utility FGC Systems	4-39
S.15	Summary of Current Field Testing Program for FGC Wastes Disposal	4-40
S,16	Disposal Options VS Impact Issues	4-46
S.17	Summary of General Conceptualized Cost Studies	4-55
S.18	Summary of TVA Cost Estimates for FGC Waste Disposal	4-57

LIST OF FIGURES

Figures		Page
S.1	EPA Program Overview Technology Control Waste and Water Pollution From Combination Sources	2-5
S.2	Generalized Schematic Water Balance for a Typical 1000 MW Coal-Fired Power Plant	4-16

1.0 INTRODUCTION

Modern fossil-fueled boilers employing conventional coal combustion (utility boilers and large industrial boilers) present a broad spectrum of potential environmental problems. In recent years the development of regulatory constraints pertaining to air and water pollution control have required and will continue to require focus on the environmental management of solid wastes and effluents.

A coal-fired utility or industrial boiler produces two broad categories of wastes.

a. Solid wastes, principally
   - fly ash
   - bottom ash (or boiler slag)
   - flue gas desulfurization (FGD) wastes

   The predominant part of the solid wastes, excluding bottom ash, are generated by the use of air pollution control devices - electrostatic precipitators, baghouses, and scrubbers - to control emissions of fly ash and sulfur dioxide (SO_2). Although there are other wastes, such as those from water treatment systems, the quantities of these are small compared to the large amounts of ash and SO_2 scrubber waste produced. Together, coal ash and FGD wastes are generally referred to as flue gas cleaning (FGC) wastes. In many cases, fly ash and SO_2 emissions are separately controlled and represent separate waste streams. In other cases, fly ash and FGD wastes are combined in a single stream, either through admixture of these wastes or through simultaneous collection of fly ash and SO_2.

b. Wastewater effluents from several sources in the power plant. The major use points for water and, hence, generation points for effluents are:

   I. Continuous:

- condenser cooling
- steam generation
- water treatment
- ash handling
- flue gas desulfurization
- miscellaneous

II. Intermittent:

- maintenance cleaning
- drainage (including coal pile runoff)

The multiplicity of uses of water in a power plant and the widely varying requirements for water quality in those uses present power plants with major opportunities for water management through a combination of:

- Wastewater management by recycle. For example, boiler blowdown is often of higher purity than original supply and can be used at many points.
- Combination of compatible streams with appropriate equalization. Ash pond and coal-pile runoff may help neutralize each other.
- Treatment of appropriate streams for reuse or discharge.

c. Furthermore in the future increasing emphasis on water recycle/treatment/reuse will generate some increasing amounts of solid wastes with potentially hazardous pollutants.

Optimum management of the potential environmental problems associated with the above two categories requires an integrated approach to the problem of waste and water pollution at power plants or industrial boilers.

The environmental legislation of the past few years and that which is now emerging, provides for the regulation of waste and water pollution from combustion sources. However, a major reduction in pollution in one medium (e.g., air) for a given pollution control requirement will lead to an increase in the level of pollutants in the other media (water, land).

Hence, a key element in environmental management is dealing with such "cross-media" impacts. Recognizing this, the regulatory framework requires the U. S. Environmental Protection Agency (EPA) to assist in the development and application of technology to minimize the potential adverse environmental impacts from such regulatory requirements. In the case of waste and water pollution control from combustion sources, a number of research, development and demonstration efforts have been required. The need for these has been the basis for the formulation of EPA's program concerning technology for control of waste and water pollution from combustion sources or briefly, the Waste and Water Program. In addition to EPA, Electric Power Research Institute (EPRI), several utilities and others have been active in this field.

Since 1974, the U. S. Environmental Protection Agency (EPA) has been conducting a program for environmental management of solid wastes and effluents from steam-electric generating plants. EPA programs like other programs on waste and water pollution control from power plants has focused principally on coal-fired power plants for two reasons:

1. Coal-fired plants offer the broadest and most complex environmental management problems. Technology transfer to other fossil fuels, where necessary, is more easily achieved than with any other fuel.

2. The nation is anticipated to rely increasingly on coal as a primary fossil-fuel for energy.

2.0 EPA's WASTE AND WATER PROGRAM

The objectives of the Waste and Water Program are to evaluate, develop, demonstrate and recommend environmentally acceptable, cost-effective technology for:

- Flue Gas Cleaning (FGC) Waste Disposal/Utilization; and
- Power Plant Water Recycle/Treatment/Reuse.

EPA's Waste and Water Program is divided into five major areas, three of which are relevant to the scope of this report:

a. FGC Waste Disposal

b. FGC Waste Utilization

c. Water Utilization/Treatment

d. Cooling Technology

e. Waste Heat Utilization

Each of these program areas includes a number of projects; these are listed in Table S.1. It should be noted that EPA projects pertaining to cooling technology or waste heat utilization are outside the scope of this report and hence not listed. The FGC Waste Disposal area of the Waste and Water Program consists of 19 projects, 5 of which were recently completed.

An overview of how some of these programs fit into power plant systems are shown in Figure S.1.

EPA's Waste and Water Program principally focuses on coal-fired utility boilers at present. Coal-fired plants (vis-a-vis oil or gas) generate the maximum range of wastes and present the most complex water management problems. Further, there is universal consensus that coal utilization in the United States is going to increase significantly in the years to come. From the viewpoint of technology for waste and water pollution control, coal-fired plants are the logical choice. While the present focus is on utility power plants, EPA's focus in the years to come will also be on large industrial boilers.

Table S.1

Projects in the Waste and Water Program

Basis: Excludes those pertaining to cooling technology and waste heat utilization

	Project Title	Contractor/Agency	Environ. Assess.	Tech. Assess. & Develop.	Econ. Assess.	Charac. Studies	Current Status
	FGC WASTE DISPOSAL						
1.	Assessment of Technology for Control of Waste and Water Pollution	Arthur D. Little, Inc.	x	x	x	x	Ongoing
2.	FGC Waste Characterization, Disposal Evaluation, and Transfer of FGC Waste Disposal Technology	The Aerospace Corp.	x	x	x	x	Completed
3.	Solid Waste Impact of Controlling SO_2 Emissions from Coal-Fired Steam Generators[a]	The Aerospace Corp.		x			Completed
4.	Lab and Field Evaluation of 1st and 2nd Generation FGC Waste Treatment Processes	U. S. Army Corps of Engineers (Waterways Experiment Station)	x	x		x	Ongoing
5.	Ash Characterization and Disposal	Tennessee Valley Authority	x	x	x	x	Ongoing
6.	Studies of Attenuation of FGC Waste Leachate by Soils[a]	U. S. Army Test & Evaluation Command (Dugway Prov. Ground)	x			x	Completed
7.	Establishment of Data Base for FGC Waste Disposal Standards Development	Stearns, Conrad and Schmidt Consulting Engineers, Inc. (SCS Engineers)	x	x			Completed
8.	Development of Toxics Speciation Model and Economic Development Document for FGC Waste Disposal	SCS Engineers	x	x	x		Completed
9.	Shawnee FGC Waste Disposal Field Evaluation	Tennessee Valley Authority The Aerospace Corporation	x	x	x	x	Ongoing
10.	Louisville Gas and Electric Evaluation of FGC Waste Disposal Options	Louisville Gas & Electric (Subcontractor: Combustion Engineering, Inc.)	x	x		x	Completed
11.	FGC Waste Leachate-Liner Compatibility Studies	U. S. Army Corps of Engineers (Waterways Experiment Station)		x	x		Ongoing
12.	Lime/Limestone Wet Scrubbing Waste Characterization and Disposal Site Revegetation Studies	Tennessee Valley Authority	x	x	x		Ongoing
13.	Development of EPA Pilot Plant Test Plan to Relate FGC Waste Properties to Scrubber Operating Variables[a]	Radian Corporation		x	x	x	Completed

a. *Direct Support of Regulation Development*

Table S.1 (Continued)

Projects in the Waste and Water Program

Project Title	Contractor/Agency	Environ. Assess.	Tech. Assess. & Develop.	Econ. Assess.	Charac. Studies	Current Status
FGC WASTE DISPOSAL (Continued)						
14. Dewatering Principals and Equipment Design Studies	Auburn University		x x			Ongoing
15. Conceptual Design/Cost Study of Alternative Methods for Lime/Limestone Scrubbing Waste Disposal	Tennessee Valley Authority		x x	x x		Ongoing
16. Evaluation of FGC Waste Disposal in Mines and the Ocean	Arthur D. Little, Inc.	x	x	x		Ongoing
17. Evaluation of Power Plant Wastes for Toxicity as Defined by RCRA	Radian Corporation Department of Energy (Oak Ridge Natl lab)	x			x	Ongoing
18. Study of Non-Hazardous Wastes from Coal-Fired Electric Utilities	Radian Corporation	x		x	x	Completed
19. Selection of Representative Coal Ash & Coal Ash/FGD Waste Disposal Sites	Versar	x				Completed
20. Characterization & Environmental Monitoring of Full-Scale Waste Disposal Sites	Contractor not yet selected	x	x	x	x	
FGC WASTE UTILIZATION						
1. Gypsum Byproduct Marketing Studies	Tennessee Valley Authority		x	x		Completed
2. Pilot Studies of a Process for Recovery of Sulfur and Calcium Carbonate from FGC Waste	Pullman-Kellogg		x	x		
3. Fertilizer Production Using Lime/Limestone Scrubbing Wastes	Tennessee Valley Authority		x	x		
4. Use of FGC Waste in a Process for Alumina Extraction from Low-Grade Ores	TRW, Inc.		x	x		Completed
WATER UTILIZATION/TREATMENT						
1. Assess Power Plant Water Recycle/Reuse	Radian Corporation		x	x	x	Completed
2. Pilot Demonstration of Water Recycle/Reuse	Contractor not yet Selected	x	x	x	x	-
3. Characterization of Effluents from Coal-Fired Power Plants	Tennessee Valley Authority	x	x		x	Ongoing
4. Water Pollution Impact of Controlling SO_2 Emissions from Coal-Fired Steam Generators [a]	Radian Corporation	x	x			Completed
5. Treatment of Power Plant Wastes with Membrane Technology	Tennessee Valley Authority		x	x		Ongoing

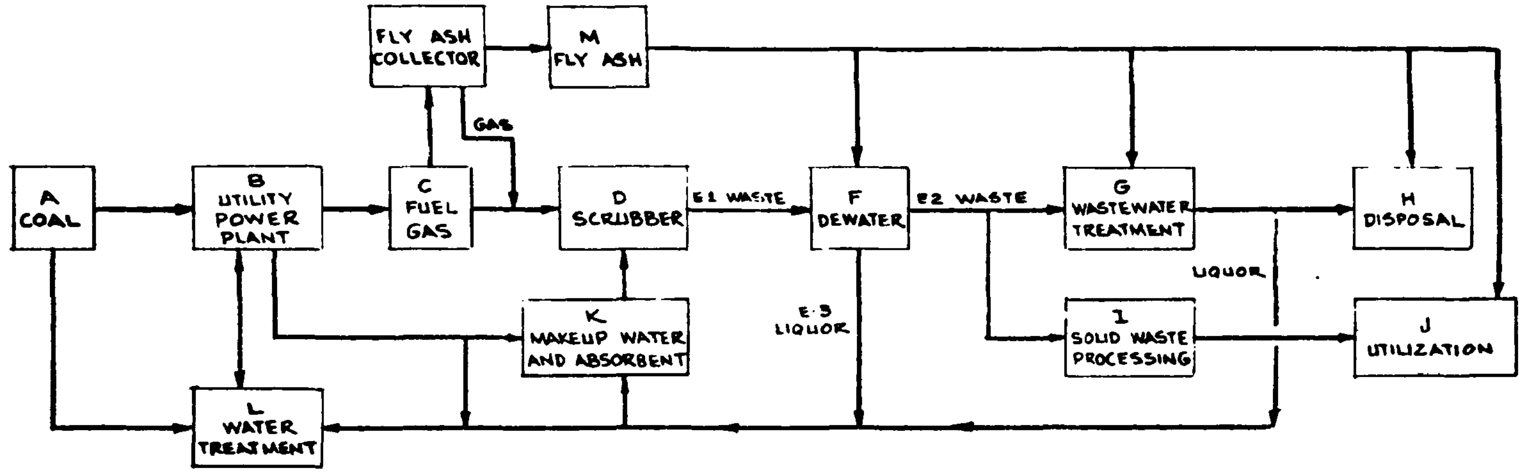
a. Direct Support of Regulation Development

Table S.1 (Continued)

Projects in the Waste and Water Program

Project Title	Contractor/Agency	Environ. Assess.	Tech. Assess. & Develop.	Econ. Assess.	Charac. Studies	Current Status
WATER UTILIZATION/TREATMENT (Continued)						
6. Power Plant Cooling Tower Blowdown Recycle by Vertical Tube Evaporator with Interface Enhancement	University of California-Berkeley		x	x		Ongoing
7. Treatment of Flue Gas Scrubber Waste Streams with Vapor Compression Cycle Evaporation [a]	Resources Conservation Co.		x	x		Completed
8. Alternatives to Chlorination for Control of Condenser Tube Biofouling	Monsanto Research Corporation		x			Completed
9. Assessment of the Effects of Chlorinated Seawater from Power Plants on Aquatic Organisms	TRW, Inc.	x				
10. Bromine Chloride - An Alternative to Chlorine for Fouling Control in Condenser Cooling Systems [a]	Martin Marietta Corporation		x			Completed
11. Evaluation of Lime Precipitation for Treatment of Boiler Tube Cleaning Waste [a]	Hittman Associates, Inc.		x	x		
12. Assessment of Technology for Control of Toxic Effluents from the Electric Utility Industry [a]	Radian Corporation		x	x	x	Completed
13. Field Testing/Lab Studies for Development of Effluent Standards for Electric Utility Industry [a]	Radian Corporation		x		x	Completed
14. Effects of Pathogenic and Toxic Material Transported via Cooling Device Drift	H_2M, Inc.	x				Ongoing
15. Assessment of Measurement Techniques for Hazardous Pollution from Thermal Cooling Systems	Lockheed Electronics Co. Northrop Corporation	x				Ongoing
16. Assessing Comparative Merits of R.O., VCE and VTFE for Cooling Tower Blowdown	Bechtel, National		x	x		Ongoing

[a] Direct Support of Regulation Development



- Characterization of effluents from coal-fired power plants (TVA), A.C.L.

- Fly ash characterization and disposal (TVA), C.M.H.
- Assess and demonstrate power plant water reuse/recycle (Radian), L.B.K.
- Renovate cooling tower blowdown by vertical tube evaporator (U of Cal.), L.
- Evaluate use of vapor compression Evaporator to reduce water pollution from FGD processes (RCC), L.

- Lime and Limestone scrubbing waste characterization (TVA), D.$E_{1,2,3}$

- Assessment of waste & water program (ADLittle) $E_{1,2,3}$G,H,K,L,M,
- Dewatering Principals and equipment design studies (Auburn U), F.

- Laboratory and field evaluation of FGC treatment processes (U.S. Army WES),G,E_2,H
- Evaluation of FGC waste disposal options (LG&E) G,H.
- Conceptual design and cost studies of alternative methods for lime and limestone scrubbing waste disposal (TVA), G,H.
- Lime and Limestone scrubbing waste conversion pilot studies (Pullman-Kellogg)
- Fertilizer production using lime and limestone scrubbing wastes (TVA), I.J.

- Assessment of waste and water program (ADL), $E_{1,2,3}$ G,H,K,L,M.
- Shawnee FGD Waste Disposal field evaluation (TVA and Aerospace),H,G,E_2.
- Attenuation of FGC waste leachate by soils (U.S.Army, Dugway), H.
- Establishment of data base for FGC waste disposal standards development (SCS Engr) H.
- Alternative disposal methods development (A.D.Little) H,$E_{1,2}$,G.
- FGC waste leachate liner compatibility (U.S.Army WES),H.
- FGD waste and fly ash beneficiation studies (TRW), J.I.
- Gypsum byproduct marketing studies (TVA).
- Environmental Effects and control of various FGC sludge disposal options (SCS Engr), H, E_1,G.
- Study of non-hazardous wastes (Radian) H,E_2,G.

Source: Arthur D.Little, Inc.

Figure S.1 EPA Program Overview Technology Control Waste and Water Pollution From Combination Sources

3.0 PURPOSE AND ORGANIZATION OF THIS REPORT

3.1 Scope of Contract

The purpose of Arthur D. Little's contract with the EPA (Contract No. 68-01-2654) is to assemble, review, evaluate, and report data from research and development as well as commercial activities in the areas of:

a. Flue Gas Cleaning Waste Disposal/Utilization; and

b. Power Plant Water Management including Recycle/Treatment/ Reuse.

These efforts are conducted to assist the EPA in conducting an ongoing program of research and development in the above-mentioned areas. Results of these efforts are required to be reported annually.

The focus of this effort is:

- Evaluation of the technical, economic, regulatory and environmental aspects of FGC waste disposal/utilization, with particular emphasis on the effects of these factors on the feasibilities and cost of various disposal/utilization options. Where information gaps exist, recommendations are made on measures to fill these gaps, and, as appropriate, conduct laboratory research to develop additional data on FGC waste properties. The staff of the Civil Engineering Department of the University of Louisville, as a subcontractor to Arthur D. Little, will conduct testing of FGC waste engineering properties and has been assisting Arthur D. Little in the review and evaluation of engineering and physical properties data.
- Evaluation of the technical, economic, regulatory and environmental aspects of power plant water recycle/treatment/reuse, where information gaps exist, recommendations will be offered for programs to fill these gaps.

3.2 Purpose of this Report

This Assessment Report is the first of a series to assess the technology for control of pollution from conventional coal-fired combustion sources (utility plants and large industrial boilers). The purpose of this report is to assemble, review, evaluate and report data from research and development as well as commercial activities pertaining to these areas. This report has two objectives:

- To assist the EPA in assuring an ongoing program of research and development in the above-mentioned areas; and
- To serve as a state-of-the-art report on Water Recycle/Treatment/Reuse and Flue Gas Cleaning (FGC) Waste Disposal/Utilization for power plants and large industrial boilers.

The review and assessment effort underlying this report involved review of the data and information available as of February 1979, on:

- water management and wastewater characterization and treatment and assessment of current R&D studies,
- generation of FGC wastes, and chemical, physical and engineering properties of FGC wastes,
- disposal options including current practice, R&D and field studies on disposal and environmental/economic assessment of disposal,
- utilization practice including technical and economic assessment of current practice and R&D studies.

The review is based upon published reports and documents as well as contacts with private companies and other organizations engaged in technology development or involved in the design and operation of water and waste management systems and waste disposal or wastewater treatment facilities. Much of the information has been drawn from the waste characterization studies and technology development/ demonstration programs sponsored by the Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI).

Based upon the review of the data and assessment of ongoing work in the above fields, identification of data and information gaps relating to each of the above fields is made. The objective is to help potential EPA initiatives in the future to close these gaps. Ultimately, adequate data should be available to permit reasonable assessment of the impacts associated with the disposal and/or utilization of FGC wastes and water management at utility plants and industrial boilers.

Throughout this work, emphasis has been placed upon wastes produced by commercially demonstrated technologies and, where data are available, by technologies in advanced stages of development that are likely to achieve commercialization in the United States in the near future. In terms of FGD wastes, consideration is limited primarily to nonrecovery FGD systems with focus on those producing solid wastes (rather than liquid wastes). There are very few recovery systems in operation or under construction in the United States, and these generally produce a small quantity of waste in comparison to nonrecovery systems.

3.3 Organization of This Report

This is the first of at least three Assessment Reports that will be produced under this contract. Since this is the first report in this series, an extensive amount of background material has been included, thereby establishing a basic source of technical information in this area. The result is an 1100-page report on waste and water management for conventional coal combustion. For the convenience of the reader, the report is divided into five (5) volumes as follows:

- Volume 1 - Executive Summary. This volumes provides a brief overview of the technical, economic and environmental aspects of water and waste management associated with coal-fired boilers.
- Volume 2 - Water Management. This volume describes water management issues including:

- An overview on water balances in coal-fired power plants including coal-pile runoff, steam generation, main condenser cooling, flue gas desulfurization (FGD), ash handling, equipment cleaning and water treatment.
- A brief account of existing wastewater-related regulations.
- An assessment of treatment technology currently available or being developed for water recycle or reuse and treatment technology for effluent discharge.
- Treatment methods for each stream, central treatment, recycle and reuse possibilities and potential application of advanced water treatment technology have been considered.

- To the extent that data are available and generically applicable, economic data have been reported. No independent economic analysis was undertaken; rather, reported costs were updated to mid-1978 using Chemical Engineering Cost Index.
- Identification of data gaps and prioritization of the gaps and some recommendations for potential EPA initiatives.

- Volume 3 - Generation and Characterization of FGC Wastes. This volume:
  - Presents an overview on technology of coal ash collection and flue gas desulfurization.
  - Discusses production trends for FGC wastes.
  - Assesses current dewatering technology.
  - Describes stabilization processes.
  - Discusses chemical, physical and engineering characterization of FGC wastes, including non-recovery flue gas desulfurization (FGD) wastes, stabilized FGD wastes and coal ash.
  - Identifies current data gaps.

- Volume 4 - Utilization of FGC Wastes. This volume:
  - Describes current commercial ash utilization.
  - Describes and assesses current R&D program on ash and FGD waste utilization.
  - Identifies constraints on utilization.
- Volume 5 - Disposal of FGC Wastes. This volume:
  - Describes current and potential disposal options.
  - Assesses ongoing and proposed R&D programs on technical, environmental and economic aspects of FGC waste disposal.
  - Identifies data gaps on environmental and economic aspects of disposal practice.

4.0 SUMMARY AND CONCLUSIONS

4.1 Overview

The various programs described in Section 2.0 have achieved significant results in a number of areas. To date, the emphasis has been on utility plants but in the future will also encompass industrial boilers. Important accomplishments of EPA's Waste and Water Program, EPRI's efforts and other work in this field include the following:

Overall Power Plant Water Management

Substantial progress has been made in characterizing all major wastewater streams in a power plant. Overall water management studies have shown that more efficient water recycle/reuse can in many cases be achieved at reasonable costs. In particular, such studies can serve as models for water management plans in new facilities. Treatment systems to maximize water reuse are being evaluated in EPA and privately funded studies and the improved evaporative systems appear promising. Studies of effluent treatment to remove priority pollutants listed under the Clean Water Act of 1977 prior to discharge are also underway.

Flue Gas Cleaning (FGC) Waste Disposal

Chemical, physical and engineering properties of FGC wastes have been characterized to a significant extent although some data gaps remain. Progress in dewatering and stabilization processes has opened up a variety of potential and currently practiced disposal options. Preliminary environmental assessment of a variety of disposal options has been completed although environmental monitoring data from field scale projects (i.e. full-scale disposal operations) are not currently available. Recently announced projects by EPA and EPRI will go a long way towards closing this data gap.

Areas for continuing evaluation relating to reducing costs of FGC waste disposal have also been identified. These include forced oxidation to gypsum, improved FGD dewatering equipment, codisposal of ash and FGD wastes and stabilization processes. Processes for stabilization of FGD wastes have been evaluated and appear suitable for environmentally sound disposal. Studies on the use of liners in FGC waste disposal operations have been undertaken and are nearing completion.

The substantial amount of data on FGC waste characterization and disposal gathered under the various programs provide a portion of the technical baseline needed for the development of RCRA related guidelines and regulations for FGC waste disposal.

FGC Waste Utilization

Technical studies point to further potential for ash and FGD waste utilization provided regulatory or public policy constraints do not discourage utilization. The use of coal ash is current commercial practice, although much greater utilization is feasible. Production of salable FGD gypsum is technically and economically feasible, given a proper match of power plant and manufacturing plant (e.g., for wallboard, cement). However, institutional and other considerations constrain utilization of FGC wastes. In the future, how regulations encourage FGC waste utilization will impact utilization substantially. Additional focus of these considerations would be worthwhile.

Continuation of some of the ongoing programs and initiation at an early date of some recently announced projects (such as EPA's characterization and monitoring of full scale FGC disposal sites and EPRI's monitoring program at Conesville) are expected to substantially close the data gaps associated with water and waste pollution from combustion sources.

At the same time, new factors for the future are:

- major growth in FGC waste generation by utility plants, and
- additionally, increasing use of coal by industrial boilers leading to FGC wastes from these sources.

Increasing use of coal in industrial boilers will add new complications to the problem of waste and water pollution control. These will principally be caused by the differences between large utility boilers and industrial boilers in terms of:

a. type and quantity of wastes generated.

b. distribution of such waste generation points (i.e., location of boilers) including proximity to urban areas. Industrial boilers will be smaller and more numerous than large utility boilers.

Focus on waste management problems arising from such differences is necessary.

4.2 Regulatory Considerations

Table S.2 lists federal legislation pertaining to:

- water effluents from power plants and/or
- the handling and disposal of FGC wastes in ponds, landfills, coal mines, and the oceans.

The Toxic Substances Control Act (TSCA) may have minor impact on utilization but it is not expected to be significant.

The principal regulatory considerations pertaining to water recycle/ treatment/reuse and FGC waste disposal/utilization are:

- Federal Water Pollution Control Act (FWPCA) of 1972
- Clean Water Act (CWA) of 1977
- Resource Conservation and Recovery Act (RCRA) of 1976

Federal Water Pollution Control Act (FWPCA)

The FWPCA established a program whereby all point source discharges to navigable waters require a permit issued by the EPA or a state delegated the authority by the EPA. The Act also required industries to use the "best practicable" control technology currently available (BPCTCA) to control pollutant discharges by July 1, 1977, and requires application of "best available" technology economically achievable (BATEA). The

Table S.2

Federal Regulatory Framework for Disposal of FGC Wastes and Water Effluents

Possible Environmental Impact	Legislation	Administrator
1. Surface Water Contamination	• Federal Water Pollution Control Act Amendments of 1972	• Environmental Protection Agency (EPA)
	• Clean Water Act of 1977	• EPA
	• Resource Conservation and Recovery Act of 1976	• EPA
2. Groundwater Contamination	• Resource Conservation and Recovery Act of 1976	• EPA
	• Safe Drinking Water Act of 1974	• EPA
3. Waste Stability/ Consolidation	• Dam Safety Act of 1972	• Army Corps of Engineers
	• Surface Mining Control and Reclamation Act of 1977	• Office of Surface Mining Reclamation and Enforcement
	• Occupational Safety and Health Act of 1970	• Occupational Safety and Health Administration (OSHA)
	• Federal Coal Mine Health and Safety Act of 1969	• Mining Enforcement Safety Administration
4. Fugitive Air Emissions	• Clean Air Act and Amendments of 1977	• EPA
	• Hazardous Materials Transportation Act of 1975	• Department of Transportation
	• Federal Coal Mine Health and Safety Act of 1969	• Mining Enforcement Safety Administration
	• Occupational Safety and Health Act of 1970	• OSHA
	• Resource Conservation and Recovery Act of 1976	• EPA
5. Contamination of Marine Environment	• Marine Protection Research and Sanctuaries Act of 1972	• EPA

Note: Water effluents can only impact items 1 and 2 and only those apply.

FWPCA Amendments of 1977 made the effective date for BATEA a variable, depending on the chemical(s) being controlled. EPA has established national effluent guidelines (based on BPCTCA and BATEA) for existing power plants, as well as New Source Performance Standards (NSPS) for plants for which construction was initiated after the regulations were proposed. The discharge limits for utilities are shown in Table S.3

Clean Water Act (CWA)

The Clean Water Act of 1977 (PL 92-217) incorporates the list of priority pollutants (129 pollutants, including heavy metals) into specific portions of PL 92-500. Section 301 of PL 92-500 now requires the EPA to set effluent limitations for each pollutant based on BATEA. Point source dischargers other than publicly-owned treatment works (POTW's) must comply with these limitations by a specified future date. The date of compliance depends on:

- type of pollutant.
- the level of treatment that is possible.

The priority pollutants were also included in Section 307 of PL 92-217, which deals with "Toxic and Pretreatment Effluent Standards." The limitations may be relaxed, in some cases, if the POTW removes all or any part of the toxic pollutants. These regulations will tighten treatment requirements for water effluents but would also result in additional solid wastes containing the pollutants. Regulatory requirements under the CWA and RCRA may need to be synchronized.

Effluents guidelines, including best available technology economically achievable (BATEA), new source performance standards (NSPS), and pretreatment standards including the priority pollutants under the Clean Water Act, are expected to be issued later this year.

Table S.3

Discharge Limits[1,2] for the Utility Industry

Stream Pollutant	BPCTCA Limit mg/1 Max.[3]	BPCTCA Limit mg/1 Avg.[4]	BATEA Limit mg/1 Max.[3]	BATEA Limit mg/1 Avg.[4]	Limit for New Sources mg/1 Max.[3]	Limit for New Sources mg/1 Avg.[4]
All Streams						
pH (except once-through Cooling	6.0-9.0		6.0-9.0		6.0-9.0	
PCBs	No Discharge		No Discharge		No Discharge	
Low-Volume Waste Streams						
TSS	100	30	100	30	100	30
Oil and Grease	20	15	20	15	20	15
Bottom-ash Transport Water						
TSS	100	30	100[5]	30[5]	100[6]	30[4]
Oil and Grease	20	15	20[5]	15[5]	20[6]	15[4]
Fly Ash Transport Water						
TSS	100	30	100	30	No Discharge	
Oil and Grease	20	15	20	15	No Discharge	
Metal-Cleaning Wastes						
TSS	100	30	100	30	100	30
Oil and Grease	20	15	20	15	20	15
Copper (total)	1	1	1	1	1	1
Iron (total)	1	1	1	1	1	1
Boiler Blowdown						
TSS	100	30	100	30	100	30
Oil and Grease	20	15	20	15	20	15
Copper (total)	1	1	1	1	1	1
Iron (total	1	1	1	1	1	1
Once-Through Cooling Water						
Free Available Chlorine	0.5	0.2	0.5	0.2	0.5	0.2
Cooling Tower Blowdown[9]						
Free Available Chlorine[7]	0.5	0.2	0.5	0.2	0.5	0.2
Zinc[9]			1	1		
Chromium[9]			0.2	0.2		
Phosphorus[9]			5	5		
Other Corrosion Inhibitors	Limits Determined on a Case-by-Case Basis					
Material Storage Runoff[8]						
TSS	50		50		50	
pH	6.0-9.0		6.0-9.0		6.0-9.0	

1 Except where specified otherwise, allowable discharge equals flow multiplied by concentration limitation. Where waste streams from various sources are combined for treatment or discharge, quantities of each pollutant attributable to each waste source shall not exceed the specified limitation for that source.

2 All sources must meet State Water Quality Standards by 1977 (Section 301 (b)(1)(c).

3 Maximum for any one day.

4 Average of daily values for 30 consecutive days.

5 Allowable discharge equals flow multiplied by concentration divided by 12.5.

6 Allowable discharge equals flow multiplied by concentration divided by 20.0.

7 Limits given are maximum and average concentrations. Neither free available chlorine nor total residual chlorine may be discharged from any unit for more than 2 hr in one day, not more than one unit of any plant may discharge free available of total residual chlorine at the same time, unless the utility can demonstrate that the units in a particular location cannot operate at or below this level of chlorination.

8 Only runoff flow from material-storage piles associated with the reference 10-yr, 24-hr rainfall is exempt from these limitations.

9 Not applicable for BPCTCA, no detectable discharge from new sources.

Source: [1]

Resource Conservation and Recovery Act (RCRA)

A major environmental concern associated with FGC waste disposal is the potential contamination of groundwater. The principal federal legislation which addresses these potential problems is RCRA. Prior to enactment of the RCRA, there was no comprehensive federal authority to regulate disposal of solid wastes. This act is designed to eliminate improper disposal of solid wastes by federally-regulated disposal of hazardous waste and by state implementation of federal regulations (with federal assistance) of disposal of non-hazardous solid waste. The Act defines a hazardous waste as a waste which poses a "substantial present or potential hazard to human health or the environment" if improperly managed.

The regulatory philosophy in the RCRA for hazardous waste is "cradle-to-grave" control. A manifest system will be used to track the movement of hazardous waste from the point of generation through transportation, treatment, storage, (often required if disposal is off-site) and disposal. Detailed standards for hazardous waste management facilities will be established by the EPA and permits will be required. In addition, criteria and test methods to identify hazardous wastes will be established; a list of wastes known to meet the criteria will be included in the regulations.

Proposed regulations under the RCRA were issued on December 18, 1978, and are under review. The criteria for identifying hazardous wastes include characteristics such as ignitability, corrosiveness, reactivity (e.g., strong oxidizing agents), and certain aspects of toxicity. The protocol for toxicity (which is the most pertinent to FGC wastes) includes subjecting the waste to an extraction procedure (EP), followed by chemical tests for metals and pesticides.

Based on RCRA guidelines published in December 1978, the steps to determine RCRA related requirements for FGC waste disposal are:

a. The proposed Extraction Procedure (EP) specified in Section 3001 protocol will be employed on each FGC waste to determine if it passes or fails the protocol.

b. If a waste passes the tests, Federal criteria can apply under Section 4004. Individual states are required to adopt and enforce Section 4004 to regulate FGC waste disposal, if they wish to receive federal financial assistance under subtitle D of RCRA.

c. If an FGC waste fails the tests, it will be considered a special case of hazardous wastes. Then waste analysis, site-selection, security inspections, monitoring, closure, and record-keeping standards of Section 3004 (hazardous wastes disposal) will apply. Design standards under Section 3004 as currently proposed are not required for FGC waste disposal. This assures that the "special waste" category will be retrieved for FGC wastes. Potentially, these could undergo significant modifications prior to scheduled promulgation in December 1979.

National Energy Act (NEA)

Aside from the regulations concerning FGC waste disposal, the regulatory development that will impact the generation of FGC wastes is the National Energy Act of 1978 (NEA).

At present, detailed regulations to implement the overall framework of NEA are being worked out by the Department of Energy (DOE). The regulations would promote the use of coal, renewable energy sources, and other alternative fuels over oil or natural gas wherever possible. While the full impact of NEA on utility and industrial power plants needs further definition, the following appear to be indicated:

a. All new boilers, gas turbine and combined cycle units with a capacity larger than 10 MW_t will be prohibited from using oil or natural gas unless specifically exempted by DOE.

b. Existing facilities that are coal capable but not using coal now may be required to switch to coal or an alternative fuel. Financial capability to use coal or alternate fuels will be condisered by DOE. DOE will consider whether an existing boiler has furnace configuration and tube spacing to burn coal. However, addition of particulates and FGD systems may not be considered substantial modification preventing a switch to coal. Furthermore, derating (i.e., decrease in capacity) of a boiler by an amount less than 25% of nominal capacity by switching to coal will not be considered substantial [57]. These regulations will apply to single units of 100 MMBtu/hr or of multiple units in one site which is aggregate are by design capable of a fuel input rate of 250 MMBtu/hr or more.

   Provisions exist for exempting certain powerplants from restrictions against burning oil or gas if the owner can demonstrate a certain degree of adverse cost effectiveness from consideration of coal as an alternate fuel.

It is anticipated that NEA will encourage use of coal over the next twenty years. Additional solid wastes and wastewater will be generated by a switch to coal. Focus on these incremental problems is essential.

Clean Air Act (CAA) -- New Source Perforamnce Standards (NSPS)

New Source Performance Standards (NSPS) were issued by the EPA in accordance with the Clean Air Act of 1970 for regulating emissions of sulfur oxide, particulates, and nitrogen oxides from large coal-fired steam boilers (>250 MMBtu/hr heat input) commencing construction on or after August 1, 1971. These NSPS, which are still in effect, are as follows:

- Sulfur oxides - 1.2 lb (SO_2)/MMBtu heat input
- Particulate - 0.1 lb/MMBtu heat input
- Nitrogen oxides - 0.7 lb (NO_2)/MMBtu heat input

The Clean Air Act Amendments of 1977, provide for review of existing air quality standards and revisions in emissions regulations for new fossil-fuel-fired utility boilers. These amendments require that new fossil-fuel-fired sources meet both a standard of performance for emissions and an enforceable requirement for specific percentage reduction of pollution for untreated fuels, reflecting the degree of emissions reduction achievable through the best system of continuous emissions reduction regardless of the sulfur content of the fuel. In accordance with these amendments, the EPA has proposed revised NSPS for utility boilers based upon an evaluation of available control technology. Comments on these revised standards are now being reviewed and revised NSPS are expected in 1979.

In accordance with the Clean Air Act Amendments of 1977, the EPA is also formulating NSPS for new industrial boilers. The sizes to be covered by the revised NSPS may include boilers as small as 10.5×10^9 joules/hr (10 MMBtu/hr) heat input. At present, all boilers under 263.7×10^9 joules/hr (250 MMBtu/hr) fall under state and local regulations.

In addition to emissions limitations and SO_2 removal requirements for new sources, the Clean Air Act Amendments of 1977 include provisions for prevention of significant deterioration (PSD) and review and revision of regulations concerning nonattainment areas. PSD provisions are roughly equivalent to those which have been enforced over recent years by the EPA and therefore represent a legislative endorsement of the EPA's administration and enforcement regarding PSD. For nonattainment areas, states must have revised state implementation plans (SIP) for achieving primary air quality standards (protective of human health). In both nonattainment and nondegradation areas, permits are required for construction of any major stationary source. As a minimum, conformance with NSPS will be required, but more stringent restrictions may be imposed to meet air quality standards.

Issues requiring further clarification concern the impacts of NSPS, RCRA and NEA with respect to each other. For instance NSPS regulations, if tightened, increase the quantity of FGC wastes for disposal and hence the quantity of wastes regulated. Similarly, RCRA related costs for disposal may impact coal utilization.

4.3 Water Recycle/Treatment/Reuse

The issue of water recycle/treatment/reuse in steam-electric power plants is a complex one encompassing technology, environmental protection, aesthetics, and economics. Prior to the advent of national environmental legislation, the magnitude and nature of water recycle/treatment/reuse was determined principally by two factors: water supply availability and economics. To provide a perspective on total water use in the utility industry, Table S.4 presents data on a state-by-state basis of water uses in thermoelectric power generation (including coal, oil, gas and nuclear power).

The largest water usage in power plants is for cooling; hence, those regions of limited water availability were the first to focus on recycle systems such as cooling towers or ponds, whereas those regions with ample water supplies often utilized once-through cooling. The installation of water treatment systems prior to the advent of environmental regulations was based principally upon operational economics, i.e., the necessity to control the quality of the water going into the boiler, and so on, in order to sustain operability, reduce maintenance, etc. The large population centers and, concomitantly, the large electric users are predominantly located in water-plentiful parts of the United States; hence, the usage of water recycle/reuse systems was, until recently, limited.

With the passage of the Water Pollution Control Act Amendments of 1972 (PL 92-500) and other increasingly stringent environmental regulations on industrial discharges and steadily increasing pressure on available water supplies, water recycle/treatment/reuse in power plants has assumed increasing importance. All fossil-fired boilers require some degree of water management including recycle/treatment/reuse. However, coal-fired boilers require the broadest application of particulate and sulfur control technology. Hence, coal-fired boilers present the most complex water management issues. In view of the nation's commitment to increasing coal utilization, water recycle/treatment/reuse at coal-fired power plants has been the focus of many EPA sponsored studies.

Table S-4

Water Used for Electric Utility Generation of Thermoelectric Power in Million Gallons Per Day, By Regions, 1975

[Partial figures may not add to totals because of independent rounding]

Water Resources Council region	Condenser and reactor cooling					Other thermoelectric uses					Water consumed	
	Self-supplied			Public supplies	Self-supplied and public supplies	Self-supplied			Public supplies	Self-supplied and public supplies		
	Fresh ground water	Surface water				Fresh ground water	Surface water					
		Fresh	Saline				Fresh	Saline			Fresh	Saline
New England	0	1,900	9,200	0.1	11,000	1.3	24	3.7	2.0	31	96	0
Mid-Atlantic	27	14,000	25,000	36	39,000	140	300	33	9.3	480	140	46
South Atlantic-Gulf	63	18,000	14,000	1.5	31,000	28	330	4.0	1.7	360	210	120
Great Lakes	8.2	25,000	0	34	25,000	56	300	0	3.1	360	52	0
Ohio	20	25,000	0	9.8	26,000	13	420	0	15	450	280	0
Tennessee	0	8,600	0	0	8,600	0	74	0	0	74	59	0
Upper Mississippi	28	13,000	0	30	13,000	6.5	420	0	3.1	430	96	0
Lower Mississippi	0	5,900	0	0	5,900	27	120	0	0	140	290	1.7
Souris-Red-Rainy	0	190	0	0	190	0	1.0	0	0	1.0	1.2	0
Missouri Basin	310	3,900	0	85	4,300	.9	25	0	.1	26	68	0
Arkansas-White-Red	46	2,800	0	0	2,800	10	1.7	0	.4	12	95	0
Texas-Gulf	31	7,600	2,800	4.9	10,000	1.1	2.5	.3	.1	4.0	380	28
Rio Grande	22	5.2	0	0	27	.2	0	0	0	.2	20	0
Upper Colorado	0	160	0	0	160	0	2.1	0	0	2.1	60	0
Lower Colorado	36	110	0	0	150	2.0	0	0	.3	2.3	47	0
Great Basin	4.3	78	0	0	83	0	0	0	0	0	5.7	0
Pacific Northwest	6.8	29	0	0	36	.2	0	0	0	.2	8.8	0
California	380	1,100	9,200	0	11,000	0	0	0	0	0	32	60
Alaska	2.2	18	1.0	0	22	0	0	0	0	0	1.0	0
Hawaii	140	32	980	0	1,200	0	0	0	0	0	0	0
Caribbean	0	0	3,300	5.0	3,300	0	0	0	0	0	5.0	2.0
United States[1]	1,100	130,000	64,000	200	190,000	290	2,000	41	35	2,400	1,900	260

[1] Including Caribbean region.

Source: [2]

4.3.1 Effluent Streams

The quality and quantity of water required at various use points and effluents generated depend on a number of factors including:

- Site location
- Ambient climatic condition
- Plant size and age
- Coal characteristics
- Plant design
- Operating philosophy
- Regulatory framework

Steam electric power plants (including coal-fired units) generate two types of wastes:

1. Chemical wastes, usually as aqueous wastes. These depend on fuel characterization, raw water quality, system design, and others.
2. Waste heat dissipated to the environment via the cooling water system.

These are separate subcategories under EPA Guidelines. This report focuses on chemical wastes.

The major use points for water and, hence, generation points for effluents in a coal-fired power plant are:

I. Continuous
- Condenser cooling
- Steam generation
- Water treatment
- Ash handling
- Flue gas desulfurization
- Miscellaneous

II. Intermittent
- Maintenance cleaning
- Drainage (including coal pile run-off)

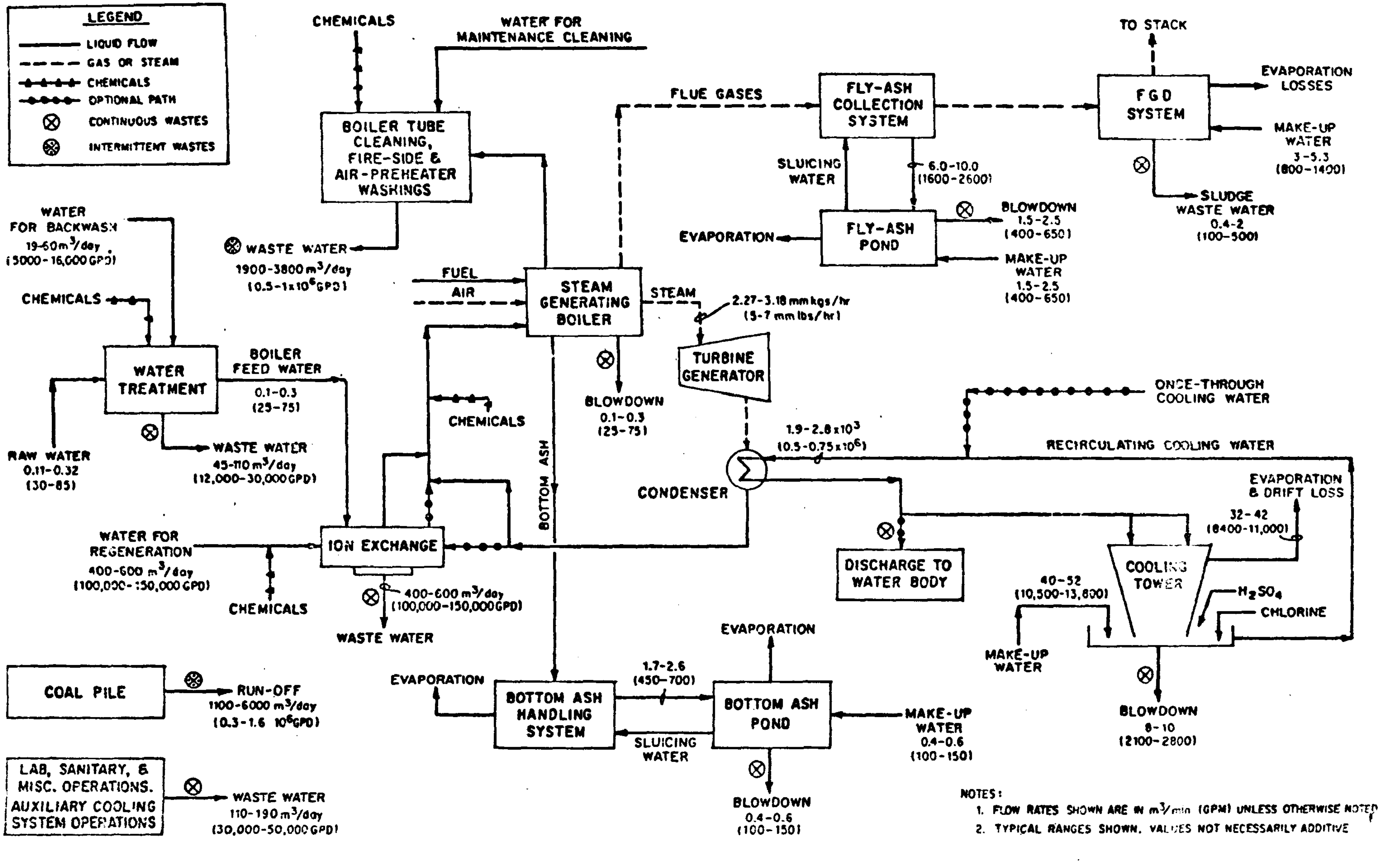
4.3.2 Water Management

Due to the multiplicity of uses of water in a coal-fired boiler and the widely varying requirements for water quality in those uses, coal-fired power plants present major opportunities for better management through a combination of:

- Proper wastewater management to minimize net effluent leaving the plant. For example, boiler blowdown is often of higher purity than the original source of supply and may be used as makeup to demineralizers.
- Combination of compatible wastewater streams with appropriate equalization for either treatment or reuse in some other use point in the power plant.
- Treatment of the appropriate streams for potential reuse in the power plant itself or, if that is economically unjustified, for discharge to a receiving stream. The quality of recycle water required in its intended reuse is the key element in determining the level of treatment for reuse.

For illustrative purpose, the water use, effluent generation, and potential for recycle around a 1,000 MW coal-fired unit are shown in Figure S.2. In Volume 2 of this report, an assessment of each effluent stream, including characterization and potential treatment methods for reuse or discharge, is presented.

Increasing the amounts of water recycled or reused in any or all of the wastewater streams is affected by the chemicals that enter either through their occurrence in natural waters or through the operation of the plant (for example, corrosion inhibitors, biocides, etc.). Hence, the nature and type of treatment of water for recycle or reuse is determined both by these factors and the regulatory limitations that may be placed on discharges to the environment. Consequently, the water treatment technologies applicable to power plants attempting to achieve high recycle or reuse rates are influenced principally by site-specific and system-specific (design and operational) factors. In addition, the differences between



Source: Arthur D. Little, Inc.

Figure S.2 Generalized Schematic Water Balance for a Typical 1000 MW Coal-Fired Power Plant existing and new (or planned) power plants on economic water recycle are many. In existing plants, piping and collection systems for wastewater management and increased recycle or reuse can be a major expense item and may potentially outweigh any other consideration.

For the reasons discussed above, economics of optimum water management cannot be summarized generically. Details on a number of individual options permitting various levels of recycle/reuse are presented in Volume 2.

It appears that substantial opportunities exist for increased water recycle/reuse by using existing technology. In fact, technology does exist for almost complete if not total reuse of water and elimination of pollutant discharges through effluents. In many cases, however, economic constraints may be prohibitive, particularly in old and existing plants. Economic considerations also raise two important factors:

1. Existing technology in many cases is from other industries and in some cases on a smaller scale than required in the utility industry.
2. The utility industry, being a regulated industry, has been very reluctant to accept economic estimates on technology unless such technology is demonstrated on a large scale in this industry.

Increasingly stringent regulations and constraints on water availability will force further emphasis on water recycle/reuse. This will be resisted principally on an economic basis since the installation and operation of the technologies required to effect high degrees of recycle or reuse will, in general, result in reduced overall plant efficiencies and increased capital investments with no concomitant increase in the generation of power. This situation will be exacerbated by the industry reluctance to install systems which have not been widely demonstrated and, furthermore, which require a degree of integration with the power generation cycle which has not heretofore been necessary. Further in some cases, industry is also questioning the cost/benefit aspect of water recycle reuse. Consequently, an effective program of technology transfer coupled with a judicious assessment of the techno-economic-environmental aspects of environmental regulations will be preeminent in determining the rapidity and magnitude of water recycle and reuse in the steam-electric power industry.

4.3.3 Data Gaps and Future Research Needs

The assessment in this report indicates that for optimum water management additional information is necessary in the following areas:

- Ash handling, particularly environmental impact aspects of dry ash handling.
- Chlorination and potential alternatives, particularly technical optimization and environmental impact assessment.
- Coal waste leachate and technical assessment of methods to simulate leachates.
- Metal cleaning wastewater treatment (particularly chelated complexes).
- Impact of chemical additives.
- Control methods for priority pollutants.

It should be noted that some of the ongoing EPA and EPRI projects will provide information and go towards closing some of the above data gaps.

Field scale demonstrations on some of the recently developed technologies for some of the above may be desirable to encourage broader acceptance of such technology for judicious water management by utilities.

Furthermore, as stated earlier in this report, increasing use of coal in industrial boilers is likely to add a new dimension to existing water management problems in the future. Problems of water and waste management at industrial boilers which tend to be small to moderate in size (as compared with large utility boilers) are different partly due to differences in control technology employed (for example, use of sodium-based FGD systems) and differences in scale of operation. Potential problems and their solutions in waste management for industrial boilers need to be better defined.

4.4 FGC Wastes Overview

As coal utilization continues to grow, the generation of FGC wastes is expected to grow dramatically. Table S.5 provides an estimate on anticipated growth in FGC wastes up to the year 2000.

Important aspects of the projected generation are:

- Fly ash collection will be principally accomplished by electrostatic precipitation or bag filtration. Dry handling is expected to increase in future.
- Flue gas desulfurization will continue to be dominated by nonrecovery systems producing a throwaway waste.

More importantly, the vast majority of FGC wastes produced will be disposed of, rather than utilized. Utilization is expected to grow but at a lesser rate than the increase in the generation of FGC wastes.

In assuming FGC waste disposal practice, it may be noted that in the past utilities operating FGC systems typically have disposed of wastes by storage in ponds, often without provision for control of overflows or seepage into groundwater. However, several factors will dramatically influence disposal options in the coming years.

a. An increase in coal-fired capacity in the United States. The total U.S. coal-fired electric utility generating capacity was estimated at over 191,000 MW in 1976 [3] and is expected to increase by 1986 to over 326,000 MW [4]. Use of coal in large industrial boilers (+25 MW equivalent or larger) is likely to further increase the total coal-fired capacity [5].

b. A major increase in the application of scrubber technology by utilities and a consequent increase in FGC waste generation. At present over 16,000 MW of generating capacity at some thirty plants utilize FGD systems. As of September 1978, over 59,000 MW of capacity have been committed [8]. Future increases are likely to be even more dramatic.

TABLE S.5

Projected Generation of Coal Ash and FGC Wastes

	1975		PROJECTED 1985		PROJECTED 2000	
	10^3 Metric Tons	% of Total	10^3 Metric Tons	% of Total	10^3 Metric Tons	% of Total
Coal Ash						
Industrial	-	-	8,590	12	19,950	19
Utility	-	-	64,440	88	84,800	81
Total	52,060	-	73,030	100	104,750	100
FGD Wastes						
Industrial	-	-	1,090	5	5,260	15
Utility	-	-	21,050	95	29,860	85
Total	6,200	-	22,140	100	35,120	100

Note: Estimates made prior to the National Energy Act of 1978.

Source: [5], [6], [7]

c. Advances in stabilization technology for FGD wastes which permit landfill disposal of partially dewatered solids instead of ponding of difficult-to-handle wastes. In the future, disposal of wastes in managed fills is likely to be encouraged. In many cases this will require stabilization prior to disposal.

d. Regulatory developments including the Clean Air Act of 1977 and the Resource Conservation & Recovery Act of 1976 (RCRA). Under the Clean Air Act of 1977, New Source Performance Standards (NSPS) for criteria pollutants are now under review by the EPA and may be significantly tightened.

Against this background, characterization of FGC wastes and environmental and economic impacts of disposal are increasingly critical aspects of coal-fired boiler system design and operations.

4.5 Characterization of FGC Wastes

4.5.1 Chemical Characteristics

The important chemical characteristics of FGC wastes with respect to the disposal operations may be classified under:

- Major components composition;
- Trace components composition; and
- Leaching potential and leachate composition.

These properties are important in assessing potential environmental impact of these solids.

Major Components

Variation in the major components in coal ash is principally caused by the variability in the mineralogy of the coal. Table S.6 summarizes the ranges observed for coal ash obtained from different coal ranks. Generally, more than 80% of the total weight of the ash is made up of silicon, aluminum, iron and calcium compounds (presumably oxides).

Table S.6

Composition of Coal Ash According to Coal Rank[a]

Constituent	Bituminous	Subbituminous	Lignite
Major Constituents			
Silicon Dioxide, SiO_2	7-68	17-58	6-40
Aluminum Oxide, Al_2O_3	4-39	4-35	4-26
Iron Oxide, Fe_2O_3	2-44	3-19	1-34
Calcium Oxide, CaO	1-36	2-52	8-52
Sodium Oxide, Na_2O	<1-3	<1-8	<1-28
Magnesium Oxide, MgO	<1-5	<1-9	3-14
Minor Constituents			
Titanium Oxide, TiO_2	1-4	1-2	1-1
Sulfur Oxide, SO_3	<1-32	3-18	8-32
Potassium Oxide, K_2O	<1-4	<1-2	<1-2
Phosphorous Pentoxide, P_2O_5	<1-5	<1-3	<1-1

[a]Constituent reflects only elemental breakdown and reported as weight percent of their oxides and are not meant to indicate the actual compounds present.

Source: [9]

Among the important factors that affect the composition of FGC wastes are the composition of the coal, boiler type and operating conditions, particulate control method, and the FGD system type and operating conditions. The principal substances making up the solid phase of FGC wastes are given in Table S.7. The calcium sulfate (hemi- or dihydrate) content depends principally on the extent of oxidation in the FGD system. Higher sulfate content is usually observed in systems burning low sulfur western coals and in forced oxidation systems. The waste can also contain a variable amount of fly ash which arises from admixing or if the FGD unit is also used as a particulate control device. Various amounts of unreacted raw materials (e.g., limestone) also can be present depending on the quality and utilization of these materials.

A significant number of generic and proprietary processes have been proposed whereby chemical and physical properties of FGC waste would be modified leading to "stabilization" of the waste. Two of these (those developed by IU Conversion System and Dravo) are now offered commercially for treating FGC wastes from utilities. Data are available on the effects of stabilization on strength and permeability properties of FGC wastes; however, only limited data are available on complete chemical characterization of the stabilized materials.

A number of dry sorbent processes are now under study and it is expected that some will be in commercial practice by 1981. Very limited data are available on the characteristics of these wastes produced by the processes.

FGC waste solids may carry with them occluded liquors which may contain a variety of dissolved substances. The major components of the liquor (species which can be present at concentrations of 100 ppm or more) include calcium, chloride, fluoride, magnesium, potassium, sodium, sulfate and sulfite with total dissolved solid levels ranging between 2,500-100,000 ppm. Table S.10 summarizes some typical concentration ranges. The concentrations of calcium, sulfate and sulfite are generally limited by the solubility products of the respective salts and the ion activities which depend on ionic strength. Thus, variability in systems and operations affect these levels.

Table S.7

Major Components in FGC Waste Solids

Process	Composition (Percent by Weight)				
	$CaSO_3 \cdot 1/2H_2O$	$CaSO_4 \cdot xH_2O$ [a]	$CaCO_3$	Fly Ash	Other
Limestone					
Shawnee	19-23	15-32	4-42	20-43	-
Cholla	11	17	3	59	10 [b]
Mojave	2	95	1	4	-
LaCygne	20	15	41	24	-
Lawrence	<1-7	11-31	2-22	(40-60)	-
Lime					
Shawnee	50	6	3	41	-
Phillips	13	19	1	60	-
Paddy's Run	94	2	0	4	-
Forced Oxidation					
Shawnee (lime)	3	52-65	2-5	30-40	-
Shawnee (limestone)	3	47-62	5-10	30-40	8.2 [b]
Black Dog (limestone)	<1	20-40	<-----remainder----->		
Dual Alkali					
Parma	14	72	8	7	-
Scholz	65-90	5-25	2-10	1	-
Gadsby	<1	82	11	9	-
Fly Ash					
Colstrip	0-5	5-20	<1	40-70	5-30% $MgSO_4$
Milton R. Young	<1	40	-	60	-

[a] Generally X=1/2 for high sulfite solids and x=2 for low sulfite solids

[b] Unknown soluble salt

Source: [10-21]

Minor and Trace Constituents

The major source of minor and trace species present in coal ash is coal which contains a large number of trace elements occluded in the mineral matrix or as organometallic compounds. Typical ranges of minor and trace species in coal ash are shown in Table S.8. A great many trace species have been detected and over a wide concentration range in various coal ash samples. A few elements originally present in the coal (notably sulfur, chlorine and mercury) are nearly completely volatilized and leave the boiler as gaseous products. Condensation of more volatile species on the surface of fly ash particles may result in a higher concentration of these species on the smaller fly ash particles. This enrichment has been observed, for example, for arsenic, antimony, selenium and lead.

The type and concentration of trace species in FGC wastes depend primarily on the amount of ash collected or mixed with the waste, the efficiency of the scrubber in capturing volatile trace constituents and the trace species content of any FGD additive. Typical data on the range of trace species in FGC wastes are given in Table S.9 and represent data on the sum of the content of the liquor and solid waste. There are little available data on the distribution of these trace species between the two phases. The presence of highly volatile species such as arsenic, mercury and selenium will depend to a large extent on the efficiency with which these are captured by the scrubber. In addition, the ash present in the inlet to the scrubber may contain adsorbed compounds of these elements and add to the total in the FGD wastes. However, for most of the available data on the trace species content of FGC wastes, there appears to be no direct correlation with the trace species content of the coal burned. This may not be surprising in view of the fact that the FGC waste solids which have been obtained came from units which do collect varying amounts of the fly ash produced; and in addition, some highly volatile species may not be collected in the scrubber.

The range of trace elements observed for FGC waste liquors is given in Table S.10. A small fraction of the total trace species present in

Table S.8

Range of Minor and Trace Species Present in Coal Ash[a]

Concentration Category	Species	Range (ppm)
10^1 - 10^4 ppm	As	2-1000
	B	15-6,000
	Ba	50-13,900
	Cu	20-3,000
	F	16-1,000
	Mn	31-10,000
	Mo	5-1,500
	P	5-10,000
	Pb	10-1,500
	Sn	10-4,250
	Sr	40-9,600
	V	10-1,000
	Zn	25-15,000
	Zr	100-1,450
1-10^2	Ag	1-50
	Be	1-200
	Ce	< 53-250
	Cl	41-270
	Co	5-440
	Cr	5-500
	Ga	10-135
	Ge	20-285
	Hg	0.01-100
	La	19-270
	Li	48-500
	Nb	21-78
	Ni	15-610
	Sb	<2-200

Table S.8 (continued)

Range of Trace Species Present in Coal Ash[a]

Concentration Category	Species	Range (ppm)
	Sc	2-155
	Se	1-50
	Th	21-54
	W	7-30
	Y	21-460
	Yb	2-23
<2	Au, Bi, Br, Cd, Hf, I, Ir, Lu, Pd, Re, Ru, Os, Rh, Rt, W	<2

[a]Most of the data were derived from coals ashed at 600°C (1140°F) using atomic absorption spectroscopy

Source: [22,23,24]

Table S.9

Total Concentrations of Trace Constituents in FGC Waste and Coal

Species	FGC Waste Solids (ppm)	Coal (ppm)
Arsenic	0.6 - 63	3 - 60
Beryllium	0.05 - 11	0.08 - 20
Cadmium	0.08 - 350	-
Chromium	3 - 250	2.5 - 100
Copper	1 - 76	1 - 100
Lead	0.2 - 21	3 - 35
Manganese	11 - 120	-
Mercury	0.001 - 6	0.01 - 30
Nickel	6 - 27	-
Selenium	< 0.2 - 19	0.5 - 30
Zinc	10 - 430	0.9 - 600

Source: [25,26]

Table S.10

Typical Concentration Ranges of Chemical Species
In FGC Waste Liquors and Elutriates

	Eastern Coal FGC Wastes (3-20 Observations)	Western Coal FGC Wastes (3-10 Observation)
pH (pH units)	7.1 - 12.8	2.8 - 10.2
TDS (ppm)	2,500 - 150,000[a]	5,000 - 95,000
Major Constituents (ppm)		
Calcium	<100 - 2,600	240 - 45,000[b]
Chloride	400 - 5,600	25 - 43,000[b]
Magnesium	0.1 - 3,400	---
Potassium	11 - 760	---
Sodium	36 - 50,000[a]+	1,650 - 9,000[b]
Sulfate	720 - 50,000[a]+	2,100 - 19,000
Fluoride	<1 - 770	0.7 - 3.0
Trace Constituents (ppm)		
Antimony	0.46 - 1.6	0.09 - 0.22
Arsenic	<0.004 - 1.8	<0.004 - 0.2
Beryllium	<0.0005 - 0.05	0.0006 - 0.14
Boron	18 - 76	8 - 140
Cadmium	0.004 - 0.1	0.011 - 0.044
Chromium	0.001 - 0.5	0.024 - 0.4
Cobalt	<0.002 - 0.1	0.05 - 0.17
Copper	0.002 - 0.4	0.002 - 0.6
Iron	0.02 - 0.1	0.11 - 8.1
Lead	0.0002 - 0.55	0.0014 - 0.37
Manganese	<0.01 - 9.0	0.007 - 2.5
Mercury	0.00006 - 0.07	<0.01 - 0.07
Nickel	0.03 - 0.91	0.005 - 1.5
Selenium	0.003 - 2.7	<0.001 - 2.2
Zinc	<0.001 - 27	0.028 - 0.88

[a] Levels of soluble sodium salts in dual alkali waste (filter cake) depend strongly on the degree of cake wash. The highest levels shown reflect simple measurements on an unwashed dual alkali filter cake (see text in Volume 3).

[b] Levels of soluble chloride components in wastes are dependent upon the chloride-to-sulfur ratio in the coal. The highest levels shown are single measurements for a western limestone scrubbing system operating in a closed-loop using cooling tower blowdown for process makeup water.

Source: [26,27]

FGC wastes is found dissolved in the waste liquor; the major portion is found in the solid phase. No direct generalized correlation exists between trace species level in the parent coal and the waste liquors. These two factors suggest that some of the levels are limited by the low solubilities of the trace metal hydroxides, oxides, or carbonates.

Leaching Potential and Leachate Composition

The potential for groundwater and surface water contamination from FGC waste disposal varies with waste characteristics, method of disposal, and site conditions. This contamination may occur by release of occluded waste liquors and/or leachings of FGC waste species. Leaching may involve surface leachings usually limited by waste dissolution and diffusion and/or flow-through waste pores. For either mechanism to occur, the waste must be nearly or fully locally saturated with moisture. The species that are dissolved in the waste liquor are more readily available than those in the solid phase. The initial leachate composition in a first flush mechanism will be roughly equivalent to composition to the occluded liquor. Subsequent pore volumes would contain levels which would be determined to a greater extent by the amount of solid waste dissolution. This has been shown experimentally with first pore volume displacement (PVD) data approximating those of interstitial liquor and successive displacements showing rapidly decreasing levels of total dissolved solids and certain highly soluble species (e.g., sodium, chloride). Pore volume refers to the interstitial space in a mass of FGC solid particles not occupied by the solids themselves. If liquors are present, they occupy this space. Initial concentrations of trace elements tend to be low generally although some have been noted to exceed drinking water standards. Successive PVD's (i.e., pore volume displacements) usually contain decreasing concentrations of most trace species. The concentrations of some trace species (e.g., arsenic and zinc) have been observed to remain relatively constant. Concentrations of calcium and sulfate have also been observed to level off based on the gypsum solubility product.

4.5.2 Physical Properties

Disposal of FGC wastes involves handling and transport, placement at a disposal site, potential reuse, and assessment of environmental impacts are key factors in ensuring reasonable disposal practices. Many physical properties of FGC wastes affect the manner in which they are carried through the disposal process and hence influence impacts. Relationships of waste consistency versus solids content (for example, Atterburg limits), viscosity, compaction characteristics, and particle size are important in determining handling methodology. Strength and compressibility properties yield data on both placement and filling conditions at the disposal site. Properties such as permeability may govern the quantity and quality of leachate and thus determine the extent of groundwater pollution. A listing of the range of values observed for physical and engineering properties of fly ash and FGC wastes is given in Tables S.11 and S.12.

The specific gravity of fly ash generally increases with its iron oxide content [33]. The specific gravity of ash-free sulfite wastes is higher than that of ash-free sulfate wastes. (See Table S.12). Both fly ash and other FGC wastes have a generally very uniform particle size distribution. As much as 70% by weight of a fly ash sample may consist of hollow spheres.

FGC wastes exhibit little or no plasticity (they convert from a semi-solid to a viscous slurry over a narrow moisture content) and are similar to silts and sandy silts.

The viscosity of fly ash is generally lower than other materials of similar grain size at equal solids content. Results of pumping tests on FGC wastes indicate that some of these wastes may be pumped at 60% solids content and that addition of fly ash increases the fluidity of the waste.

Table S.11

Physical and Engineering Properties of Fly Ash

Property	Range of Values
Grain Properties[a]	
Specific Gravity	1.97 - 2.85
Grain Size	88 - 93% in the 2-74μm range
Coefficient of Uniformity	1.2 - 1.4
Atterburg Limits	not plastic
Compaction Properties[b]	
Bulk Dry Density	0.96 gm/cc (average)
Field Density	1.12 gm/cc (average)
Controlled Compacted Density	Up to 1.65 gm/cc
Optimum Moisture Content	16 - 31%
Maximum Proctor Dry Density	1.14 - 1.65 gm/cc
Permeability[c]	0.5 - 5 x 10^{-4} cm/sec
Strength Parameters[d]	
Angle of Internal Friction	28° - 38° (at densities of 0.8 to 1.2 g/cc)

[a]Source: [28, 29, 30]

[b]Source: [31, 32-34, 35, 36]

[c]Source: [32, 35, 36]

[d]Source: [32]

Table S.12

Physical and Engineering Properties of FGD Wastes

Property	Range of Values: Sulfite Rich	Range of Values: Sulfate-Rich
Grain Properties[a]		
Specific Gravity	2.49 - 2.86	2.34 - 2.35
Grain Size	85-93% in the 2-74μm 4-10% >74μm	66-76% in the 2-74μm 18-30% >74μm
Coefficient of Uniformity	1.3 - 1.5	2.3 - 2.5
Atterburg Limits	Little or no Plasticity	Little or no Plasticity
Compaction Properties[b]		
Maximum Dry Density	1.15 - 1.36 gm/cc	1.26 - 1.52 gm/cc
Optimum Moisture Content	35-52%	13-33%
Compressibility	Up to 10% of Original height	Much less than 10% of Original Height
Permeability[c]	$(0.9 - 4) \times 10^{-5}$ (unstabilised) $(0.005 - 14) \times 10^{-5}$ (stabilized)	$(1 - 98) \times 10^{-5}$ (unstabilized) ------
Strength Parameters[d]		
Angle of Internal Friction	30-36° (unstabilized)	up to 42° (unstabilized)
Effective Cohesion	∿0 (unstabilized)	∿0 (unstabilized)

[a]Source: [33,37,38,39,40,41,42,43]

[b]Source: [44, 45, 46]

[c]Source: [16,26,40,47,48]

[d]Source: [33,40,47]

The compressibility of fly ash near its maximum dry density is low. Since the density of fly ash is lower than compacted natural soils, it may cause less settlement when placed over subsoils of equal fill stiffness.

The compaction behavior of sulfate and sulfite FGC wastes is significantly affected by the particle morphology, grain size distribution and specific gravity of the material. Generally, addition of fly ash to sulfate- and sulfite-rich wastes increases their maximum dry density and decreases their moisture content at the maximum dry density. Repeated impacts on sulfite-rich wastes appear to cause progressive breakdown of the waste particles. Sulfate wastes are generally less compressible than sulfite wastes due in part to different particle morphology. Consolidation tests indicate that uncompacted sulfite-rich FGD wastes may compress as much as 10% of their original height in a fill while sulfate-rich wastes are much less compressible.

The shear strength of freshly placed fly ash depends primarily on its dry density. Aged fly ash may exhibit greater strength due to greater cohesion produced by pozzolanic cementation. Angles of internal friction may increase to 43° and cohesion to more than 100 psi.

FGD wastes generally exhibit insignificant effective cohesion but unconfined compression strength in the 10-20 psi range is obtained for samples at their maximum dry density. Strength parameters for stabilized wastes are sensitive to moisture content and age of the waste. Addition of stabilizing agents such as fly ash and lime causes great increases in strength for the cured materials.

Fly ash is a freely draining material. The permeability of sulfite-rich wastes is generally lower than that of sulfate-rich wastes, although well-managed gypsum formation in a dual alkali plant may produce low permeability waste. Addition of stabilizing agents may decrease permeability by one or more orders of magnitude. A decrease in permeability is also observed with an increase in fly ash content due to a decrease in the void ratio (or increase in solids content).

4.5.3 Research Needs in Characterization

Major data gaps exist in the characterization of coal ash and FGD wastes with respect to:

- Data from field scale operations. There is an important need to characterize both stabilized and unstabilized wastes in terms of their behavior in the actual field disposal operation.
- Data on leaching behavior and leachate characteristics which will lead to better methods of assessing environmental impacts.
- Characterization of dry sorbent FGC process wastes and environmental impacts associated with their disposal.
- Data on trace species migration from ash/FGD waste co-disposal and from stabilized FGC waste disposal into the surrounding environment.
- Data on variation of waste properties (physical and chemical) with various stabilization processes.
- Data on speciation of trace contaminant, both inorganic and organic. Speciation refers to the actual chemical compounds of the trace contaminants. While analytical methods usually indicate the concentration of such trace contaminants, the nature of the compounds in which the trace contaminant occurs (i.e., speciation) is usually unknown.

4.6 FGC Waste Disposal

4.6.1 Impact Issues

The environmental impact issues requiring consideration in handling and disposal of FGC wastes are:

- Air-related. These include fugitive particulate emissions, emissions of SO_2 and H_2S and emissions of trace metal compounds;

- Water-related. These include groundwater contamination, surface water point source discharges and runoff;
- Land-related. These include physical stability (subsidence, liquefaction or other structural failure, erosion, etc.) and land use considerations; and
- Biological impacts both in the site and adjacent areas.

Potential impact issues are highly site- and system-specific. With that understanding, the major types of impact issues associated with various disposal options will be discussed below. The range of waste types and possible disposal conditions is sufficiently broad to eliminate the potential for "generally significant" issues to be associated with any of the disposal options. Further, site-specific application of appropriate control technology can be employed to mitigate adverse impacts. In other words, issues of potential significance in FGC waste disposal can best be defined in terms of specific waste types, disposal practices, and disposal environments. The significance of many potential impact issues may be better quantified by additional field-scale operating experience (and environmental monitoring) with FGC waste disposal. This is particularly desirable for defining potential issues in the categories of water quality and biological impacts.

4.6.2 Disposal Options and Potential Impacts

A number of methods are potentially available for the disposal of FGD wastes either on land or in the ocean. Applicability of disposal options for FGD wastes can be broadly categorized on the basis of the nature of the wastes and the type of disposal.

Table S.13 lists potential disposal options for the various types of wastes. In this table sulfur is included as a potential waste product; however, it is more likely that sulfur as a final product from recovery FGD systems will be produced for utilization. More importantly, recovery FGD processes are likely to require prescrubber systems to remove particulates, chlorides, and other flue gas constituents which might contaminate absorbent liquors. Prescrubber blowdown from these systems will

Table S.13

Potential Disposal Options

	Ash	FGD Waste	Codisposal	Sulfur
Land Disposal				
Wet Pond (Conventional)	C	C	C	-
Gypsum Stacking	-	P	-	-
Dry Impoundment	C	C	C	P
Surface Mine	C	P	C	P
Underground Mine	P	P	P	P
Ocean Disposal				
Shallow - Outfall	P	P	P	-
Concentrated (conventional) Dump	P	P	P	-
Dispersed Dump	P	P	P	-
Reef Construction (Stabilized)	P	-	P	-
Deep - Concentrated (conventional) Dump	P	P	P	-
Dispersed Dump	P	P	P	-

C - commercial practice

P - reasonable potential

Source: Arthur D. Little, Inc.

result in wastes analogous to the wastes from nonrecovery FGD systems (although in smaller quantities). Hence, in the future if recovery pro cesses are used, it will thus reduce, not eliminate, FGD wastes.

At present, all FGC wastes are disposed of on land. To provide a perspective, Table S.14 summarizes data on present disposal practices on utility FGC systems. In addition to the commercially operating units, a number of FGC disposal systems are in operation for testing, development and/or data gathering purposes. A list of such current field testing programs on FGC wastes and associated data on the systems involved is presented in Table S.15.

A brief review of land disposal methods and potential ocean disposal options is presented below.

4.6.2.1 Land Disposal

The principal methods of land disposal are:

- Wet ponding;
- Dry impoundment; and
- Mine disposal.

Wet Ponding: This method is at present more widely used than any other. Ponding can be employed for a wide variety of FGD wastes including unstabilized materials; however, ponding has been employed with the Dravo stabilization process. Ponds can be designed based on diking or excavation and can even be engineered on slopes. But the construction of dikes or other means of containment for ponds is usually expensive. In the future, particularly if stabilization of FGD wastes is widely practiced, ponding will probably be limited to those sites that can be converted to a pond with minimal construction of dams or dikes. A special case of wet ponding is gypsum stacking now

Table S.14

Present Disposal Practices

Utility FGC Systems

(No. Plants/Total Capacity in Mw)

Waste	Western Dry Fill	Western Wet Pond	Eastern Dry Fill	Eastern Wet Pond
FGD Only	–	1/200	-	2/365
Co-disposal	8/4135	13/6705	2/245	6/1965
Stabilized	-	-	6/2615	1/1650
Totals	8/4135	14/6905	8/2860	9/3980

Source: Arthur D. Little, Inc.

Table S.15

Summary of Current Field Testing Programs for FGC Waste Disposal
(Status as of March 1979)

Location/Utility (Plant)	Sponsors[a]	Principal Contractors[a]	Scrubber System
Land Disposal			
Pilot/Prototype			
TVA (Shawnee)	EPA(IERL)/TVA	Bechtel/TVA	Conventional Lime Conventional Limestone Forced Oxidation
Louisville Gas & Electric (Paddy's Run)	EPA/IERL	LGE/CE/UL	Conventional Lime (Carbide)
Gulf Power (Scholz)	EPA(IERL)/EPRI	CEA/ADL	Dual Alkali (Limestone
Gulf Power (Scholz)	EPRI	CIC/Radian/Ardaman	Limestone Forced Oxidation
(Not applicable)	EPRI	-	-
Full Scale			
Columbus & Southern Ohio (Conesville)	EPRI(IERL)	MB/Batelle	Conventional Lime (Thiosorbic)
Louisville Gas & Electric (Cane Run)	EPA(IERL)	LGE/Bechtel	Dual Alkali (Lime)
Minnesota Power (M.R.Young)	EPA(IERL)	UND/ADL	Alkaline Ash
(Monitoring 3 Disposal Areas)	EPA(IERL)	WES	Conventional LIme & Limestone
(Multiple Site Monitoring)	EPA(IERL)	Not selected yet	Many
(Unspecified)	-	MB	Conventional Lime
Ocean Disposal			
Pilot/Prototype			
Columbus & Southern Ohio (Conesville)	DOE/EPA(IERL)/	SUNY/IUCS/NYSERDA	Conventional Lime (Thiosorbic)
(Not Applicable)	EPA(IERL)	NEA/ADL	MANY

[a] ADL - Arthur D. Little
CE - Combustion Engineering
CEA - Combustion Equipment Associates
CIC - Chiyoda International
DOE - Department of Energy
EPA - U.S. Environmental Protection Agency
EPRI - Electric Power Research Institute
IUCS - IU Conversion
LGE - Louisville Gas and Electric
MBI - Michael Baker, Jr., Inc.
NEA - New England Aquarium
NYSERDA - New York State Energy Research & Development Authority
PASNY - Power Authority of the State of New York
SUNY - State University of New York
TVA - Tennessee Valley Authority
UL - University of Louisville
UND - University of North Dakota
WES - Army Corps of Engineers (Waterway & Experiment Station)

Table S.15 (Continued)
Summary of Current Field Testing Programf for FGC Waste Disposal

Waste Characteristics Type	Waste Characteristics Form	Disposal Mode	Program Status
Sulfite-Rich	Many	Wet & Dry Impoundment	Underway
Gypsum	Filter Cake (Unstab)	Dry Impoundment	Underway
Sulfite Rich	Filter Cake (Stab &Unstab)	Dry Impoundment	Underway
Sulfite Rich	Filter Cake (Stab & Unstab)	Dry Impoundment	Planned
Gypsum	Thickened Slurry (Unstab)	Stacking	Underway
-	-	Liner Study	Planned
Sulfite-Rich	Filter Cake (Stab)	Dry Impoundment	Planned
Sulfite-Rich	Filter Cake (Stab)	Dry Impoundment	Planned
Sulfite-Rich	Filter Cake (Unstab)	Surface Mine	Underway
Unspecified	Ash & FGD Waste Slurries	Wet Ponds (unlined)	Underway
Many	Many	Many	Planned
Sulfite-Rich	Slurry (Stabilized)	Underground Mine	Proposed
Sulfite-Rich	Filter Cake (Stab)	Reef Construction	Underway
Many	Many	Conventional Dump	Underway

under evaluation. In this case, if the operation were analogous to that for phos-gypsum, gypsum slurry (typically from forced oxidation systems) would be piped to a pond and allowed to settle and the supernate recycled. Periodically the gypsum would be dredged and stacked around the embankments, thus building up the embankment.

Leaching from wet ponds is likely to be an important environmental issue that must be addressed in pond design and operation. Recent R&D efforts on wet ponding have centered on:

- Effective means of containing pollutants within the disposal area; i.e., study of potential liner material.
- Better definition of leaching mechanism from lined and unlined ponds.

Dry Impoundment Methods: These may include any of the following variations:

- Land disposal of dry ash.
- Interim ponding followed by dewatering and sometimes excavation and landfilling;
- Mechanical dewatering and landfilling of FGD wastes;
- Blending with fly ash and landfilling of FGD wastes; and
- Stabilization through the use of additives (non-proprietary or otherwise).

Typically, for dry impoundment type of disposal, the wastes, if necessary, are thickened and dewatered to a high solids content and blended with fly ash and lime or other additives like cement, Calcilox®, etc., thus forming a material with cementitious properties. This material is transported to the disposal site where it is spread on the ground in

0.3 to 0.9 meters (1 to 3 foot) lifts and compacted by wide track dozers, heavy rollers or other equipment. Layering proceeds in 0.3 to 0.9 meters (1 to 3 foot) lifts in segments of the site. The ultimate height of a disposal fill is site-specific but may be 9 meters (30 feet) to as high as 25 meters (∿80 feet) or more. A properly designed and operated dry impoundment system can enhance the value of the disposal site after termination or at least permit post operational use.

Mine Disposal: A disposal method that is receiving increased attention is mine disposal. It appears that surface coal mines and underground room and pillar mines for coal, limestone, or lead/zinc ores offer particular potential. Of the four categories of mines noted above, coal mines, and in particular surface area-type coal mines, are the most likely candidates for waste disposal. Coal mines offer the greatest capacity for disposal, and they are frequently tied directly to power plants. In fact, many new coal-fired power plants are "mine-mouth" (located adjacent to the mine or within a few miles of it) and the mine provides a dedicated coal supply. Since the quantity (volume) of FGC wastes produced is considerably less than the amount of coal burned, such mines usually would have the capacity for disposal throughout the life of the power plant. The space available in surface mines for FGC waste disposal is also a function of the overburden and swell ratio and strictures on final contouring.

In general, inactive surface mines are considerably less promising than active mines for FGD waste disposal. Unreclaimed surface mines can be used for disposal of wastes between remaining spoil banks, and these may offer suitable sites for disposal. However, because of recent surface mine reclamation and other legislation, the number of sites and total capacity available for wastes in the future will be limited.

In active surface mines, there are basically three options for the placement of FGD wastes:

- In the working pit, following coal extraction and prior to return of overburden;
- In the spoil banks, after return of overburden but prior to reclamation; and
- Mixed with or sandwiched between layers of replaced overburden.

At present there are only two commercial operations involving mine disposal of FGD wastes in surface coal mines--one at Texas Utilities' Martin Lake Station and the other at Square Butte's Milton R. Young Station (North Dakota). Both stations fire lignite and the disposal involves returning combined fly ash and calcium-sulfur solids from SO_2 removal to the respective mines. The operation at the Baukol-Noonan mine which supplies coal to the Milton R. Young Power Station is an EPA mine disposal demonstration project. At this time both pit-bottom and spoil bank disposal are being employed. Mine disposal of FGD wastes can potentially be employed for subsidence control, acid mine drainage neutralization, reclamation of mine areas or as soil amendments for tailings disposal from mining operation. Thus, there could be subsidiary benefits from this type of disposal.

4.6.2.2 Ocean Disposal

Ocean disposal of FGD wastes is not practiced in the United States today. However, if it could be practiced under environmentally acceptable conditions, it could represent an important option, particularly in Federal Regions 1 and 2 (the Northeast) where land for disposal is limited. For this and other reasons, EPA has been studying the disposal of FGD wastes in the ocean. Ocean disposal may be considered in the shallow ocean (i.e., on the continental shelf) or deep ocean (off shelf). Each of these has a different ecosystem with a different set of potential impacts. At present a number of viable techniques exist for transporting FGC wastes to offshore disposal sites.

At present, regulation of dispersed ocean dumping of stabilized and unstabilized FGD waste falls under the Marine Protection Research and Sanctuaries Act and is administered by the Environmental Protection Agency. The dumping would be required to be limited to an EPA-prescribed dumpsite under the specified disposal criteria.

- Trace contaminant (e.g., Hg, Cd) content of the dumped materials would be no higher than 50% above that of background sediments at the dumpsite;
- Concentrations of the dumped material in the water column four hours after release would not exceed 1% of the 96-hour LC_{50} of the material to local sensitive species; and
- No feasible alternatives to ocean disposal are available.

Stabilized, brick-like FGC waste may be used to create artificial fishing reefs with EPA concurrence. Artificial fishing reefs are not subject to the Ocean Disposal Criteria but FGC waste disposal may be a special case. While ocean disposal of FGC sludges is an option that may be available to throwaway system users with economic access to the ocean, new ocean disposal initiatives are now discouraged by the regulatory agencies. At present, two studies under EPA sponsorship or participation involve the ocean disposal of FGC wastes.

4.6.3 Potential Impacts

Potential impacts are determined by:

- Characteristics of wastes
- Mode of disposal
- Characteristics of the site.

Potential impacts that should be considered in planning a disposal operation are summarized in Table S.16. Proper application of site specific control technology as discussed in Sec. 4.6.4 can mitigate against adverse impacts.

Table S.16

Disposal Options Vs Impact Issues

Disposal Mode	Impact Issues					
		Water Quality		Air Quality		
	Land Use	Surface	Groundwater	Fugitive	Gaseous	Biota
Wet Ponding	X	X	X			X
Dry Impoundment	X	X	X	X	X	X
Mine - Surface		X	X	X	X	X
- Underground			X		X	X
Ocean - Shallow		X				X
- Deep		X				X

Source: Arthur D. Little, Inc.

4.6.4 Impact Control Measures

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 becomes 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. Important considerations in the application of present control technology are briefly discussed below:

a. Site Selection: Site selection may or may not be considered control technology. However, there is no question that proper site selection could help ameliorate or even eliminate most of the potential disposal impacts discussed above. Specifically, 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 (surface or aquifers). For example, a small stream or very pure aquifer may impose greater constraints than a relatively large stream or impure aquifer.
Air Quality	Absence of "non-attainment area" and Class I Prevention of Significant Deterioration designations for total suspended particulates. Usually this is even more important for the Power Plant Siting.

Biological Effects	Absence of sensitive biological resources.

b. Control Options: Process operations to ameliorate environmental impacts of FGC waste disposal are:

1. Dewatering: 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 which disposal approach is employed, including those discussed below.

2. Stabilization: Stabilization appears to be highly relevant to the mitigation of land use issues, including the potential for abnormal events (i.e., disposal area liquefaction or other catastrophic failure modes), and the suitability of disposal sites for a broader range of post closure uses requiring increased bearing strength. Stabilization techniques resulting in decreased waste permeability and elimination or reduction of hydraulic load can be considered mitigative of potential water quality impacts due to leachate migration. This factor should be considered in balance with the requirements for disposal area runoff on a site-specific basis.

   Stabilization reduces permeability and hence reduces rate of contaminant transfer from a disposal site. However, long-term cumulative contaminant migration could be important. In particular, it is not clear that reductions in long-term trace contaminant availability would take place when fly ash is used as a stabilization additive to a waste initially containing no ash. However, migration of contaminants to the environment at a slower rate is more desirable.

Cementitious stabilization process, because of increased particle size, may also be considered mitigative of the potential for post-disposal fugitive particulate emissions from dry FGC waste disposal operations, and may minimize or prevent gaseous emissions by reducing exposure of waste to water and biological organisms.

In ocean disposal, cementitious stabilization may remove liabilities of FGC wastes as benthic substrates and as sources of sulfite-related depletion of dissolved oxygen. However, questions of sulfite and trace contaminant availability, among others, preclude definitive judgment on this issue at this time.

3. Forced Oxidation: The intentional production of sulfate-rich, rather than sulfite-rich FGC wastes, is presently a subject of considerable interest. In ocean disposal, the sulfate-rich products of forced oxidation would have the obvious advantage of mitigating the potential for sulfite-related depletion of dissolved oxygen. This advantage would be shared in land disposal operations (especially wet impoundments), but its relative importance is less clear. A dominant question concerning the mitigative potential of forced oxidation for land disposal is whether or not the process results in increased or decreased physical stability. Based on experience with soils, gypsum FGD wastes comprised of relatively uniform, sand-sized particles may exhibit considerable failure potential in the absence of: 1) effective compaction and dewatering, and/or 2) codisposal with materials of varying particle size (i.e., fly ash). However, if FGD gypsum is analogous to phos-gypsum, recrystallization mechanisms occurring in the disposal pile may improve stability.

c. Co-disposal of Wastes and Creation of Waste/Soil Mixtures

Although the term co-disposal is often used in reference to the creation of disposal mixtures of two waste streams (e.g., FGD wastes and coal ash), it is used here to imply a broader range of potential opportunities. Specifically, for land disposal of FGD wastes, "co-disposal" might also include the application of technologies for the creation of soil/waste mixtures. If soils with the proper characteristics are available, the creation of soil/waste mixtures may be an alternative to the addition of fly ash where only limited increases in physical stability are desired in a disposal operation, or where trace contaminant availability needs to be reduced to facilitate revegetation or decrease water quality impacts. Traditional co-disposal involving fly ash plus FGD waste appears to have substantial advantages over independent disposal in terms of improved physical stability and (potentially) decreased permeability. This might be especially relevant to sulfate-rich FGC wastes of uniform particle size. However, in some situations the extent to which the ash serves as a reservoir of certain trace contaminants could prove a liability from the standpoint of potential water quality degradation.

d. Use of Liners: Liners may not be usually required for FGC waste disposal except under certain site specific conditions. However, the use of liners may be desirable. Field experience with liners for FGC waste disposal at present is limited, but ongoing and recently announced programs are likely to close this gap.

4.6.5 Future Research Needs

A number of programs have been undertaken (and are in progress) by the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), and others. These efforts have provided much of the baseline information for environmental assessment. Provided these programs continue, additional data and insight permitting better environmental assessment will be obtained.

Research needs pertinent to environmental assessment of FGC disposal are:

a. Acquisition of field data on the actual impacts of full-scale disposal operations under varying environmental conditions. Field-scale monitoring of large disposal operations over a period of several years is warranted. EPRI's proposed program at Conesville Plant of Columbus and Southern Ohio Electric is one such example. EPA is also planning an extensive two-year study on characterization and environmental monitoring of full-scale utility disposal sites.

b. A corrollary of the above would be the development of correlations and tools of extrapolation to relate existing lab/pilot scale data on physical stability and water quality impacts to full-scale field data.

c. Integrated study and evaluation of the environmental trade-offs in co-disposal of various FGD wastes and various coal combustion ashes. (It appears that this type of initiative could emphasize laboratory work with limited pilot and full-scale field verification.)

d. Development of basic data (laboratory and field-scale) on the biological impact potential of principal land-based FGC waste disposal options, especially data relating to water-related impacts of major soluble species and trace contaminants. Typical questions are:

   - What are the biological and health effects of mixtures of trace metals (in the form found in liquors), such as zinc, copper, lead, mercury, cadmium or nickel in combination with selenium in particular, but also in combinations with other trace metals? Are synergistic effects significant?

- What is the uptake of potentially toxic materials by vegetation and wildlife associated with disposal areas?
- What are the levels of ambient concentration of waste-related potentially toxic materials in vegetation and surface water that may produce chronic health problems for wildlife?

EPA is presently supporting biological testing work on FGC wastes at Oak Ridge National Laboratory and will support field scale testing beginning in 1980 at TVA.

e. Development of basic (laboratory and field) data on the potential for fugitive particulate emissions from areas previously used for the dry disposal of FGC wastes.

f. Socio-economic impacts of FGC waste disposal on land need to be better defined.

In the future, FGC waste generation will not be limited to those from coal-fired utility systems. Coal utilization in industrial boilers (25 MW or larger) is also likely to grow substantially in the future. FGC wastes from such coal-fired industrial boilers (which may be analogous in composition to solid wastes from utility boilers or maybe liquid wastes) present additional waste management issues due to differences in distribution of generation facilities, in quantity of FGC wastes generated at each facility and other factors. These issues also require further evaluations and study.

4.6.6 Economics of FGC Waste Disposal

The economics of waste disposal is quickly becoming one of the most important factors in the implementation of FGC systems. Generic studies of FGC process technologies and the evaluation of specific process applications now routinely incorporate analyses of waste processing and disposal costs. In addition, numerous generalized economic studies have also been undertaken. These studies basically fall into one of two categories. First, studies involving conceptualized designs and generic cost estimates for a variety of different waste types and disposal options using a model plant approach in order to evaluate the comparative economics of disposal alternatives and to investigate the sensitivity of waste disposal costs to a range of design and operating parameters; and second, economic or cost impact studies focused on assessing the waste disposal costs on an industry-wide basis for compliance with RCRA and/or other regulatory scenarios.

At present, there is little published cost data on full-scale commercial disposal operations to provide a basis for these generalized studies. More accurate accounting of waste disposal costs is expected to be employed, especially for new plants. Additional cost data are also expected to become available from a number of FGD demonstration systems such as the dry impoundment at LG&E's Cane Run Station and the mine disposal operation at the Baukol-Noonan mine in North Dakota. In addition, the planned full scale utility waste disposal study at a number of sites by the EPA will develop broad baseline data on costs of FGC waste disposal.

An overview of the principal waste dispcsal cost studies is provided in the following sections. A more detailed review is given in Volume 5 of this report. All major cost studies to date have been based on existing practices and do not fully consider RCRA related requirements. Some studies on RCRA related impacts are expected by mid-1979.

4.6.6.1 Costs of Waste Disposal Alternatives

Fly Ash

A number of generalized economic studies relating to the disposal of fly ash have been performed. One of the more important of these is the study conducted by NUS [49] sponsored by the Utility Water Act Group. The purpose of this study was to evaluate the costs associated with dry fly ash removal systems for new power plants comparing dry ash handling and disposal versus wet handling and disposal. The results of this study indicate that the cost of a dry system may be considerably less expensive than that for a wet system. For the 1,000-MW model plant considered, waste handling and disposal costs ranged from $8 to $17 per dry ton with the cost for a dry system almost half that for a wet system.

FGD Wastes

Most of the studies of a general nature developing comparative economics for waste disposal alternatives and completed prior to 1979, have been sponsored either by the EPA or EPRI. Most of these have dealt with existing practices for waste disposal and have not attempted to specifically address the possible impacts of RCRA on design and operation. Such studies have been performed by TVA [50, 51], Aerospace [52, 58-62], Michael Baker, Jr. Inc. [53], and Arthur D. Little [54]. All of the studies involve medium or high sulfur coal-fired power plants and all use a model plant approach for preparing cost estimates. Table S.17 summarizes these studies with regard to their general scope and the cost bases employed. For those studies that are now ongoing, base years for most recent cost estimates are shown.

Unfortunately, the design and operating assumptions in these various studies as well as the battery limits assumed for the disposal systems differ. Costs are generally presented in lump sum form, covering the entire waste processing and disposal facilities, and breakout of modular costs for different sections of the waste disposal plant and/or waste disposal operations are usually difficult. Hence, direct comparisons of cost estimates frequently are not possible. In this regard, efforts are now underway to develop a standard cost basis for future cost analyses of FGD systems and disposal operations prepared by EPA contractors.

Table S.17

Summary of General Conceptualized Cost Studies for FGC Waste Disposal

FGD WASTES

Contractor	Sponsor	Type of Scrubber		Mode of Operation		Disposal Options Considered					No. Cases	Base Year	Reference
		Conv. High S	Forced Oxidation	SO_2 Only	SO_2 + Ash	Dry Landfill	Wet Pond	Surface Mine	Underground Mine	Ocean			
TVA	EPA	Limestone[a]	Limestone	✓	✓	✓	✓	✓	-	-	150+	1979/1980	50, 51
Aerospace	EPA	Limestone	Limestone	✓	✓	✓	✓	-	-	-	-30[c]	1976/1977	52
Michael Baker	EPRI	Lime	-	✓	-	✓	✓	-	-	-	4	1976	53
ADL	EPA	Lime	-	✓	-	-	-	✓	✓	✓	16	1977	54
NUS	UWAG			Fly Ash Only		✓	✓	-	-	-	2	1974	49

[a]Four cases include lime scrubbing.

[b]Included only for forced oxidation.

[c]Number of cases studied varies with report.

Source: Arthur D. Little, Inc.

The most comprehensive of the studies performed to date is that being conducted by TVA. More than 150 cases and case variations are being evaluated including dry impoundment, wet ponding, and surface mine disposal of stabilized and unstabilized wastes. For the most part, costs have been based upon wastes from either conventional direct limestone scrubbing systems or limestone scrubbing systems incorporating forced oxidation; however, a few cases of conventional direct lime scrubbing have also been considered. All of the costing work has been rather general in nature, focusing on gross effects of major parameters and variables on disposal economics. The principal variables studied include power plant capacity, sulfur and ash content of the coal, distance to the disposal site, land requirements and availability, and waste processing requirements.

Generally, costs are presented on integrated system basis (including both waste processing and disposal) starting at the scrubber battery limits. Simplifying assumptions have been made with regard to the engineering properties of various types of wastes and equipment design parameters. The design bases are generic and partly based on prototype data; they represent some engineering studies. Similarly, the cost estimates are based on cost studies of the processes. The estimates are general in the sense that they do not represent actual systems. Actual systems are often very site specific in nature. The properties and equipment design bases are now being reviewed and modified to more closely reflect variations in different types of wastes, and efforts are being made to provide costs on a modularized basis to allow addition and deletion of processing units for comparison with other cost estimates.

A summary of disposal costs estimated by TVA for a model 500 MW utility burning typical high sulfur midwestern coal (3.5% and 5.0% sulfur) is presented in Table S.18. Only costs for onsite disposal (one mile from the plant) of ash and FGD wastes from a direct limestone scrubbing system are shown. For wet ponding, the costs are based upon simultaneous fly ash and SO_2 scrubbing; and the range of costs shown reflects variations in sulfur content of the coal, land availability (constraints on the

Table S.18

Summary of TVA Cost Estimates for FGC Waste Disposal

Basis: 500 Mw Plant (30-year lifetime)
High Sulfur Coal
7,000 hours operation/year (years 1-10)
Onsite Codisposal (1-mile)
Limestone Scrubbing
Coal - 3.5 and 5.0% sulfur, 16% ash
Mid-1980 Cost Basis

Disposal Mode	Annual Revenue Requirements ($/dry ton)[a] Wet Ponding (Simultaneous Ash & SO_2 Scrubbing)	Dry Impoundment (Separate Ash & SO_2 Control)
Unstabilized	$6-12	-
Ash-Blending	-	$8-9
Stabilized	$14-20[b]	$11-13[c]
Unstabilized Gypsum (Forced Oxidation)	-	6-8

[a]No monitoring costs included

[b]Stabilization via Dravo's Synearth[R] Process

[c]Stabilization via IUCS's Poz-O-Tec[R] Process

Source: [50,51]

acreage of the site), pond lining requirements (type of lining) and the density of the settled waste.

The basis used by TVA in estimating dry impoundment costs differed depending upon the type of waste. For conventional sulfite-rich wastes, it was assumed that the wet scrubber would follow an electrostatic precipitator. The dry ash would then be admixed with the FGD wastes either with or without the addition of stabilization chemicals prior to landfill. In the case of gypsum from forced oxidation systems, it was assumed that blending of dry ash with the gypsum would not be required due to its better dewatering and handling properties. Hence, simultaneous ash and SO_2 removal was assumed for forced oxidation systems. The ash blending and stabilization cases for conventional wastes, therefore, include not only process equipment but also the incremental cost of an ESP over a wet particulate scrubber neither of which are included in the forced oxidation system. (It should be noted that forced oxidation systems have not yet been fully demonstrated on high sulfur coals and the use of wet particulate scrubbers may be impractical under the revised NSPS.)

The range of costs shown for dry impoundments incorporates variations in the sulfur content of the coal, and, for stabilization, variations in the additive feed rate. No variations in land availability were considered and it was assumed that no lining would be required.

Power plant size (quantity of waste) and distance to the disposal site were determined to be particularly important factors in waste disposal costs. Over the range of power plant capacity from 200 Mw to 1500 Mw annual revenue requirements for waste disposal varied according to a capacity (quantity) factor of 0.55-0.65. Increasing the distance to the disposal site from 1 mile to 10 miles, increased revenue requirements by 30-40% for dry impoundment and 40-125% for wet ponding.

Another important factor affecting wasted disposal costs for a new plant is the actual on-stream time for the plant. The costs shown in Table S-18 are based upon an estimated annual average of 7000 hours of operation per year, which might be experienced during the first ten years of the plant life. However, as the plant ages, the annual operating hours will generally decrease. TVA estimates that the actual annual average on-stream time of a plant over its 30-year lifetime would be expected on the order of 4500 hours/year. Use of this lower operating factor would obviously indicate higher cost estimates for waste disposal reported on a $/ton basis. However, while use of such a lifetime average operating factor may provide a higher estimate of disposal costs, a proper comparison of costs can only be made on a levelized basis by discounting future costs.

Aerospace has been preparing cost estimates for FGC waste disposal since 1974 under contract to EPA. These estimates have been updated and revised as more waste properties data and disposal operating requirements have become available. Much of the work has focused on various types of wet ponding of wastes including disposal of unstabilized waste in ponds provided with under drainage. Costs have also been developed for landfilling of stabilized wastes, surface disposal of gypsum and production of wallboard grade gypsum from limestone forced oxidation systems (for comparison with conventional limestone scrubber waste disposal). In general, the cost estimates for wet ponding are lower than those prepared by TVA (on an equivalent basis), but there are significant differences in assumptions for design of the pond and pipeline transport systems.

The costing by Michael Baker, Jr., [53] and Arthur D. Little [54] are more limited in scope than either the Aerospace or TVA studies. The Michael Baker analysis was part of a larger study of stabilization technology sponsored by EPRI, and involved a comparison of landfilling stabilized and unstabilized (ash-blended) wastes. Cost estimates, based upon inputs from commercial stabilization process suppliers, indicated that stabilization would result in about a $.70/dry ton increase in cost over simple ash blending for a 1000 Mw, high sulfur coal-fired plant assuming an additive feed of 2 weight percent (dry basis). While no equivalent case was considered by TVA, interpolation between the serious cases considered indicate a difference of about twice this amount based upon TVA's work.

Waste disposal cost estimates prepared by Arthur D. Little focused exclusively on disposal of wastes in the ocean and mines. These costs were developed as part of an ongoing study for the EPA to evaluate the feasibility of ocean and mine disposal. The estimates were based upon very generalized conceptual systems. Unlike the other costing work described above, these costs do not include waste processing; rather, only the waste transport and disposal operations. Based upon a preliminary analysis, waste disposal in on-site mines was found to be slightly less expensive than conventional dry impoundment. Ocean-disposal costs varied greatly depending upon the disposal mode and distance off-shore; however, some ocean disposal methods were found to be cost competitive with land disposal, especially where off-site land disposal would be required. These costs are being reviewed and additional mine disposal costs are being independently prepared by TVA.

In developing generalized cost studies for waste disposal, such as those discussed above, it is important to recognize the fact that it is frequently difficult to totally divorce the waste disposal system from the scrubber. This is particularly true when comparing systems with different types of ash collection or scrubber technology (e.g., forced oxidation), and it may be equally important when developing the design basis for the waste processing facilities. In most cases, waste processing will be coupled directly to FGC scrubbers or thickeners, and the waste processing plant must be capable of handling the short-term sustained peak loads expected for the FGC system itself, especially with regard to variations in coal sulfur and ash content. Such considerations need to be factored into the capacity of the equipment itself. Alternatively, provision must be made for a buffer between the FGC system and parts of the waste processing plant (such as interim storage of filter cake and ash). It is best, therefore, to evaluate waste disposal in the context of total FGC system costs rather than independently.

4.6.6.2 Economic (Cost) Impact Studies

Two studies have recently been completed assessing the impact of waste disposal regulations on the industry-wide costs for FGC waste disposal for the electric utility industry. One study performed by Radian [55] for the U.S. EPA (IERL) focused on the cost impact of RCRA on future FGC waste disposal. The other study performed by SCS Engineers [56] for the U.S. EPA (MERL) assessed the impact of a range of different regulatory scenarios on the cost of waste disposal. Draft reports on both of these studies are now in review.

The results of the Radian assessment indicate that the capital costs related to the disposal of utility nonhazardous wastes will increase about 36%, or about one billion dollars (in mid-1979 dollars) for plants in operation by 1985 due to compliance with RCRA. However, annual revenue requirements are estimated to increase by only about 6%, or about 70 million dollars. These estimates were based upon a model plant cost estimation approach using a 1,000-MW plant. The major impacts of RCRA were assumed to be in distance from plants to disposal sites (greater distances being required under RCRA to locate suitable sites) and the use of lined rather than unlined ponds.

The SCS study assessed the impact of five different regulatory scenarios ranging in severity from regulation at the state level with no change in current disposal practices to enforcement of regulations at the federal level with chemical stabilization universally required (where specifications would be given for acceptable stabilization techniques). Costs were based upon a set of 10 model plants representing different geographic regions, coal types, and rural versus urban locales. Waste disposal cost estimates were prepared for six different disposal options drawing from the TVA cost model previously discussed. Results indicate that annual revenue requirements for plants in operation by 1985 can increase by up to 75-80%, or 2.3 billion dollars (1980 dollars) under the most stringent regulatory scenario assumed. This most stringent scenario would correspond to an increase of about 1.3 mills/kwh in consumer power costs (1980 dollars).

4.6.6.3 Economic Uncertainties and Data Gaps

There are a number of uncertainties concerning FGC waste disposal that importantly affect overall disposal economics and viability of disposal modes. We feel that the two most important relate to land use/availability/cost and long-term maintenance of retired disposal sites. They are not strictly data gaps in the sense that they can be readily resolved through current studies and R&D efforts; rather, they are social/technical/economic issues that will require continuing consideration and evaluation with increasing coal utilization and the growing implementation of nonrecovery FGC systems.

Current data gaps related to the economics of FGC waste disposal which can be addressed by government and/or industry initiatives include both cost information per se as well as waste properties and disposal requirements directly impacting disposal costs. The most important of these data gaps are the following:

- There is a general lack of reliable cost information from commercial operations of most types of FGC disposal. This is particularly true of wastes from industrial boilers which are likely to become more important in the future. Ongoing and planned EPA projects should at least partially fill this gap.
- There have been no definitive studies on the disposal of wastes from dry sorbent systems and the associated costs.
- Existing physical and engineering properties data on some types of wastes are not adequate as a basis for developing designs needed for reliable estimates of cost-effective disposal systems. Examples include: the disposal of gypsum untreated in dry impoundments; the amount of ash and lime required for adequate stabilization of some sulfite-rich wastes; and the potential use of stabilized FGC waste materials as liners for dry impoundments of blended coal ash/FGD wastes (i.e., as disposal of coal ash/FGD wastes).

- RCRA is likely to impose some additional costs due to constraints pertaining to waste analysis, site selection, monitoring, closure. These need to be defined further. Ongoing EPA and DOE studies are expected to provide data on this issue.

4.7 FGC Waste Utilization

At present, although utilization of FGC wastes is feasible, the percentage of FGC wastes generated that is utilized in the United States is modest in comparison with other industrial nations. In 1977, 21% (12.7 million metric tons) of the coal ash and none of the FGD wastes generated were utilized [7]. Many European countries and Japan utilize proportionately much more of the FGC wastes that they produce than the United States. Although differences in raw material availability and marketability account for some of this difference, in general there are institutional factors which favor increased utilization abroad and hinder expansion of domestic utilization. This situation may change as the utilization of coal for electric power expands and an energy and resource conservation ethic begins to take shape.

The principal present and potential uses of coal ash are:

- Structural fill (landfill cover, land recovery, surface mine reclamation, highway or similar embankments, etc.)
- Use in building materials (cement, concrete block, aggregate, etc.)
- Paving materials (road base, etc.)
- Agricultural use (soil amendment or stabilizer)
- Environmental uses (road icing control, sludge dewatering, neutralizing, acid mine drainage, etc.)
- Recovery of chemicals (alumina, calcium, oxide, etc.)

Commercial utilization of coal ash is expected to increase in the United States , continuing the historical trend. The increasing reliance on coal as a utility fuel with attendant increases in ash production may result in the percentage of utilization being unchanged or even decreasing despite efforts to promote ash utilization through increased market visibility and technological development. Tightening environmental control regulations concerning disposal of wastes and constraints on land availability in some areas, however, would continue to enhance the attractiveness of utilization.

In contrast to coal ash, there are essentially no markets developed for utilizing wastes from nonrecovery FGD systems in the United States, and the utilization of FGD sludge is expected to progress more slowly because of the need to demonstrate commercial viability.

In Japan, gypsum is produced in FGD systems and is marketed for use in wallboard production and the manufacture of cement. However, in the United States, there is little current market for gypsum as a byproduct material. Studies indicate the possibility that production of FGD gypsum for utilization may offer economic advantages over FGC waste disposal in some site-specific cases; in particular, use in portland cement manufacture may be promising [65]. The use of FGD sludge from nonrecovery FGD processes as a filler material and fertilizer and the use of sulfur from recovery FGD processes are potential utilization options. However, these are not considered promising at this time. Further development of the fertilizer production process is needed to establish its viability, as are plant toxicity studies. Conversion of FGD sludge to elemental sulfur with recovery of the absorbent for recycle to the scrubber has been studied. Other possible uses of nonrecovery FGD wastes that continue to be explored include use as a concrete additive, a low grade construction base for construction of artificial reefs, for soil amendments, and for mine subsidence control.

Economics of utilization vary widely with site- and system-specific conditions and, hence, are not generalized here. Available data are assessed in Volume 4 of this report.

As an alternative to nonrecovery FGD systems, recovery FGD systems produce sulfur or sulfuric acid as a byproduct. Markets for these products, though, are quite location-specific and the cost for producing the byproduct with FGD systems is high. Successful applications will probably be in specific locations where a market for the products exists or in areas where availability of disposal options for nonrecovery processes is so constrained that the cost of waste disposal is high. It is important to note that most recovery systems also produce wastes; e.g., blowdown from prescrubbers (which remove fine particulate matter and chlorides from the flue gas prior to its entering the sulfur dioxide absorber) and blowdown of contaminants from the regenerative portion of the process.

A variety of explanations have been given for the slow growth of utilization in the U.S., usually in some way related to the research perspective of the organization doing the assessment. Specifications, quality control, lack of markets, consumer bias, lack of technical development, and many other reasons have been put forward as hindering increased utilization of ash and sludge in the United States. All of these reasons are valid in at least some instances, and sometimes across the board. However, on balance a combination of three types of factors constrain FGC waste utilization:

- Technical considerations, particularly in comparison with alternative materials;
- Institutional barriers related to poor understanding of the byproducts and failure to develop markets by either the utility industry or user industries; and
- Possible environmental concerns related to some uses.

Considering the anticipated growth in the generation of FGC wastes, removal of or reduction in barriers to FGC waste utilization becomes important. In some cases, technical problems preclude successful large-scale utilization. The more serious impediments are apparently institutional in nature and require study and assessment.

4.8 Emerging Technologies and the Future

At present conventional coal combustion remains the dominant method of electric power generation. As the Nation continues its increasing reliance on coal, this trend will continue. However, several R&D efforts at EPA, DOE, EPRI and other organizations are being focused on ways to burn or utilize coal more effectively.

Any possible alternatives for the utilization of coal must deal with the following issues:

- Air pollution control leading to particulate and sulfur oxides control (in future NO_x control also).
- Water pollution control leading to effluent standards and water management for recycle/reuse.
- Solid waste management to deal with the ultimate disposal of wastes from the above two.

Potential options to use coal are:

a. Conventional combustion including flue gas cleaning (FGC).

b. Coal cleaning and conventional (or other) combustion of coal with adequate flue gas control.

c. Fluid bed combustion (FBC).

d. Low Btu gas and combined cycles.

e. Coal liquefaction.

f. Magnetohydrodynamics (MHD).

Considering coal utilization over the next twenty years, some of these technologies are likely to reach significant levels of commercialization. It should be emphasized that all these technologies will have their own waste management problems. All these technologies will generate wastes; however, quantity, the physical and chemical characteristics and point of generation (mine end, utility end, or other) of the wastes would be different from those associated with conventional coal combustion.

a. Coal Cleaning

Coal cleaning processes can be broadly categorized into

- Mechanical coal cleaning.
- Advanced cleaning processes.

Mechanical Cleaning: Mechanical cleaning processes are based on differences in specific gravity or surface characteristics of the materials being separated. They can be designed to remove a large fraction of the pyritic sulfur, generally the major part of the sulfur in high-sulfur coals. Pyritic sulfur occurs as discrete particles. It is much heavier than coal, with a specific gravity of 5.0, compared to coal's 1.4. Hence, when raw coal is immersed in a dense medium, the coal floats and the pyrites sink. This process is widely used to remove shale and rocks, etc. (specific gravities from 2 to 5) but pyrite is more dispersed and finer crushing of the coal than is generally practiced for shale and rock removal alone is required to free it for removal.

Advanced Cleaning Processes: Several physical and/or chemical treatments have been proposed for improved pyritic sulfur removal.[63] These are:

(1) High-gradient magnetic separation (HGMS) - separation of pyrite by exploiting its magnetic properties.

(2) Magnex process - a "pretreatment" process allowing better magnetic separation.

(3) Meyers process - a chemical leaching of pyrite from the coal.

(4) Otisca process - washing with a heavy liquid rather than a water suspension.

(5) Chemical comminution - a "pretreatment" process that chemically breaks down the coal to smaller sizes.

(6) Ledgemont oxygen leaching process - dissolution of pyrites and some organic sulfur using a process simulating the production of acid mine water.

(7) Bureau of Mines/DOE oxidative desulfurization process - a higher temperature, air instead of oxygen variation of the ledgemont process.

(8) Battelle hydrothermal process - leaching of pyrites and organic sulfur under high pressure.

(9) KVB process - gaseous reaction of the sulfur with nitric oxide.

b. Fluid Bed Combustion (FBC)

Fluidized-bed combustion (FBC) is an important technological alternative for industrial applications and perhaps coal-based power generation. Its basic principle involves the feeding of crushed coal for combustion into a bed of inert ash mixed with limestone or dolomite. The bed is fluidized (held in suspension) by injection of air through the bottom of the bed at a controlled rate great enough to cause the bed to be agitated much like a boiling fluid. The coal burns within the bed, and the SO_x formed during combustion react with the limestone or dolomite to form a dry calcium sulfate.

FBC has the following advantages:

- The flexibility to burn a wide range of rank and quality of coals.
- A higher heat transfer rate than in conventional boilers, which reduces the requirements for boiler tube surface and furnace size and also lowers capital costs.
- An increased energy conversion efficiency through the ability to operate without the power requirements needed for flue gas cleaning.
- Reduced emissions of SO_x and NO_x.

- A solid waste potentially more readily amenable and acceptable to disposal than that from a wet-scrubber applied to conventional boilers although current quantities on a dry weight basis will be substantially higher because of high stoichiometric requirements.
- The potential for operation at an elevated pressure sufficient to use with a combined gas-turbine/steam-turbine cycle for generating electricity at higher efficiency.

c. Low Btu Gas and Combined Cycles

Coal can be gasified to produce a low-Btu gas. Since the gas cannot economically be stored or shipped more than a few miles before combustion, it is effectively a form of direct combustion of coal. The gas is cleaned before burning so that no emission controls are required at the combustion facility. Low-Btu gas can be burned directly in a boiler to produce steam for industrial use or for the production of electricity in a conventional steam turbine. Alternatively, the gas generator can be integrated with a combined cycle plant. EPRI [64] concludes that this combination offers potential advantages over conventional combustion. Texaco [64] is planning to proceed with a demonstration facility (90-100 Mw) based on the Texaco gasifier and a combined cycle power plant at Southern California Edison facilities.

d. Coal Gasification to High Btu Gas

Gasification technology to produce high Btu gas is also under development. However, this method is not focused on electric power production.

e. Coal Liquefaction

Conversion of coal to liquid hydrocarbons is also under intense study. Processes for liquefying coal can be one of three general categories.

(1) Conversion to low Btu gas followed by catalytic synthesis.

(2) Pyrolysis.

(3) Direct liquefaction involving solvent refining or catalytic hydrogeneration.

Three processes all based on direct liquefaction (Exxon Donor Solvent, H-Coal and Solvent Refined Coal-SRC-II) are under development.

f. Magnetohydrodynamics (MHD)

The interest in MHD stems mainly from high expected thermal efficiency for an entire system including a conventional steam cycle. In MHD generators, a stream of very hot gas (roughly 5,000°F), flows through a magnetic field at high velocity. Because the gas at high temperatures is an electrical conductor, an electrical current is produced through electrodes mounted in the sides of the gas duct. Coal-fired systems are under research and study.

REFERENCES TO VOLUME I

1. Rice, J. K. and Strauss, S. D., "Water Pollution Control in Steam Plants", Power 120 (4), 1977.

2. Geological Survey Circular 765. U. S. Geological Survey, Washington D. C. 1976.

3. National Electric Reliability Council 7th Annual Review of Overall Reliability and Adequacy of the North American Bulk Power Systems, NECR, Research Park, Terhune Road, Princeton, N.J., 1977.

4. 1977-1978 Electrical World Directory of Electrical Utilities, McGraw-Hill Book Company, New York, N.Y. 1978.

5. Annual Environmental Analysis Report, prepared by Mitre Corporation, Consad Research, Control Data Corporation, and International Research and Technology; Report to ERDA, under Contract EE-01-77-0135 September 1977.

6. Weaver, D. E., et al., SCS Engineers, Data Base for Standards/ Regulations Development for Land Disposal of Flue Gas Cleaning Sludges. EPA-600/7-77-118, December 1977.

7. Ash at Work, Vol. X, No. 4, 1978, published by the National Ash Association, Washington, D. C.

8. "EPA Utility FGD Survey - April-May 1978" by B. Laseke, M. Melia, M. Smith and W. Fisher, PEDCO Environmental Inc., EPA 600/7-78-D57c, September 1978, Environmental Protection Agency, Washington, D. C. 20460

9. Ray, S. S. & Parker, F. G., "Characterization of Ash from Coal-Fired Power Plants", Tennessee Valley Authority, Chattanooga, Tenn., under Interagency Agreement D5-E-721.

10. Effect of Forced Oxidation on Limestone/SO_x Scrubber Performance, Prepared by Robert H. Borgwardt, Industrial Environmental Research Laboratory (IERL), EPA, 1977.

11. SCS Engineers, "Chemical Speciation of Contaminants in FGD Sludge and Wastewater," Interim Report Under EPA Contract 68-03-2371, Phase II, March 1978.

12. Duedall, I. W., et al. State University of New York, at Stony Brook, "A Preliminary Investigation of the Composition, Physical and Chemical Behavior, and Biological Effects of Stabilized Coal-Fired Power Plant Wastes (SCPW) in the Marine Environment." Draft Final Report to New York Energy Research and Development Administration, New York November 1977.

13. Mahloch, J. L., "Chemical Properties and Leachate Characteristics of FGD Sludges," presented at AIChE Symposium, August 29 - September 1, 1976, Atlantic City, New Jersey.

14. Ifeadi, C. N. and H. S. Rosenberg, "Lime/Limestone Sludges - Trends in the Utility Industry," Proc. Symposium on Flue Gas Desulfurization, Atlanta, Ga., November, 1974.

15. Interess, E., et al., "Evaluation of the General Motors Double Alkali SO_2 Control System," EPA Report No. 600/7-77-005, January 1977.

16. LaMantia, C. R., et al., "Final Report: Dual Alkali Test and Evaluation Program," (3 vols) EPA-600/7-77-050a, b, & c, May 1977.

17. LaMantia, C. R., et al., "Application of Scrubbing Systems to Low Sulfur/Alkaline Ash Coals,: report prepared by Arthur D. Little. Inc., for the Electric Power Research Institute, Research Project 785-1, December 1977.

18. University of North Dakota Test Plan

19. Sondreal, E. A., and P. H. Tufte, "Scrubber Developments in the West," Presented at the 1975 Lignite Symposium by ERDA/Grand Forks Energy Research Center, Grand Forks, North Dakota, 1975.

20. PEDCo Environmental Specialists, Inc., "Survey of Flue Gas Desulfurization Systems: LaCynge Station, Kansas City Power and Light Co." (EPA-600/7-78-048d, March 1978).

21. Proc., Symposium on Flue Gas Desulfurization - Hollywood, Florida, November 1977 (Vol. 1) (EPA-600/7-78-058a, March 1978).

22. "Coal Fired Power Plant - Trace Element Study" by the Radian Corporation to the EPA, Vol. I (TS-1a) and Vol. II (TS-1b), September 1975.

23. Technical Report for Revision of Steam Electric Effluent Limitations Guidelines, EPA, September 1978.

24. Jones, B. F., et al., "Evaluation of the Physical Stability and Leachability of Flue Gas Cleaning Wastes," by Radian Corporation to EPRI under Research Project 78 6-2, (February 1979).

25. Weeter, D. W., "State of the Art Review of FGD Sludge Stabilization Using Lime/Fly Ash Admixtures," paper 78-57.1, 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25, 1978.

26. Rosoff, J., et al., "Disposal of Byproducts from Nonregenerable Flue Gas Desulfurization Systems: Second Progress Report." EPA-600/7-77-052, May 1977.

27. Rosoff, J. et al., "Disposal of Byproducts from Nonregenerable Flue Gas Desulfurization Systems-Funal Report", Rought Draft, under EPA Contract 68-02-4010, March 1978.

28. Amos, D. F., and J. D. Wright, "The Effect of Fly Ash on Soil Physical Characteristics," Proc., 3rd Mineral Waste Utility Symposium, U. S. Bureau of Mines and I.I.T. Research Institute, Chicago, 1972, pp. 95-104.

29. Johnston, P. H., "The Effect of Fly Ash Addition on the Geotechnical Properties of Flue Gas Desulfurization Sludges," M. Eng. Thesis, University of Louisville, Louisville, KY., 1978.

30. Abernethy, R. F., M. J. Petterson, F. H. Gibson, Major Ash Constituents in U. S. Coals, Bureau of Mines Report of Investigation No. 7240, U. S. Department of the Interior, Bureau of Mines, Pittsburgh, 1969.

31. Bacon, L. D., "Fly Ash for Construction of Highway Embankments," Proc., 4th Int. Ash Utilization Symposium, ERDA, St. Louis, 1976, pp. 262-292.

32. DiGioia, A. M., and W. L. Nuzzo, "Fly Ash as a Structural Fill," Meeting Preprint JPG-70-9, ASME-IEEE Joint Power Generating Conference, Pittsburgh, 1970.

33. Johnston, P. H., "The Effect of Fly Ash Additon on the Geotechnical Properties of Flue Gas Desulfurization Sludges," M. Eng. Thesis, University of Louisville, Louisville, KY., 1978.

34. Mateos, M., and D. T. Davidson, "Lime and Fly Ash Proportions in Soil-Lime-Fly Ash Mixtures and Some Aspects of Soil-Lime Stabilization," Bulletin No. 335, Highway Research Board, Washington, 1962, pp. 40-64.

35. Gray, D. H., and Y. K. Lin, "Engineering Properties of Compacted Fly Ash," Proc., ASCE, Vol. 98, SM4, April 1972, pp. 361-380.

36. Lamb, D. W., et al., "Fly Ash as Construction Material for Material for Water Retaining Structures," Proc., 4th Int. Ash Utilization Symposium, ERDA, St. Louis, 1976, pp. 369-379.

37. Krizek, R. J., et al., "Characterization and Handling of Sulfur Dioxide Scrubber Sludge with Fly Ash," paper, Eng. Fnd. Conference, Hueston Woods, Ohio, October 1976.

38. Krizek, R. J., et al., " Engineering Properties of Sulfur Dioxide Scrubber Sludge with Fly Ash," paper, Eng. Fnd. Conference, Hueston Woods, Ohio, October 1976.

39. Lord, W. H., "FGD Sludge Fixation and Disposal," Proc., FGD Symposium EPA, Atlanta, November 1974, pp. 929-954.

40. Thacker, B. K., "Geotechnical Properties of Flue Gas Desulfurization Sludges," M. Eng. Thesis, University of Louisville, Ky, 1977.

41. Edwards, R. A., and R. C. Reed, "CEA Dual Alkali FGD Sludge/Flush and Sludge/Fly Ash/Lime Landfill and Compaction Demonstraton," Southern Company Services, Inc., Birmingham, April 1977.

42. Ballard, Brian and Mark Richman, "FGD System Operation at Martin Lake Steam Electric Station," paper presented at Joint Power Generation, Conference, Dallas, Texas, September 10-12, 1978.

43. Personal Communication with utility plant personnel, February 1979.

44. Elnaggar, H. A., and J. G. Selmeczi, "Properties and Stabilization of SO_2 Scrubbing Sludges," Proc., 1st Symposium Coal Utilization, NCA/BCR Louisville, October 1974, pp. 182-197.

45. Bodner, B. S., "The Effects of LIme and Fly Ash Addition on the Geotechnical Properties of FGD Sludges," Eng. Thesis, University of Louisville, Louisville, Ky, 1978.

46. Hagerty, D. J., et al., "Engineering Properties of FGD Sludges," Proc., Spec. Conference on Geotech Practice for Disposal of Solid Waste Materials, ASCE, Ann Arbor, Michigan, June 1977, pp. 23-40.

47. Klym, T. W., and D. J. Dodd, "Landfill Disposal of Scrubber Sludge," paper, National ASCE Environmental Engineering Meeting, Kansas City, October 1974.

48. Duvel, W. A., Jr., et al., "Laboratory Investigations: Interaction of Acid Mine Drainage with FGD Sludge," by Michael Baker, Jr., Inc., to EPA under Contract ME-76893, Draft Report May 1978.

49. Atwood, K. E., and Greenway, W. R., "Fly Ash Handling System Study Related to Steam Electric Power Generating Point Source Category Effluent Guidelines and Standards for Utility Water Act Group, C. W. Rice Division of NUS Corporation, Pittsburgh, Pa., July 1975.

50. Barrier, J. W., et al., "Economics of Disposal and Lime-Limestone Leachate Wastes: Sludge Fly Ash Blending and Gypsum Systems". Tennessee Valley Authority under Interagency Agreement EPA-IAG-D7-E721. Environmental Protection Agency, Washington, D. C., 20460, Draft Report May 1978.

51. Barrier, J. W., H. L. Faucett, and L. J. Henson, "Economics of Disposal of Lime/Limestone Scrubbing Wastes," Tennessee Valley Authority EPA 600/7-78-023a, Environmental Protection Agency, Washington, D. C., February 1976.

52. Leo, P. L. and J. Rossoff, Aerospace Corporation, "Controlling SO_2 Emissions from Coal-Fired Steam-Electric Generators: Solid Waste Impact," Two Volumes, EPA Rpt. No. EPA-700/7-78-044a and b. Environmental Protection Agency, Washington, D. C., 20460, 1978.

53. "State of the Art of FGD Sludge Fixation," W. A. Duvel, W. R. Gallagher, R. G. Knight, C. R. Kolarg, R. J. McLaren, Michael Baker, Jr., Inc., EPRI FP-671, Project 786-1, Electric Power Research Institute, Palo Alto, Ca. January 1978.

54. "An Evaluation of the Disposal of FGD Wastes in Mines and the Ocean - An Initial Assessment," R. R.Lunt, et al. EPA-600/7-77-051 Environmental Protection Agency, Office of Research and Development, Washington, D.C. 20460, May1977.

55. Jones, B. F., et al., Radian Corporation, "Study of Nonhazardous Wastes from Coal-Fired Electric Utilities," DCN 200-187-41-08 Report to EPA-IERL, Research Triangle Park, N.C., 27711, Draft Final Report, December 15, 1979.

56. SCS Engineers "Economic Impact of Alternative Flue Gas Desulfurization (FGD) Sludge Disposal Regulations in the Utility Industry" Report to EPA Municipal Environmental Research Laboratories, Cincinnati, Ohio, Draft Final Report, January 1979.

57. "Fuel Exemptions for Existing Plants", Power, April 1979, p. 20.

58. Leo, P. P. and Rossoff, J., Control of Waste and Water Pollution from Coal-Fired Power Plants: Second R&D Report, EPA-600/7-78-224, November 1978.

59. Fling, R. B., et al, Disposal of FGC Wastes: EPA Shawnee Field Evaluation: Initial Report, EPA-600/2-76-070, March 1976.

60. Fling, R. B., et al, Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation: Second Annual Report, EPA-600/7-78-024, February 1978.

61. Fling, R. B., et al, Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation: Third Annual Report, Published as an EPA Report.

62. Rossoff, J., et al, Disposal of By-Products from Nonregenerable Flue Gas Desulfurization Systems: Initial Report, EPA-650/2-74-037-a, May 1974.

63. Personal communication from J. D. Kilgroe of EPA to C. J. Santhanam, Arthur D. Little, Inc., February 1979.

64. Personal communication from F. Guptill of Texas Development to C. J. Santhanam, Arthur D. Little, Inc., January 1979.

65. Ash at Work, Vol. X, No. 4, Page 4, 1978.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-80-012a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Waste and Water Management for Conventional Coal Combustion Assessment Report--1979 Volume I. Executive Summary		5. REPORT DATE January 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) C.J. Santhanam, R.R. Lunt, C.B. Cooper, D.E. Kleinschmidt, I. Bodek, and W.A. Tucker (ADL); and C.R. Ullrich (U. of Louisville)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Arthur D. Little, Inc. 20 Acorn Park Cambridge, Massachusetts 02140		10. PROGRAM ELEMENT NO. EHE624A 11. CONTRACT/GRANT NO. 68-02-2654
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 9/77 - 8/79 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Julian W. Jones, Mail Drop 61, 919/541-2489.

16. ABSTRACT The report is an executive summary, the first of five volumes giving a detailed assessment of the state-of-the-art of water and waste management technology for conventional combustion of coal. Various R and D programs sponsored by EPA and private industry have achieved significant results in many areas. Substantial progress has been made in characterizing major wastewater streams and in determining physical, chemical, and engineering properties of flue gas cleaning (FGC) wastes. Overall water management studies have shown that more efficient water recycle/reuse can be achieved, and can serve as models for water management plans in new facilities. Generation of FGC wastes is expected to increase dramatically. Utilization of FGC wastes is also expected to grow, but much more slowly. Major FGC waste disposal methods are ponding, disposal in managed fills, and mine disposal. Progress in dewatering and stabilization processes is expected to increase the relative attractiveness and viability of the latter two methods. Potential environmental impacts are primarily contamination of surface water and groundwater, and land degradation (physical instability, large land requirements); actual impacts are site- and system-specific. Applying appropriate control technology can mitigate adverse impacts. Disposal costs are $9-15 per dry ton of FGC wastes.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Water	Pollution Control	13B	07B
Coal	Flue Gases	Stationary Sources	21D	
Combustion	Cleaning	Flue Gas Cleaning	21B	13H
Assessments			14B	
Management			05A	
Waste Disposal				

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 99
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)